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Analysis of the Mechanical Behaviour of Double-wall Steel Boxed Cofferdam Structures

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Abstract

In recent years, double-wall steel boxed cofferdams with bottom structures have been applied in the construction of deep-water caps for bridges. However, their mechanical properties are affected by many factors. To elucidate the mechanics influencing such double-wall steel boxed cofferdam configurations, an analytical and computational model was proposed. Through the three-dimensional finite element software midas civil, calculations and analyses were executed on a steel boxed cofferdam design example from the 10# pier pile foundation of the Xinjiang Kalasuke Reservoir's extra-large bridge and its platform construction. The alterations in mechanical states triggered by adjustments to the influential parameters, such as wall plate thickness, water injection height between double walls, and support rod spacing within the double walls of the steel boxed cofferdam, were discussed. Results show that, the optimal wall thickness for this cofferdam variant is between 5 and 6 mm, the controllable water injection height ranges from 3.4 m to 4.5 m, and consistently low-stress states occur across the bottom skeleton, secondary beam, and bottom plate throughout the construction process. The spacing between double-wall horizontal components greatly influences the stress and deformation of the inner and outer wall plates. The obtained conclusions provide a significantly reference value for the design theory and practical application of double-wall steel boxed cofferdam structures.

Keywords: Double-wall steel boxed cofferdam, Wall plate thickness, Water injection height, Spacing of support rods, Finite element method

1. Introduction

As a global leader in bridge construction, China has constructed nearly 800,000 road bridges and over 200,000 railway bridges [1]. With the ongoing introduction of innovative bridge structures, processes, and materials, the application and research on these new technologies have reached unparalleled dimensions of breadth and depth. In this context, considerable advancements have been made in deep-water foundation technology for bridge construction, with steel cofferdams being increasingly utilized during the construction of high pile platforms. Steel boxed cofferdams serve as significant temporary waterproofing structures during bridge construction [2]. When the bottom surface of the cap is elevated above the riverbed, or when a substantial layer of soft soil exists beneath the cap, steel boxed cofferdams can be employed as waterproofing measures for deep water foundation construction. Typically, a steel boxed cofferdam comprises a box structure with a bottom plate, wall plate, inner support, suspension, and positioning system. Its primary function is to provide a dry environment for platform construction. The bottom plate acts as a template for pouring bottom concrete, while the siding functions as a lateral form for pouring bottom concrete and cap concrete. The top surface can serve as an operational platform for concrete pouring. Single- and double-wall forms are the two main variations of steel boxed cofferdams. Single-wall steel boxed cofferdams are structurally simple, require lesser amounts of steel, and are straightforward to manufacture and assemble [3]. More recently, double-wall steel boxed cofferdams have emerged, offering a high degree of construction initiative by leveraging the buoyancy of water for assembly and sinking the hanging box. Their superior stiffness and excellent water isolation make them more compatible with the construction requirements of deep waters, high flow rates, and large-sized caps. They can also function as a protective platform against collisions [4]. However, because of their complex structure, high manufacturing precision requirements, and generally uneconomical component sizes selected during design, double-wall steel boxed cofferdams often fail to optimally exploit the mechanical properties of their materials. Consequently, investigating the mechanical influencing factors of double-wall hanging box steel cofferdams holds practical relevance for guiding engineering applications.

During construction and usage, steel cofferdams are subjected to varying degrees of damage and deformation, which can influence the safety of deep-water foundation construction. Previous studies on steel cofferdams predominantly targeted steel sheet pile cofferdams, steel sleeve cofferdams, and steel boxed cofferdams. Given the complex mechanical response mechanism of steel boxed cofferdams, an intensive study on their mechanical behavior and influencing factors is critical for ensuring the safety in deep water foundation construction. Numerous scholars have investigated aspects such as on-site monitoring [5], structural construction technology [6], mechanical properties [7], and structural optimization [8] of steel cofferdams. The more recently introduced double-wall hanging box steel cofferdam,

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however, has seen less discussion regarding the factors affecting its mechanics. Studies that elucidate the mechanical response mechanisms of double-wall steel boxed cofferdams in engineering applications are lacking in effective theoretical foundations, thereby necessitating further work.

This study proposes an analytical and computational model of a double-wall steel boxed cofferdam structure. Through the three-dimensional finite element software midas civil, calculations and analyses were conducted on the steel boxed cofferdam used in the 10# pier pile foundation of the Xinjiang Kalasuke Reservoir's extra-large bridge and platform construction. This study aims to enhance the design theory and engineering applications of double-wall steel boxed cofferdam structures.

2. State of the art

Numerous scholars have undertaken extensive studies on steel cofferdams. Banerjee [9] applied an elliptic integral to accurately address seepage problems, deriving a design diagram formula to obtain the seepage rate. This approach aids in preventing bottom uplift and piping that could potentially lead to cofferdam failure. However, his study lacked finite element analysis for verification. Kord J. Wissmann [10] executed a finite element analysis on the tension of sheet piles under combined soil - structure interaction, assessing the impacts of unit size and locking performance, among other factors, on sheet pile tension. This work resulted in an estimated formula for pile lock pulling force, yet this formula had limited applicability. Using the panel method of potential flow theory, Park M S [11] utilized ANSYS numerical analysis to calculate the hydrodynamic load of annular cofferdams, studying the structural characteristics during installation. Nonetheless, his work did not discuss wall plate thickness. In the construction of deep-water piles and platforms at Halda River Bridge, Dhar B C [12] proposed the use of prefabricated steel cofferdams. Although this solution can decrease project costs, the exploration of support spacing for these prefabricated steel cofferdams was lacking. In accordance with the limit design theory of axisymmetric plate shells, P. de Buhan [13] employed linear variable pressure to simulate backfill soil. Through mechanical analysis under various boundary conditions, shell thickness was determined to be a vital factor impacting its stress. Yet, comparative studies investigating mechanical behavior under multiple factors were absent. In the construction of steel composite pile cofferdams, Thomas S D [14] used the SEEP/W finite element model to conduct a numerical simulation predicting the performance of passive pressure relief systems. However, deformation analysis of steel cofferdams was missing. In I.D. Lefas's study [15] on a steel cofferdam support system, the STAAD structural analysis program was utilized to conduct finite element analysis of a 30 m-radius cofferdam. Although this study had guiding significance for cofferdam development, it lacked mechanical sensitivity evaluation of cofferdam structures. Jones B D [16], examining the design of a double-wall cofferdam at the Boston Harbor pier in the UK, conducted a numerical simulation of ship impact on the cofferdam, describing the design method and outcomes. However, discussions on wall plate thickness were absent. For the temporary cofferdam structural design of a new dry dock, Sundaravadivelu R [17] proposed a steel sheet pile beam cofferdam scheme, using STAAD Pro software for stress analysis while discussing cofferdam mechanical behavior. Yet, a detailed analysis of stress weak points was missing. Monika Sulovska [18] employed PLAXIS geotechnical finite element calculation software and a numerical simulation method based on the finite element method to conduct stability analysis of a double-wall cofferdam. However, exploration of cofferdam water injection height was lacking. Jae-Hyun Kim [19] put forward a large-diameter steel pipe cofferdam method as an alternative to conventional methods such as sheet pile or caisson pipe cofferdams. This technique used a suction installation method for rapid deployment. Still, studies on factors influencing cofferdam mechanics were lacking. On the basis of a case study of a double-wall steel cofferdam accident, Khee-Kwong Han [20] presented the study background, analyzed failure reasons, evaluated post-failure finite element analysis results, and summarized actual failure causes. Despite these extensive findings, discussions on the mechanical influence laws of steel cofferdam structures were not included.

Numerous studies on steel boxed cofferdams have been conducted in China. Liu Libin [21] simulated the construction process and managed the project of a steel boxed cofferdam using building information modeling technology. However, his study lacked an analysis of the steel boxed cofferdam's mechanical sensitivity factors. Using the steel boxed cofferdam of the 83# pier cap of the Longmen Bridge's east approach as an example, Ma Lanjin [22] designed temporary structures of the cofferdam and performed stress calculations and analyses using midas civil software. However, he did not investigate support spacing. Xu Jingang [23] resolved the construction issue of steel boxed cofferdam caps in unfavorable marine climates by improving steel boxed cofferdam construction technology. Yet, his work did not analyze the changes in structural mechanical states caused by adjustments to the sidewall plate thickness. Bai Hongyuan [24], during the construction and use of the second pier deep water foundation steel cofferdam at the Wuhan Tianxingzhou Yangtze River Bridge, conducted a mechanical characteristic analysis on the steel boxed cofferdam assembly platform. The mechanical influencing factors of steel cofferdam wall plate thickness, however, were not analyzed. Utilizing a certain bridge's deep-water foundation as the study object, Liu Xiaomin [25] discussed the design and construction control points of a large double-wall steel boxed cofferdam under high tide difference. His single-component structural calculation and comprehensive MIDAS numerical simulation calculation lacked an analysis of deformation characteristics. Chen Jiahai [26] employed the Latin hypercube sampling method to generate calculation parameters for the component size and load of steel boxed cofferdams. He obtained system influencing factor sequence, determined primary and secondary influencing factors on steel boxed cofferdam design through gray relational analysis, and optimized its design. However, his studies lacked a focus on bottom plate thickness. Zhou Jingku [27], using the Lagos light rail viaduct project across Lake Lagoon in Nigeria as an example, introduced the three main functions of a hanging box and described a force calculation and construction method for steel boxed cofferdams under working conditions. Despite these insights, his work did not explore the mechanical impact of section size on the cofferdam bottom skeleton.

In conclusion, while numerous studies have been performed on the mechanical properties of steel cofferdams, research focusing on the mechanical influencing factors of double-wall steel boxed cofferdams remains sparse. This study proposes an analytical and computational model for double-wall steel boxed cofferdam structures. This model explores how adjustments to influential factors such as wall plate thickness, water injection height between the double walls, bottom skeleton section size and bottom plate thickness, and spacing of support rods within the double walls influence changes in the mechanical state of the structures. The findings from this study will serve as references for future applications and computational analyses of this type of steel boxed cofferdam.

The remainder of this study is organized as follows: The third section describes the engineering background and working conditions of a double-wall steel boxed cofferdam and builds a finite element analysis model. The fourth section discusses the mechanical influencing factors of double-wall steel boxed cofferdams. The final section summarizes the article and presents the relevant conclusions.

3. Methodology

3.1 Engineering background

The engineering background for this study is the double-wall steel boxed cofferdam construction cap of the 10# pier pile foundation for the Xinjiang Kalasuke Reservoir's extra-large bridge in China. The steel boxed cofferdam consists of two parts: the wall plate system and the bottom plate structure. The wall plate system of the steel boxed cofferdam is divided into 12 small sections planely and into 2 sections vertically. The bottom section is 5 m high, while the top section stands at 6.3 m, with a double siding width of 1.5 m. This system primarily comprises a steel wall plate, horizontal ring plate, horizontal reinforcing plate, vertical rib section, diagonal bracing, and diaphragm. The steel wall plate is 6 mm thick. The horizontal ring plate adopts steel plates of two thicknesses: 10 and 12 mm. The vertical rib section utilizes 75×50×6 steel, and the diagonal bracing employs ∠100×8 steel. The diaphragm uses steel plates of two distinct thicknesses: 10 and 12 mm. The siding plan is shown in Figure 1. The bottom plate of the steel boxed cofferdam is primarily composed of ground keel, panel distribution beams, and panels. The bottom plate is made from I32b steel, which forms the bottom skeleton. Panel distribution beams are composed of ∠75×50×6 steel. Panels have a thickness of 6 mm. The structural plan view of the bottom plate is illustrated in Figure 2.

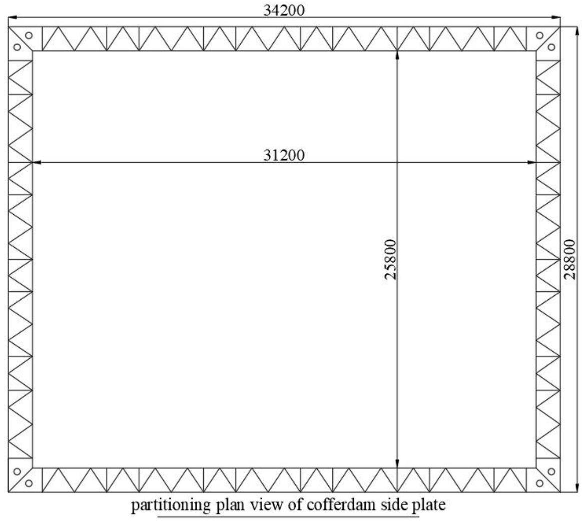

Fig. 1. Cofferdam side plate plan view (unit: mm)

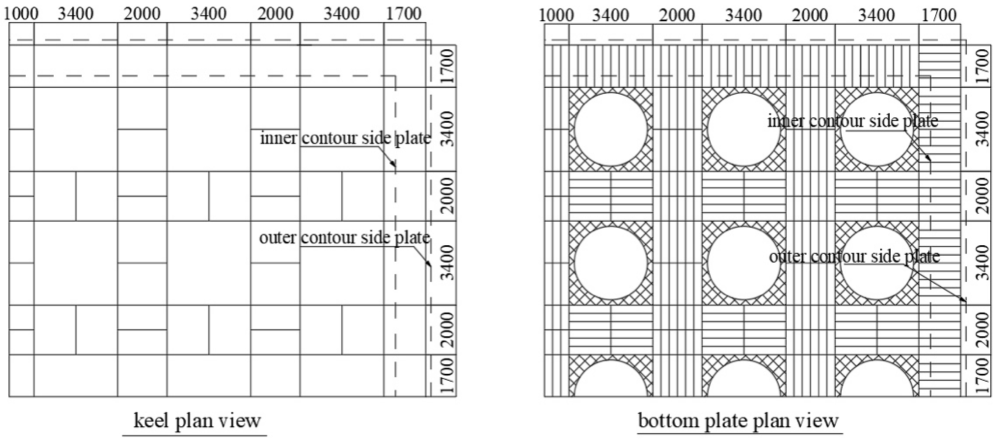

Fig. 2. Bottom plate structural plan view (unit: mm)

3.2 Condition introduction

The construction process involves changes in structural construction, external loads, and structural systems. The complex construction process is divided into different stages in this study to obtain accurate calculation results. Specifically, the construction is divided into six conditions from the beginning of the traction floating platform to the completion of pouring the cap concrete, as indicated in Table 1.

Table 1. Construction conditions

Condition	Construction steps for a steel cofferdam	Load
Condition 1	Insert the first round of four steel casings, separate the floating platform and the construction platform, place the construction platform on the mounting beam of the steel casings, and realize the structural system conversion.	Structure weight, crawler crane weight, railing load, wind load, flowing water load, and hydrostatic pressure load
Condition 2	Insert the remaining steel casing to form bored piles, place the construction platform on the pile-hanging beams of the steel casing, and increase the number of pile-hanging beams to 18.	Construction platform, steel casing weight, railing load, crawler crane weight, wind load, flowing water load, and hydrostatic pressure load
Condition 3	Inject water between the double walls of the steel cofferdam, install the boom, use the lowering device to slowly lower the bottom section steel cofferdam and top section steel cofferdam to the designed position, plug	Bottom concrete load, construction platform, steel casing, steel cofferdam system weight, railing load,

	the bottom plate of the steel cofferdam, and dredge and pour underwater back-sealing concrete.	wind load, running water load, and hydrostatic pressure load
Condition 4	Make back-sealing concrete gain strength.	Construction platform, steel casing, steel cofferdam system, back cover concrete, bulkhead concrete weight, railing load, wind load, running water load, and hydrostatic pressure load
Condition 5	Remove the panels and distribution beams on the construction platform, restructure the internal bracing, and pump water out of the steel cofferdam once the bulkhead concrete strengthens.	Construction platform, steel casing, steel cofferdam system, back-seal concrete, bulkhead concrete weight, railing load, wind load, flowing water load, and hydrostatic pressure load
Condition 6	Cut off the excess steel casing and broken pile heads, and pour concrete for the cap in layers.	Construction platform, steel casing, steel cofferdam system, back cover concrete, bulkhead concrete weight, railing load, wind load, flowing water load, and hydrostatic pressure load

3.3 Principles of finite element analysis

The numerical simulation is performed using the three-dimensional finite element software midas civil. The overall and local forces and deformations of the double-wall steel boxed cofferdam structure under different construction stages are analyzed to reveal its mechanical changes. Through the virtual work equation [28], a solution domain is discretized, that is, the continuum is replaced with a structure composed of many units that are continuous with one another only at the nodes. By analyzing this discretized structure in accordance with the displacement method similar to structural mechanics [29], this study obtains the basic expression, Equation 1.

$$[K]\{\delta\}=\{R\} \tag{1}$$

Where [K]: overall stiffness matrix, {δ}: node displacement matrix of the entire structure, {R}: node load matrix of the entire structure.

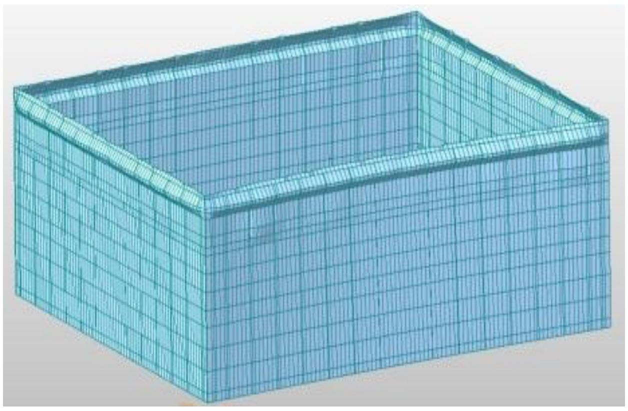

Fig. 3. Finite element model

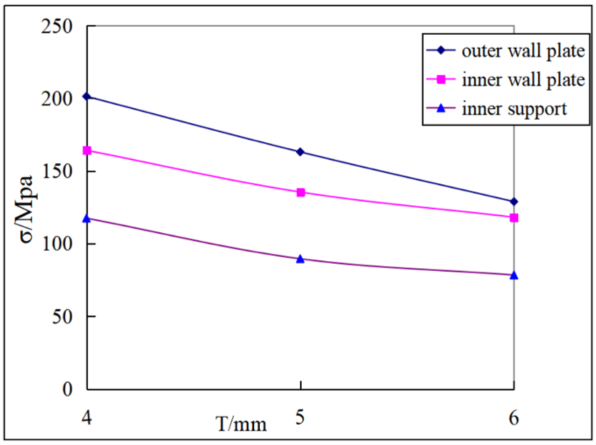

Fig. 4. Stress change diagram of inner and outer wall plates and inner support

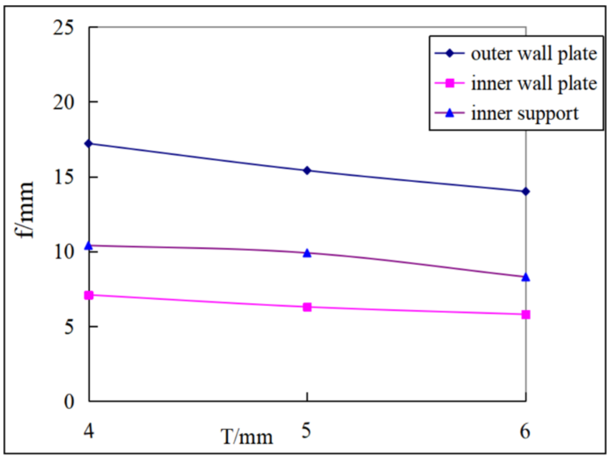

Fig. 5. Deformation change diagram of inner and outer wall plates and inner support

4. Result Analysis and Discussion

4.1 Effect of the wall plate thickness of the steel boxed cofferdam on its mechanical behavior

Based on the comprehensive calculation results under each working condition of the double-wall steel boxed cofferdam, the maximum stress appears in the fifth operational stage, i.e., the pumping phase. The impact of different thicknesses on the overall structure of the steel boxed cofferdam is analyzed by comparing conditions in which the wall plate thickness of the steel boxed cofferdam is 4, 5, and 6 mm. From this analysis, a more reasonable and economical wall plate thickness for the steel boxed cofferdam can be derived.

Figures 4 and 5 depict the stress characteristics of the inner support and wall plates. They also illustrate the deformation rules for these parts when the steel boxed cofferdam wall adopts various thicknesses. As the wall plate thickness of the steel boxed cofferdam decreases, the stress and deformation of the inner and outer wall plates increase. In particular, the stress and deformation of the outer wall plate escalate fastest. When the wall plate thickness is reduced to 4 mm, the maximum stress of the outer wall plate reaches 201.2 MPa, which is close to the allowable stress. The maximum stress drops to 168 MPa with the wall plate thickness being further reduced to 5 mm. The wall plate thickness should not fall below 4 mm to ensure the safety of the steel boxed cofferdam structure.

4.2 Effect of water injection height between double walls on the mechanical behavior of the steel boxed cofferdam

During the fifth pumping stage, the stress and deformation of the inner and outer wall plates, horizontal diagonal bracing, horizontal ring plate, and vertical diaphragm reach their maximum values throughout all construction stages. Thus, this stage is considered the most hazardous phase in the entire construction process. For this reason, optimizing the stress experienced by the double-wall steel boxed cofferdam becomes necessary. Under normal construction conditions, increasing the compartment water injection height can improve the stress conditions of each component of the steel boxed cofferdam. The water injected into the compartment helps counteract part of the hydrostatic pressure exerted on the exterior of the steel boxed cofferdam wall. However, while an increased water injection height may reduce the stress on the outer wall plate, it could potentially intensify the stress on the inner wall plate and other components. The impact of changes in compartment water injection height on the stress and strain of the double-wall steel boxed cofferdam can be determined by comparing, calculating, and analyzing compartment water injection heights of 3.5, 4.5, and 5.5 m. Moreover, the optimal compartment water injection height for maximizing the stress exerted on the steel boxed cofferdam can be identified.

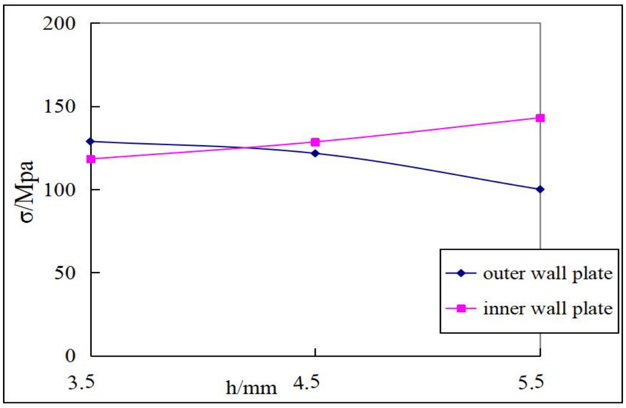

Fig. 6. Stress change diagram of inner and outer wall plates

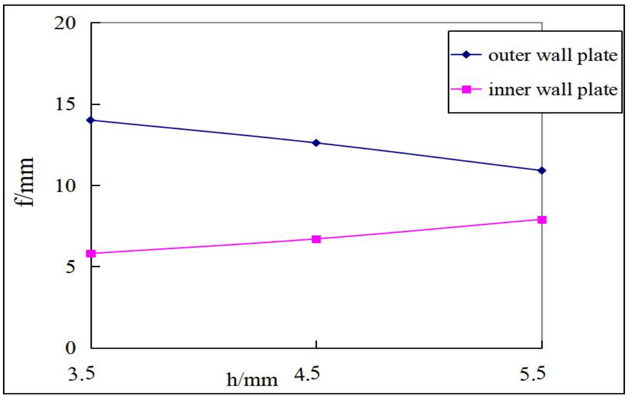

Fig. 7. Deformation change diagram of inner and outer wall plates

From Figures 6 and 7, the stress change characteristics and deformation rules of the steel boxed cofferdam structure with different water injection heights between double walls can be observed. As the water injection height between the double walls increases, the stress and deformation of the outer wall plate decrease significantly, while the stress and deformation of the inner wall plate increase considerably. When the water injection height is 5.5 m, the stress on the outer wall plate reduces to only 100 MPa, whereas the stress on the inner wall plate escalates to 143 MPa. In this scenario, the forces acting on the inner and outer wall plates show imbalance. Nevertheless, maintaining a water injection height between 3.5 and 4.5 m ensures that the stress on the inner and outer wall plates remains less than their allowable stress. This method leaves a certain degree of stress reserve, ensuring a safe operating margin. Given that the water injection height between double walls can be adjusted at any time on the basis of actual measured data from the steel boxed cofferdam, it is considered an effective method for improving the stress conditions of the steel boxed cofferdam wall. Controlling the water injection height between double walls within a range of 3.4–4.5 m is advised to optimize the material properties of steel and ensure that the stress and displacement of the inner wall plate do not become excessive.

4.3 Effect of bottom skeleton section size and bottom plate thickness on the mechanical behavior of the steel boxed cofferdam

Throughout the entire construction phase, the stresses on the bottom skeleton, secondary beams of the bottom plate, and the bottom plate itself are relatively small. The maximum stress value occurs during the third working condition when underwater concrete is poured. Because the concrete has not yet developed strength at this stage and no adhesive force exists between the concrete and steel casing, all the weight from the concrete is borne by the bottom plate structure. This condition results in the highest stress on the bottom plate structure during the third construction stage. In the first and second working conditions, the bottom plate structure only bears its own weight and the weight of the bottom section of the steel boxed cofferdam, resulting in relatively smaller forces. When the bottom concrete develops strength, a bonding force emerges between the concrete and steel casing, which creates an anchoring effect on the bottom plate structure. At this stage, the stress and displacement of the bottom plate, bottom plate secondary beam, and bottom skeleton are minimal. Reducing the section size and bottom plate thickness of the bottom skeleton during design may be beneficial to conserve steel materials. For comparison, the section sizes of the bottom skeleton and bottom plate are reduced to I28b with t=5 mm thickness and I25b with t=4 mm thickness, respectively. These adjustments are then implemented into the calculations and analysis of the bottom plate's structural stress during the third construction stage, at which the stress is at its highest.

Table 2. Comparison of structural stresses when using different bottom skeleton section sizes and bottom plate thicknesses

Bottom skeleton section sizes and bottom plate thicknesses	Bottom skeleton (Mpa)	Bottom plate secondary beam (Mpa)	Bottom plate (Mpa)
I25b、T=4mm	90.4	101.9	106.5
I28b、T=5mm	74.3	86.5	69.6
I32b、T=6mm	63.3	75.2	49.4

Table 3. Comparison of structural deformations when using different bottom skeleton section sizes and bottom plate thicknesses

Bottom skeleton section sizes and bottom plate thicknesses	Bottom skeleton (mm)	Bottom plate secondary beam (mm)	Bottom plate (mm)
I25b、T=4mm	5.2	6	6
I28b、T=5mm	4.3	4.9	4.9
I32b、T=6mm	3.3	3.7	3.7

According to the data from Table 2, the stresses of the bottom skeleton, bottom plate secondary beam, and bottom plate increase as the section size and thickness of the bottom plate of the bottom skeleton decrease. When the section size of the bottom skeleton is I28b and the bottom plate thickness is 5 mm, the maximum stress occurs at the mid-span of the bottom plate secondary beam and its connection with the bottom skeleton. This stress is 86.5 MPa, which is 11.3 MPa higher than the stress on the bottom plate secondary beam at the original section size. When the section size of the bottom skeleton is I25b and the bottom plate thickness is 4 mm, the maximum stress is observed on the bottom plate. This maximum stress is 106.5 MPa, which is 57.1 MPa higher than the stress on the bottom plate at the original section size. Although the stress on the bottom plate increases most significantly when the section size and thickness of the bottom plate of the bottom skeleton decrease, it remains less than the allowable stress.

Table 3 shows that the z-direction deformation of each component in the bottom plate structure increases. This increase happens when the section size and thickness of the base plate in the bottom skeleton decrease. The displacements along the z-direction of the bottom plate secondary beam and the bottom plate remain equal across different section sizes and always display the largest displacement values. With a section size of I25b for the bottom skeleton and a bottom plate thickness of 4 mm, the maximum displacement in the z-direction is 6 mm, which is 2.3 mm greater than the original size's z-direction displacement. When the bottom skeleton adopts a section size of I28b and the bottom plate has a thickness of 5 mm, the maximum z-direction displacement is 4.9 mm, which is 1.2 mm greater than the original size's z-direction displacement. The increases in displacement for each member of the bottom plate are relatively small.

In summary, the reduction in the section size and thickness of the bottom skeleton's bottom plate exerts a minor impact on the stress and deformation of each component of the bottom plate. When the section size and thickness of the bottom skeleton's bottom plate are reduced to I28b, t=5 mm and I25b, t=4 mm, respectively, the bottom plate structure remains in a safe state.

4.4 Effect of spacing of horizontal components between double walls on the mechanical behavior of the steel boxed cofferdam

The maximum stress on the steel boxed cofferdam wall is observed in the fifth pumping stage, with a maximum stress value of 128.8 MPa. The spacing between the horizontal components is set to 0.5 and 1.5 m to explore the effect of spacing between horizontal components within the double walls on the steel boxed cofferdam's stress and deformation. Afterward, individual calculations are performed for the fifth working condition, which corresponds to the largest pumping stage of the steel boxed cofferdam wall.

According to Figures 8 and 9, the spacing between horizontal components within the double walls has a relatively significant impact on the stress and deformation of the inner and outer wall plates. When the spacing between horizontal members is 0.5 m, a relatively small reduction in stress occurs on the outer wall plate. However, when the spacing is increased to 1.5 m, the stress on the outer wall plate increases rapidly, and the range of deformation change for the outer wall plate is relatively large. Similarly, when the spacing is reduced to 0.5 m or increased to 1.5 m, the stress and strain changes of the inner wall plate are relatively large.

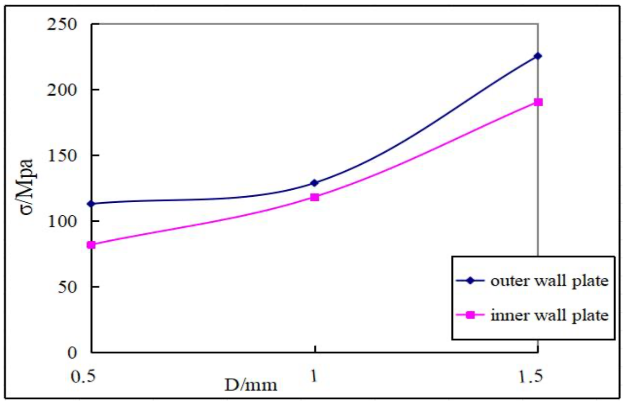

Fig. 8. Stress change diagram of inner and outer wall plates

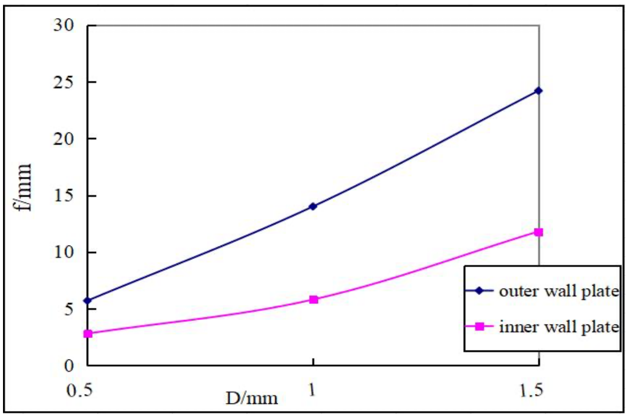

Fig. 9. Deformation change diagram of inner and outer wall plates

5. Conclusions

To clarify the mechanical influence laws of a double-wall steel boxed cofferdam structure, this study used midas civil to establish a finite element analysis model of this structure. The factors influencing the mechanical deformation characteristics of the double-wall steel boxed cofferdam, including wall plate thickness, water injection height between double walls, bottom skeleton section size and bottom plate thickness, and spacing of support rods between double walls, were analyzed. The following conclusions could be drawn:

(1) The reduction in the thickness of the inner and outer wall plates of the steel boxed cofferdam significantly impacts the stress on the inner and outer wall plates and the deformation of the outer wall plate. On the contrary, the impact on the stress on the inner support and the deformation of the inner support and inner wall plate is relatively small. An optimal thickness range of 5–6 mm is identified.

(2) Increasing the compartment water injection height can effectively reduce the stress on the outer wall plate. However, if the compartment water injection height is excessively high, the stress on the inner wall plate will increase rapidly. Controlling the compartment water injection height between 3.5 and 4.5 m ensures that the inner and outer wall plates are in the most favorable stress state.

(3) The spacing of horizontal components within the double walls of the steel boxed cofferdam significantly impacts the stress and deformation of the inner and outer wall plates. When this spacing increases to 1.5 m, the stress on the outer wall plate exceeds the allowable stress. Consequently, excessive spacing between horizontal components within the double walls of a steel boxed cofferdam should be avoided during design.

(4) Concentrated stress occurs at the connection between the inner support and the inner wall plate. The stiffness at this connection plays a major controlling role. During the design phase, measures should be taken to prevent damage to the entire steel boxed cofferdam structure due to low stiffness and excessive displacements at the connections. For instance, the thickness of connecting steel plates could be enhanced.

This study focused on the mechanical influencing factors of a double-wall steel boxed cofferdam. The conclusions could serve as a reference for optimal design of such a structure. However, because this study lacks on-site measured data, further investigation will need to incorporate on-site monitoring data for a more comprehensive exploration of the mechanical stress characteristics of new combined retaining structures.

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