Simulation Analysis of Composite Steel Cofferdam Based on ANSYS Finite Element Method

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Abstract: The design and use of cofferdam in hydraulic engineering has always been the key and difficult point of the project. A well-designed cofferdam can help solve major problems and reduce construction difficulty. The South-to-North Water Transfer Project is a major livelihood project in China. The maintenance and maintenance of canal slopes under continuous water conditions has always been a major problem to be solved urgently. Based on the finite element theory, the three-dimensional model of the cofferdam built by CATIA is analyzed by using ANSYS software. Through the simulation results, the cofferdam deformation is analyzed to ensure the design safety and provide the basis for future optimization.

Keywords: Cofferdam; finite element; ANSYS; mechanical properties

1. Introduction

The South-to-North Water Diversion Project, as a sustainable people's livelihood project and a major strategic project for optimizing the allocation of water resources in my country, has played a positive role in the development of the three aspects of society, economy and ecology. The core part of the construction of a water conservancy project is the cofferdam, which is used to ensure the dry land operation conditions of the construction. Different construction environments require targeted cofferdam design to meet construction requirements [1].

The South-to-North Water Diversion Project is different from ordinary water conservancy projects. Its transportation water source is drinking water, and the construction must ensure that it does not pollute the water source. Therefore, the earth-rock structure cofferdam widely used in ordinary water conservancy projects is not considered due to its serious pollution, large construction volume, and damage to the canal slope [2]. After a lot of research, it is found that both Germany and Austria have used steel structure flood walls to resist floods. Now learn from its combined structure, design a self-sinking combined steel cofferdam suitable for channel slope repair work, but change the installation form of drilling and fixing on the ground, so that the main structure is assembled on the self-sinking base, and it can be installed on the self-sinking base. Under the condition of continuous flow of channels, the dry land operation of the damaged slope can be solved, which can solve the safety hazards caused by the damage of the canal slope lining of the middle route of the South-to-North Water Transfer Project [3-5].

This paper takes the combined steel cofferdam for the existing water channel slope as the research object. Through the static and transient dynamics analysis of the cofferdam structure's deformation, it ensures the safety of the design and accumulates construction experience to guide the combined steel cofferdam. Design and construction.

2. Cofferdam Structure

In the existing cofferdam design scheme, the combined cofferdam is formed by splicing several cofferdam units with a length of two meters according to actual needs. Each cofferdam unit consists of four cofferdam bases, columns, baffles and support rods. Partial composition. The two ends of each base are provided with snap shots to facilitate the splicing and installation of other base units. Slots and channels are provided on the upper surface of the base, and channels of the same specification are provided on both sides of the column. When assembling, insert the column into the slot, the lower end of the baffle plate is inserted into the channel, and both ends of the baffle plate are stuck in the channel on the sides of the columns on both sides to complete the assembly of a cofferdam unit.

Repeat this procedure to connect several cofferdam units to form a whole cofferdam. This design can either be put into the corresponding position of the canal slope by the hoist after the completion of the splicing on the shore, or the parts can be hoisted in the corresponding position for underwater installation.

The four parts of the cofferdam unit are modeled using CATIA. Since this analysis only considers the influence of geometric dimensions on the overall structural strength of the cofferdam, and ignores the unfavorable factors brought about by the structural connection of each part, the four structures of the cofferdam unit are merged into a whole during the modeling process to facilitate the later

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period. Analyze, and at the same time, modeling in this way can also avoid problems such as the definition of contact surfaces in the post-analysis process of ANSYS using the assembly model, which greatly reduces the difficulty of analysis and saves calculation time while ensuring accuracy.

3. Dynamic Response Analysis of Cofferdam under Wave Load

The existing cofferdam design basically focuses on the soil condition and overall stability of the construction site. The design focuses on the mechanical strength of the combined structure due to different specific operating conditions. When the cofferdam model is known, only by simulating the load conditions closer to reality can a more realistic finite element analysis and result simulation of the structure be carried out. During the construction of the canal slope, the cofferdam structure will be impacted by water level pressure and waves. Once the structure undergoes relative displacement or local deformation, it will pose a great safety threat to the overall construction safety. The existing cofferdam is used on the side of the canal slope, and its main working surface is parallel to the water flow and will not accept wave impact. Therefore, the effect on waves only considers the impact of its changing water level on the cofferdam surface [6-9].

According to the existing design structure, the actual water pressure and wave model are simulated, and the finite element dynamic response analysis is carried out. The analysis is divided into static and dynamic parts. The static analysis uses the analysis method of the ordinary cofferdam design process that ignores the influence of waves, that is, only applies stable water pressure to the water surface on the cofferdam, and analyzes whether the rigidity and strength of the cofferdam structure are qualified according to the finite element statics calculation results. The dynamic analysis intends to consider the effect of wave load on the cofferdam on the basis of applying stable water pressure, and the structure needs to be subjected to modal analysis, harmonic response analysis, transient dynamic analysis and spectrum analysis [10,11].

3.1. The Motion Analysis Equation of the Structural System

The analysis of the dynamic response of the cofferdam system under different loads is a process of establishing, solving and analyzing the motion equation of the whole system under all loads. The motion equation of the structural system, that is, the motion of the structural system caused by the joint action of various loads, can be equivalently described by establishing the corresponding type of mathematical equation.

In the application of specific engineering systems, quality is generally equivalent to a function of continuous distribution in three-dimensional space. At the same time, an inertial force term is added to the dynamic analysis equation, and the law of motion is described as a second-order partial differential equation including time and space. Now based on the direct balance method, a differential equation describing the law of motion of the cofferdam system is established. Considering the damping force, elastic force of the system structure itself, and the water pressure and frictional tension acting on the system, the entire cofferdam system is in dynamic equilibrium. The cofferdam structure system can list the following dynamic balance equations:

$$[\mathrm{M}]\{\ddot{\mathrm{U}}\}+[\mathrm{C}]\{\dot{\mathrm{U}}\}+[\mathrm{K}]\{\mathrm{U}\}=\{F_p\} \quad (1)$$

In the formula, $[\mathrm{M}],[\mathrm{C}],[\mathrm{K}]$ are the mass, damping, and stiffness matrices of the cofferdam system; $\{\mathrm{U}\},\{\dot{\mathrm{U}}\},\{\ddot{\mathrm{U}}\}$ are the displacements of each grid node of the three-dimensional model, respectively Vector, velocity vector and acceleration vector, $\{F_p\}$ is the external load vector.

Analyzing equation 2-1, because the cofferdam system is determined, its mass, damping, and stiffness matrix $[\mathrm{M}],[\mathrm{C}],[\mathrm{K}]$ are known.The displacement vector $\{\mathrm{U}\}$ of the response of the structure under external load$\{F_p\}$ can be calculated. The required $\{\ddot{\mathrm{U}}\},\{\dot{\mathrm{U}}\},\{\mathrm{U}\}$ are all functions of time [12].

3.2. Structural Dynamic Response Analysis

The dynamic analysis of the cofferdam structure under the external load mainly includes the determination of the inherent dynamic characteristics of the cofferdam structure and the corresponding vibration displacement of the cofferdam under the external load. According to the different external dynamic load forms and the content of the solution concerned, the dynamic analysis can be divided into static analysis, modal analysis, harmonic response analysis, transient dynamic analysis and spectrum analysis. In this paper, only static analysis, modal analysis and transient dynamics analysis are carried out according to the actual situation.

3.2.1. Load analysis

1) The static load is the pressure of the water pressure on the cofferdam, and the load formula is the water pressure formula:

$$\mathrm{P}=\rho\mathrm{gh} \quad (2)$$

According to the actual situation and to simplify the calculation, ρ is taken as 1000kg/m^3, g is taken as 10m/s^2, and the value range of h is 0~3.5m.

2) With reference to local hydrological data, the maximum current velocity is about 1.2m/s, the maximum wave level is level 2 small waves, the maximum wave height is about 0.3m, and the wave wavelength is 0.4m. Through the observation and analysis of the flow cross-section, the water flow is simulated as a sine function of the vertical displacement of the wave changing with time [13-15]. The general formula of the sine function is: $x=A\,sin(\,\omega t+\phi)+k$, the simplified model steps are as follows:

$$T=L/V_{\mathrm{w}} \quad (3)$$

In the formula, T is the function period in seconds (s); L is the wavelength in meters (m); $V_{\mathrm{w}}$is the wave speed in meters per second (m/s).

$$\omega=\frac{2\pi}{T} \quad (4)$$

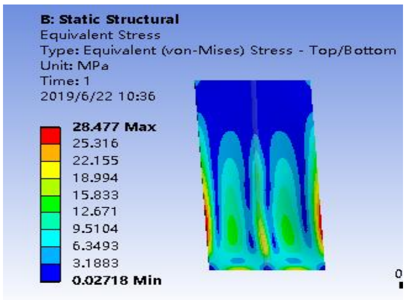
The analog waveform function is as follows:

$$z = 0.3\sin(6\pi * t) + 3.5 \qquad (5)$$

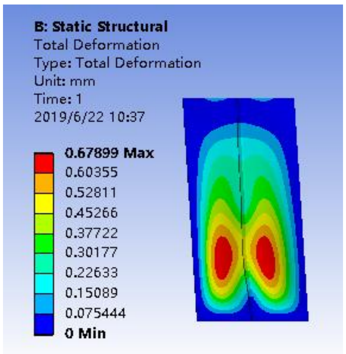
In the formula, z is the height from the water surface to the bottom of the canal, in m; t is time, in s.

3.2.2. Static analysis

Use the finite element software to import the existing three-dimensional model, load the load as shown in formula (2) on the bearing surface, and fix the bottom and two sides of the cofferdam. The analysis results are shown in Figure 1.



a. Stress



b. Total deformation

Figure 1 Stress diagram and total deformation diagram for static analysis

According to the analysis result, the maximum stress is 28.477MPa, and the maximum total deformation is 0.679mm.

3.2.3. Modal analysis

The natural dynamic characteristics of the structure can be obtained by modal analysis. Generally, attention is paid to the natural frequency and vibration mode of the structure to avoid resonance when an alternating external load is applied, which is not conducive to the stability of the structure. Characteristics, generally pay attention to the natural vibration frequency and mode shape of the structure, to avoid resonance when an alternating external load is applied, which is not conducive to the stability of the structure [16].

The first six vibration frequencies and modes of the cofferdam structure are shown in Figure 2 below. Because the structure described in this article is relatively simple in external load, the deformation trend of the mode shape can be ignored, and only the natural frequency of each mode shape is considered to avoid resonance. From the results of the above analysis of the first six modes, the first mode is the main mode, and the natural frequency is 23.969 Hz, which is far from the wave 3.33 Hz. The second, third, fourth, fifth, and sixth modes are automatically. The vibration frequencies are 65.364 Hz, 66.007 Hz, 66.291 Hz, 70.238 Hz, 72. 401Hz. Therefore, it can be seen that the wave load will not resonate the cofferdam structure and cause adverse effects.

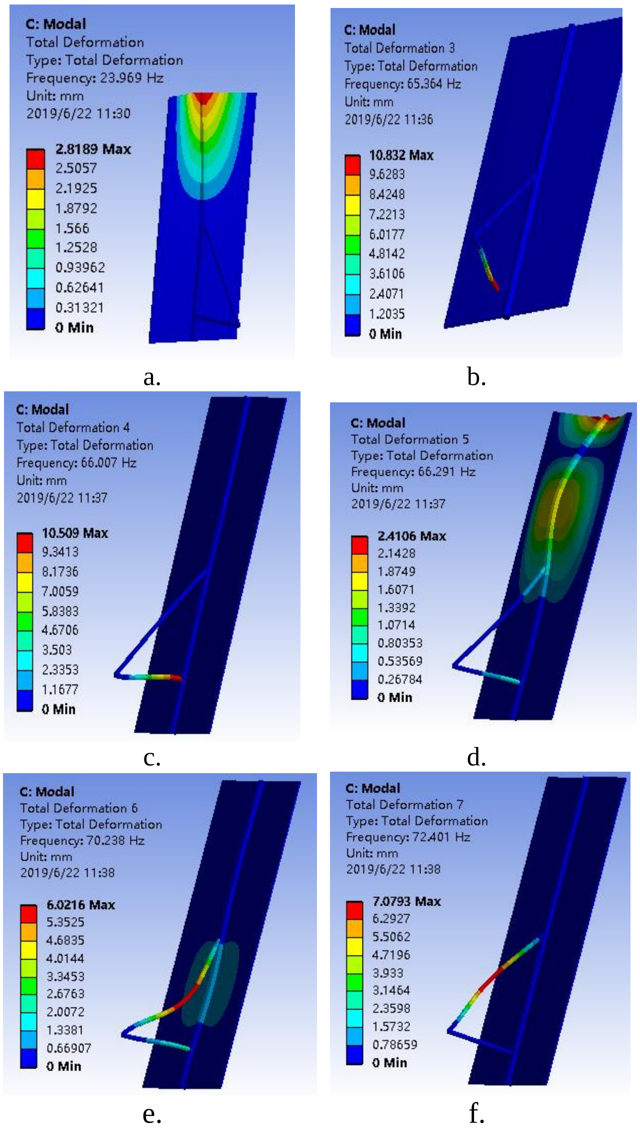


Figure 2 The first six-order vibration frequency and mode of cofferdam structure

3.2.4 Transient dynamic analysis

When the external load changes with time, the external load vector $\{F_p\}$ is a function of time or changes with time, and the cofferdam is loaded on the water surface with the following functional loads:

$$p = \rho gz \qquad (6)$$

The results of transient dynamics analysis are shown in Figure 3. The maximum stress of the cofferdam is 29.312MPa and the maximum deformation is 0.74341mm.

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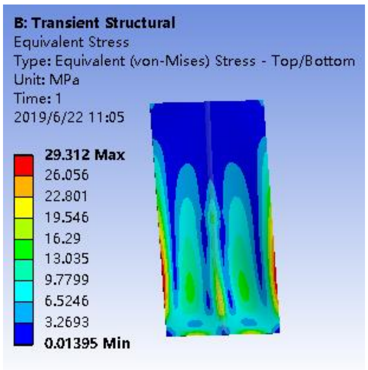
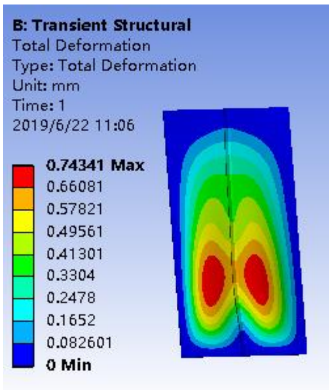


a. Stress



b. Total deformation

Figure 3 Stress diagram and total deformation diagram for dynamic analysis

3.3. Analysis and Summary

Comparing the static analysis results and the transient dynamic analysis results respectively, the error rate ρ can be obtained, as shown in the following formula:

$$\rho = \delta_M/\delta_S \quad (7)$$

After calculation, the stress error rate is $\rho_1 \approx 1.03$, and the total deformation error rate is$\rho_{12} \approx 1.095$. It can be concluded that whether the dynamic load of the simulated waveform function is applied has a certain effect on the simulation analysis result, that is, the dynamic load of the alternating sine function will have a greater adverse effect on the cofferdam structure, which is the result of the analysis. The results are more real and reliable.

The material used in the design of the cofferdam in this paper is Q235, and the yield strength is about 235Mpa. In summary, the simulation results show that the design is safe and reliable.

4. Summary

Through the above analysis, in the future design and calculation of cofferdam systems and other mechanical structures bearing similar loads, it is necessary to establish and load more accurate load models in order to obtain more realistic and reliable simulation data for subsequent optimization and production. And the construction provides reliable data support.

Factory processing is shown in Figure 4, and on-site construction is shown in Figure 5.

Figure 4 Factory processing

Figure 5 On-site construction

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