The Deformation and Stress Analysis of Na Ba Reservoir Concrete Face Rock-Fill Dam

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Abstract: Based on the APDL (ANSYS Parametric Design Language) and combined with the actual project related to parameters of filling material, imported Duncan-Chang constitutive model which has been widely applied in soil mass and rock-fill in the ANSYS software. With the three-dimensional nonlinear finite element analysis by the mid-point incremental method, what have been computed are the deformation and stress analysis of Na Ba reservoir CFRD (Concrete Face Rock-fill Dam) in filling period. The calculation results provide practical reference for the dam during construction safety filling stress and deformation analysis and real-time monitoring.

Key words: Concrete face rock-fill dam, deformation and stress analysis, Duncan-Chang constitutive model, nonlinear finite element analysis.

1. Introduction

Na Ba reservoir project for water retaining in Wangmo County Guizhou province is a CFRD (Concrete Face Rock-fill Dam). The dam located in upstream Naba river and Wangmo river junction mouth about 1.0 km, about 4 km away from the Xintun, about 12 km away from the wangmo county. The dam crest elevation is 796.5 m, the height of the riverbed toe board foundation surface is 722.0 m, the dam maximum height is 74.5 m. The length of crest is 354.0 m, the width is 9 m, and the net width is 8 m. In order to reduce the dam construction, to reduce project cost and increase the overall stability of crest, crest structure will be set to “V” type concrete wall and integrated with downstream retaining wall. The top elevation of parapet is 797.7 m, and the bottom elevation is 791.8 m. The parapet of 5.9 m, above the normal water level (790.8 m) 1.0 m, the top of the wall is higher than the dam crest 1.2 m. Parapet at the bottom of the upstream side set the path of 0.8 m wide to walk and check; downstream parapet is 5.63 m. The main rock-fill area of the dam is made up of river bed gravel material near

the dam site area. Used in the limestone, materials of LiGu ditch are the downstream rock-fill area, cushion area, transition area, drainage area, special cushion layer materials and filter materials. The total dam filling volume is 1.89 million m^3 . The cross-section diagram of the dam is in Fig. 1.

2. Material and Methods

2.1 Duncan-Chang Constitutive Model and Parameters Determination

At present, in the soil of the nonlinear finite element analysis, the application of soil constitutive model with nonlinear elastic model, Duncan E-V model, Duncan E-B model, elastic-plastic model, elliptic-parabolic double yield surface model, modified Cambridge model, etc. [1]. The Duncan E-B model is used in this paper. The parameters are obtained from the conventional triaxial experiments, including K , n , R_f , C , ϕ , K_{ur} , $\Delta\phi$, K_b , m , G , F and D . The details are in the Table 1.

2.2 Stress Analysis Process Design

In Duncan-Chang model, the elastic modulus of each unit is different, because the force of each unit is different. Therefore, each unit is assigned to a material

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Fig. 1 The cross-section diagram of the dam (Unit: m).

Table 1 Na Ba CFRD material parameters for deformation and stress calculation.

Material name	Main rock-fill	Secondary rock-fill	Clay	Bedrock
R_f	0.8	0.7	0.8	0.7
K	1,400	1,200	1,250	1,950
n	0.5	0.4	0.5	0.5
K_b	1,000	800	700	1,248
m	0.3	0.2	0.2	0.3
K_{ur}	1720	1520	950	1000
n_{ur}	0.5	0.45	20	0.5
φ_0	30	45	20	35
$\Delta\varphi$	0	5	0	2
γ_d	1,893	2,256	1,727	1,960

number, and each calculation of a load step will be based on the Duncan-Chang model, dynamically modifying the material constants as the basis for the next step of the calculation, to achieve nonlinear solution process [2]. Specific steps process is shown in Fig. 2.

There are several common methods of analysis as following:

(a) The midpoint incremental method

The midpoint incremental method divides the load into several stages of load increments, making two finite element calculations for each incremental load. Step 2 finite element analysis the elastic parameters are calculated according to Eqs. (1, 2):

$$E = 0.25E_0 + 0.75E_m \quad (1)$$

$$\mu = 0.25\mu_0 + 0.75\mu_m \quad (2)$$

In Eqs. (1) and (2), E_0 and μ_0 are respectively as the

initial elastic modulus and Poisson's ratio, E_m and μ_m are the elastic modulus and Poisson's ratio were calculated from the results of the first step.

(b) Calculation of initial stress field

The following methods are used to determine the initial stress state of the new filling layer.

$$\sigma_1 = \gamma h \quad (3)$$

$$\sigma_3 = K_0 \gamma h \quad (4)$$

$$K_0 = 0.95 - \sin \varphi \quad (5)$$

In Eqs. (3-5), γ is the unit weight of the new fill soil; h is the centroid of the elements in the soil depth below the surface; K_0 is the static pressure coefficient of the soil; φ is the internal friction angle of this material.

(c) Displacement correction method

The new fill layer displacement correction algorithm is:

$$u' = 2yu / (h + y) \quad (6)$$

In Eq. (6), h is the thickness of the new fill soil; y is the distance between the internal nodes of the soil layer and the new filling surface; u is finite element calculation displacement [3].

This article selects the mid-point incremental method to realize the three-dimensional nonlinear finite element analysis and calculation.

Fig. 2 Stress simulation analysis flow chart.

3. Results and Discussion

3.1 Finite Element Model Establishment

The model includes bedrock, silt clay layer, main rock-fill area and secondary rock-fill area. The meshing of the whole model is divided into 8-node tetrahedral element. There are 45,890 units, set a total of four kinds of materials. The three-dimensional finite element model is shown in Fig. 3.

3.2 The Material Parameter Selection for Stress Calculation

Referring to relevant engineering and experimental data, the calculation parameters of stress and deformation of each part are shown in Table 1.

3.3 The Selection of Stress Analysis Model Unit

3.3.1 The Entity Unit

The solid65 tetrahedron 8 nodes element is selected for the dam entity unit, which is beneficial to the uniform division of the dam meshing.

3.3.2 The Contact Unit

The model selection of contact element is Contact 173 or Contact 174. Three dimensional 4 nodes low-order quadrilateral element, which can be located on the surface of 3-D solid or shell element (such as solid45 or shell1181), and can be degenerated into a triangular element with 3 nodes [4, 5].

3.4 Stress Analysis Calculation of Working Conditions

Agreed to calculation model coordinate system: the positive x axis is from upstream to downstream. The positive Y axis is for the elevation direction. The positive Z axis is from the right bank to the left bank.

Calculation of working condition:

In order to simulate the actual construction of the dam filling process, the dam is divided into 10 loads, each filling up 7 meters until the last layer of filling 4.5 meters to the crest.

3.5 The Calculation Results

The calculation results are shown in Figs. 4-7.

Fig. 3 The three-dimensional finite element model.

Fig. 4 The vertical displacement contour.

Fig. 5 The horizontal displacement contour.

Fig. 6 The maximum principal stress contour.

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