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STRESS ANALYSIS OF POLYMER DIAPHRAGM WALL FOR EARTH-ROCK DAMS UNDER STATIC AND DYNAMIC LOADS

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ABSTRACT

Compared with plastic concrete and normal concrete, the polymer diaphragm wall has the characteristics of light weight, early strength, environmental conservation and durability. During its construction, it has speedy, economic, and practical characteristics and few influences on the dam. The polymer diaphragm wall has been successfully used in earth-rock dams. But at present the static and dynamic characteristics of earth-rock dams are seldom studied. The Duncan-Chang E-B nonlinear model is used and the contact element is set up between the diaphragm wall and the dam for the FEM model.A comparison of stresses on the diaphragm wall among polymer, plastic concrete and normal concrete under static and seismic loads shows that the stress on the polymer diaphragm wall is the least and it is not easy to be failed. The polymer diaphragm wall for earth-rock dams has preferable security.

1. INTRODUCTION

Grouting and diaphragm walls are commonly used in seepage reinforcement projects. High-strengthor plastic concrete diaphragm walls havebeen widely applied indam reinforcement engineering, but at the same time, the defects emerged.For example,high stress problems caused by high elastic modulus, lower strength and impermeability as well as poordurabilityofplasticconcrete diaphragm walls. Besides,higher cost,larger area of construction site scene,longerconstruction period and even bigger disturbance to the original dam are also problems. Based on the actual demands of engineering construction,increasingly widespread attention have drown on the study of organic polymer chemical grouting materials represented by polymers with expansive properties from 1970s and a wealthof achievements have been obtained[1-3].In China, under the joint efforts of Zhengzhou University and other units,a complete set of fast repair polymer grouting technology has been successfully researched and developed, it means a breakthrough progress have been made in the field of theoretical research and engineering application. Compared with traditional techniques, polymer grouting has many obvious advantages such as speedy, light weight, good impermeability, thinner diaphragm wall, environmental materials, durability and so on. Although at present great progresses have been made on materials, equipment, and constructional technologies of grouting in and abroad, studies refer to the theory of polymer grouting are seldom [4-7]. A large number of literature only introduce characteristics of materials, grouting technologies and construction effects of polymer, rarely involved in grouting mechanism and the stress and strain analysis of diaphragm wall under the static and dynamic loads[8-11]. The commercial software ALGOR is adopted toestablishstaticand dynamic analysis model of dam considering nonlinearity of soil, meanwhile the contact element is set up between the dam and the diaphragm wall to simulate open or contact state. The differences of stress distribution and failure characteristics among the polymer, plastic concrete and normal concrete diaphragm wall under the static and seismic loads are compared and analyzed on the basis of an example computation and analysis, which provide theoretical analysis reference for design and construction of the diaphragm wall.

2 Calculation model and material parametersof dam polymer diaphragm wall

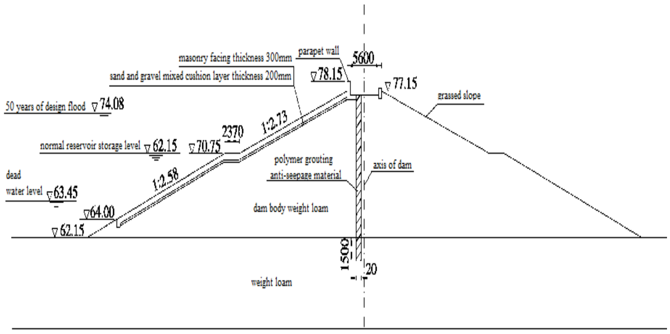

Fig. 1 Sketch of polymer diaphragm wall for an earth-rock dam

Jiulong reservoir dam situated in Xinyang Henan is an homogeneous earth dam with good engineering geological conditions as the length of the crest is about 340m and the dam foundation is consist of weight loam,fine sand and mica-quartzose schist (show in figure 1).In order to handle the dam body seep from upstream to downstream, along the dam vertical direction about 0.5m away from the dam axis build a polymer diaphragm wall using grouting technology.The dam top elevation is 77.15m, the dangerousconstruction section is 1+500~1+200,and the length of the diaphragm wall is 215m.

2.1 Basic assumptions

To simplify the calculation, FEM analysis adopt several assumptions as follows:

(1)Earth-rock dam is simplified to a plane strain problem;
(2)The dam body and foundation use the Duncan-Chang E-B nonlinear model;

(2)Leave out the change of the dam body in-situ stress beforeexcavation and grouting,the internal stress of the dam is equal to the hydrostatic pressure and the soil pressure.

2.2 Mechanics parameters of polymer materials

Study results are shown in table 1, figure 2 and figure 3 based on the data obtained in the density and elastic modulus tests of non water reaction type polyurethane polymermaterials[6-7] and experiments of relationships between material density and tensile strengthor compressive strength.

2.3 Foundation and dam body materials

Therelationshipbetween dam body and foundation stress-train of earth-rock dam can be described with nonlinear Duncan-Chang E-B model[12].

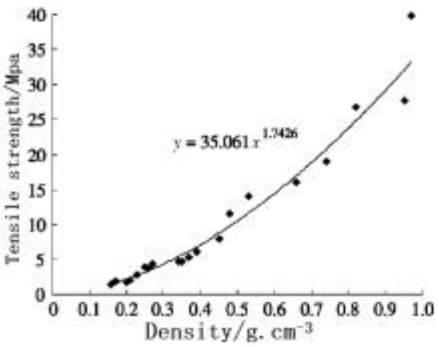

Fig. 2 Relationship between tensile strength and density of polymer materials

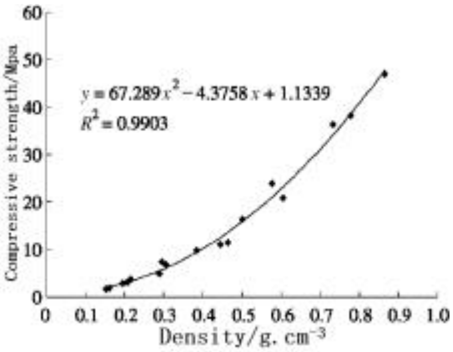

Fig. 3 Relationship between compressive strength and density of polymer materials

Table 1 Elastic modulus and density of polymer materials

Sample number	1	2	3	4	5	6	7	8	9	10
Density/(g.cm-3)	0.16	0.27	0.29	0.35	0.36	0.40	0.42	0.47	0.49	0.53
Elastic modulus/Mpa	18.2	20.3	40.8	109	136	202	214	218	225	229

$$E_t = Kp_a\left(\frac{\sigma_3}{p_a}\right)^n\left(1-R_f\frac{(1-\sin\varphi)(\sigma_1-\sigma_3)}{2c\cos\varphi+2\sigma_3\sin\varphi}\right)^2 \quad (1)$$

$$B_t = K_b p_a\left(\frac{\sigma_3}{p_a}\right)^m \quad (2)$$

WhereE_t=tangent elastic modulus;B_t=bulkmodulus;σ_1 and$\sigma_3$represent the maximum and minimum principal stress respectively;p_a=atmosphericpressure;R_f =damage ratio;K=number of elasticitymodulus;n=index of elasticity modulus;K_b= number of bulk modulus;m=index of bulk modulus;c and$\varphi$are termed as cohesion and internal friction angle of soil expressed in the following Eq.(3)

When the material is unloaded

$$\varphi = \varphi_0 - \Delta\varphi lg\left(\frac{\sigma_3}{p_a}\right) \quad (3) \qquad E_{ur} = K_{ur}\, p_a\left(\frac{\sigma_3}{p_a}\right)^{n_{ur}} \quad (4)$$

WhereE_{ur} =unloading elasticity modulus;n_{ur} =unloading elasticity modulusindex;$\Delta\varphi$=internal friction angleratio[13].

2.4 Contact element[14]

Contact element is set up to simulate the statesof relative sliding,slip and separate occurred between interfaces.Assuming that $F_s$andF_n arethe frictional force and the normal force,K_t andK_n are named as viscosity coefficient and normal stiffness, u is the tangential displacement and d represents the distance of contact points.

3. Compute results and analysis

Using ALGOR software to mesh thedam with 8 node isoparametric element, where the materials, foundation, bedrock and diaphragm wall are set in the light of different material groups. The polymerdiaphragm wall is 5 cm thick

Table 2 Parameters of dam materials and bed rock

materials	gravity(dry) /(kN·m-3)	gravity(wet) /(kN·m-3)	K	K_{ur}	n	R_f	K_b	m	c /(kN·m-2)	φ /(°)	$\Delta\varphi$ /(°)
Soil of dam body	16.0	1932	300	360	0.5	0.95	200	0.4	14.6	29.5	0
Soil of dam base	16.5	19.6	300	360	0.5	0.95	200	0.4	14.6	29.5	0
gravel	15.4	18.6	470	564	0.5	0.77	400	0.4	0	32.5	0
bedrock	19.6	21.6	720	850	0.7	0.86	530	0.6	0	44.0	5.0

Table 3 Comparison of dam displacements under static load

polymer/mm				Plastic concrete/mm				Normal concrete/mm			
upstream		downstream		upstream		downstream		upstream		downstream	
flat	vertical	flat	vertical	flat	vertical	flat	vertical	flat	vertical	flat	vertical
4.0	-34	2.1	-32	3.1	-32	2.8	-30	2.3	-29	2.0	-27

the material density is about in a range between 0.1 to 0.2 g/cm3,the elastic modulus of polymer material is equal to 20Mpa,the tensile and compress strength are equal to 2.12Mpa and 2.94Mpa.By contrast, the diaphragm wall of plastic and normal concrete are set the same thickness of 20cm, and yet each own their distinct physical properties.For plastic concrete,the gravity is 18.7KN/m3,the elastic modulus is 2000Mpa,and the values of tensile and compressive strength are 0.3Mpa and 2.5Mpa orderly,while for normal concrete,the gravity is 23KN/m3,the elastic modulus is 2500Mpa,with the tensile strength 1.5Mpa and the compressive strength 25Mpa.Calculation and analysis for the three kinds of diaphragm walls above aredoing under two working conditions, and the vibration frequency and modal analysis are also carried out at the same time.During the period of seismic acceleration time-history analysis, E-centro seismic wave of 0.6g amplitude modulation is used. The seismic acceleration is set along the cross-section of the earth-rock dam provided that the integral damping matrix treated as the Rayleigh damping.

Condition 1:stress analysis of earth-rock dam under dead weight and hydrostatic pressure;

Condition 2: dynamic stress analysis of earth-rock dam under the action of Elcentro earthquake wave of 0.6g amplitude modulation.

Fig. 4 Model of earth-rock dam with diaphragm wall

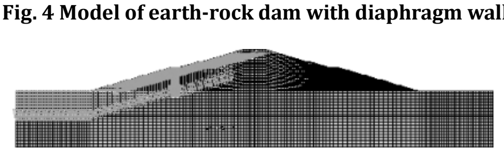

Fig. 5 Earth-rock dam under gravity andhydrostaticstress

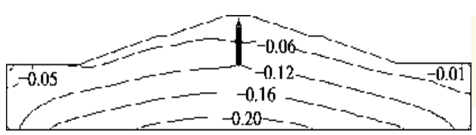

Fig. 6 Isoline of maximum compression stress of plasticconcrete diaphragm wall under static load

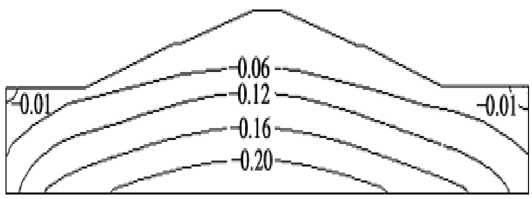

Fig. 7 Isoline of maximum compression stress of polymer diaphragm wall under static load

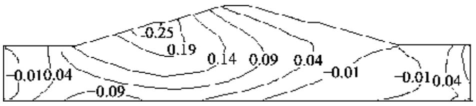

Fig. 8 Isoline of maximum stress of polymer diaphragm wall under earthquake

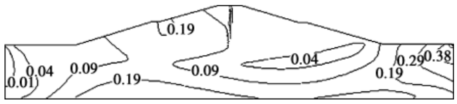

Fig. 9 Isoline of maximum stress of normal concrete wall under earthquake

The force diagrams ofFEM under static load as figure 4 and figure 5 shown,yet the maximum stress distribution under kinds of conditions reveal in figure6~9 (with the unit of Mpa).Table 3 exhibits the comparison of horizontal and vertical displacement of upstream and downstream among three kinds of diaphragm walls while chart 11 compares the maximum stress time travel curve under seismic load.Form 4 makes a comparison of the calculation results of natural frequency,figure13 and figure 14 shows the maximum stress of diaphragm walls under the static and seismic load .

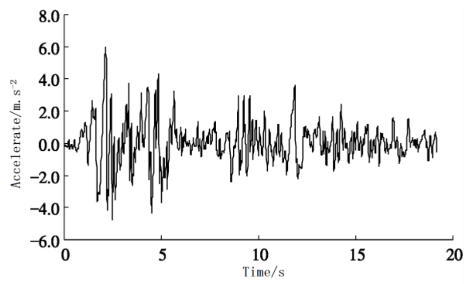

Fig. 10 Time-history of 0.6g Elcentro earthquake acceleration

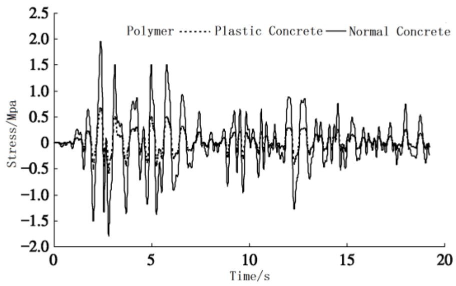

Fig. 11 Comparison of maximum stresses of diaphragm wall under earthquake

Computational analysis above shows that polymer diaphragm wall coordinates well with the deformation capacity of the dam body soil under the condition of bearing due to the smaller material modulus,as for plastic concrete andnormal concrete,greater stress(greater stress emergein diaphragm wall illustrated in stress contour maps by figure 6 and figure 9) emerge in the diaphragm wall after loading deformationresult from poor abilities to change coordinately.Earth-rock dams under seismic dynamic load are just similar to static situations.Therefore,the internal stress value of polymer diaphragm wall is much less than that of normal concrete as well as plastic concrete proved by FEM analysis of earth-rock dams under static and dynamic load.For condition1, the diaphragm wall maximum compressive stress of normal concrete and plastic concrete are 4.39 Mpa and 2.32 Mpa respectively, yet 0.183 Mpa for polymer material (as figure 12 shown). As for material ultimate compressive strength, polymer is 2.94 Mpa while plastic concrete is 2.5

Table4 Comparisonoffrequencies of diaphragm walls rad/s

Order	Polymer concrete	Plastic concrete	Normal concrete
1	7.82	7.82	7.81
2	11.55	11.59	11.64
3	13.08	13.08	13.08
4	14.44	14.46	14.47
5	15.92	15.93	15.93
6	16.65	16.66	16.66
7	18.26	18.25	18.24
8	18.75	18.79	18.83
9	20.53	20.53	20.53
10	22.31	22.34	22.34

Mpa,, the later one is close to failure limit, by contrast, the former one still has a lot of safety stock. For condition 2, the internal maximum stress of diaphragm wall made of normal concrete and plastic concrete are far greater than polymer (figure 13) when compare the maximum stress time-

still has a lot of safety stock. For condition 2, the internal maximum stress of diaphragm wall made of normal concrete and plastic concrete are far greater than polymer (figure 13) when compare the maximum stress time-history curves of the three which formed via carrying out the earthquake time-history response analysis by virtue of inputting the seismic wave. The maximum tensile stress in normal concrete and plastic concrete are respectively reached to 2.01 Mpa and 0.71 Mpa, conversely, that for polymer is merely 0.27 Mpa. Moreover, the tensile strength limit of polymer material is about 2.12 MPa, while the values of that for normal concrete and plastic concrete materials are 1.5 Mpa and 0.3 Mpa, that means plastic and normal concrete are already exceed the limit of rupture, whereas polymer diaphragm wall is far away from its failure limit. Besides, based on the nature frequency computational comparison of earth-rock dams with three diaphragm walls made of different materials, we can draw a conclusion that the natural vibration frequency increased slightly in turn as with the earth-rock dam diaphragm wall structures using material of polymer, plastic concrete and normal concrete on condition that under the same vibration mode of same order frequency(as shown table 4), inevitably, it has a direct relationship with an orderly increase of of diaphragm wall materials'elastic modulus.

4. Conclusions

(1)By comparing the inner maximum compressive stress values of diaphragm walls made of three kinds of materials

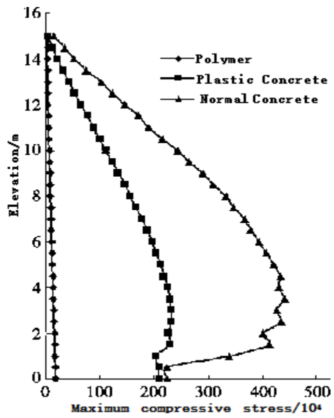

Fig. 12 Comparison of maximum stresses of diaphragmwalls under gravity and hydrostatic stress

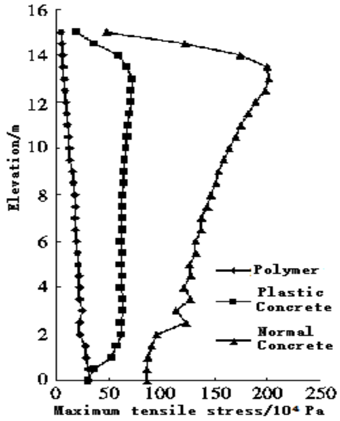

Fig. 13 Comparison of maximum stresses of diaphragm walls under earthquake

under deadweight and hydrostatic pressure,we can find that polymer diaphragm wall is the smallest oneunder the same condition.Further,the internal stress of plastic concrete diaphragm wall has already closed to the compressive failure limit,however,polymer diaphragm wall haspreferable security. Analysis show that it has a closely relationship with the elastic modulus of diaphragm wall material.Great effect is made on deformation coordinated property between diaphragm wall and soil body for the reason that soil elastic modulus is far less than concrete material.

(2)Contrasteddynamic stress values of the three when earthquake acceleration is inputted by means of time-history analysis,the result obviously reveal that the maximum stress value within the diaphragm wall of normal concrete and plastic concrete are far greater than polymer diaphragm wall.Considering the ultimate tensile strength of 3 kinds of materials,it can easily draw a conclusion that plastic concrete and normal concrete diaphragm wall have already exceeded the tensile stress limit,on the contrary,the polymer diaphragm wall is far less than failure limit,that was to say the polymer diaphragm wall still has high security reserves.

(3)Based on natural frequency calculation of earth-rock dams under the same order frequency of vibration mode,it's confirmed that the natural frequency slightly increased according to the order of polymer,plastic concrete and normal concrete.Following this,a conclusion can be drown that it has a direction relationship with the slightly increase of materials elastic modulus.

(4)Polymergrouting hasmany advantages when comparedwith the traditional grouting reinforcement technology.Specifically,it has the characteristicof speedy,lightweight,good permeability,thinner size of diaphragm wall, environmental materials, durability as well as better coordinated deformation compatibility with the dam soil. Account for the advantages above, the inner stress value of polymer diaphragm wall always less than the limit stress.At present,the polymer material and diaphragm grouting technology is undoubtedly a very excellent reinforcement material and technology for dam constructions,which is worth for deep research and promoting.

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