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Nonlinear analysis of stress and strain for a clay core rock-fill dam with FEM

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Abstract

Based on the Duncan-Chang hyperbolic nonlinear elastic material model, this paper carried out the stress and strain numerical analysis of a clay core rock-fill dam, which is a certain building reservoir dam in Yunnan province. By loading on each layer step by step and with the static nonlinear finite element simulation of deposition, it obtained the results of the stress and deformation of the clay core rock-fill dam. The calculation showed that the great difference in deformation modulus causes non-smooth variations in deformation, stress and strain between the transition area and the rock-debris fill. From the analysis it can be seen that the present design of the dam is reasonable since no any abnormal stresses and deformations occurred in the dam. Moreover, this also indicated a feasible and provided a valuable evident for the optimization of cross-section zones in a project.

Keywords:clay core rock-fill dam; stress-strain analysis; Duncan-Chang model; static nonlinear FEM

1.Introduction

In water conservancy and hydropower construction[1], rock-fill dam built in early time was usually done by the method of accumulating the riprap and water rush shoot with high pressure, so the compactness of stone was poor and the settling and horizontal displacement were large. Considering this, there is relatively the small number of rock-fill dam in the 1950s. As the soil mechanics, the soil test technology and rolling equipment progress, core rock-fill dam and inclined core rock-fill dam made of the

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soil seepage control body have achieved a great development. Especially after 1960s, vibration grinding is gradually popular and become the standard machine to compact rock-fill. Then the number of rock-fill dam is increasing. With the increasing number of rock-fill dam, more and more engineering problems arouse the attention of scholars. Many scholars at home and abroad took different degree of researches and published many papers and monographs about rock-fill dam in various aspects. This paper mainly paid attention to the deformation and stress and stability of clay core of rock-fill dam for numerical simulation analysis, hoping to guide the engineering.

The dam described in this paper is the clay core of rock-fill dam. The axis length, height and crestelevation are respectively 156.0m, 59.2m and 1786.4m.The width on top of the dam is 8m. The upstream dam slope is divided into 2 levels, which are respectively 1:1.9 and 1:2.5. Downstream dam slope is also divided into two levels, which are both 1:1.8. Middle MaDao is set as 2m. The dam seepage uses clay core, whose axis is in the same line with the dam axis, and the base has a depth in bedrock for 1.5m. The dam shell is divided into two parts and filled with two materials: limestone white clouds shell of rock-fill and white clouds debris. There are filter layers set between the core and dam shells. The foundation of the dam is all located on the high-weathering fossil sandstone. The layout plan, the 3-D topography map and the typical sections of the valley is shown in figure 1, 2, 3 below

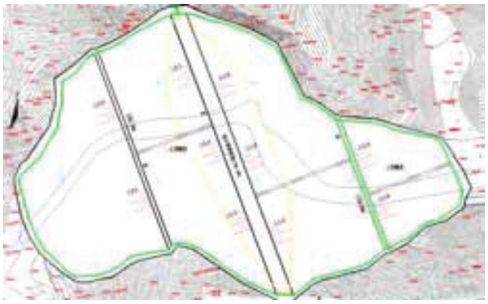

Fig.1 Hub plan of dam

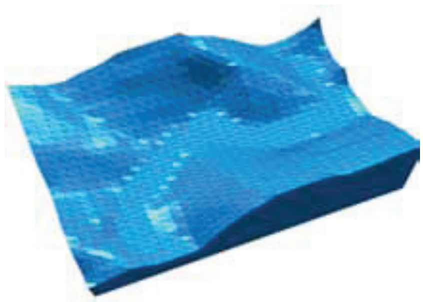

Fig.2 Three-dimensional topography dam-site river valley

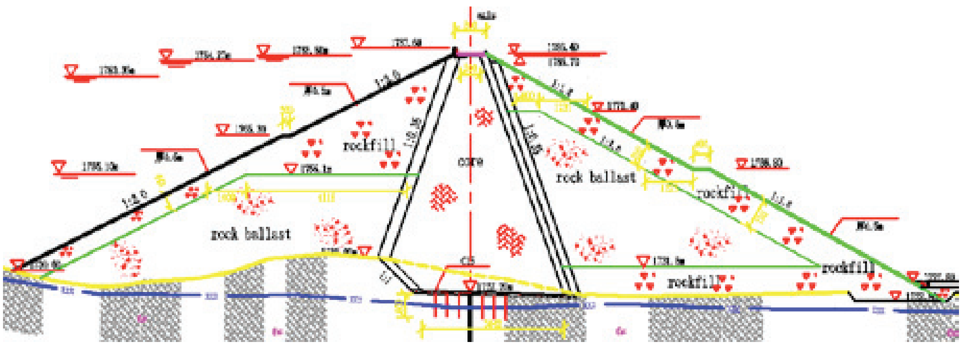

Fig.3 Typical section of dam

2 Calculation theory

In the stress and strain analysis of the rock-fill dam, the most extensive application now is the Duncan-Chang nonlinear elastic models[2-3]. There is much mature experience to do the determination of the model parameters and it is easy to test, so it is widely used in the calculation of rock-fill dam.

The tangent modulus of model can be expressed as

$$E_t = kp_a(\frac{\sigma_s}{p_a})^n[1-\frac{R_f(1-\sin\varphi_0)(\sigma_1-\sigma_3)}{2c\cos\varphi_0+2\sigma_3\sin\varphi_0}]^2$$

The elastic modulus while unloading and reloading is

$$E_{ur} = k_{ur}p_a(\frac{\sigma_s}{p_a})^n$$

The tangent volume modulus is described below [4]

$$B = k_b p_a(\frac{\sigma_s}{p_a})^m$$

Where C is cohesion, φ_0 is internal friction angle, p_a is atmospheric pressure, K 、 K_b 、 K_{ur} are modulus numbers, m 、 n are modulus indexes, R_f is break ratio defined as

$$R_f = \frac{(\sigma_1-\sigma_3)_f}{(\sigma_1-\sigma_3)_{ult}}$$

Where $(\sigma_1-\sigma_3)_f$ is the principal stress difference when the soil is in destruction, $(\sigma_1-\sigma_3)_{ult}$ is the principal stress difference corresponding to the asymptote of hyperbolic line

$$\varphi = \varphi_0 - \Delta\varphi\lg(\frac{\sigma_s}{p_a})$$

Where $\Delta\varphi$ is internal friction angle correction parameter, determined by test. Eight of the calculation model parameters are c 、 φ_0 、 K 、 K_b 、 K_{ur} 、 m 、 n 、 R_f, which can be determined by conventional triaxial test, their calculation values see table 1.

3 Computational model

The 3-D finite element grid is shown in figure 4 shows and the 3-D entity unit 10 nodes are adopted. The finite element method is used for the simulation of filling construction. Based on the horizontal layers rising step by step, it takes the location of every 2m for a load step and caculates until to the top(1786.40m). Valley dam body and finite element mesh section are shown in figure 4, 5, 6.

Fig.4 Hub plan of dam

Fig.5 Three-dimensional topography dam-site river valley

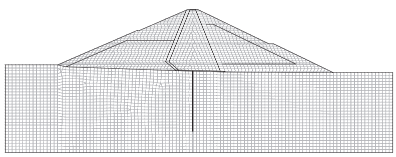

Fig.6 Typical section of dam

Table.1 Computational parameters of finite element

Parameters	core	rock-fill	debris	filter
ρ (kN/m3)	17.6	19.7	22.3	22.3
c (kPa)	80.1	56	64.1	64.1
φ_0	21.7	57.8	37	30
$\Delta\ \varphi_0$	12.4	18.8	7.0	/
Rf	0.76	0.8	0.68	0.72
K	117.8	1050	1192	1141
n	0.47	0.35	0.49	0.20
Kb	85.2	500	933	423
m	0.26	0.25	0.4	0.51
Kur	550	2100	/	1800

4 Result

In this paper, the stress calculation results are given when the dam finishes filling. The displacement in the direction of parallel flow, vertical displacement, stress level, vertical stress, shear stress, maximum principal stress and minimum principal stress in the dam sections are listed.(see Fig 7～Fig 13). From Fig12 it shows obviously that because the characteristics of core and dam shell are different, in the dam formed a "the arch" effect inside[5]. The core is unloaded significantly and stress concentration took place at the transition layer.

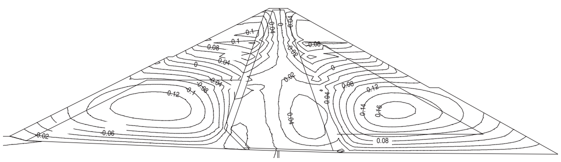

Fig.7 The displacement in the direction of parallel flow (m)

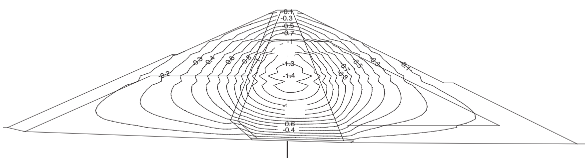

Fig.8 Vertical displacement isoline (m)

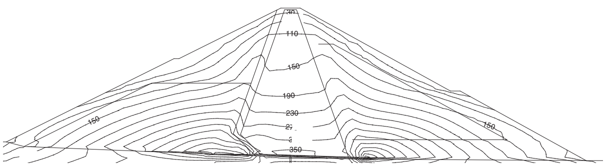

Fig.9 Horizontal stress isoline (kPa)

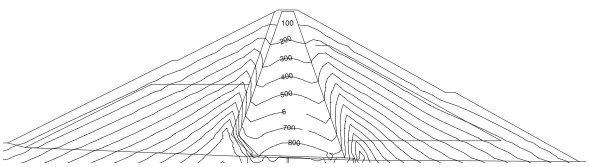

Fig.10 The vertical stress isoline (kPa)

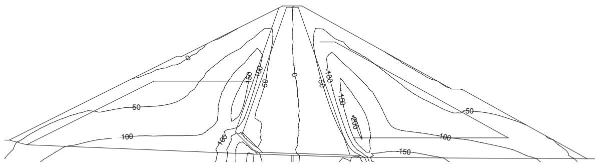

Fig.11 Shear stress isoline (kPa)

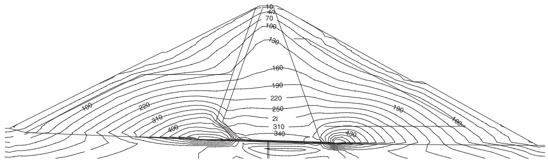

Fig.13 Minimum principal stress isoline (kPa)

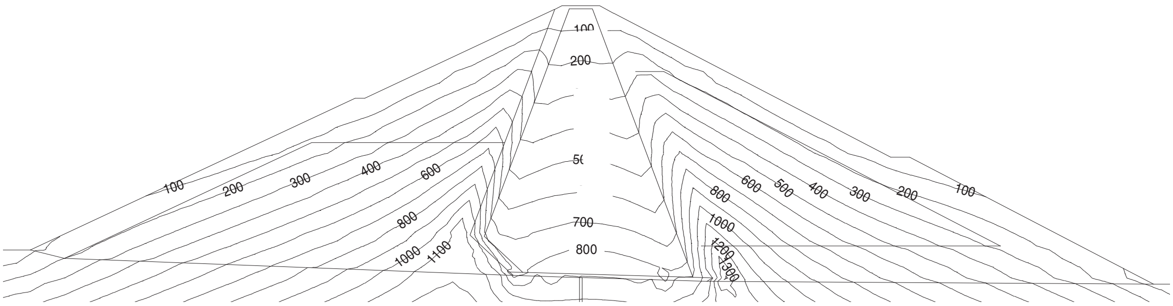

Fig.12 Maximum principal stress isoline (kPa)

From the results obtained(Fig 7～Fig 13), we can get: The small principal stress is not the tensile stress and no any abnormal stresses and deformations occurred in the dam. So the dam is safe and reliable.

5 Conclusion

Analysis and calculation show that the deformation and stress distribution of the dam meet with the features of the distribution of a general clay core rock-fill dam. Due to the influence of the transition layer, the “arch effect” of the seepage body in core is significant and the core is unloaded sharply. The maximum principal stress occurs at the place close to the dam foundation, downstream side of core. The minimum principal stress occurs in the central of dam slope. Since the filling process is near to the core, it may lead to “limit equilibrium zone” appearing. This must be strengthened in the construction.

References:

[1] Shutian Bai, Yihao Cui. The Mechanical Properties of Rockfill[J]. Journal of hydroelectric engineering, 1997(3):21-30.

[2] Chongjun JIANG,Yuhe Huang,Junjie WANG. Journal of chongqing jiaotong university (natural science) [J]. Water Power, 2007,10;26(B10):129-132,146.

[3] Hangzhou Li, Hongjian Liao. Non-linear Constitutive Model for Geomaterials under Complicated Stress State [J].Chinese journal of applied mechanics, 2006,6;23(2):318-321.

[4] Shengyuan Mu, Zhengzhong Wang. DuncanChang Model Parameters Sensitivity and Statistical Analysis of Rockfills[J]. China rural water and hydropower, 2009(3):97-100.

[5] Jiasong Zhang, Xing Li,Zhiguo Liu, Qingan Lin. Earth dam clay heart strong arch effect analysis[J]. Water conservancy science and technology and economy, 2007,2;13(2):84-86.