Research on creep deformation of rockfill material and post-construction deformation of rockfill dam

Recherche sur la déformation faible des materiaux d' enrochements et le déplacement après la construction du barrage en enrochement

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ABSTRACT

By developing a large scale stress controlled tri-axial testing machine, the creep deformation properties of rockfill material under different conditions were studied. From the laboratory test, it can be found that the creep deformation of rockfill has a direct relationship with cell pressure and stress level. Based on creep deformation test of rockfill samples and the monitoring data of built dams, an empirical model for creep deformation analysis of rockfill material is developed, which assumes the creep deformation of rockfill follows a logarithmic attenuation formula. According to the proposed mathematic model, numerical analysis for a concrete faced rockfill dam was conducted. Stress and deformation status of the dam under the long term operation condition is presented. It could be found that the creep deformation of rockfill has significant impacts on the stresses of concrete face slabs.

RÉSUMÉ

Avec le dévelopement de machine d'essai triaxiale controllée par des contraintes à grande échelle, les charactéristiques de la déformation faible des matériaux d'enrochments sous de differentes conditions ont été etudiées. Selon des essais dans l'aboratoire, on peut trouver que la déformation faible des enrochements est directment relative à la pression de cellule et au niveau des contraintes. Sur des essais de la déformation faible des échantillons d'enrochement et des auscultations des barrages construits un modèle empirique est établi pour analyser la déformation faible des matériaux d'enrochement. Celui a assuré la déformation faible d'enrochement à suivre la formule d'atténuation logarithmique. D' après du modèle mathématique proprosé l'analyse numéricale sur un barrage en enrochement à masque amont en béton est realisé. Cela ensuite a donné des contraintes et la déformation dans la condition par l'opération de la période longue. Il montre que la déformation faible d'enrochements à créer des impacts considérables sur les contraintes des dalles de masque en béton.

Key words: creep deformation, rockfill, CFRD

1. INTRODUCTION

As a granular material, the stress and deformation of soil has a close relationship with time. No matter clay, sand and rockfill, its deformation under certain load can not be completed instantly. It will develop in a period of time with a certain rate. Normally, in the deformation analysis of soil, the development process of soil deformation with time under the condition of fixed load is called creep deformation. For the creep deformation of soil, previous studies were mainly focus on clay material. There are fewer studies on the creep deformation of rockfill materials. From field monitoring data of the built projects, the creep deformation of rockfill was observed. Many compacted rockfill dams have presented obvious long term deformation after completion of construction, such as Cechana concrete faced rockfill dam in Australia [1], TSQ-1 concrete faced rockfill dam in China [2], etc. Although the long term deformation of these dams may relate with several factors, such as creep deformation of rockfill, softening of rockfill with the action of water, weathering of rockfill by circulation of wetting and drying, changing load of upstream water level, etc., considerable proportion of the long term deformation is caused by creep deformation of rockfill. Therefore, it is necessary to consider creep deformation in the deformation analysis of rockfill dam, especially for high rockfill dam.

At present, the mechanism of creep deformation of rockfill is still unclear. From author's point of view, the main reason of creep deformation of rockfill material is the breakage of particles and the process of its rearrangement. For the non-cohesive materials as rockfill, the main part for bearing external load is the friction at the contact point of particles. The local stress concentration of the contact point will lead to breakage of particles, and then the redistribution of the stress of rockfill and the rearrangement of particles. This adjustment process may take certain times to be finished. Besides, the variation of the physical and chemical conditions inside rockfill will also lead to the development of rockfill deformation.

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2. STUDY ON CREEP DEFORMATION PROPERTIES OF ROCKFILL MATERIAL BY LABORATORY TEST

The creep deformation test of rockfill is conducted by stress controlled large scale triaxial testing machine. The main technical specifications are:

Sample size: Φ300×700mm
Maximum cell pressure: 4MPa
Maximum vertical load: 1000kN

The testing machine can provide stable constant load for a long time. The maximum time for stable load is 6 months.
The testing material is limestone rockfill. The dry density of the samples is 2.20g/cm^3. The maximum particle size of the samples is 60mm. During the test, the controlled cell pressures are 0.4MPa, 1.0MPa and 1.6MPa. Based on the strength parameters from conventional triaxial test, the creep deformation tests were conducted under the stress level of 0.2, 0.4, 0.6 and 0.8.

2.1 Creep deformation properties of rockfill

The relationship of axial strain and volumetric strain with the time are shown in Fig. 1 and Fig. 2. It could be noticed that: shortly after vertical load applied, the axial strain and volumetric strain of the sample increased rapidly. After that, under the action of stable constant load, the deformation of the sample went into the stage of creep deformation. The axial strain and volumetric strain gradually increased. The rate become slowly with the increasing of time and finally trend to stable.

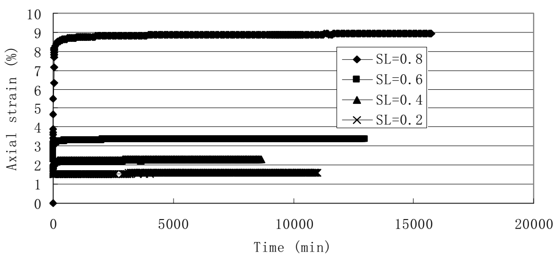

Fig. 1. Axial strain under cell pressure of 1.0MPa

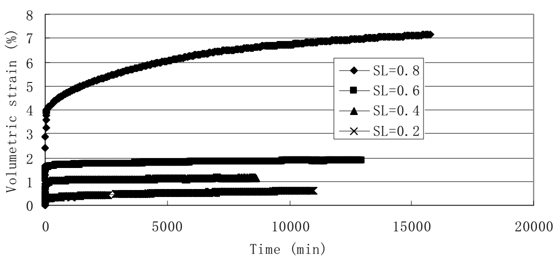

Fig. 2. Volumetric strain under cell pressure of 1.0MPa

2.2 Impact of stress level on creep deformation

From testing results, the axial strain is linear with logarithm of time (as shown in Fig. 3). For the test of different stress level, the samples with high stress level will produce more axial creep deformation. Similarly, the volumetric strain is also nearly linear with logarithm of time (Fig. 4). But it presents rather steep slope. The volumetric strain is also increased with the rising of stress level.

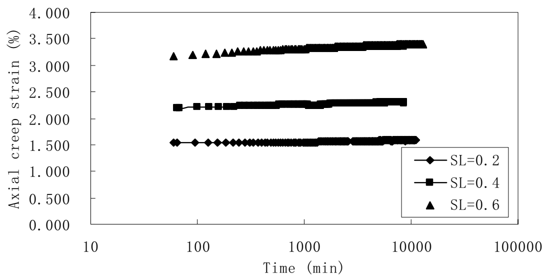

Fig. 3 Axial strain under different stress level (σ_3=1MPa)

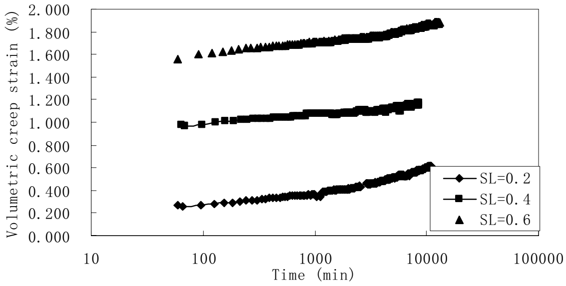

Fig. 4 Volumetric strain under different stress level (σ_3=1MPa)

2.3 Impact of cell pressure on creep deformation

Fig. 5 and Fig. 6 are creep deformation under different cell pressures. It could be noticed that the axial strain and volumetric strain are all increased with the raising of cell pressure.

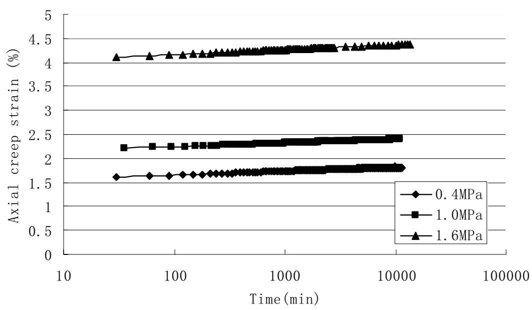

Fig. 5 Axial strain under different σ_3 (SL=0.6)

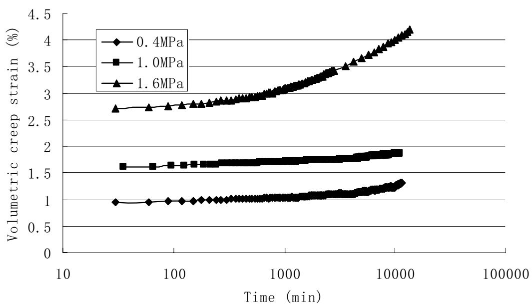

Fig. 6. Volumetric strain under different σ_3 (SL=0.6)

3. MATHEMATIC MODEL FOR CREEP DEFORMATION ANALYSIS

According to the results of creep deformation test, the creep deformation of rockfill presents an obvious linear relation with logarithm of time. Therefore, with the laboratory testing results and the deformation observation of rockfill dams, an empirical model based on the assumption that creep deformation is linear with the logarithm of time is proposed to describe the development of creep deformation of rockfill material.

The total strain of rockfill under the action of external load could be divided into two parts, i.e. instant strain and creep strain:

$$\Delta\varepsilon = \Delta\varepsilon^{ep} + \Delta\varepsilon^{creep}$$

Where, $\Delta\varepsilon^{ep}$ is increment of instant strain, $\Delta\varepsilon^{creep}$ is increment of creep strain.

Suppose t_0 is the initial time of creep deformation, then, the increment of creep deformation from t_0 to t can be calculated by:

$$\Delta\varepsilon^{creep} = \varepsilon_{10}(\lg t - \lg t_0)$$

Where, ε_{10} is the parameter of the model. Its value equals to the creep deformation increment at the time of $10t_0$. It could be used to represent the values and developing speed of creep deformation.

For considering the impact of stress status on creep deformation, different formulas were proposed to calculate volume deformation and shear deformation respectively.

$$\varepsilon_{v10} = c_1 \frac{\sigma_3}{P_a}$$

$$\varepsilon_{s10} = c_2 S_l^{\,c_3}$$

Where, c_1, c_2 and c_3 are parameters, P_a is atmospheric pressure, S_l is stress level.

The component of creep strain is allocated by Prandtl-Reuss principle, i. e.

$$\{\Delta\varepsilon^{creep}\} = \frac{1}{3}\Delta\varepsilon_v^{\,creep}\{I\} + \Delta\varepsilon_s^{\,creep}\frac{\{s\}}{\sigma_s}$$

Where, {s} is partial stress tensor, {I} is unit tensor, σs is generalized shear stress.

4. POST CONSTRUCTION DEFORMATION ANALYSIS OF CONCRETE FACED ROCKFILL DAM

Based on the proposed model, a concrete faced rockfill dam with its height of 133m and the plinth built on deep alluvium was selected to conduct 3D stress and deformation analysis with the consideration of creep deformation of rockfill. The typical dam section is shown in Fig. 7. The instant deformation of rockfill is computed by Duncan's hyperbola model. Linear-elastic model is applied for concrete structures, include plinth, face slabs and connect slabs.

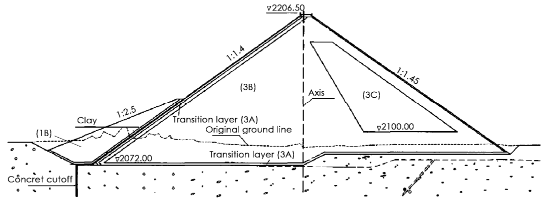

Fig. 7. Typical dam section

According to laboratory creep deformation test and considering the observed data of similar dams, the parameters for creep deformation computation are: c1=0.01%、c2=0.15%、c3=0.9.

The settlement and horizontal displacement of the riverbed section after completion of dam construction are shown in Fig. 8 and Fig. 9. The maximum settlement of the dam is about 0.3m, located at the central part of the dam. The horizontal displacements of upstream and downstream part rockfill are point to upstream and downstream respectively. Its maximum values are located at the middle part near upstream and downstream surface.

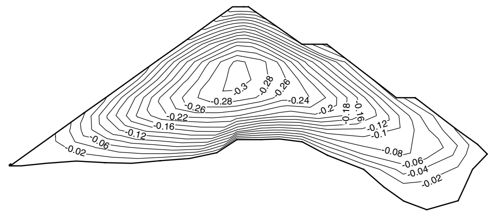

Fig. 8. Settlement of rockfill after dam construction

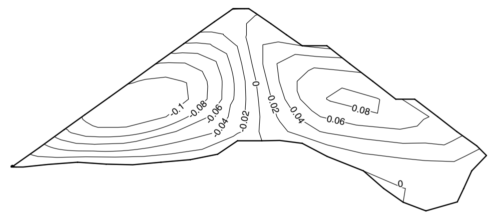

Fig. 9. Horizontal displacement after dam construction

The incremental displacement after 5 years of dam construction completed is shown in Fig. 10. From the figure, it shows that the deformation of rockfill is still developing after dam completion. Relatively, the upper part of the dam has more creep deformation.

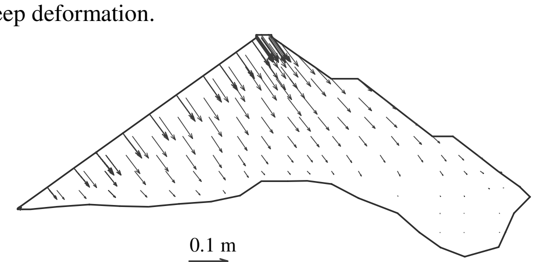

Fig. 10. Increment disp. after 5 years of dam completion

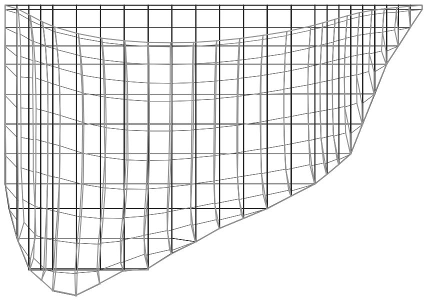

Fig. 11 shows the normal displacement of face slab after 5 years of dam completion. Due to the creep deformation, the region of maximum normal displacement of face slab is moved to the upper part of face slab, when compared with the situation without considering rockfill creep deformation.

Fig. 12 Deformation of face slab after 5years of dam completion

Fig. 12 shows the face slab deformation after 5 years of dam completion. It could be noticed that the slabs produce bending deformation under the action of water load. The creep deformation has further increased the deformation of face slabs at the top part of riverbed sections. Compared with the situation without considering creep deformation of rockfill, the stress of concrete face slabs in dam axis and upstream slope direction are increased. But the creep deformation has not changed the general stress state of face slabs. Only the stress values have been increased.

5. CONCLUSIONS

According to the laboratory creep deformation test of rockfill material and the numerical analysis of concrete faced rockfill dam, following conclusions could be gotten:

(1) The laboratory test shows that creep deformation is presence for rockfill material. Especially under the condition of high confining pressure and high stress level, the creep deformation of rockfill become more obvious.

(2) The process of creep deformation of rockfill is mainly due to the breakage and rearrangement of rockfill particles.

(3) The creep deformation of rockfill is related with many factors, which include: properties of original rock, rockfill gradation, compaction density, stress level, etc. From laboratory test, the creep deformation of testing samples has directly related with cell pressure and stress level.

(4) The development of creep deformation of rockfill could be described by considering the creep strain has linear relationship with logarithm of time.

(5) From the numerical analysis of concrete faced rockfill dam, the creep deformation of rockfill has significant impact on stress and deformation of dam and face slabs. It could lead to the increase of the stress of face slabs both in dam axis and upstream slope.

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