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To cite this article: Yucong Gao *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **507** 012033

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Study on Effects of Water Drop for High Concrete Face Rockfill Dams in Narrow Valley

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Abstract. In order to analyze the influence of sudden drawdown of dam water level of high concrete face rockfill dam (CFRD), the paper took a narrow valley high CFRD project for example and conducted a comparative study of stress and deformation of panel and dam between different drop amplitude of dam water level. An elastoplastic hardening soil (HS) constitutive model was used to predict the behavior of CFRD. Then, through analyzing the calculation result of six calculation Cases, the paper summarized the effect of dam water level drawdown speed and amplitude on deformation and stress respectively of panel and rockfill zones. The results showed that owing to the arching effect of the CFRD in narrow valley, total deformation of concrete face slab occurring near the dam crest. However, the pressure and tensile stress of concrete face slab along the dam axial direction have a significant influence on the separation of the slab pieces, and potential seepage at the joints in the slab. The study indicates that the hardening soil model could better to analysis of the behavior of high CFRDs and to predict the performances of high CFRDs.

1. Introduction

Concrete faced rockfill dams, which covered by concrete slabs at the upstream face as part of an impermeable barrier for the water, have been broadly constructed in many parts of the world due to their various advantages, such as good adaptability to topography, inherent flexibility and lowest-cost [1-3]. Compare with other types of dams, CFRD has own advantage, however, some high CFRDs, such as Campos Novos (Brazil, 202m height), Barra Grande (Brazil, 185m height) and Tianshengqiao (178m, China), have significant structural failure because of concrete-slab fractures which are clearly related to stresses on the concrete facing [4]. Because of the particle size, material type and purpose of the rockfill, the dam body is usually divided into zones, shown in figure 1 [5]. Since the 2 and 3A zones have little effect on deformation of concrete face, therefore those two zones are not taken into account in models.

2. Numerical modeling

The finite element program PLAXIS 3D is employed in this paper and describes the effect of different drop amplitude of dam water level on high CFRD in narrow valley. The earliest research was conducted CFRDs in 2D plane strain conditions, however, 2D plane strain conditions are not representative of reality because of the cross-valley arching effect which plays an important role in high CFRDs, therefore, 3D conditions are more appropriate than 2D conditions for modeling such a dam.



This CFRD was analyzed with the height of 180.0m and crest length of 540m is similar to NN2 CFRD located in the Lao People's Democratic Republic. This dam has an upstream slope of 1V:1.4H (vertical: horizontal) and a downstream slope of 1V: 1.4H. The dam is constructed on a narrow valley with 40m wide and abutment slopes are 35.8° for both left and right abutments. The CFRD simulation has been conducted under 3D modeling with 75233 4-node tetrahedral elements and 105237 nodes. Because of the foundation and abutment are not main point of this research, they were assumed to be linearly elastic, with a Poisson's ratio of 0.2 and a Young's modulus of 5.0GPa. The concrete face slab was built by 3D solid element with thickness varied from 0.3m at the dam crest to 0.8m at the toe, and assumed to be linearly elastic, with Poisson's ratio of 0.2 and a Young's modulus of 20.0GPa. The 3D CFRD mesh for this study generated by PLAXIS is illustrated in figure 2. To simplify the dam simulations, the construction stage was divided into 37 steps, there is one steps for the first impoundment stage and the dam water level reach 170m. The drop amplitude of dam water level in the same velocity as 5m/day are 25m, 50m, 75m, 100m, 125m and 150m, respectively.

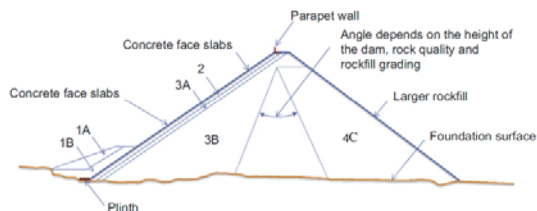


Figure 1. Typical CFRD configuration.

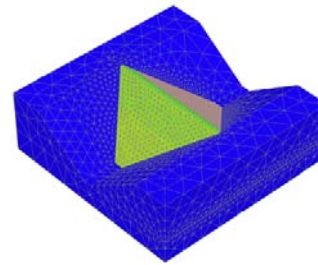


Figure 2. 3D finite element mesh.

An elastoplastic hardening soil (HS) constitutive model was used to predict the behavior of CFRD. In theory, the dilatancy behaviour has an influence on the volumetric strain for real behavior of dense sand. Therefore, the HS model is more suitable in representing the rockfill behaviour than the hyperbolic elastic model, especially for the analysis of high rockfill dam [6]. Such parameters for the CFRD simulation in this study are shown in table 1. The unit weights of the rockfill are 21.0kN/m^3 for zone 4C and 21.5kN/m^3 for the zone 3B and others.

Table 1. Parameters for the CFRD.

	φ	ψ	E_{50}^{ref} (MPa)	E_{oed}^{ref} (MPa)	m	R_f	Other
3B	47.09	3.2	80	55	0.29	0.78	$E_{ur}^{ref} = 3E_{50}^{ref}$, $P_{ref} = 100\text{kPa}$, $c = 1\text{kPa}$ $OCR = 1$, $K_0^{nc} = 1 - \sin\varphi$, $\nu = 0.3$
4C	42	-5	20	17	0.68	0.68	

3. Concrete face slab deformation and stress

The overall pattern of deformations and stress indicate that, as example by 75m water level drawdown in figure 3, owing to the load of impounding, the concrete face slab both settles and moves towards the downstream, with the maximum values of pressure stress perpendicular to the dam axial direction occurring approximately in the mid-section and total deformation occurring near the dam crest, since the arching effect of the CFRD in narrow valley. However, the stress along the dam axial direction shows that pressure stress occurring in the mid-section of the slab and tensile stress occurring near the abutment. They have a significant influence on the separation of the slab pieces, and potential seepage at the joints in the slab.

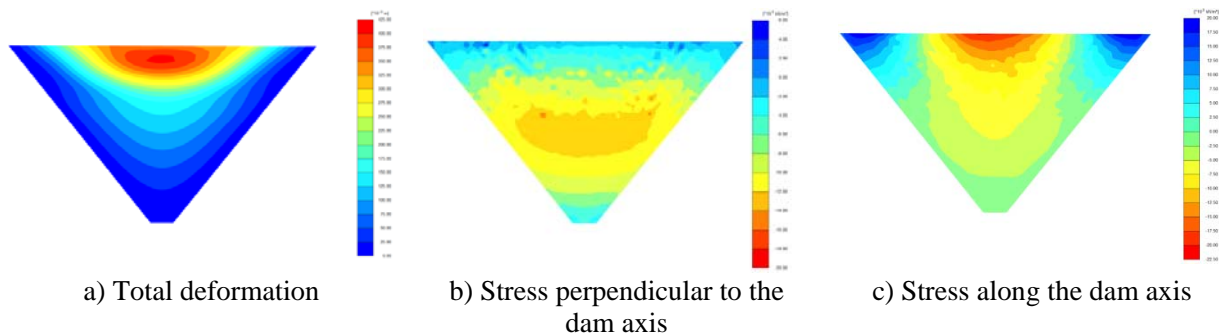


Figure 3. Total deformation and stress of the concrete face slab due to impounding

Figure 4 shows the maximum values of deformation and stress of the slab. The maximum values of total deformation decrease with the drop amplitude of water level decreased. However, the maximum values in the water level of 145m which after drop amplitude of 25m has discrepancy. The figure 4 (b) indicates that both pressure and tensile stress, the increasing amplitude of maximum values of stresses along the dam axis decreased as lower dam water level after drawdown. The figure 4 (c) shows that the water level after drawdown has little influence on maximum stress of perpendicular to dam axis.

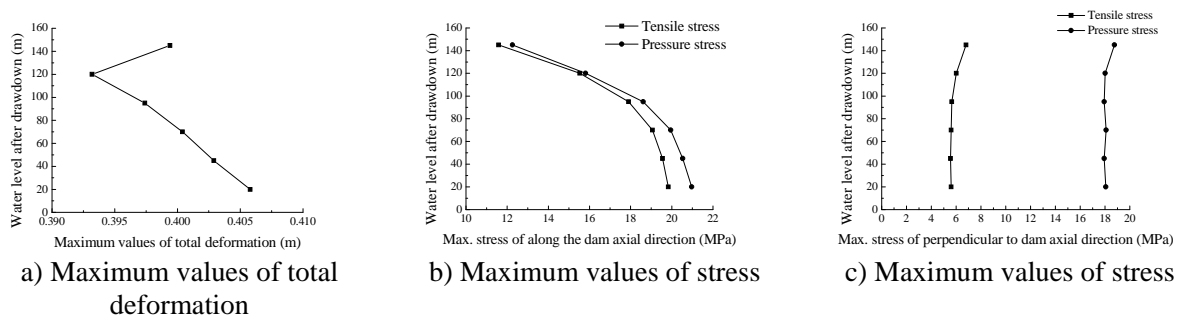


Figure 4. Maximum values of deformation and stress after different amplitude of water level drawdown.

4. Settlement behavior of CFRD

Examples by 75m drop amplitude of dam water level, the figure 5 (a) and (b) show the settlement of CFRD after drawdown for transection of perpendicular (ToP) and transection of along (ToA) the dam axis, respectively. The maximum settlement of rockfill for ToP simulated from both models occurs in zone 4C at downstream side since the stiffness of rockfill in zone 4C is lower than those in zones 3B. The maximum settlement of rockfill for ToA occurs in the mid-section of rockfill and mirrored at the valley axis. The figure 5 (c) shows that maximum amplitude values of settlement for ToP and ToA decreased with the lower of drop amplitude of dam water level.

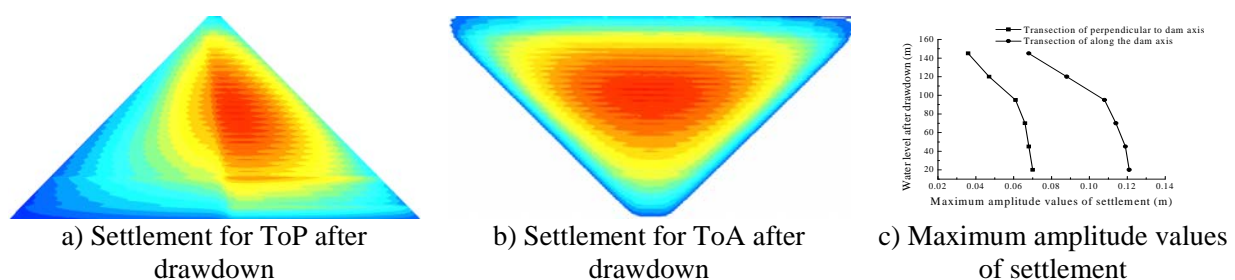


Figure 5. Settlement behavior of CFRD after drawdown.

5. Summary

In this study, 3D finite element analysis of high CFRD is carried out and computed the effect of water drop on stress and deformation of high CFRD. The rockfill material is represented by the hardening soil model. The results show that since the narrow valley, the total deformation of concrete face slab occurring near the dam crest; the stress along the dam axial direction shows that pressure stress occurring in the mid-section of the slab and tensile stress occurring near the abutment. They have a significant influence on the separation of the slab pieces, and potential seepage at the joints in the slab; and the maximum amplitude values of settlement for transection of perpendicular and along the dam axis decreased with the lower of drop amplitude of dam water level. The results obtained from 3D non-linear finite element analysis using hardening soil model are found to be in relatively good agreement in predict the performances of high CFRDs and satisfactorily reflect the deformation characteristics of rockfill masses.

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