Study on Wetting Deformation Characteristics of Damming Materials under Triaxial Compression

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Abstract: The wetting deformation of dam material will lead to uneven settlement of dam body, which will harm dam safety. A large static triaxial test instrument was used to conduct a single line triaxial compression humidification test on dam material in the main rockfill area of a power station. The humidification deformation rule and its relationship with confining pressure and stress level were analyzed. The experimental results show that the wetting axial strain is inversely proportional to the stress level, and the wetting volume strain is proportional to the confining pressure. The wetting model can effectively reflect the changing law of dam materials, and the research results provide experimental basis for the calculation and design of the dam body wetting deformation.

Keywords: Damming materials; Single line method; Triaxial compression; Wetting test; Parameters of humidification model.

1. Introduction

Faced rockfill dams are more and more widely used in water conservancy and hydropower projects [1~3]. Wet deformation of dam material means that rockfill is immersed in water under a certain stress state, and the particles slip, break and rearrange each other due to water lubrication and water softening of particle minerals, which leads to stress redistribution and additional deformation. Under the conditions of dam impoundment, rainfall infiltration and water level rise and fall, dam materials are prone to water saturation, resulting in humidification and deformation of dam materials [4-6]. Especially in the main rockfill area, when the amount of humidification deformation is large, it may lead to cracks in the dam body or structural damage of the panel, thereby reducing the service life of the entire rockfill dam project and bringing huge losses to the project [7~10]. Therefore, large-scale static triaxial test equipment is proposed to conduct humidification test on dam materials used in the main rockfill area in the project [11-12], study the humidification deformation characteristics and influencing factors of dam materials, and summarize the parameters of the humidification model. The results can provide experimental basis for the calculation and design of the humidification deformation of this project and similar faced rockfill dams.

2. Project Overview

The single-stage vertical shaft single-speed mixed-flow reversible pump-turbine units with a capacity of 400MW were installed in a pumped storage power station, with an installed capacity of 1600MW and a full operation hours of 6h. Both the east and west main dams of the upper reservoir of the power station are made of reinforced concrete face rockfill dams, the maximum dam height is 132.5m, and the dam body is filled with weak weathering materials excavated from the mountain in the reservoir, which are divided into main rockfill area, increased mold area, downstream rockfill area, transition area and cushion material. The average uniaxial saturated compressive strength of weak weathering material excavated in the warehouse is 102MPa, which is a hard rock. The average softening coefficient of the rock is 0.79, which is unsoftened rock.

3. Test Method

3.1 Test Equipment

A large static triaxial tester was used for the test. The sample size was Φ300×600mm, the maximum axial static load was 1500kN, the axial force resolution was 0.1kN, the displacement resolution was 0.001mm, the displacement measurement accuracy was 0.3%F.S, the ambient pressure was 0 ~ 4MPa, and the drainage resolution was 1ml. The large static triaxial tester was shown in Fig. 1.

Fig. 1 Large dynamic triaxial tester

3.2 Test Process

(1) Sample preparation

In this test, weakly weathered dam materials in the rock recovery area are used, and the maximum particle size is 600mm, which exceeds the requirements of the sample particle size in the laboratory test, and the test preparation should be conducted by scaling method. The purpose of sample preparation is to provide test materials for various tests with representative coarse granular soil after necessary preparation procedures. According to the grading requirements of the design, the mixed method combining the similar grading method and the equivalent substitution method is adopted for scaling to ensure that the particle size content of less than 5mm is unchanged after scaling. The test grading after scaling is shown in Fig. 2.

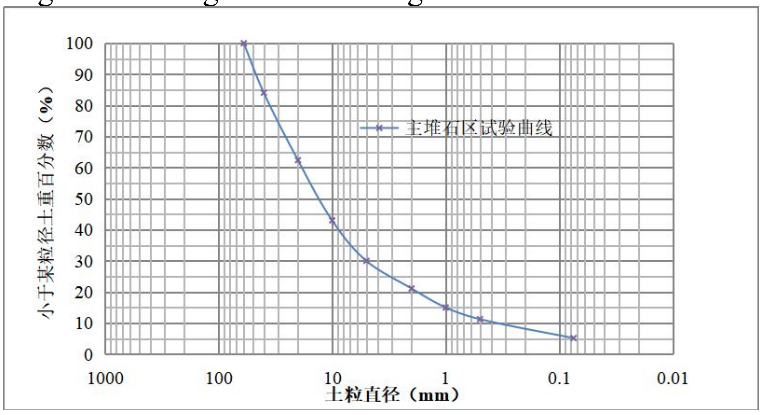

Fig. 2 Test grading curve of main rockfill area

According to the design requirements, the design porosity of the main rockfill area is n≤20%, the specific gravity of dam material is obtained through the test, and the controlled dry density of sample preparation is calculated, as shown in Table 1. The sample was prepared by stratified vibrating method, each layer was 10cm, and the sample was formed by controlled dry density. The sample was saturated by head saturation method, and the saturation reached more than 99%.

Table 1. Test on dry density and porosity of damming materials

Dam body zoning	Dominant lithology	Mean specific gravity	Fill design index	Test dry density calculated according to minimum design fill index (g/cm³)
The main rockpiling area	Weakly weathered excavation	2.64	Porosity n≤20%	2.112

(2) Test procedure

According to the relevant provisions of the 《Standard for geotechnical testing method》(GB/T50123-2019), the "single line method" is used to carry out the humidification deformation test of dam materials. The main steps are as follows:

1) Conventional consolidation: The predetermined confining pressure of 200kPa, 500kPa and 800kPa is applied to the air-dried sample, and the change of water quantity in and out of the pressure chamber is calculated by the change of lateral cylinder volume. Since water is incompressible, it can be considered that the change of water quantity in and out of the pressure chamber is equal to the change of sample volume, and according to this, whether the sample is consolidated and stable is judged;

2) Dry sample shear: shear the air-dried sample according to the shear rate of the static triaxial test under the condition of exhaust gas until the axial stress reaches the stress corresponding to the predetermined stress level, and the stress levels are 0.2, 0.4 and 0.8;

3) Deformation stability: control the confining pressure and axial stress unchanged, until the axial deformation of the sample is stable;

4) 4) Saturation stage: water is carried out from the bottom of the sample to saturate the sample. The axial deformation and drainage volume of the sample were measured during the saturation process;

5) Humidification stage: keep the confining pressure unchanged, continue to shear the sample at the static triaxial test shear rate under drainage conditions until the preset stress level of the sample, and measure the axial displacement, load and volume changes during shear until the deformation is stable. The test diagram is shown in Fig. 3.

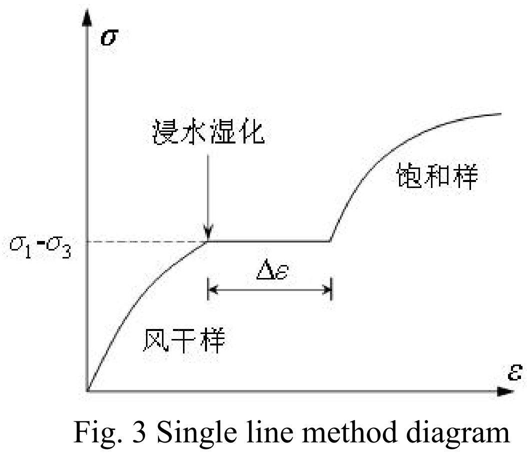

Fig. 3 Single line method diagram

4. Test Results and Analysis

4.1 Introduction to the humidification model

In order to consider the strain increment caused by water immersion deformation of dam materials in the stress-strain analysis process, it is necessary to sort out the relationship between the humidified body strain vs , humidified shear strain s and stress level lS through tests. Shen Zhujiang proposed a two-parameter humidification calculation model:

$$\begin{cases} \varepsilon_{vs} = c_w \\ \gamma_s = b_w \dfrac{S_l}{1-S_l} \end{cases} \quad (1)$$

In the formula, c_w 、b_w are the humidification parameters of the bulk strain and shear strain, and S_l is the stress level.

Subsequent studies by some scholars found the relationship between strain and stress conditions of humidified body, and established a three-parameter model:

$$\begin{cases} \varepsilon_{vs} = c_w \left(\dfrac{p'}{P_a} \right)^{n_w} \\ \gamma_s = b_w \dfrac{S_l}{1-S_l} \end{cases} \quad (2)$$

In the formula, c_w 、 n_w are the humidification coefficient and index of the bulk strain, b_w is the humidification parameter of the shear strain, p_a is the atmospheric pressure, p' is the small principal stress of humidification, expressed by the confining pressure, and S_l is the stress level.

The volume strain and shear strain calculated by the above model are allocated to each strain component according to the Prandtl-Reuss flow rule, and the above two models are used to organize the parameters in this experiment.

4.2 Analysis of humidification test results

The humidification deformation process curve of dam-building materials in the incremental mold area is shown in Fig. 4~12, and the deformation results of humidification test are shown in Table 2. It can be seen from the test results that under the same confining pressure, the humidification axial strain, humidifying volumetric strain and humidifying shear strain are proportional to the stress level, that is, the larger the stress level is, the larger the three strains are; while at the same stress level, the humidifying deformation is proportional to the confining pressure, that is, the humidifying deformation increases with the increase of confining pressure.

Table 2. Results of humidification and deformation in the main rockfill area

Dam body zoning	Confining pressure (kPa)	Stress level	Wetting axial strain (%)	Wetting volume strain (%)	Wetting shear strain (%)
The main rockfill area	200	0.186	0.040	0.108	0.004
		0.382	0.304	0.136	0.259
		0.794	0.770	0.272	0.680
	500	0.194	0.061	0.179	0.001
		0.386	0.436	0.245	0.355
		0.805	1.041	0.313	0.937
	800	0.201	0.141	0.222	0.067
		0.404	0.446	0.324	0.337
		0.795	1.562	0.393	1.431

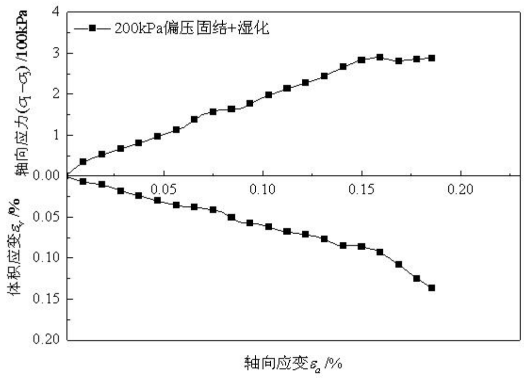

Fig. 4 Relationship curve of $(\sigma_1-\sigma_3) \sim \varepsilon_a$ and $\varepsilon_v \sim \varepsilon_a$ in main rockfill area (stress level 0.186)

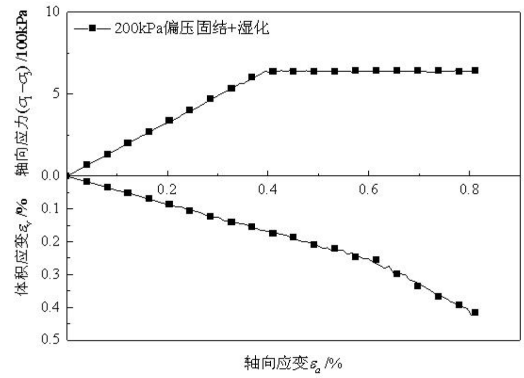

Fig. 5 Relationship curve of $(\sigma_1-\sigma_3) \sim \varepsilon_a$ and $\varepsilon_v \sim \varepsilon_a$ in main rockfill area (stress level 0.382)

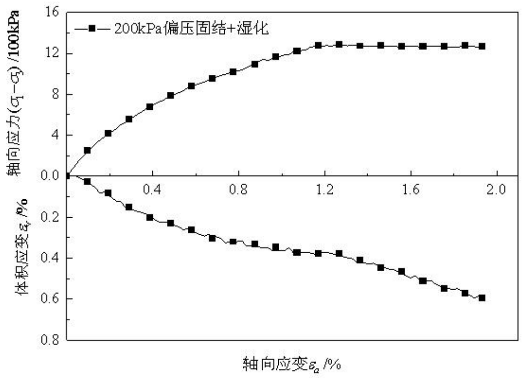

Fig. 6 Relationship curve of $(\sigma_1-\sigma_3) \sim \varepsilon_a$ and $\varepsilon_v \sim \varepsilon_a$ in main rockfill area (stress level 0.794)

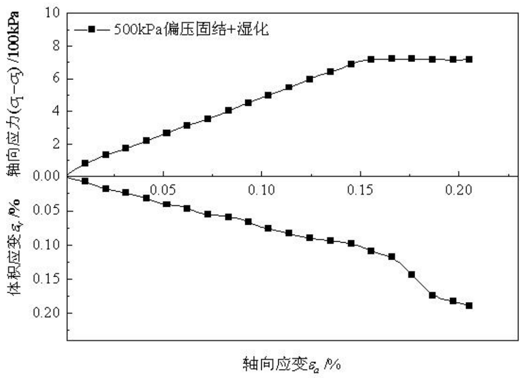

Fig. 7 Relationship curve of $(\sigma_1-\sigma_3) \sim \varepsilon_a$ and $\varepsilon_v \sim \varepsilon_a$ in main rockfill area (stress level 0.194)

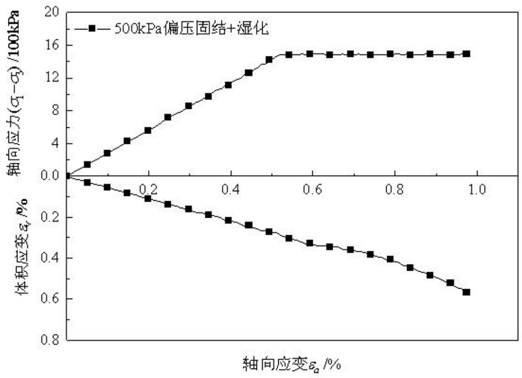

Fig. 8 Relationship curve of $(\sigma_1 - \sigma_3) \sim \varepsilon_a$ and $\varepsilon_v \sim \varepsilon_a$ in main rockfill area (stress level 0.386)

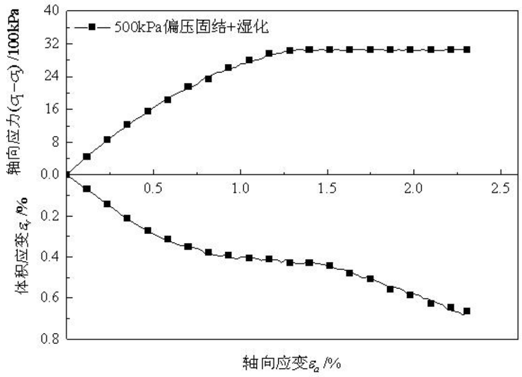

Fig. 9 Relationship curve of $(\sigma_1 - \sigma_3) \sim \varepsilon_a$ and $\varepsilon_v \sim \varepsilon_a$ in main rockfill area (stress level 0.805)

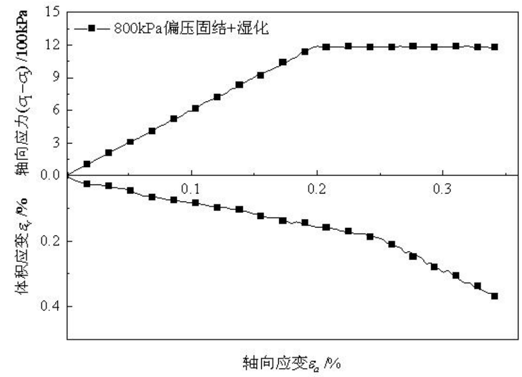

Fig. 10 Relationship curve of $(\sigma_1 - \sigma_3) \sim \varepsilon_a$ and $\varepsilon_v \sim \varepsilon_a$ in main rockfill area (stress level 0.201)

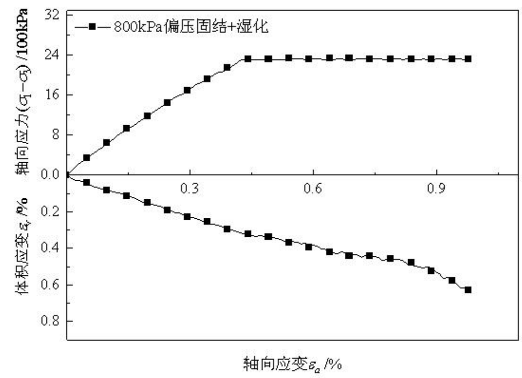

Fig. 11 Relationship curve of $(\sigma_1 - \sigma_3) \sim \varepsilon_a$ and $\varepsilon_v \sim \varepsilon_a$ in main rockfill area (stress level 0.404)

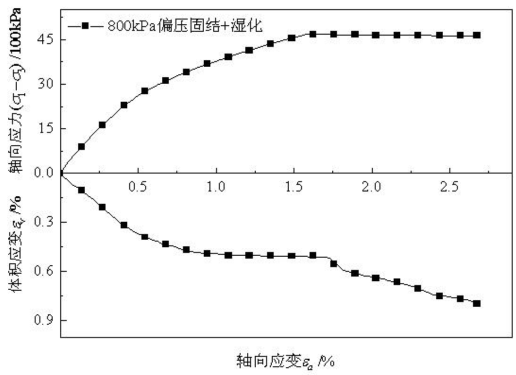

Fig. 12 Relationship curve of $(\sigma_1-\sigma_3)$~ε_a and ε_v~ε_a in main rockfill area (stress level 0.795)

According to the results of the humidification deformation test, the ε_{vs}~$p^{'}/p_a$ and γ_s~$S_l/(1-S_l)$ relationship curves are drawn, as shown in Fig. 13-14, and the parameters of the humidification model are obtained by fitting and sorting, as shown in Table 3. As can be seen from Table 3, the humidification shear strain parameters bw of the two models are equal. Among the humidification volume parameters, the two-parameter model holds that the sample volume does not change with the change of confining pressure during the humidification process, while the three-parameter model holds that the humidification volume deformation is related to the small principal stress of humidification. In the actual test process, the sample volume increases with the increase of confining pressure, so the accuracy of the three-parameter model is higher.

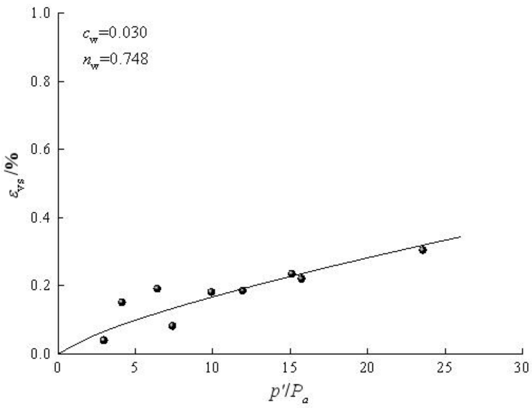

Fig. 13 ε_{vs}~$p^{'}/p_a$ relation curve of main rockfill area

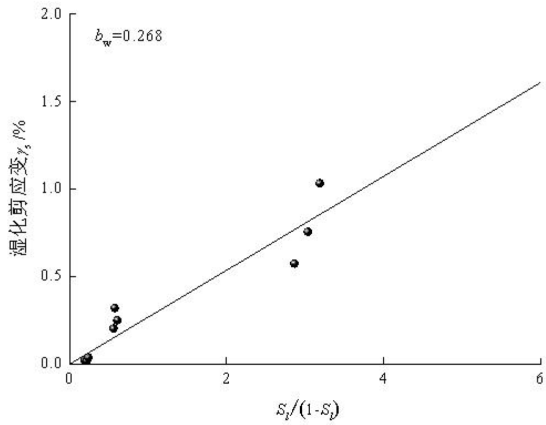

Fig. 14 $\gamma_s \sim S_l/(1-S_l)$ relation curve of main rockfill area

Table 3. Wetting model model parameters

Dam body zoning	lithology	Two-parameter		Three-parameter		
		c_w (%)	b_w (%)	c_w (%)	n_w	b_w (%)
The main rockfill area	Weak weathering excavation	0.177	0.268	0.030	0.748	0.268

5. Conclusion and Prospect

5.1 Conclusion

In this paper, the model parameters of the two-parameter model and the three-parameter model are sorted out through the single line method humidification test, and the humidification deformation characteristics of dam construction materials are studied. The conclusions are summarized as follows:

(1) The wetting deformation is proportional to the confining pressure and stress level. The greater the confining pressure is, the greater the wetting deformation is, and the higher the stress level is, the greater the wetting deformation is.

(2) The experimental results show that the three-parameter model has better fitting effect than the two-parameter model.

(3) The two wetting deformation models can reflect the wetting deformation characteristics of weakly weathered dam-building materials used in the test well, indicating that the wetting deformation characteristics of dam-building materials conform to the general law.

5.2 Prospect

The results of this study can provide experimental basis for the calculation and design of engineering humidification deformation. The next step will be to study the influence of dry density and particle size pairs on the humidification deformation of dam-building materials. Meanwhile, the in-use humidification deformation model will be improved through the test results, so as to further reveal the humidification deformation characteristics of dam-building materials and provide more accurate test parameters for engineering design calculation.

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