Application of Larson Type Steel Sheet Pile in Preventing Breach Sealing

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Abstract. Research background: In recent years, with the continuous occurrence of extreme rainfall, excessive concentration of rainfall occurred from time to time, and dike breach was one of the most harmful disasters in flood disasters. For example, in July 2024, a dike breach occurred in TuanzhouDongting Lake, Huarong County, Yueyang, Hunan Province, and a dike breach occurred in Xiangtan County, Hunan Province, On August 10, 2023, the dike on the east side of Tanli Trunk Canal in Tanli Town, Wen 'an County, Hebei Province, upstream of the Daqing River, broke.

Purpose and significance: every breach in embankment engineering poses a serious threat to the safety of people's lives and property, so it is of great significance to conduct research on quickly and effectively sealing embankment breaches. Traditional methods of sealing breaches mostly use throwing stones, but the stones are limited by their weight and shape, and are washed away by the water flow before stabilizing on the riverbed, making it difficult to effectively seal breaches. Therefore, traditional throwing stone sealing methods are often difficult to succeed at breaches with turbulent water flow. This article explores the application of steel sheet piles from the perspective of sealing gaps, analyzes and summarizes the construction process and technology of Larson IV steel sheet piles in sealing gaps, and establishes finite element models based on different sealing schemes to calculate and analyze performance indicators such as strength, stiffness, and stability. Due to the strong anchoring force of soil on steel sheet piles, the success rate of sealing is greatly improved compared to stone throwing sealing, and the sealing time is significantly saved. The calculation results show that using steel sheet pile enclosure structure to seal embankment breaches is completely feasible.

Keywords: Larson type steel sheet pile; Crack closure; Finite element modeling analysis

1 Introduction

Embankment engineering refers to water retaining structures built along the edges of rivers, canals, lakes, coasts, flood discharge areas, diversion areas, and reclamation areas. It is also an important component of flood control and water storage projects. In

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recent years, with the increase of extreme weather worldwide, potential breach events have occurred frequently, such as the breach of the Dongting Lake embankment in Tuanzhou, Huarong County, Yueyang City, Hunan Province in July 2024; From October 7th to October 9th, 2021, a production embankment overflow and bursting incident occurred in Ziyang Village, Chaoyi Town, Dali County. In June 2010, a breach occurred in the embankment of Changhe River in Jiangxi Province, as shown in Figure 1.

Fig. 1. Site of embankment breach

The traditional method of sealing breaches mostly uses trucks to throw and fill stones, which is more suitable for breaches with small scale and low flow rate; Due to factors such as the weight and volume of rocks, it is often difficult to successfully seal large-scale, high flow rate breaches. Therefore, exploring a method that can quickly seal breaches in embankments has become an urgent problem that water conservancy workers need to solve.

As is well known, steel sheet pile enclosure structure is a common construction structure for cofferdams. As a structural material, steel sheet piles have the characteristics of high strength, high toughness, and high stability, which can ensure that they can effectively withstand various stresses in different engineering application scenarios. Therefore, steel sheet piles are often used as structural materials for building enclosure structures. Steel sheet pile cofferdam is suitable for complex geological conditions such as deep water foundation pits, sandy soil, and high-speed beaches due to its strong bearing capacity, good waterproofing performance, and high economy. [1]As a type of steel structure, steel sheet piles have a high reuse rate. Zhong Qi et al. [2] and Zhou Xinya et al. [3] selected and designed the steel sheet pile cofferdam, which improved the construction efficiency of the cofferdam.

Taking the Larson type steel sheet pile enclosure structure as an example, finite element numerical simulation analysis was conducted based on different construction closure sequences to analyze the stress state and anti overturning ability of the steel sheet pile enclosure under high flow velocity. A feasible notch closure construction method was summarized. The calculation results show that the driving depth of steel sheet piles is usually 1-2 times the water level height. In this state, the steel sheet pile enclosure structure has strong anti overturning ability, and its stiffness, strength, and stability can meet the requirements for sealing breaches. Therefore, the application of steel sheet pile enclosure structure to seal breaches is feasible.

2 The Choice of Breach Plugging Scheme

In the early stage of the break, the break door is usually at a higher water level, and the flow velocity and drop of the break door are also the maximum. At this time, if the break is immediately blocked, the average flow energy area NA[4] is large, and the sealing method of rippestone block is often difficult to succeed.1998 Jiujiang River breach(The flow rate is 3.5m/s, The water level drop is 3.4m,NA is 11.9t/(s·m)).After years of experience, the researchers found that when NA > 10t/ (s·m), the riprap blocking method is often difficult to succeed. Therefore, a series of engineering measures can be considered to reduce the average NA of the flow energy area, so as to improve the success rate of breach plugging. As shown in Figure 2

2.1 Berm Construction

At the early stage of the dike breach, the water surface drop is large, the original dike damage surface is loose, it must be strengthened on both sides of the wrap head, effective wrap head reinforcement treatment can curb the problem of more serious landslide at the dike head, avoid greater losses in the rescue process, so as to create conditions for the later dike breach plugging operation. The so-called levee wrapped head technology refers to the initial stage of the levee breach, maintenance of the broken levee at the breach, and treatment as soon as possible when a small part of the water is found to have just appeared. In the process of rush repair of the wrap head, it is necessary to dig out the soft part of the embankment body first, and then choose the appropriate material to build the wrap head. After the treatment of the wrapping head of the levee, the bidirectional berm can be constructed in the direction of the vertical levee axis, which can minimize the slope of the water flow and lay the foundation for the next steel sheet pile construction. The cross-sectional layout of the embankment is shown in Figure 2. The vertical berm length needs to be analyzed according to the specific breach situation, and it is best to control the average flow energy area NA within 10t/(s·m), so that the success rate of plugging the breach will be greatly improved. Combined with the theoretical analysis, the vertical berm length should be about twice the width of the dike break, so that the transverse anti-slip strength of the dike break will be significantly improved, creating good geological conditions for the next step of implanting steel sheet piles.

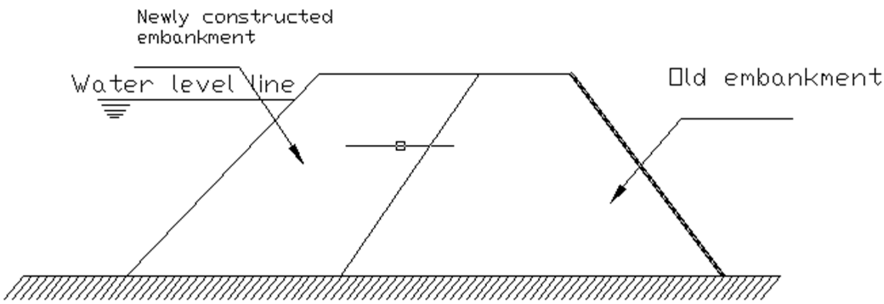

Fig. 2. Berm profile layout

2.2 Implantation and Spatial Arrangement of Steel Sheet Pile

Steel sheet piles can be implanted after the completion of the berm construction. For the spatial arrangement of steel sheet piles, the author simulated two types of linear and arch sealing methods. The calculation results show that the arch arrangement in the horizontal direction can better resist the upstream water pressure and increase the stability of the steel sheet pile envelope structure. The schematic diagram of the structure layout is shown in Figure 3.

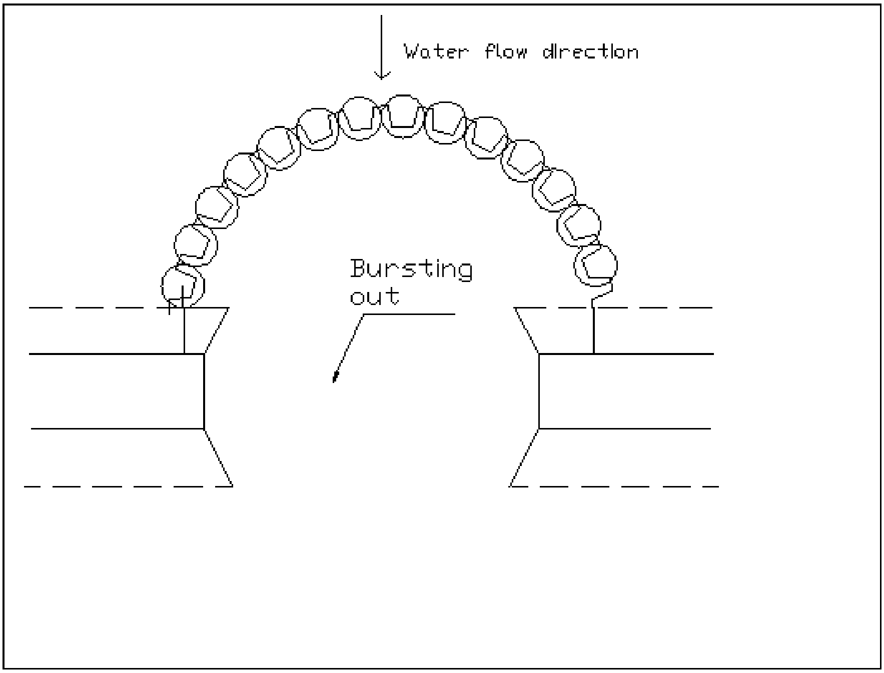

Fig. 3. Local pilot hole plan of Larsen type steel sheet pile

Table 1. Mechanical properties of Larsen steel sheet pile

Model number	width (mm)	height (mm)	Plate thick-ness(mm)	Interface characteristics per meter of plate			
				Area of section(cm^2)	Theoretical weight(kg/m^2)	Moment of inertia(cm^4)	Modulus of section (cm^3)
Larsen IV type	400	170	15.5	242.5	190	38600	2270
Larsen VI type	600	210	18	225.5	177	56700	2700

Considering that the water flow in the construction area has a certain flow rate, it is difficult to implant steel sheet piles directly. The screw drill pilot hole can be used to implant steel sheet piles. The pilot hole implantation can reduce the lateral displacement of steel sheet piles, enhance the anti-overturning ability and stability, and thus improve the construction efficiency.

2.3 Determination of Planting Depth of Steel Sheet Pile

Based on the specific hydrogeological conditions of the breach location, establish a finite element numerical model for analysis and calculate the depth of steel sheet pile implantation. The mechanical properties of Larson type steel sheet piles are shown in Table 1. The location of the breach is on the right side of the embankment, with a width of 5.6m, a water level of 3.5m, and a water flow velocity of 10m/s. According to the detailed geological survey data of this location, the geological structure mainly includes cultivated soil, silty clay, and silt. The characteristics of each soil layer are shown in Table 2.

Table 2. Model calculated material parameters

Name	Depth /m	Thickness /m	Severe /$kN \cdot m^{-3}$	Material cohesion /$kN \cdot m^{-2}$	Angle of internal friction/(°)
Heavy cultivated soil	0～0.6	0.6	16.5	8.0	10
Silty clay	0.6～1.7	1.1	19.5	23.6	15.0
Silt	1.7～4.8	3.1	17.2	12	6.0
Medium sand	4.8～7.3	2.5	18.2	3.0	28
Mucky soil	7.3～15	7.7	17.5	15.0	10.0

Firstly, determine the geometric dimensions and parameters of the finite element numerical model, partition the mesh, solve the calculation, and finally obtain the calculation results.

2.3.1 Model Construction.

The embankment body, foundation, steel sheet piles, and internal support components are all simulated using solid elements. In terms of boundary conditions, based on existing research and engineering practice, the bottom of the model is set as a fixed boundary constraint, the surrounding areas are set as normal boundary constraints, and the top is set as the free end. In terms of grid division, local grid refinement is carried out around the breach while ensuring computational accuracy and efficiency. The finite element mesh division is shown in Figures 4 and 5.

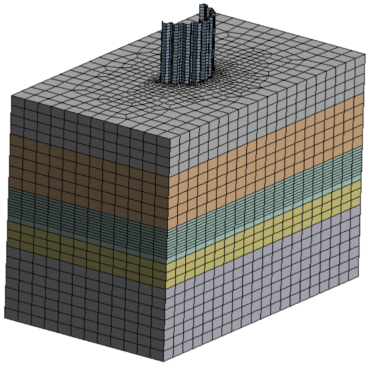

Fig. 4. Local mesh model of Larson type steel sheet pile

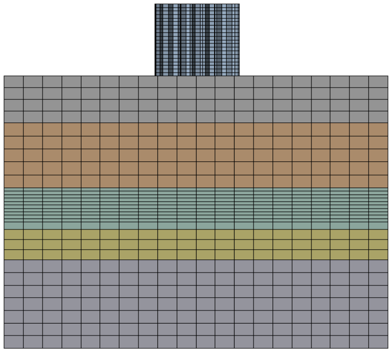

Fig. 5. Elevation model of Larson type steel sheet pile

2.3.2 Calculate Parameter Settings.

The mechanical properties of both foundation soil and roadbed fill exhibit significant nonlinear characteristics. Therefore, in the simulation process, the Mohr Coulomb elastoplastic constitutive model was used to simulate the foundation soil and roadbed fill. Steel sheet piles are simulated using plate elements, with an elastic modulus of 210GPa, Poisson's ratio of 0.3, and a bulk density of 78.5kN/m3; The steel support adopts beam elements, and the importance coefficient of the structure is γ 0=1.1. Materials such as steel sheet piles, internal supports, and roadbeds exhibit linear mechanical properties before reaching their yield strength, therefore elastic constitutive models are used for simulation calculations.

2.3.3 Model Calculation Analysis.

Based on a series of environmental and construction technology parameters simulations at the location of the breach, key construction technology parameters are obtained. Based on the theory of linear elastic buckling of structural small displacement materials, the stability of steel sheet pile enclosure results is analyzed through eigenvalue buckling analysis. The calculation of linear buckling load determines the critical load, buckling mode, and depth of steel sheet pile. [5].

For the convenience of calculation, the model conducted equivalent calculation analysis on the interaction between waves and water flow [6]. The calculation results of the model show that the burial depth of the steel sheet pile is 4m, the maximum horizontal displacement of the steel sheet pile is 87mm, and the maximum stress is σ 3=87.2MPa<[σ]. The calculation results are shown in Figures 6 and 7.

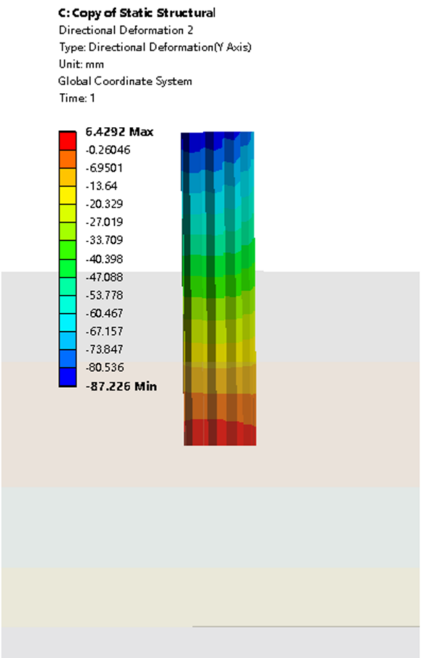

Fig. 6. Cloud map of maximum deformation of Larson type steel sheet pile

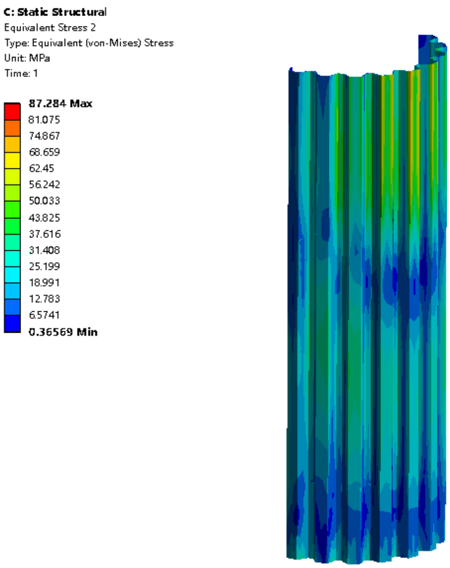

Fig. 7. Cloud map of maximum stress of Larson type steel sheet pile

2.4 Selection of Steel Sheet Pile Construction Sequence

According to the size of the breach and the site construction conditions, two different construction sequences can be considered.

Scheme 1: Close the two ends to the middle span

This method can be considered when no Marine pile driver is available on site. The concrete construction sequence is to implant steel sheet piles into the span at the same time from the top of the two occupied berm. With the forward construction of steel sheet piles, the construction of earth and rock in the rear can be promoted synchronously, thus increasing the stability of steel sheet pile structure.

Scheme 2: Midspan closure at both ends

In the case of having a Marine pile driver on site, it can be considered to start construction directly from the middle position of the breach. The concrete construction sequence is to insert steel sheet piles from the top of the arch to both ends of the berm at the same time. With the forward construction of steel sheet piles, the water flow posture will gradually change direction, and two currents will form a convection form to the position near the closure, acting as a stilling pool. In this way, the resistance of steel sheet piles will be reduced during the closure. After closure, the earth and rock sealing construction can be promoted synchronously until the sealing is completed.

In the construction process, in order to resist the impact of water flow, the steel sheet pile needs to be welded with the guide frame immediately after it is inserted to the design elevation, and form a whole with the steel sheet pile implanted in the early stage to cooperate with the force and increase the overall stability of the structure.

3 Conclusion

The construction of embankment breach sealing is one of the projects with complex construction organization, high technical content, and high safety risks. It has always been a key and difficult point in flood control and emergency rescue. Therefore, it is necessary to find a technical method that can quickly seal the breach. Based on theoretical analysis, this article preliminarily summarizes the key technologies for embankment sealing, explores the feasibility of applying steel sheet pile enclosure structure to embankment sealing, and summarizes the implementation points, which can provide useful reference for rescue construction teams participating in embankment sealing. The research results indicate that in general, the burial depth of steel sheet piles should be one to two times the depth of water flow to meet the technical requirements of stiffness, strength, and anti overturning. This article only conducted static analysis on a certain breach model, and has not yet conducted dynamic numerical simulation on the driving process of steel sheet piles. The next step of research should focus more on the dynamic study of the driving process.

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