Experimental Study on the Dynamic Behaviors of the Material for Clay core wall sand dams

Xu Shangjie[1,2], Dang Faning[1],Tian Wei[1],Cheng Mo[2]
1. Xi'an University of Technology, Xi'an, Shanxi 710048, China;
2. Shandong Provincial Institute of Water Resources, Ji'nan, Shandong 250013,China
xushangjie@sina.com

Abstract: The Clay core wall sand dams are mostly constructed on the tremendously thick covering layers with the base built with gravelly coarse sand and the upstream and downstream built with sanded shell into which gravelly coarse sand by manpower. The structures of these dams are generally loose and are presumably thereby considered not to meet the requirements against earthquake. In order to perform further safety analysis and liquefaction judgment with these dams in relation to their anti-seismic capacity, a typical dam with clay core and sanded shell was chosen and experiments were carried out to observe the dynamic behaviors of the dam, including the dynamic strength, the dynamic deformation and the dynamic pore pressure of the dam base and its upstream sanded shell. The results showed that the vibration stress ratio of gravelly coarse sand decreased with the increment in vibration frequency and increased with the increment in consolidation ratio, that the elastic modulus of gravelly coarse sand decreased with the increment in strain, and that the damping ratio of gravelly coarse sand increased with the increment in strain. In conclusion, the denser the dam material is, the better the anti- seismic behavior is, the sand used in the dam is non-linear in nature, The model of vibration pore water pressure growth is characterized by simplicity in expression, convenience in application, and being able to used in widespread way, etc. It reveals what inherent in the relationship of the increment of residual pore pressure with multiple factors, and hence can be used in the dynamic analysis of effective stress. [The Journal of American Science. 2009;5(2):57-63]. (ISSN: 1545-1003).

Key words: gravelly coarse sand, earthquake liquefaction, dynamic behaviors, upstream sanded shell

1 Introduction

More than 90% of reservoirs were constructed during the period of the so-called "Great leap forward" around the year of 1958 as some kind of special products with most of the dams being of clay-core-sand-shell type. And the filling of these dams were accomplished using the so-called "tactics of human sea" with their internal structures comparatively loosely built with no consideration into their capacity against seism at all. Consequently, these dams have been presumed not to be able to reach anti-seismic requirements from the beginning. Even worse, these dams have undergone operation of 50 years with severe problems associated with aging. Therefore, it has been extremely critical to evaluate the real property of anti-seism of these dams so as to perform reasonable measures for improving their anti-seismic capacity , and thus reducing probability of their leading to catastrophic outcomes brought by possibly occurring seism in the future while leaving them there for multiple usages. In this study, the materials from the dam for Houlonghe reservoir were chosen to observe experimentally their dynamic properties with respect to the anti-seismic capacity of the present dam made from them. The dam for Houlonghe reservoir is located on the middle stream of the east branch of Gu river at Yatou town, Rongcheng city, Shandong province, China, which is a typical clay-core-sand-sand-shell dam. This dam controls water flow of about $61km^2$. And the reservoir with a total capacity of about 5.3 millionm^3, is a important medium sized one of its kind and comprehensively applied for flood prevention and water supply. The dam was constructed in 1959 and has affiliated with aging diseases seriously after undergoing operation of 50 years. In 2004, it was listed as dangerous one after safety assessment by the national security department for reservoir and dam, and thus needs danger control and reinforcement.

The dam is a clay-core-shell-wall dam with its upstream being sanded shell and its base made from gravelly coarse sand. The reservoir has been set to be in defense against earthquake of seven degrees by Richter scale. But the judgment has been made through reconnaissance that there has been existing the probability of seismic liquefaction with the sanded shell in the upstream of the dam and the sanded layer in the base of it in the circumstance of earthquake. Therefore, we carried out the research to study the dynamic characteristics of gravelly coarse sand in order to provide theoretical basis for related institutions involving in the analysis of the dynamic safety of the dam and supply data for the evaluation of seismic liquefaction.

2 Samples for the experimentation

The experimental soil material was the loose soil obtained from the typical sections of sanded shell in the upstream and the sand layer at the base of the dam for Houlonghe reservoir. The characteristics of the two soils were shown in table 1. The dry density of them: the soil of the upstream sanded shell: γ_d=1.62g/cm^3, the soil of the sand layer at dam base:γ_d=1.58 g/cm^3.

Table 1. The characteristics of soils obtained from sanded shell in the upstream and sand layer at the base

sampling positions	sampling depth（m）	particle size (mm)/%					nonuniform coefficient	curvature coefficient	Name in door
		>2	2～0.5	0.5～0.25	0.25～0.075	<0.075			
upstream sanded shell	3.0	13.7	29.1	32.4	19.0	5.8	5.91	1.41	gravelly coarse sand
the sand layer at dam base	1.5	22.6	33.2	28.2	12.8	3.2	9.73	1.08	gravelly coarse sand

3 Methods of experimentation

The DSZ-100 electromagnetic vibration triaxial apparatus was employed for the observation of the seismic behavior of the material of the dam. The sample was 3.91cm in diameter, 8cm in high, and greater than 90% in saturation. Three consolidation ratios were used in this experiment: Kc=1.0,1.5,2.0. The consolidation stresses were 0.05MPa,0.10MPa, 0.15MPa, respectively. Sine wave with 1Hz in frequency was used with dynamic wave is.

Method for liquefaction experiment: The tested sample was prepared in such way that a given amount of dried sand by baking was mixed with water,and then boiled to be dried after thorough stirring. The process of consolidation of the sample was accomplished by applying axial stress σ_1 and lateral stressσ_3 to the sample under desired conditions and then the liquefaction test was performed by applying given axial circulation stress in the circumstance of no draining.

Method for measuring dynamic elastic modulus and damp ratio: Dynamic elastic modulus (Ed) is the ratio of dynamic-stress σ_d and dynamic-strain ε_d , which reflects the relationship between dynamic-stress and dynamic-strain during the phase of modification in shape under the action of periodically loading. Damp ratio λ is the ratio of damp coefficient c and critical damp coefficient $c_{cr.}$, measured by cyclic triaxial test, indicating the energy-dissipation per vibrating cycle, and is therefore also called the equivalent gummy damp ratio of soil. The method used for examining dynamic-elasitc modulus and damp ratio in this study was as follows: the samples were consolidated with different stresses , and then the samples were respectively implemented with dynamic stresses from low grade to high grade progressively in step with 10 times per graded cycle in under the circumstance of non-draining. The resultant hydraulic pressure in the accessory small openings in the samples was dissipated after the termination of every graded loading before the implementation of the next graded loading in order to keep the valid stress constant during the process of the test.

The criteria for demolition examination at equal consolidation was set at 5% of the peak of the axial strain (double peaked value). The criteria for demolition examination at non-equal consolidation was also set at 5% of the axial halved peak value plus residual deformation.

4 Dynamic characteristics of the Materials of the dam

4.1 The characteristics of Dynamic Intensity

Dynamic intensity refers to the dynamic shearing stress leading to sample failure with a given number of circulating vibration force, N_f. The relationship curve, $\sigma_d/(2\sigma_3)$～N_f was displayed on uni-logarithm grapy sheet base on the results of the test. The curve was established with the results of the test when the number of circulations at 10, in viewing of that the earthquake defence intensity had been set at seven degrees by Richter scale for the dam of Houlonghe reservoir. The ratios of liquefaction-stress when N_f at 10 were shown in table 2, and the relationship curve of the dynamic shearing stress ratio $\sigma_d/(2\sigma_3)$ of upstream sanded shell and the number of vibration destruction, N_f was shown in Figure 1.

Table2. Liquefaction- stress ratio of the materials of the dam

sampling positions	Liquefaction- stress ratio $\sigma_d/2\sigma_3$		
	1. 0	1. 5	2. 0
upstream sanded shell	0. 30	0. 40	0. 515
the sand layer at dam base	0. 32	0. 43	0. 535

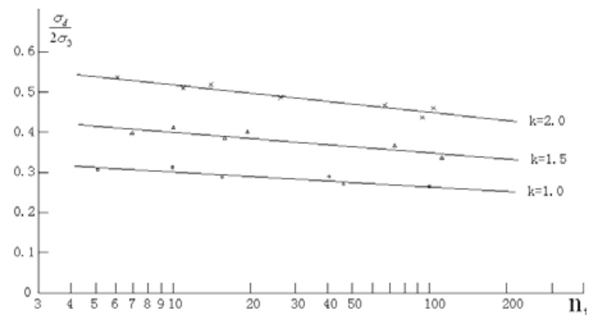

Fig 1. The relationship curve of $\sigma_d/(2\sigma_3)$

The values of dynamic stresses at different consolidation stresses were obtained from liquefaction-stress ratios when the times of circulating force at 10, and thus then the Mohr circle could be drawn for the determination of the dynamic strength parameters. The dynamic strength parameters, Φ_d and C_d at three different consolidation stresses were shown in table 3. The Mohr circles of upstream sanded shell of the dam at different stresses were shown in Figure 2.

Table3. dynamic strength parameters at three different consolidation stresses of the materials of the dam

sampling positions	1.0		2.0		3.0	
	Φ_d (degree)	C_d (MPa)	Φ_d (degree)	C_d (MPa)	Φ_d (degree	C_d (MPa)
upstream sanded shell	14.81	0	25.69	0	30.55	0
the sand layer at dam base	14.2	0	24.6	0	30.92	0

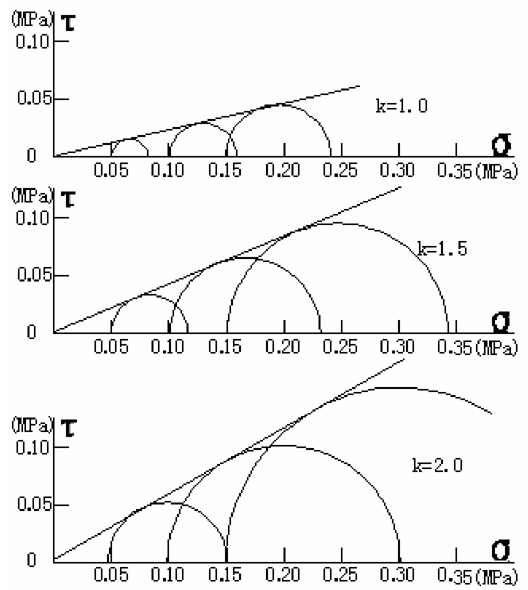

Fig 2. The Mohr circles of upstream sanded shell at different stresses(n=10).

In order to perform the liquefaction analysis, the liquefaction shearing stress, τ_{fd}, under different static stresses, $\sigma_{fs,}$ had to be determined. The curve representing relationship of initial shearing stress ratio, $\beta=\tau_{fs}/\sigma_f$, with $\alpha=\tau_{fd}/\sigma_{fs}$ were obtained from the results of the test as shown in Figure 3.

The shearing stress during liquefaction cycle, τ_{fd} , resulted from the combination of a certain initial effective directed stress σ_{fs} and the initial shearing stress τ_{fs}(e.g. anti-liquefaction shear stress)could be obtained from the curve.

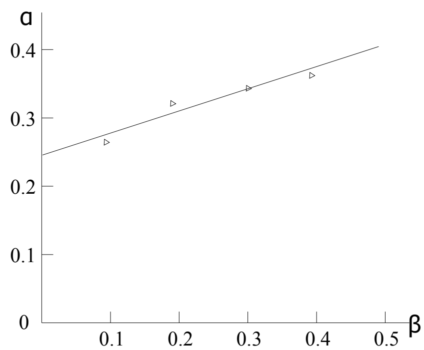

Fig 3. The relationship of α and β in upstream sanded shell

4.2 The characteristics of dynamic deformation

The relationship between the maximal dynamic elastic modulus E_{dmax} and the averaged effective consolidation pressure $\sigma_0^/$ was determined, and the relationship curve of the elastic modulus $E_{d,}$ and damp ratio λ_d against dynamic strainε_d was established for the determination of the characteristics of dynamic deformation.

According to the results of the test, the relationship of maximal dynamic elastic modulus E_{dmax} and the averaged effective consolidation stress $\sigma_0^/$ was determined by the following equation.

$$E_{d\max} = kP_a\left(\frac{\sigma_0^/}{P_a}\right)^n \qquad (1)$$

In the equation, $\sigma_0^{/}$ is the averaged main effective stress when samples being consolidated, which is determined by the equation: $\sigma_0^{/}=(\sigma_1^{/}+2\sigma_3^{/})/3$; k and n are test constants relative to properties of soils used in tests. Pa is the atmospheric pressure.

$E_{dmax}\sim\sigma_0^{/}$ relationship curve was drawn on the double logarithm coordination sheet, wherein K was the intercept of the curve on the vertical axial of the coordination, and N was the slope ratio. The values of k and n for the materials of the dam when consolidation ratio at 1 were shown in Table 4.

Table 4. k and n with the material of the dam

the material of the dam	k	n
upstream sanded shell	40	0.681
the sand layer at dam base	38.5	0.635

The dynamic elastic modulus E_d decreased with the increasing of axial strain while it increased with the increasing of the consolidation stress ratio. Nevertheless, the ratio of modulus Ed and maximum of dynamic elastic modulus E_{dmax} , E_d/E_{dmax} did not change significantly with the alteration of consolidation pressure. The relationship of E_d/E_{dmax} and ε_d were depicted on the halved logarithm coordination sheet based on the results of the test. The following equation was obtained after approximation of the curve for $E_d/E_{dmax}\sim\varepsilon_d$.

$$E_d/E_{dmax}=1/(1+\varepsilon_d/w) \qquad (2)$$

In the equation, w is the approximation parameter.

The curve for the relationship between damp ratio λ_d and dynamic strain ε_d was depicted on the halved logarithm coordination sheet. the half logarithm squared paper. The following equation was obtained after approximation of the curve for the $\lambda_d\sim\varepsilon_d$ relationship:

$$\lambda_d=a\varepsilon_d/(b+\varepsilon_d) \qquad (3)$$

In the equation, a and b are the approximation parameter.

The relationship curve of E_d/E_{dmax}、λ_d and ε_d with the shell of the upstream of the dam was showed in Figure 4. The approximation parameter for elastic modulus w with dam material and the approximation parameters for damp ratio, a and b were shown in Table 5.

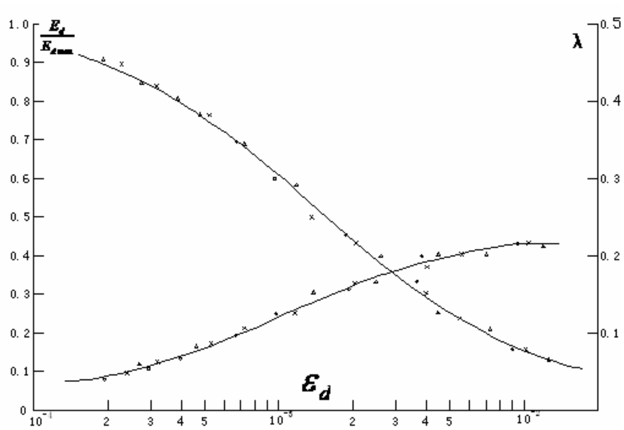

Fig 4. The respectively corresponding relationshipof E_d/E_{dmax}、λ_d and ε_d in upstream sanded shell

Table 5. Approximation parameterof elastic modulus damp ratio

the material of the dam	w	a	b
upstream sanded shell	0.001596	0.4767	0.001
the sand layer at dam base	0.001303	0.2223	0.006

4.3 The characteristics of dynamic pore pressure

During the vibrating triaxial test , the changes in small opening hydraulic pressure were recorded simultaneously with computer and thus the curve for the relationship of changes in small opening hydraulic pressure with times of vibration was obtained. Data of the test was arranged with the vibration pore water pressure growth model proposed by the Institute of Water Resources, the Yellow River Committee, China ,which is denoted in the following exponential function.

$$U = 1-(1-U_0)10^{-K\xi/(1-\xi)} \qquad (4)$$

In the equation, ξ is the ratio of the destruction-to-times in logarithm, which could be obtained by the equation, $\xi = \log N / \log N_f$; U_0 is the relative pore pressure ratio of the first cycle.

The test constants k was determined by the following equation.

$$K = \alpha N_f^{-\beta} \qquad (5)$$

U_0 was determined by the following equation.

$$U_0 = \gamma N_f^{-\theta} \qquad (6)$$

N_f was determined by the following equation.

$$\alpha_d = A N_f^{-B} \qquad (7)$$

Whereinα_d was the ratio of dynamil stress, which was determined by the equation, $\alpha_d=\sigma_d/(2\sigma_3)$. Thus, the pore pressure of any time vibration was determined by the following 7 constants, namely, A、B、γ、θ、α、β and u_f, where u_f was the averaged value of pore pressure ratio with predetermined destruction standard in the same consolidation ratio .

Different consolidation ratio and consolidation pressure has taken into consideration in this model, which is thus characterized by simplicity in expression, convenience in application, and being able to used in widespread way, etc. It revealed what inherent in the relationship of the increment of residual pore pressure with multiple factors, and hence could be used in the dynamic analysis of effective stress.

5 Conclusion

(1) The results showed in the present test with dynamic strength that the vibration-stress ratio of the material of the dam increased with the reduction of times of vibration, and the numerical points of stress ratio at different confining pressure fell relatively well into a narrowly-defined band under the same consolidation ratio and thus could be expressed as a straight line, indicating that the results were comparatively is reasonable. The results also showed that the stress ratio of each kind of dam material increased with the increment of consolidation ratio and the dynamic strength index increased significantly with the increment of consolidation ratio, indicating that the denser the dam material is, the better the anti-seismic behavior is.

(2) The results in the dynamic modulus and damp measurements showed that the dynamic elastic modulus of the dam material decreased with the increment of the strain and damp ratio increased with the increment of the strain, indicating that the sand used in the dam is non-linear in nature. The strain ranged from 10^{-4} to 10^{-2} in this test, in which modulus ratio and damp ratio were the actual values. The values

of the modulus ratio and damp ratio in other ranges could be obtained through simulation curve.

(3) The model of vibration pore water pressure growth is characterized by simplicity in expression, convenience in application, and being able to used in widespread way, etc. It reveals what inherent in the relationship of the increment of residual pore pressure with multiple factors, and hence can be used in the dynamic analysis of effective stress.

Correspondence to:

Xu Shangjie
Xi'an University of Technology
Xi'an, Shaanxi 710048, China

Cheng Mo
Shandong Provincial Institute of Water Resources
Ji'nan, Shandong 250013, China
xushangjie@sina.com

References:

1. YUAN Ju-yun, XU Chao, ZHAO Chun-feng. Soil lab test and in-situ testing[M].Shanghai: Tongji University Press, 2004.
2. Institute of Hydraulic Research,YRCC, Study on the anti-seismic properties ofSand and Gravel in Xiaolangdi earth rockfill dam,(national technology tacking report of 8th five-year plan) ,1994.
3. Shandong Provincial Institute of Water Resources, Engineering Geological Investigation of Houlonghe reservoir in Rongcheng city.
4. XU Bin, KONG Xian-jing, ZOU De-gao, Study of dynamic pore water pressure and axial strain in saturated sand-gravel composites[J]， Rock and Soil Mechanics， 2006,27(6).
5. SUN Jing, YUAN Xiao-ming, SUN Rui. Reasonabilitycomparison between recommended and code values of dynamic shear modulus and damping ratio of soils.
6. Earthquake Engineering and Engineering Vibration,2004, 24(2): 125－133.
7. BORDEN R H, SHAO L, GUPTA A. Dynamic propertiesof piedmont residual soils[J]. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 1996,
8. TOWHATA I, ISHIHARA K. Undrained strength of sand undergoing cyclic rotation of principal stress axes[J]. Soils and Foundations, JSSMFE, 1985, 25(2)

Received: 9/20/2008