A study on the application of cage-type retaining wall in flood control

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Abstract. Sub-embankment and geo-bag embankment had been adopted to increase the retaining height in flood control. However, these methods have taken up a lot of manpower and material resources, because of shortage of time, poor soil supplement and inconvenient construction procedures, which limited the scope of application. Cage type retaining wall has the advantages of quick and convenient installation, strong mobility, low cost and easy disassembly during the flood season. The stability of cage type retaining wall is the core issue in engineering application. In this paper, the stability of retaining wall is calculated with various lengths of geomembrane which is laid in the upstream. The results show that stability safety factors of the structure are 1.28, 1.58, 1.74 and 1.9 when the lengths of geomembrane are 0.0, 0.5, 1.0 and 2.0 respectively, which could meet the engineering requirements. Besides, application notices are also discussed in this paper.

1. Introduction

The engineering measures such as constructing sub-embankment for increase of height and dissipation of waves had been mainly adopted in flood control to increase the retaining height of the dike temporarily, so that the flood peak could pass smoothly. The temporary cofferdam is required to be stable, anti-seepage, impact-resistant, and the civil work of it should simple construct, repair and remove; The layout should make the water flow smoothly without local scour. Cofferdam joints and slope connections should be reliable to avoid cofferdam failure which will cause concentrated leakage. Traditional temporary water retaining and flood control technology is often limited by site conditions, and soil materials are often in short supply, which will affect its use, like clay embankment, earth bag embankment, willow stone (soil) pillow, pile willow (pile plate) soil and other technologies. Comparing it, rigid metal (non-metal) prefabricated structure water retaining wall has some advantages, like fast and convenient installation, good water retaining effect, stability structure. However, the cost of this new structure is relatively high, reaching RMB 2200 per linear meter[1], thus, the scope of its application is also limited. It is urgently to develop a new-type retaining wall in flood control which is safe and reliable, economical and easy to construct, which has the advantages of quick and convenient installation of combined assembly structure, but not completely relying on the rigidity and anchoring of the structure to maintain stability. In order to meet the market demands, we have developed a cage-type retaining wall which can be used in the flood season as the bank protection sub-embankment or temporary cofferdam.

It not only requires the stability of flood wall structure, but also needs to ensure that there is no seepage damage under the action of water head. The impervious material in flood fighting and rescue engineering should be reliable and convenient to construct Conventional impervious
materials such as concrete, clay, etc. have a limitation, because of the rescue time, site conditions, cost and other factors. So it is an important problem to settle urgently in flood control to develop a new-type retaining wall which is safe and reliable, economical and easy to construct, making use of the advantages of quick and convenient installation of combined assembly structure, but not completely relying on the rigidity and anchoring of the structure itself to maintain stability. The composite geomembrane is a water-tight anti-seepage material which is made with plastic film as anti-seepage substrate, compounded with non-woven fabric. Due to advantages of high tensile strength, good anti-seepage performance, convenient for construction and low cost, it is an anti-seepage material for water conservancy and hydropower project with strong competitiveness[2]. In addition, the geomembrane has good aging resistance, especially applicable to use in water and soil. Therefore, it is widely applied for channel seepage prevention, reservoir anti-seepage reinforcement against risk of diseases[3-5], reservoir basin anti-seepage[6-7], construction cofferdam[8], water gate[9] and similar projects. However, further study is still needed to exert its excellent engineering properties in flood control.

The retaining wall is a folding-open cage structure which is mainly composed of square steel and wire mesh. The water retaining wall is mainly composed of square steel, wire mesh, folding open cage structure, with a wear-resistant waterproof bag that can be filled with water, soil, sand, gravel and other materials, and with embedded composite geomembrane upstream face for water retaining or temporary cofferdam. This paper mainly introduces the structure of the cage-type retaining wall, calculates the anti-slip stability, and analyzes the influence of the seepage pressure generated by the composite geomembrane embedded at different depths in front of the wall by establishing a model and conducting calculation through the use of finite element software COMSOL-Multi-physics, and the notices in the engineering application of the retaining wall are also discussed in this paper.

2. Structure Design and Implementation of Cage-type Retaining Wall

2.1 Structure Design of Cage-type Retaining Wall

![Fig.1 Structure of Cage-type Retaining Wall](image)

Fig. 1 is a structure of the square steel frame, steel mesh, built-in water bag, and anti-seepage-cloth. The square steel frame is made of Q235 square steel by welding, the anti-seepage-cloth is made of PVC and the steel mesh is made of φ6m steel wires, with the spacing of 10cm. The cage-type retaining wall may be assembled in combination according to different water retaining requirements. As shown in Fig. 1b, the bottom layer consists of two 1.5m units of the cage-type retaining wall and the top layer consists of one 1.0m unit. The assembled multi-layer retaining wall is up to 4.0m high, which can meet the needs of flood control temporary cofferdams, etc.
2.2 Engineering Application Process of Cage-type Retaining Wall

The engineering application process of the cage-type retaining wall is as shown in Fig.2. During the non-flood season, a storage warehouse of the retaining wall is stetted in the river section where the flooding may occur. When the flood season comes, the materials such as the square steel frame are quickly carried to the area where the embankment or sub-bank needs to be heightened. The materials are assembled into the cage frame unit quickly, and the frame units are combined together in the engineering site. Then, the composite geomembranes are be laid out, thus a cage-type retaining wall is formed. Next, it will be filled with water or soil, even the mixture. Generally, the water in the river way may be pumped into the cage-type retaining wall to maintain the stability. Alternatively, the materials such as soil, silt or gravel may also be filled locally according to the site conditions.

Compared to other flood control measures like geo-bag and masonry wall, the cage-type retaining wall has the following three advantages:

1. Only small storage space required, and quick and easy to install: A batch of square steel frames are prefabricated before the coming of the flood season. The frames have regular shapes and can be piled up in storage, therefore, only a small storage space is required. When the flood season comes, the frames will be applied in water retaining after simply assembled without welding, and layout of the geomembrane. According to engineering experience, the preparation of the cage-type retaining wall for 1km embankment can be completed by 15 workers within 8 hours;

2. Light structure, and flexible: It can provide quick reinforcement for the weak parts of the engineering structure. The 1m-unit frame needs 27kg square steel, and the 1.5m-unit frame needs 36kg. When the flood season comes, the cage-type retaining wall may be quickly transported to the weak part of the engineering structure, and putted into use after assembled, thus it starts working.

3. Low engineering invest: According to engineering experience, the total investment amount of the cage-type retaining wall is RMB1875/linear meter in 3 years, including materials and labor costs. It is only 1/3 of the total investment amount of the soil bag wall within 3 years which is RMB 5250/linear meter. In addition, the annual investment amount will gradually decreases, with the increase of the operation time.

3. Stability Calculation of the Cage-type Retaining Wall

The stability of the cage-type retaining wall is the key whether the engineering benefits may be brought. Fig.3 shows the forces applied onto the cage-type retaining wall during its application, where, the main loads include the structural weight (including the weight of the frame and the water filled inside), upstream water pressure, wave pressure and base uplift pressure. Normally, when a horizontal geomembrane bedding is laid in front of the water wall, the length of the bedding plays a key role in reducing the base uplift pressure. Therefore, to perform the checking calculation for the stability of the retaining wall, the value of the base uplift pressure should be first calculated first.
According to the structural form of the cage-type retaining wall, this paper will optimize the laying length of the horizontal geomembrane which is embedded on the upstream face of the retaining wall. The optimal design is carried out in the light of the selected four cases, i.e. 2m, 1m, 0.5m and 0m (no geomembrane is laid out) to determine the optimal layout length in front of the wall. On this basis, the check calculation on the stability of the retaining wall is conducted.

3.1 Base Pore Calculation
The three-dimensional finite element model is established (Fig. 4), based on the structure of the cage-type retaining wall and the daily water retaining and flood-season use of cofferdam. The X direction of the model is the direction of the parallel flood-control wall, it is positive from the left bank to the right bank, and the calculation range is 10m for each of the left and right banks. The Z-direction is the direction of the horizontal vertical flood control wall, it is positive from the upstream to the downstream, and the calculation range is 20m for each of the upstream and downstream. The Y direction is the vertical direction, it is positive from the bottom surface to the top surface, and the 6m taken downward from the horizontal surface is the calculation range in the vertical direction of the model. In the model, the length of the retaining wall is 10m, and the depth of the composite geomembrane as the anti-seepage body in the water-facing surface is 2.0m, 1.0m, 0.5m, and 0.0m, respectively.

The 6m below the ground is taken as the calculation range of the model. It is divided into three layers, and each layer is 2m thick. Layer 1 simulates clay, Layer 2 simulates micro-weathered bedrock, and Layer 3 simulates fresh bedrock. The permeability coefficient and pore ratio of each layer gradually decrease with the increase of the depth, as shown in Table 1. The cage-type retaining wall operates in the static water retaining state, with the upstream retaining water height of 1.0m and the downstream water retaining height of 0m. The dimension of each standard cage is 1*1*1m. The volume of each built-in bag is 1m$^3$. The built-in bags are filled with water inside, and the water weight is 1T. The anti-seepage cloth on the upstream face is embedded by 2.0m, 1.0m, 0.5m and 0.0m respectively. The calculation conditions are shown in Table 2.

There are mainly three boundary types in the calculation model, the known water head boundary, the seepage boundary and the impervious boundary: (1) The known water head boundary includes the upstream of the flood control wall, the anti-seepage cloth and the water contact level; (2) The seepage boundary is the downstream of the flood wall zone; (3) The impervious boundary includes the boundaries on both sides of the flood control wall and the interception boundary of the upstream foundation bottom. The computational analysis of the model is mainly carried out using the general finite element software COMSOL Multi-physics.

| Table 1 Calculation Parameters of the Model |
|--------------------------------------------|
| Material                  | Seepage Coefficient (m/s) | Pore Ratio |
|----------------------------|----------------------------|------------|
| Anti-seepage cloth        | $1.0 \times 10^{-10}$     | 0.01       |
| Embankment                | $1.0 \times 10^{-7}$      | 0.2        |
| Layer 1                   | $1.0 \times 10^{-6}$      | 0.20       |
| Layer 2                   | $1.0 \times 10^{-7}$      | 0.19       |
| Layer 3                   | $1.0 \times 10^{-8}$      | 0.18       |

| Table 2 Calculated Conditions |
|-------------------------------|
| Calculated Conditions | Depth of Anti-seepage Cloth (m) | Upstream Water Level (m) | Downstream Water Level (m) |
|-------------------------|---------------------------------|--------------------------|----------------------------|
| a                       | 0                               | 1.0                      | 0                          |
| b                       | 0.5                             | 1.0                      | 0                          |
| c                       | 1.0                             | 1.0                      | 0                          |
| d                       | 2.0                             | 1.0                      | 0                          |
The base pore water pressure distribution is shown in Fig. 5. The pore pressure distribution line is taken as the bottom center line of the retaining wall. It can be seen from the figure that the bottom hole pressure of the water retaining wall is generally distributed linearly, and gradually decreases with the increase of the length of the horizontal geomembrane bedding in front of the wall. When the bedding in front of the wall is 2m long, the maximum hole pressure of the dam foundation is 3739Pa, with the water head of 0.37m water head. When the bedding in front of the wall is 1m long, the maximum pore pressure of the wall foundation is 4915Pa, with the water head of 0.49m. When the bedding in front of the wall is 0.5m long, the maximum pore pressure of the wall foundation is 5995Pa, with the water head of 0.60m. And, when no geomembrane is laid out in front of the wall, the maximum pore pressure of the wall foundation is 9800Pa, with the water head of 0.98m head. Under each working condition, the downstream pore pressure of the wall is 0.
3.2 Check-calculation of Retaining Wall Stability
For the anti-sliding stability calculation of the cage-type retaining wall, refer to the provisions of Section 7.3.6 of the Design Specification for Sluice (SL 265-2016), and the calculation formula for anti-sliding stability is [10]:

\[ K = \frac{f'}{\sum W - \sum P} \]

Where,

\[ \Sigma W \] normal score of all the loads applied onto the dam (including the uplift pressure), relative to the sliding plane, in kN;
\[ \Sigma P \] tangential score of all the loads applied onto the dam (including the uplift pressure), relative to the sliding plane, in kN;
\[ f' \] shear-resistant friction coefficient between the base surface of the sluice chamber and the rock foundation.

When the cage and built-in water bag are placed on the ground, the cage will be embedded into the soil, and will generate friction, and even the built-in water bag is no water, it will also generate friction relative to the ground. When the built-in water bag is filled with water to achieve water retaining, and when the anchor rib is inserted into the bottom of the retaining wall, the friction coefficient of the foundation surface is 1.48 according to the field test.

According to the provisions of Section E.0.1 [10] of the Design Specification for Sluice (SL 265-2016), the average wave height and average wave period for the wave pressure can be calculated according to the formula of the test station. The base uplift pressure is obtained by integration after the pore water pressure at the bottom of the retaining wall is obtained through the finite element calculation.

The calculation results about the stability of the cage-type retaining wall are shown in Table 3. It can be seen from the table that the anti-sliding stability safety factor of the cage-type retaining wall is 1.28 even if no geomembrane is laid, which is 0.03 higher than the specified value of 1.25, which can meet the requirements. When the 0.5m-long geomembrane horizontal bedding is laid out, the anti-sliding stability safety factor of the structure is increased to 1.58. When the laying length is 1m and 2m, the anti-sliding stability safety factors are 1.74 and 1.91, respectively. From the calculation results, it is known that the setting of the geomembrane horizontal bedding is very necessary, which can significantly improve the overall anti-sliding stability of the structure. From engineering safety and economy, it is recommended that the length of geomembrane bedding should be 0.5m.

### Table 3 Calculation Results about the Stability of Cage-type Flood Control Wall

| Calculated Conditions | Water Pressure (N) | Uplift Pressure (N) | Wave Pressure (N) | Self Weight (N) | Horizontal Force (N) | Vertical Force (N) | Base Friction Coefficient | Anti-sliding Stability Safety Coefficient | Allowable Standard Value |
|-----------------------|--------------------|---------------------|------------------|----------------|----------------------|---------------------|--------------------------|--------------------------------------------|------------------------|
| a                     | 4900.00            | 4951.00             | 1017.23          | 10054.80       | 5917.23              | 5102.90             | 1.48                     | 1.28                        | 1.25                    |
| b                     | 4900.00            | 3723.00             | 1017.23          | 10054.80       | 5917.23              | 6331.80             | 1.48                     | 1.58                        | 1.25                    |
| c                     | 4900.00            | 3113.00             | 1017.23          | 10054.80       | 5917.23              | 6941.30             | 1.48                     | 1.74                        | 1.25                    |
| d                     | 4900.00            | 2409.00             | 1017.23          | 10054.80       | 5917.23              | 7645.40             | 1.48                     | 1.91                        | 1.25                    |

4. Application Notice of Cage-type Retaining Wall
The cage-type retaining wall has outstanding advantages, and can meet the needs of flood control. However, the following three points shall be noticed in actual application:

1. The cage-type retaining wall adopts the composite geomembrane as the anti-seepage body, and its density is less than that of water. Therefore, the weight measures shall be taken during the embedding of the geomembrane, to prevent it floats and the seepage diameter is shortened;
(2) When the composite geomembrane is being embedded, it needs to be attached to the cage-type retaining wall by the strapping tape. Therefore, it is recommended to reserve about 5cm during strapping and embedding, in order to prevent the “cramp effect” [11] if the membrane is stretched during embedding.

(3) In the friction coefficient field test, the foundation of the cage-type retaining wall is clay. The measured friction coefficient can meet the requirements. When the foundation of another type of soil is used, the field test shall be carried out to determine the actual friction coefficient. If the requirements are not met, the embedding depth of the anchor bar may be increased or the soil or stone may be filled to keep the overall stability of the structure.

5. Conclusion
During the flood control, there are many problems such as urgency in time, insufficient supply of soil materials, and inconvenient construction. The cage-type retaining wall has the advantages of quick and easy installation and low engineering cost. It can be filled with water, silt, earth or gravel, according the site conditions to achieve stable and safe water retaining with reliable structure and strong applicability, which can meet the flood control requirements and has worth of popularization.

The check-calculation on the anti-sliding stability of the cage-type retaining wall is carried out based on different laying lengths of the geomembrane horizontal bedding (0m, 0.5m, 1.0m and 2.0m). The calculation results show that even if the composite geomembrane is not laid, the structure can also maintain the general stability, and the safety factor is 1.30. However, the laying of the geomembrane with a certain length can significantly reduce the uplift pressure and improve the overall stability of the structure. From engineering safety and economy, it is recommended to lay the geomembrane with the length of 0.5m.

In the actual application of the cage-type retaining wall, weighing measures are required for the composite geomembrane in the horizontal bedding section, and 5cm should be reserved during strapping to prevent the occurrence of the “cramp effect”. The overall anti-sliding stability coefficient of the structure shall be measured by the field test. When it does not meet the requirement, the stability can be increased by increasing the depth of anchor bar or filling the cage with earth or gravel.

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