Calculation and Analysis of Fatigue Life of Gravity Dam Based on FEM

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Abstract. Gravity dam is a hydraulic structure subjected to high stress loads by its own weight to maintain its stability. Gravity dams mainly bear the pressure of reservoir water changes, the impact of high-intensity earthquakes, the wind and waves, the vibration of generator sets, etc. Therefore, the structural safety of dams is a major event related to engineering safety. It has very important theoretical significance and practical value for dam structural safety analysis. In this paper, the concrete gravity dam is taken as the main research object. The dam is modeled by the finite element method. According to the water level of the dam reservoir, the static and dynamic analysis of the dam under various responses, the deformation situation and strain situation of the dam is studied. Then combined with seismic wave selection and power spectrum estimation method, the seismic performance of the dam is analyzed. The specific method is to find the weak point of the dam and study the fatigue life of the dam to obtain the overall fatigue life of the dam.

1. Introduction
Since the establishment of China, more than 80,000 dams have been built. These dams have played an important role in China's national economy and played a major role in economic construction. They also played a major role in protecting the lives and property of the downstream people. Therefore, the safety of dams cannot be ignored in the national economic construction and development. Once problems occur, the damage and losses will be immeasurable. The fatigue life of the dam is an important factor in the safety of the dam. Therefore, calculating and analyzing the fatigue life of the dam will play an important role in the safety of the dam.

2. Development of fatigue calculation and analysis at home and abroad
A large amount of research has been conducted on the fatigue life of concrete at home and abroad. Saito uses fracture theory to describe the failure mechanism of concrete. The fatigue failure mechanism of concrete is expounded from the perspective of energy absorption and energy consumption of concrete. Ravindra studied and modeled various damage variables of concrete fatigue damage by means of residual strength. Zhu Jinsong described the three maximum strain development laws of concrete gradually appearing in the fatigue damage process by the maximum strain method. Miner's linear cumulative damage theory and its modification method are still one of the most important methods for studying fatigue life applications. By 1977, Janson et al. proposed the classical
mechanics of damage mechanics, which became an indispensable method for calculating fatigue accumulation and damage models. The study of continuous media such as concrete in damage mechanics The wider the more. Chaboche proposed a cumulative damage theory for the study of the stress range and the number of cycles of the material, which links the microplastic strain inside the material with the fatigue damage.

3. Main technical route
In this paper, the structural analysis and seismic analysis of the dam are first carried out, and then the fatigue life of the dam is calculated. The specific route of this study is shown in Figure 1:

![Figure 1. Technology Roadmap](image)

4. Project Overview
The analysis object of this paper is a widely used gravity dam. The foundation of the gravity dam is embedded in the bedrock and the foundation is rigid. The density of the material of the dam is 2400kg/m³, the modulus of elasticity is 35GPa, and the Poisson's ratio is 0.2. Calculate and analyze the water level to take 120m. The lateral specific dimensions of the gravity dam are shown in the schematic diagram of the gravity dam.

![Figure 2. Schematic diagram of the gravity dam (unit: m)](image)

5. Model establishment

5.1. Unit type selection
Because the dam is a long, long entity, the computational model can be reduced to a plane strain problem. According to the analyzed problem, the PLANE42 unit is used to draw the mesh model. The PLANE42 unit can be used both as a planar unit and as an axisymmetric unit. The unit is defined by four nodes, each with two degrees of freedom. The translation of the node coordinate system in the x and y directions. The unit has plasticity, creep, expansion, stress stiffening, large deformation and large strain capability, and has an option to support additional displacement shapes.
5.2. Define material properties
Meshing the solid model, that is, dividing the solid model into a number of sub-areas by one unit. These regions or units have material properties, so the material properties of the cells must be defined before meshing. The material properties mainly include the ratio of the ratio, the modulus of elasticity $E$, and the density $\rho$. Poisson's ratio $\mu = 0.2$, elastic modulus $E = 35$ GPa, and density $\rho = 2400$ kg/m$^3$ were sequentially defined according to the definition of the material. The unit system must be unified when defining various material properties.

5.3. Grid model establishment
There are specific steps in meshing. After the cell properties are defined, the key steps of mesh shape and density meshing are determined. Meshing has a direct relationship with the final calculation results, so a reasonable way should be chosen for meshing.

This paper chooses the method of free division to properly divide the boundary of the dam model. The meshing diagram is shown in Figure 4.

5.4. Impose constraints and loads
Select all nodes at the bottom of the dam to fix all degrees of freedom. Gravity is applied to the gravity dam by applying a gravitational acceleration field. For the upstream of the dam, the water pressure load is applied according to the actual working conditions.

6. Analysis and calculation for dam fatigue life
The basic steps for fatigue life analysis of a dam are shown in Figure 5.
6.1. Analysis and calculation of seismic performance for dam

6.1.1. Seismic performance analysis

(1) Modal analysis
First set the analysis type and set the modal analysis options, then perform the modal analysis solution and save the solution results. The modal analysis is used to analyze the frequencies of each order. The modal analysis of each order frequency is shown in Fig. 6.

(2) Spectral response analysis
Set the analysis type and spectral response analysis options, define the response spectrum analysis frequency table and the response spectrum value, then perform the response spectrum analysis and save the results.

(3) Modal expansion analysis
Set the analysis type, define the modal expansion analysis, and set the modal expansion analysis. Perform modal expansion analysis to solve and save the solution results.

(4) Combined modal analysis
Set the analysis type, combine it by the square root method, perform the combined modal analysis, and save the solution result.

Figure 6. Calculate the frequency of each step

6.1.2. Finite element calculation result
The first order stress cloud of the dam is shown in Figure 7.

Figure 7. the first order stress cloud map
The 16th order stress cloud of the dam is shown in Figure 8.

Figure 8. the 16th stress cloud map
6.2. Dam fatigue life analysis
In this study, the 16th-order stress condition of the dam was selected for fatigue life analysis.

6.2.1. Define position, event, and load maxima
Find the point where the maximum stress of the dam is the most vulnerable part of the dam. As shown in Figure 9. In the figure, MAX is the point at which the maximum stress of the dam is.

![Figure 9. Maximum stress point of the dam](image)

6.2.2. Dam S-N curve setting
Calculation of the fatigue life of the structure requires the use of data from previously collected S-N curves. The service life of the dam concrete is calculated based on the fatigue curve of the existing concrete. The stress life fatigue curve setting for the dam is shown in the Input S-N Curve Value dialog box in Figure 10.

![Figure 10. Enter S-N curve value dialog box](image)

6.2.3. Specify event name, number of repetitions, scale factor
Specify the event name, number of repetitions, and scale factor. The dialog box is shown in Figure 11.

![Figure 11. Specify event name, number of repetitions, scale factor dialog box](image)

6.3. Fatigue life calculation result
Through the above basic steps, ANSYS software was used to analyze and calculate the dam fatigue life results. The dam fatigue life analysis results are shown below.
PERFORM FATIGUE CALCULATION AT LOCATION 1 NODE 0
*** POST1 FATIGUE CALCULATION ***
LOCATION 1 NODE67
EVENT/LOADS 1 1 even1 AND 1 2 even1
PRODUCE ALTERNATING SI (SALT) = 34.937 WITH TEMP = 0.0000
CYCLES USED/ALLOWED =0.1000E+06/ 0.3851E+06 = PARTIAL USAGE =0.20000
CUMULATIVE FATIGUE USAGE = 0.20000
The cumulative fatigue coefficient is 0.20000<1, and the fatigue life of the dam can meet the requirements of use.

7. Conclusion
The dam belongs to a large-scale hydraulic structure, and its construction quantity and cost are very large, and the stability of its structure is also extremely high. In this paper, for the general dam situation, the dam model is established and the dam is calculated and analyzed for fatigue life by ANSYS finite element analysis software.

With the development of society and the gradual improvement of water conservancy engineering technology, the fatigue problem of hydraulic structures like dams will surely receive more and more attention. Therefore, for such hydraulic structures, from structure to geological factors, to materials and even to Research on deeper internal influences will inevitably begin. The author believes that there are more studies in this direction:
- In the division of the finite element analysis grid, it is possible to carry out more dense meshing of larger loads at the load distribution of the dam.
- The seismic response and life analysis of the dam can be used for secondary development using APDL combined with C++ software. The integrated system will be designed and analyzed more efficiently.

Acknowledgements
This paper has been supported by the scientific research foundation project of Yunnan Provincial Department of Education (2014Y386).

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