Soil Dynamics and Earthquake Engineering 99 (2017) 9–19

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Seismic response of concrete-rockfill combination dam using large-scale shaking table tests

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ARTICLE INFO

Keywords:
Concrete-rockfill combination dam
Shaking table test
Dynamic earth pressure
Residual deformation
Failure pattern

ABSTRACT

Concrete-rockfill combination dam (CRCD), a new type of dam, is mainly composed of an upstream concrete wall and a downstream inclined rockfill body. It is not in direct contact with the bedrock foundation but a water stop, which is different from conventional concrete gravity dam. The dynamic characteristics of CRCD are not quite fully understood yet. In this paper, large-scale models of CRCD were constructed and key parameters, such as acceleration-time response, dynamic earth pressure, deformation and failure pattern of slope were monitored. Results showed that the amplification factors in the upper part (0.6 H) increased with the height. The model dam showed obvious concentration and amplification effect on the low frequency component. The total earth pressure acting on the back face of the wall varied approximately nonlinear along the wall height when the PGA exceeded 0.4*g*. In addition, the CRCD model exhibited good seismic performance with small residual deformation under earthquake. A shallow sliding mode of failure at a height of 0.8 H was measured from the base on the downstream slope. Therefore, it was prudent to undertake some aseismatic reinforcement measurements at the top 1/5 thickness zone of the slope. These model test results could provide a certain reference value for preliminary understanding and qualitative analysis of a prototype CRCD.

1. Introduction

The type and size of dam are dependent upon the geology, hydrology, topography of the site as well as the availability of the construction materials. Concrete gravity dam (CGD) and concrete-faced rockfill dam (CFRD) are two most commonly used dams, among others. Concrete gravity dam (CGD) is proportioned so that itself weight alone maintains the stability, but the temperature control and cracking are major problems [1–3]. Although, CFRD is well known for convenience in construction as well as good seismic performance, its non-uniform settlement induces cracking of the concrete slab [4–7]. In view of the limitations of the conventional CGD and CFRD, a new concrete-rockfill combination dam (CRCD) was proposed. The CRCD is mainly composed of an upstream concrete wall and a downstream inclined rockfill body to bear the water pressure together. Among them, the concrete wall not only reduces the amount of concrete compared with CGD to be the anti-seepage structure of CRCD, but also enhances strength and impermeability compared with the face slab of CFRD. Moreover, the downstream inclined rockfill body could result in potential savings of construction rockfill materials in comparison with rockfill dams.

It is well known that the CGD is directly built on the bedrock to restrict its displacement. However, this renders the dam heel more prone to induce undue tensile stresses thus severely affecting stability. Rescher [8] pointed out that installing a base joint at the dam-foundation interface can reduce the tensile stress at dam heel. This paper introduces Rescher's method of installing a base joint such that the CRCD is not in direct contact with the bedrock. The CRCD can then be constructed in the bedrock or overburden foundation (see Fig. 1) by

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http://dx.doi.org/10.1016/j.soildyn.2017.04.015
Received 18 January 2017; Received in revised form 21 March 2017; Accepted 19 April 2017
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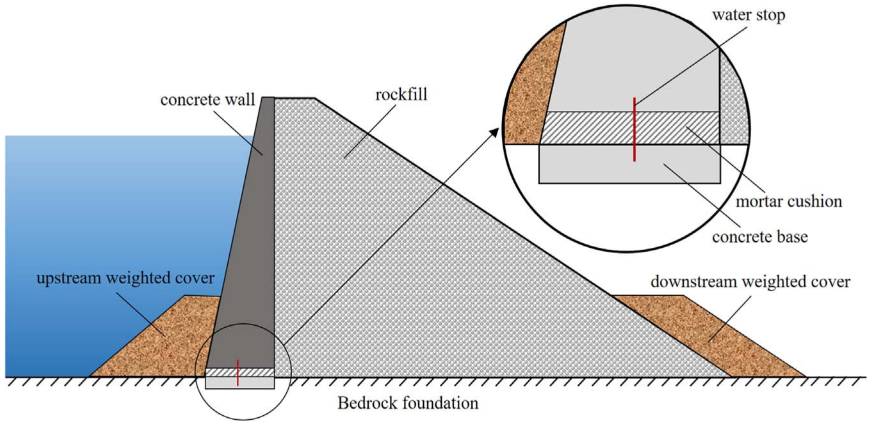

Fig. 1. Schematic diagram of CRCD.

ensuring the maximum displacement of the concrete wall base does not exceed the allowable value of the shear failure of the water stop [9–11].

Seismic analysis and evaluation of existing dams play an important role in guiding the design of new dams [12–16]. Therefore, as a new type of dam, the dynamic characteristics of CRCD need to be further studied. Shaking table test is widely used in geotechnical engineering in order to study mechanism of structure and dynamic characteristics. Centrifuge shaking table tests are generally regarded as being better than 1-g tests from the viewpoint of stress levels. However, the similitude of soil particle size is far less satisfied due to the relatively small model size. Large-scale shaking table tests are considered preferable for the present study, not only for the investigation of the seismic behaviors of dam models, but also for the validation of theoretical approaches and numerical methods commonly adopted in practice [17,18], though the scale effect is an unavoidable problem in a shaking table test.

Liu et al. [14] conducted a series of large-scale shaking table tests to investigate the dynamic failure modes of model-scale CFRD, and the findings agreed with its prototype-scale counterpart. Shi et al. [19] evaluated the dynamic deformation of landslide dams under aftershocks adopting large-scale shaking table tests. Torisu et al. [17] conducted shaking table model tests in a 1-g gravity field and hollow cylindrical torsional shear tests to verify performance-based seismic design criteria. Saleh et al. [20] studied the effect of hydrodynamic pressure on rigid and elastic dam models by conducting centrifuge shaking table tests in a N-G gravity field. Yang et al. [21] used large-scale shaking table to compare the seismic earth pressure distribution of

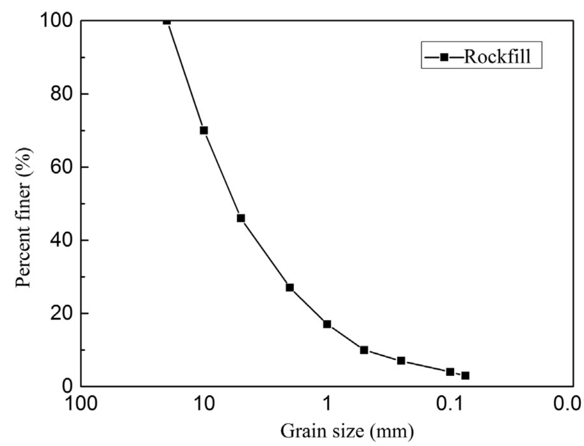

Fig. 2. Gradation curve of model materials.

Table 2
Technical parameters of the test materials.

Materials	E (GPa)	ν	ρ (g/cm^3)	c (kPa)	φ (deg)
Concrete wall	24.0	0.20	2.40	—	—
Bedrock foundation	30.0	0.25	2.40	—	—
Rockfill	0.1	0.33	1.84	40	50

Table 1
Similitude requirements.

Type	Quantity	Relationship	Similarity coefficient (prototype:model)	Prototype parameter (no prototype)	Required model parameter	Actual model parameter
Geometry property	Length (l)	C_l	30.00	30 m	1.0 m	1.0 m
Material property	Density of the rockfill (ρ)	$C_\rho=1$	1.00	2.1g/cm^3	2.1g/cm^3	1.84g/cm^3
	Density of the concrete (ρ_c)	$C_{\rho c}=1$	1.00	2.40g/cm^3	2.40g/cm^3	2.40g/cm^3
	Density of the water (ρ_f)	$C_{\rho f}=C_\rho$	1.00	1.00g/cm^3	1.00g/cm^3	1.00g/cm^3
	Frictional angle of rockfill (φ)	$C_\varphi=1$	1.00	—	—	—
	Young's modulus of concrete wall (E)	$C_E=C_\rho C_l$	30	24 GPa	0.8 GPa	24 GPa
Dynamic property	Acceleration (a)	$C_a=1$	1.00	—	—	—
	Time (t)	$C_t=C_l^{1/2}$	5.48	—	—	—
	Frequency (f)	$C_f=C_l^{-1/2}$	0.18	—	—	—