Seismic Behaviors on CFGRD

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Abstract: The goal structure is the concrete-faced grouted rockfill dam (CFGRD) in Zhoushan of China. Based on the properties non-linearity, the structural interaction and the seismic uncertainty, the dynamic non-linear constitutive model has been established in order to evaluate the seismic safety of the CFGRD as well as its interactive zones. Their dynamic sensibility has also been explored with the dynamic FEM. According to the results of the comprehensive dynamic response field distributions, the rock-bolts family of the CFGRD plays the principal role for the seismic safety.

1. Introduction
The Zhoushan area is located at the junction of the two major seismic belts in the north and south. The Jiangshan-Shaoxing fault is a famous active fault zone in the area. Combined with the overall seismic sensitivity characteristics of the rockfill dam, its complex structure and shape make it vulnerable to catastrophic loads such as ground motion. Before the Wenchuan earthquake, people thought that the panel dam had good seismic performance. An earthquake completely revised the consciousness of Chinese engineers, and the Zipingpu concrete rockfill dam caused by severe earthquake damage in the earthquake [1]. Under the influence of the same complex and obviously uncertain ground motion effects, such complex hydraulic large-scale systems cannot be evaluated by conventional and existing singular and qualitative models and methods [2]. Therefore, the multi-style seismic wave excitation-based big data dynamic analysis and evaluation method proposed in this paper has an important role in promoting the research work of this kind of problem. The obtained analytical data, research results and conclusions are the popularization and application of this kind of panel filling stone dam.

2. Basic theory and model of seismic research of 2 panel filling stone dam

2.1. Research on material dynamic constitutive model
The modified elastic matrix [D*] in three-dimensional space is as follows:

\[
[D^*] = \left[ \frac{T^*}{\sigma} \right]^T \left[ D^* \right] T^* \tag{1}
\]

This paper considers that the dynamic elastic modulus of panel-filled rockfill dam materials generally obeys the hyperbolic distribution and can be expressed by formula (2)[5]:

\[
E_{d_i}^{-1} = a_e + b_e e_{dm} + c_e e_{dm}^2 \tag{2}
\]
$a_e$, $b_e$, and $c_e$ in formula (2) are test parameters, and the initial dynamic elastic modulus $E_d^i$ of the dam material can be conveniently calculated ($\varepsilon_{in} = 0$) according to formula (2). The dynamic elastic modulus $E_d$ and the initial dynamic elastic modulus $E_d^i$ satisfy the modified Hardin-Drnevich model as in equation (3):

$$\frac{E_d}{E_d^i} = \frac{1}{1 + A_e \left( \frac{E_d}{E_{Er}} \right)^{B_e}}$$  \hspace{1cm} (3)

In formula (3), $A_e$ and $B_e$ indicate the shape parameters of the curve related to the properties of the filler; $E_{Er}$ represents the modulus reference strain, and the influence of the confining pressure on the dynamic elastic modulus of the material due to the filling of the rockfill dam is through the dynamic strain of the material. The performance evolves to show, so the relationship between the modulus reference strain and the confining pressure is established as in equation (4):

$$\varepsilon_{Er} = \frac{1}{1 + \left( \frac{\sigma_{3e}}{\sigma_{Er}} \right)^{c_e}}$$  \hspace{1cm} (4)

Where $\varepsilon_{Er}$ is the modulus reference confining pressure and $c_e$ is the fitting parameter.

The damping ratio $\zeta$ also satisfies the modified Hardin-Drnevich model as follows:

$$\zeta = \frac{1}{\zeta_{max}} \frac{1}{1 + A \left( \frac{\varepsilon_{dm}}{\varepsilon_{Dr}} \right)^{B_d}}$$  \hspace{1cm} (5)

In the formula (5), $A_d$ and $B_d$ represent the curve shape parameters related to the soil properties; $\varepsilon_{Dr}$ indicates the damping reference strain, and the dynamic pressure accumulation process of the dam material can be used to reveal the confining pressure in the dam body. Based on the influence of the damping ratio, this paper establishes the relationship between the material damping reference strain and the confining pressure of the dam foundation by means of formula (6):

$$\varepsilon_{Dr} = \left( \frac{\sigma_{3e}}{\sigma_{Dr}} \right)^{d_d} \frac{1}{1 + \left( \frac{\sigma_{3e}}{\sigma_{Dr}} \right)^{d_d}}$$  \hspace{1cm} (6)

Where $\sigma_{Dr}$ is the damping reference confining pressure and $d_d$ is the fitting parameter.

2.2. Acceleration spectrum
The full-text seismic calculation is based on the Wenchuan seismic wave, and other waveforms are auxiliary. The specific acceleration spectrum is shown in Figure 1:
3. Simulation model and parameters

3.1. Finite element model and parameters

In this paper, the dynamic finite element method is used to analyze and simulate the sensitivity of the overall vibration mode and dynamic response of a gravity reinforced concrete slab-filled rock dam under ground pulsation\(^6\). Model material zoning of dam-bedrock system used in seismic sensitivity simulation: considering dam foundation rock mass, dam body filling stone, reinforced concrete slab on upstream dam surface, upstream irrigated stone and anchoring system of filling stone body interface. The finite element method mesh model is shown in Figure 2. The model uses a hexahedral stress element for 3D simulation calculation. The total number of model elements is 52318 and the total number of nodes is 58215. The dam body and bedrock system are subjected to multiple sets of representative seismic wave excitations respectively. The seismic input boundary is the boundary layer of the bedrock bottom. The calculation considers the loading combination as gravity + hydrostatic pressure + hydrodynamic pressure + seismic load. The simulation study takes the upstream water level as the design flood. Bit 108.30m; downstream water level 85.25m. In order to prevent the numerical model from escaping under ground motion, a spring is applied to the dam foundation to simulate the viscoelastic artificial boundary\(^7\). The length of the bolt in the dam body masonry is 50cm, the anchoring length is 30cm, the panel part is buried 20m, and the spacing and row spacing are 50cm; the density of the anchoring bar is 7850kg/m\(^3\); the self-vibration frequency corresponding to the first-order mode is used as the fundamental frequency, and the subsequent seismic sensitivity simulation analysis of the dam system is carried out.

3.2. Vibration mode analysis

For gravity dams, it is usually only necessary to calculate the 5th order low frequency mode. At the same time, the frequency of earthquake-induced vibration under full dam conditions is lower than that under empty or semi-empty conditions. The vibration frequency of gravity dams (including concrete dams and rockfill dams) is 4–15Hz. The study only provides the second-order mode with the lowest frequency for conservative calculations\(^8\). The self-vibration frequency corresponding to the first-order mode is used as the fundamental frequency, and the subsequent seismic sensitivity simulation analysis of the dam system is carried out.
4. results and analysis

4.1. Sensitivity analysis of overall dynamic response of dam-bedrock system

According to the simulation calculation results (Fig. 3): under the action of various excitation waveforms, the dynamic response field magnitude of the panel system has an oscillating upward trend; due to the strong constraints of the two sides of the mountain, the transverse river response field The level is the smallest; the magnitude of the final gravity of the dynamic stress field is the largest; in the displacement field response, the magnitude of the calculation result is the highest [9].

4.2. Sensitivity analysis of seismic dynamic response of reinforced concrete slab

The ground motion sensitivity study is carried out with the contact opening normal opening degree as the main evaluation index. The results show that (Fig. 4): Due to the non-confirmed influence of the seismic spectrum input, the open or closed performance between the two types of materials in the region is extremely sensitive. Under the excitation of Wenchuan wave, the maximum opening degree between the panel at the upstream dam position and the stone filling body at the end of the ground motion reaches 7mm; while under the excitation of Kobe wave, the maximum opening degree is only $3 \times 10^{-7}$ mm, and the open position rises to The upstream dam surface turns.

4.3. Study on seismic dynamic response sensitivity of upstream anchor system

The anchor system between the upstream dam face panel and the stone wall is an important structural link to maintain structural integrity, especially to enhance the dynamic stability of the system (Figure 5).
In the dynamic displacement field excited by multiple seismic waves, the Kobe wave calculation results are significantly lower than the former two, especially the dynamic displacement of the anchor system under the excitation of Hanshin wave reaches the 1m-level in-situ vibration stress field, under the excitation of Wenchuan wave The distribution generally showed a trend of cumulative stress growth with the extension of the earthquake time course, while the Hanshin wave and Kobe wave excitation showed slight fluctuations; especially in the later period of the earthquake, the dynamic stress level of Wenchuan wave was two percentage points higher than the latter two. The Kobe wave results are the lowest of the three. The dynamic strain field distribution law of each family seismic wave excitation is very similar to the displacement field: from Wenchuan wave, Hanshin wave to Kobe wave, the dynamic strain level decreases by nearly 1 percentage point. It can be seen that the upstream anchorage system of the reinforced concrete slab stone dam is extremely sensitive to the seismic spectrum input\cite{10}. For this dam type, the overall seismic safety of the structure should be ensured. The anchoring system between the upstream panel and the slab stone should be carefully designed. Design criteria should be appropriately increased if necessary.

5. Conclusions
In this paper, the main research conclusions are obtained by analyzing the seismic sensitivity characteristics of the whole and joints of a typical reinforced concrete slab stone dam.

1. The main structure of the face dam is extremely sensitive to seismic waveform excitation;
2. The uncertainty of seismic waves is one of the threats to the safety of panel dams;
3. Regardless of the form, the joint between the dam and the panel is always a dynamic sensitive concentration zone;
4. Local strengthening in panel dams is extremely necessary, and the main pulling stress in these areas often breaks through the ultimate tensile strength of concrete materials;
5. It is necessary to study the seismic wave excitation sensitivity of the panel dam.

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