Research on Dynamic Characteristics of Loess Homogeneous Dam under Seismic Waves

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Abstract. Based on the relevant provisions of the seismic design code, the three-dimensional nonlinear seismic response analysis of an actual loess homogeneous dam engineering is carried out. The seismic waves use the ground motion time history generated by the relevant design response spectrum of the set seismic site. The research results show that the homogeneous dam in the V-shaped valley has a significant amplification effect in the middle of the valley. The acceleration amplification area of the dam is above 4/5 of the dam height and within the range of 1/3 of the dam axis length. The regularity shows obvious "whiplash effect" and three-dimensional river valley effect.

Keywords: Loess homogeneous dam; seismic response; acceleration; permanent deformation.

1. Introduction

Embankment dam has the advantages of easy material selection, convenient construction, low cost, strong foundation adaptability and good seismic performance. It is one of the main dam types for water conservancy and hydropower construction [1]. The dynamic response of embankment dams and their failure modes under seismic waves have always been the research hotspots in the geotechnical engineering community [2].

After the "5·12" Wenchuan earthquake, China put forward higher requirements on the seismic safety of large-scale water conservancy and hydropower projects. Through investigation and analysis of earthquake damage, it has conducted in-depth studies on dam seismic design, earthquake damage mechanism, and seismic reinforcement measures, etc [3, 4]. Zhang Yu analyzed the dynamic response characteristics of the concrete face rockfill dam by performing two-dimensional finite element dynamic calculation on a 250 m high face rockfill dam [5]. Li Hongjun studied the influence of the seismic wave generated by setting the relevant response spectrum and uniform probability response spectrum of the seismic site on the dynamic response of the core rockfill dam built on the deep covering layer [6].

This paper is based on the finite element principle, the dynamic model adopts the equivalent linear model. The ground motion time history is generated by the relevant design response spectrum of the set seismic site according to the relevant specifications. Dynamic response characteristics is Analyzed.

2. Calculation model and parameters

2.1. Calculation model

The maximum height of the homogeneous earth dam is 86m. The dam crest is 339m long and 10m wide. The upstream dam face slope is 1:3, and the downstream dam face slope is 1:2.5. Cushion-type horizontal drainage is set at the bottom of the dam foundation. Curtain grouting is used for the anti-seepage of the dam foundation and both banks, and the control standard is 5Lu.

Establish the following calculation coordinate system: X axis is the upstream and downstream direction, pointing upstream as positive. Y axis is the dam axis direction, pointing the right bank as positive. Z axis is the vertical direction, pointing upward as positive.

The range and boundary of the calculation model are determined as follows: the surrounding boundary and the bottom boundary are all 10 times the height of the dam. The dam is stratified from the bottom to the top, and is divided into one layer every 9m high. The grid of the dam is shown in Figure 1.



Figure 1. Three-dimensional finite element grid of the dam

2.2. Calculation parameters

Dam materials are considered as non-linear materials, and the calculation model adopts E-B non-linear model. The rock mass below the river bed and the bedrock on both banks is regarded as an elastic material, and the covering layer is considered as a non-linear material. The non-linear calculation parameters of the dam material are shown in Table 1.

Table 1. Calculation parameters of dam materials.

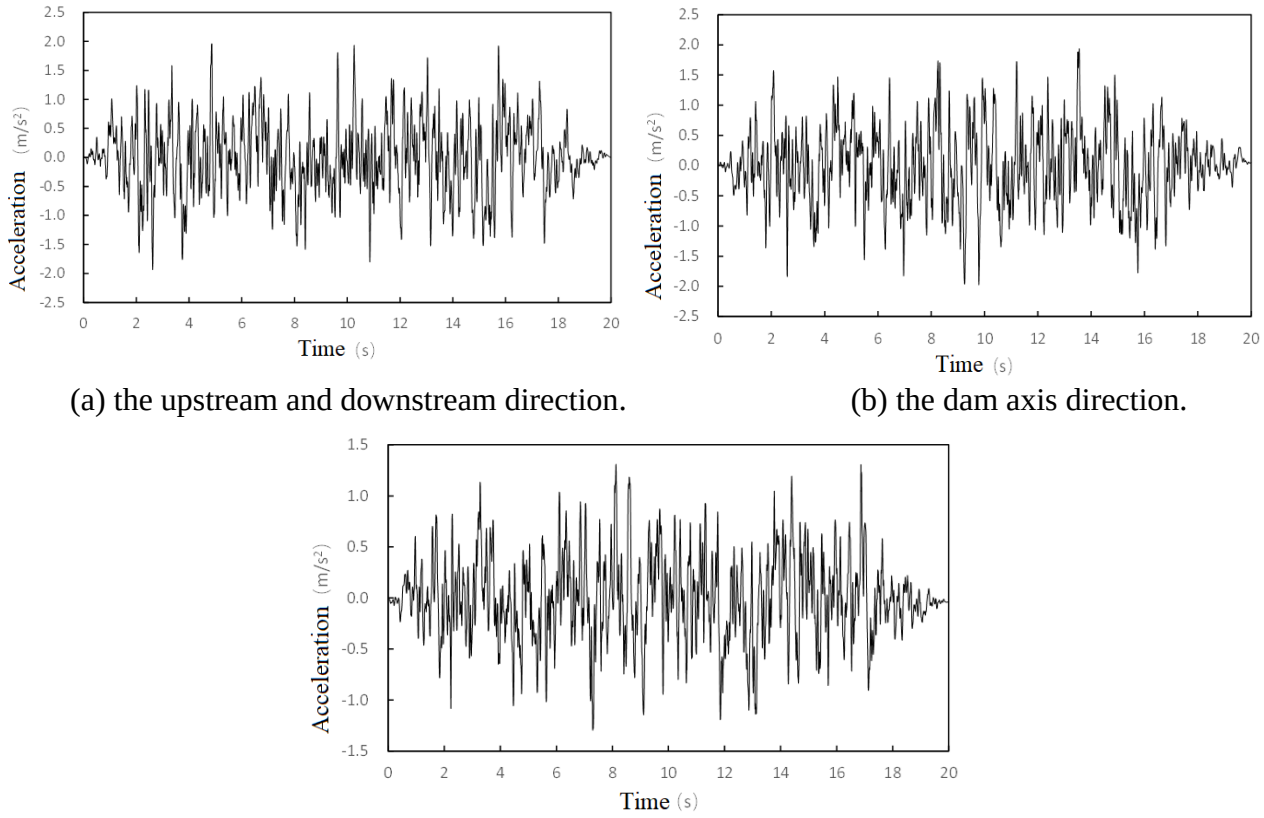
Project	Density	*Kur*	*K*	*n*	*Rf*	*Kb*	*m*	*φ0*	*⊿φ*	*c*
Dam material	1.72	600	280	0.3	0.7	150	0.35	34.7	7.9	35.9
Drainage material	2	900	700	0.5	0.75	400	0.5	36	4.0	0
Weakly Weathered Mudstone	E=0.3GPa, μ=0.3,f=0.4,c=60KPa									
Slightly weathered mudstone	E=0.5GPa, μ=0.25,f=0.6,c=200KPa									
Q_4/Q_3	E=0.1GPa, μ=0.4,f=0.4,c=15KPa									

Table 2. Parameters of equivalent linear model for dynamic calculation of dam materials.

Project	Density	K_1	n_1	φ	c	μ	λ_{max}
Dam material	1.72	1197	0.54	34.7	35.9	0.35	0.27
Drainage material	2	1210	0.56	36	40	0.3	0.24

2.3. Seismic waves parameters

The peak ground motion acceleration in the project area is a=0.20g, the corresponding basic earthquake intensity is VIII degree. The dam foundation is a Class II site, and the characteristic period of the ground motion response spectrum is 0.30s. The calculated input ground motion adopts the seismic wave acceleration time history generated by the set seismic code response spectrum. The input seismic wave time history are shown in Figure 2. The ground motion lasts 20s, and the peak acceleration of the vertical direction is taken as 2/3 of the horizontal direction in the calculation.



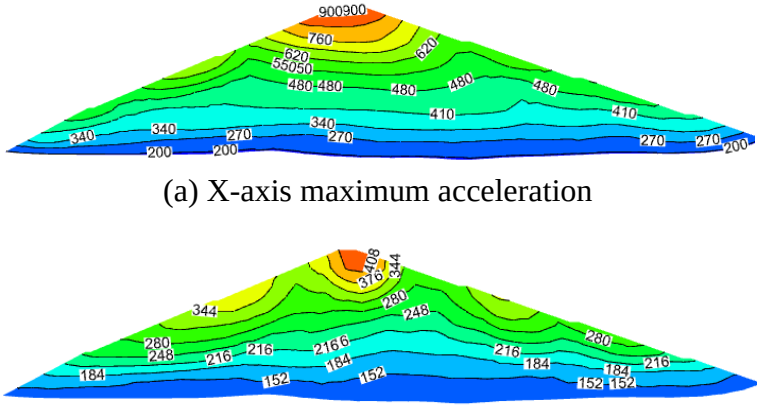
(a) the upstream and downstream direction. (b) the dam axis direction.

(c) the vertical direction

Figure 2. Input seismic wave acceleration time history.

3. Seismic response

This section calculates and analyzes the impact of seismic action on the dam. Under seismic load, most of the dynamic response inside the dam is weak, and the dynamic response is relatively strong on the surface of the dam in the middle of the river bed and near the dam crest. The maximum acceleration of the dam along the river is 921.5cm/s^2, the magnification is 4.7. The vertical maximum acceleration is 434.9cm/s^2, and the magnification is 3.3. From Figure 3, it can be seen that due to the "whiplash effect" and the mountain constraint around the reservoir, the dam along the river and the vertical acceleration laws increase along the dam elevation. The acceleration of the dam crest position is the largest. The acceleration of the dam near the two banks of the river bed is smaller than the position in the middle of the river bed.

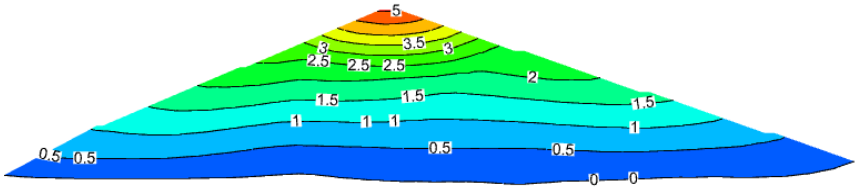


(a) X-axis maximum acceleration

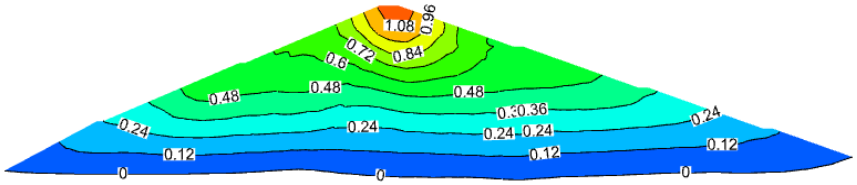
(b) Z-axis maximum acceleration

Figure 3. Acceleration cloud diagram of the maximum profile position of the dam.

Under the action of the earthquake load, the maximum dynamic displacement of the dam along the river is 5cm, and the maximum vertical dynamic displacement is 1.2cm. From Figure 4, it can be seen that due to the "whiplash effect" and the mountain constraint around the reservoir, the dam along the river and the vertical displacement laws increase along the dam elevation. The displacement of the dam crest position is the largest. The displacement of the dam near the two banks of the river bed is smaller than the position in the middle of the river bed.



(a) X-axis maximum displacement

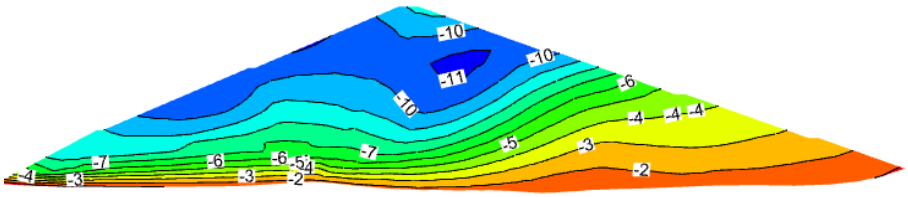


(b) Z-axis maximum displacement

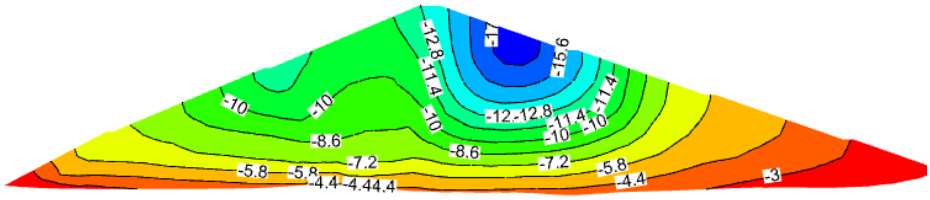
Figure 4. Displacement cloud diagram of the maximum profile position of the dam.

4. Seismic permanent deformation

The pseudo-static method is used to calculate the permanent deformation of the dam under the earthquake load. The results show that the permanent deformation of the dam along the river basically shows the downstream deformation, and the vertical earthquake permanent deformation shows the seismic subsidence. Under the action of the basic intensity earthquake, the maximum downstream permanent deformation is 11.2cm, and the maximum seismic subsidence is 17.6cm (accounting for 0.2% of the dam height). From Figure 5, it can be seen that the permanent deformation and seismic subsidence of the dam downstream basically increase along the elevation of the dam. The maximum value of the permanent deformation appears the top of the dam near the two banks of the river bed. The maximum value of the permanent deformation appears the 2/3 dam height on the upstream side in the middle of the dam.



(a) X-axis permanent deformation



(b) Z-axis permanent deformation

Figure 5. Permanent deformation cloud diagram of the maximum profile position of the dam.

5. Conclusions

Under the action of earthquake load, most of the dynamic response inside the dam is weak, and the dynamic response is relatively strong on the surface of the dam in the middle of the river bed and near the dam crest.

Permanent deformation basically manifests as an increase along the elevation of the dam. The maximum value of permanent deformation and seismic subsidence appears the 2/3 dam height on the upstream side in the middle of the dam. It is recommended to increase seismic measures to ensure the safety of the dam crest under seismic conditions.

Acknowledgments

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