Research Article

Research on Design of Extensible Mobile Flood Control Wall in Underground

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1. Introduction

In recent years, a short period of heavy rain has frequently caused waterlogging problems in cities and towns, especially in underground garages, subway, and other underground space entrances. The timely blocking of flood inflow can effectively avoid the crisis of human safety and the normal operation of rail transit. In addition to the rational design of the flood drainage pipe network, there is an urgent need for a device that is convenient, quick, and easy to install and has a good flood control effect to play an active role. The mobile flood control wall can not only be installed quickly during the flood season but also can be easily disassembled and folded for storage during the non-flood season. As a temporary flood control equipment to deal with sudden storms and floods, it is widely used at the entrances and exits of important underground spaces in cities and towns.

The first mobile flood wall in the world was installed in the urban area of Cologne, Germany in 1984, and then the same type of flood wall was put into use successively in places such as the Danube River in Austria, Baja, Hungary, and Brado in the Czech Republic [1–3]. At the beginning of the 21st century, China begins to design and produce mobile flood control wall equipment. The new mobile flood control wall with aluminum alloy material instead of steel plate has been successfully put into use in Suzhou, Shanghai, Wuhan, and other places [4–6]. Many scholars at home and abroad have conducted a lot of research work on the structural design, material selection, and performance analysis of flood control walls [7–10]. Pan [11] designed an ecological flood control based on the full use of the basic functions of flood control projects. The wall is used for flood control and river treatment during flood season, which can effectively improve river pollution and protect the ecological environment on both sides of the bank. Xu et al. [12] used the elastic mechanics method to analyze and solve the problems of material selection and size design in order to better grasp the force and deformation of the mobile flood control wall during work, which played a guiding role in the flood control project. Ni et al. [13] elaborated on the application prospects and structural characteristics of light mobile flood control walls, combined with theoretical calculations and finite
element analysis techniques and focused on explaining the structural forces and failure modes of light mobile flood control walls. Zhang et al. [14] studied a new type of mobile flood control wall based on urban underground space entrances and exits. The stability and safety of flood control walls were analyzed through the material mechanics method, which provided a positive reference for urban underground space flood control.Getter et al. [15] used dynamic methods to carry out finite element simulations and analyzed the maximum impact load that the flood wall can withstand under dynamic conditions, providing additional guidance for static design schemes. In addition, the scientific research team and the company also applied for a number of patented technologies related to mobile flood control walls under the strong support of national policies [16–19] and manufactured various types of assemblies for use in flood control projects. However, most of the existing mobile flood control walls are made of aluminum alloy materials and have a single structure. There is still room for optimization in terms of overall structure design and material selection of key components such as main baffles, support rods, and beams.

According to the requirements of flood control at the entrances and exits of important underground spaces, considering the versatility of equipment and the convenience of installation and disassembly, this paper designs an expandable and mobile underground flood control wall. Corrosion-resistant and impact-resistant interstitial-free-steel materials are selected for key components such as the connecting column, rotating handle, and support rods. The connecting column, rotating handle, and support rods are spliced through the structural design of the connecting column, and the expansion of the flood control wall is controlled by rotating the handle, and the pressure is reduced by increasing the contact area during the flood control process. It can effectively alleviate the adverse effects of urban waterlogging on underground space projects.

2. Design Principle

The expandable and mobile underground flood control wall has well flood control and impact resistance. It is mainly composed of a retractable baffle, a plug-in support rod, a mortise-and-tenon structure connecting column, a rotating handle, a safety bolt, and pins. The design principle of the equipment is universal performance and easy installation and disassembly. The schematic diagram of the assembly is shown in Figure 1 below. The main stressed components are the baffle, support rods, and connecting column. When sudden storms and floods cause serious waterlogging problems in towns, the retractable baffle with support rods on the back is fixed to the entrance and exit of the underground space with pins, and the baffle and support rods are connected by plug-in connection with a tilt angle of 45 degrees to 105 degrees. If the waterlogging area is large, the baffle can be unfolded by the rotating handle; or the baffle can be spliced according to the modularity through the connecting column, and the different working methods of the flood control wall can be determined according to the different intensity and scope of the waterlogging. The underground flood walls designed in this paper are all mechanical structures, which are convenient to assemble, disassemble, and maintain. They ensure that there is no risk of leakage during the process of blocking waterlogging and ensure that the maximum stress and offset distance are within a safe range when the flood wall is fully expanded.

3. Basis of Theoretical

3.1. Combined Load Analysis. This paper considers the effects of combined loads such as static water, dynamic water, and impact to calculate and analyze the bearing capacity of the expandable and mobile flood wall assembly. Static water load is the most common load state of flood control walls, as shown in Figure 2. The pressure of static water acts on the baffle of the flood wall, and the load of the baffle is transferred to the support rod. Therefore, the hydrostatic pressure $q_1$ can be calculated by the following:

$$q_1 = \rho ghL,$$

where, $\rho$ is the density of water (if the content of suspended solids in the water is large, a larger water density can be selected appropriately), $h$ is the water retaining height of the flood wall, $L$ is the span length of the flood wall, and $g$ is the acceleration of gravity.

When the flood control wall is fixed in the flowing water area, if the longitudinal direction of the flood control wall is not parallel to the direction of the water flow, the movement of the water will generate a dynamic water load on the baffle, as shown in Figure 3. Since the dynamic water load is caused by the impulse of water, according to the impulse, we get

$$F \cdot \Delta t = m \cdot (v \sin \alpha).$$

Then the calculation (3) of the dynamic water load $q_2$ is as follows:

$$\begin{cases} q_2 h \Delta t = \rho (hLv \sin \alpha \Delta t)v \sin \alpha, \\ q_2 = \rho (v \sin \alpha)^2 L, \end{cases}$$

where, $\alpha$ represents the angle between the flood and the baffle, and $v$ represents the water velocity.

When waterlogging disasters occur, the floods are often accompanied by drifting objects of different shapes. When they hit the flood wall, the impact load generated cannot be ignored. This article takes small drifting objects such as block and bicycle wheels as the main analysis objects and assumes that the drifting objects will not deform when impacted. Suppose the elastic stiffness of the baffle is $C_F$ (N/m). According to the principle of conservation of energy, the kinetic energy of the drifting object is transformed into the strain energy of the assembly, which is obtained by the energy conservation formula:

$$\frac{1}{2} m (v \sin \alpha)^2 = \frac{1}{2} C_F \epsilon^2,$$
where, \( m \) is the mass of the drifting object, \( v \) is the speed of the drifting object (approximately equal to the water speed), \( \alpha \) is the attack angle of the drifting object and the flood wall, and \( \eta \) is the structural deformation. The impact load can be expressed as (5), and the schematic diagram of the impact load is shown in Figure 4.

\[
F = \eta C_F = v \sin \alpha \sqrt{m C_F}. \tag{5}
\]

3.2. Stability Analysis. The design of an expandable mobile underground flood control wall in this paper focuses on safe flood prevention at the entrances and exits of underground spaces in cities and towns, and the inclination angle of the baffle is \( 45^\circ \leq \theta \leq 105^\circ \) under working conditions. The analysis of assembly stability [20, 21] mainly focuses on the
calculation of anti-sliding stability, anti-tilting stability and base stress calculation of the baffle and support rod along the bottom of the foundation, as well as the calculation of the internal force of the connecting column. The formula for calculating the anti-sliding stability of support rod of the flood control wall along the bottom of the foundation is as follows:

\[ K_c = \frac{f \sum G_{rod}}{\sum L_{rod}} \]  

(6)

where, \( K_c \) represents the safety factor of anti-sliding stability along the base surface of the support rod, which must be less than 1.25 under the basic load combination; \( f \) represents the coefficient of friction between the base surface and the foundation, and the flood control wall is mostly in a cement layer. Take \( f = 0.45 \), \( \sum G_{rod} \) represents all the vertical loads acting on the support rod; \( \sum L_{rod} \) represents all the lateral loads acting on the support rod. The formula for calculating the anti-tilting stability of the baffle of the flood control wall is as follows:

\[ K_0 = \frac{\sum M_{beffle}}{\sum H_{beffle}} \]  

(7)

where \( K_0 \) represents the anti-tilting stability safety factor, and the basic load combination needs to be less than 1.50; \( \sum M_{beffle} \) represents the vertical anti-tilting moment of the baffle; \( \sum H_{beffle} \) represents the lateral anti-tilting moment of the baffle. The base stress calculation formula is as follows:

\[ P_m = \frac{\sum G_{rod}}{S_{rod}} \pm \frac{\sum (M_{beffle} + H_{beffle})}{W_{beffle}} \]  

(8)

where \( P_m \) represents the maximum or minimum base stress of the support rod; \( \sum G_{rod} \) represents all the loads acting on the support rods of the flood control wall perpendicular to the horizontal plane; \( \sum (M_{beffle} + H_{beffle}) \) represents the load acting on the flood control wall baffle. The sum of all moments above; \( S_{rod} \) represents the area of the base surface of the support rod; \( W_{beffle} \) represents the cross-sectional distance of the baffle mandrel. The schematic diagram of the force is shown in Figure 5.

In order to increase the working area of the flood control wall, two ways of modular splicing and rotating expansion are designed in this paper. When the connecting column and baffle are subjected to horizontal force, they are prone to bend and fracture to different degrees. Therefore, the gapless atomic steel material is selected for the key components such as the baffle and the connecting column, and the tenon-and-mortise structural connecting column is designed to effectively increase the stability and impact resistance of the flood control wall. When analyzing the internal force of the assembly during the flood control process, first determine the position of the dangerous section of the connecting column, as shown in Figure 6. Then calculate the maximum bending moment \( M_{max} \) and shear force \( F_{max} \) on the dangerous section according to the possible load combination.

Approximately calculated from the relevant formulas of material mechanics, the maximum normal stress of the dangerous section is

\[ \varphi_{max} = \frac{M_{max}y}{I_z}, \]  

(9)

where, \( I_z \) is the moment of inertia of the dangerous section, and \( y \) is the ordinate of the normal stress point. The maximum shear stress of the dangerous section is

\[ \varphi_{max} = \frac{F_{max}Q_z}{I_b}, \]  

(10)

where \( Q_z \) is the area moment of the area on the either side of the dangerous section from the neutral plane to the neutral plane, and \( b \) is the width of the horizontal slope. After obtaining the maximum normal stress and maximum shear stress on the dangerous section, you can refer to the following (11) for internal check.

\[ \begin{cases} \varphi_{max}k < 1, \\ \varphi[\varphi] < 1, \end{cases} \]  

(11)

where \( k \) represents the safety factor, which is generally 0.58. [\( \varphi \)] represents the allowable normal stress, and \( [\varphi] \) represents the allowable shear stress.

4. Experimental Verification and Discussion

During the modeling process, the selected materials and property parameters are shown in Table 1. The main baffle is made of 6005A-T6 aluminum alloy, and the connecting column, support rod, and rotating handle are made of IF alloy steel [22, 23].

The finite element analysis software Abaqus and HyperMesh & Hyperview are used for solution calculation and pre- and postprocessing. First consider the simulation experiment of the assembly in the hydrostatic state, and the experimental results are shown in Figure 7 below. When the
flood still contacts the entire baffle plane, the main force-bearing components are transmitted to the support rod. At this time, the maximum stress on the support rod is 45.682 Mpa, and the displacement of the assembly in still water is 0.532 mm, which can effectively block the effect.

The assembly is vulnerable to the impact of objects of different shapes on the surface of the baffle in the dynamic state. At this time, it is necessary to focus on the impact of the impact load on the assembly. Assuming that the dynamic water speed is 3 m/s when the flood season comes, the arc-shaped block (8 Kg) driving the roadside impacts the flood control wall at the same speed.

When the block shown in Figure 8 impacts the flood control wall, the main force-bearing parts of the assembly are baffles, connecting columns, and support rods. The simulation experiment was carried out to analyze the maximum stress of each component of the flood control wall and the dangerous section under the combined load of dynamic water and impact. The experimental results are shown in Figure 9 below. The maximum stress at the fixed bracket of the support rod is 220.762 Mpa, the maximum stress at the mortise and the tenon joint of the connecting column is 56.919 Mpa, the maximum stress at the fully expanded state of the baffle is less than 23.970 Mpa, and the maximum offset distance of the assembly is 32.334 mm.
The simulation results show that the maximum bearing capacity of the extensible mobile flood control wall designed in this paper meets the allowable stress of the material under the combined loads of static water, dynamic water, and impact, and the safety is guaranteed, and it can be put into use when the flood season comes. The specific simulation data are shown in Table 2.

### 5. Conclusion

The expandable mobile underground flood control wall adopts mortise and tenon structure splicing and modular extension design. It is mainly used to protect the entrances and exits of important underground spaces in cities and towns during flood season. The finite element simulation experiment proves that it can be used under combined loads such as static water, dynamic water, and impact. Meet the safety performance requirements. Compared with traditional flood walls, it has the following advantages: (1) Modular and extended design, the size of the equipment can be set independently according to the working environment. (2) Mechanized design to ensure that there is no risk of electric leakage and electric shock during flood prevention work, and maintenance is convenient. (3) The telescopic design of the mortise-and-tenon structure provides quick installation and operation, convenient disassembly and storage and greatly reduces labor intensity. (4) The selected material has good corrosion resistance and impact resistance and can be disassembled for the passage of people and vehicles in an emergency.

### Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

### Conflicts of Interest

The authors declare that they have no known conflicts of interest.
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