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RESPONSE OF PLASTIC CONCRETE CUT-OFF WALLS IN EARTH DAMS TO SEISMIC LOADING USING FINITE ELEMENT METHODS

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SUMMARY

In this paper, the dynamic behavior of plastic concrete cutoff walls in earth-dams subjected to earthquake loading has been studied using finite element methods. The analysis has been performed at the end of dam construction prior to dam impounding. The behavior of materials of the dam, foundation, and cutoff wall has ideally been assumed to be linear and elastic. The sinusoidal shear wave with an amplitude of $0.4g$, a duration of 5 sec. and a frequency of 1.3 Hz has been used for simulating the seismic loading on the dam. The numerical results of the analysis have shown that the greatest possible shear stresses and tensile stresses in the cut-off wall occurred at the ground level. Moreover, with increasing the rigidity of the wall these stresses along wall increase. This dictates that at the ground level, designers should pay attention to the safety of the dam wall.

INTRODUCTION

Experience has shown that water leakage and internal erosion in bodies and foundations of embankment dams are main reasons of many problems and failures in earth-dams [1]. To reduce these problems, plastic cutoff walls may be used. Such a cut-off wall must be resistant when subjected to earthquake loading. This requires that the wall be adequately deformable. Plastic concrete may be an appropriate material providing such deformability.

In this paper, the behavior of an earth-dam with a height of 50 m, a crest width of 15 m, an upstream and a downstream slope of 1V:3H, a foundation depth of 70 m, a wall thickness of 1 m, and a wall length of 50 m has been studied. As shown in Fig. 1, this dam has a clayey core with a slope of 2V:1H. Thus, the crest width is 10 meter. The cutoff wall is penetrated 4.5 m into the clayey core (Fig. 1).

Mechanical properties and strength parameters of dam materials are given in Table 1. As mentioned before, the behavior of all materials are assumed to be ideally linear and elastic. It is remembered that the internal friction angle of the foundation material in Table 1 is used for producing the initial stresses using

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at-rest pressure coefficient, k_0 ($k_0 = 1 - \sin\phi$). Six-node triangular elements were used in the finite element model. Absorbing boundaries were employed in two sides of the model. Fig. 2 shows the finite element mesh of model.

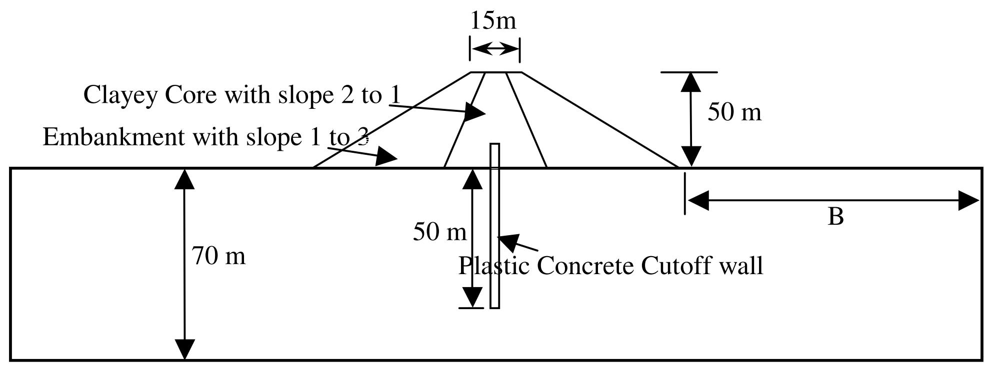

Fig. 1 Model Geometry

Table 1 Mechanical Properties of model materials

Material	Specific Weight (kN/m^3)	Poisson Ratio	Modules of Elasticity (kN/m^2)	Internal Fiction Angle (degree)
Embankment	20	0.25	9E4	-
Clayey core	17	0.35	3E4	-
Plastic concrete cutoff wall	21	0.25	4E6	-
Material of foundation	21	0.20	1E6	20

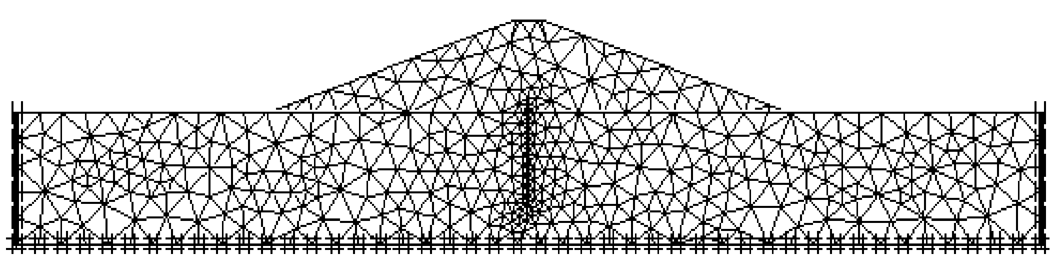

Fig. 2 Finite element mesh of model

MODEL PERFORMANCE

Horizontal boundaries of model

The horizontal boundaries at two sides of the dam were chosen from the dam toe such that the stress variation under static loading is negligible (distance B in Fig. 1). For this purpose, three analyses were performed by B= H =50, B= 2H = 100 and B= 3H =150 m. Character H denotes the dam Height. It was found B= 3H = 150 m is sufficient for horizontal boundaries. For the performance of dynamic analyses, absorbent boundaries, suggested by Lysmer and Kuhlemeyer [4], were used at two side boundaries.

Material damping

The Reighly type damping was used for the soil material. This is shown by:

$$C = \alpha \mathrm{M} + \beta \mathrm{K} \tag{1}$$

where C, M, and K are damping, mass, and stiffness matrices, respectively. α and β are Rayleigh damping coefficients. Note that α and β correspond to the mass and stiffness, respectively. The values of these coefficients depend on the frequency and in general are expressed by:

$$\alpha + \beta\omega_i^2 = 2\omega_i\xi_i \tag{2}$$

where ξ_i is the critical damping ratio of system at angular frequency ω_i of the system. When each of the Rayleigh damping coefficient is zero, the other one is determined.

$$\frac{\partial \xi_i}{\partial \omega_i} = 0 \qquad \Rightarrow \qquad \xi_{\min} = \sqrt{\alpha\beta} \tag{3}$$

$$\alpha = \xi_{\min}\omega_i \qquad \text{and} \qquad \beta = \frac{\xi_{\min}}{\omega_i} \tag{4}$$

Thus the coefficients of Rayleigh damping depend on the natural frequency of the system. To obtain the natural frequency of the system for the case that the damping of system is zero, analyses were performed with a 5 sec loading, (period of one wave with 0.2 Hz frequency) maximum acceleration of 0.4g, and a frequency of 0.2 to 20 Hz. From these analyses, the maximum shear stress versus the frequency was obtained. Fig. 3 shows this for three elevations of –7.87, -24.54 and –41.20 along the cut off wall. It is seen that the maximum shear stress at all elevations occurs at frequency of 1.3 Hz. Therefore this is the system resonance frequency. Based on theses analyses, the coefficients of Rayleigh damping were obtained and used in the rest of analyses.

PARAMETRIC ANALYSIS

ICOLD recommends that the modules of elasticity of the wall material must be 4 to 5 times that of the adjacent soil [3]. In this section, the influence of the wall material modulus on the maximum value of the maximum shear stress ($\tau_{\max}$) and the maximum value of the maximum tensile stress ($\sigma_{t,\max}$) is studied.

Figs. 4 and 5 show the variation of maximum value of maximum shear stresses and maximum value of maximum tensile stresses of wall versus depth for different values of elasticity modulus ratio (modules of elasticity for the wall material divided by the modules of elasticity of the adjacent soil). The loading was sinusoidal with a frequency of 1.3 Hz, amplitude of vibration of 0.4g and a time of loading of 5 sec. As shown, with increasing the stiffness of wall material the values of stress on the increase. Also the maximum stress on the wall elevation was occurred at the foundation level. This is because an inertia force due to the dam vibration is exerted to the foundation ground at this level. In fact, the wall at this zone behaves as a cantilever object supported at the ground surface level. Therefore in design of cutoff wall, special care should be taken. A gradual increase in wall width or reinforcing the cut off wall at this zone may prevent the wall from possible break.

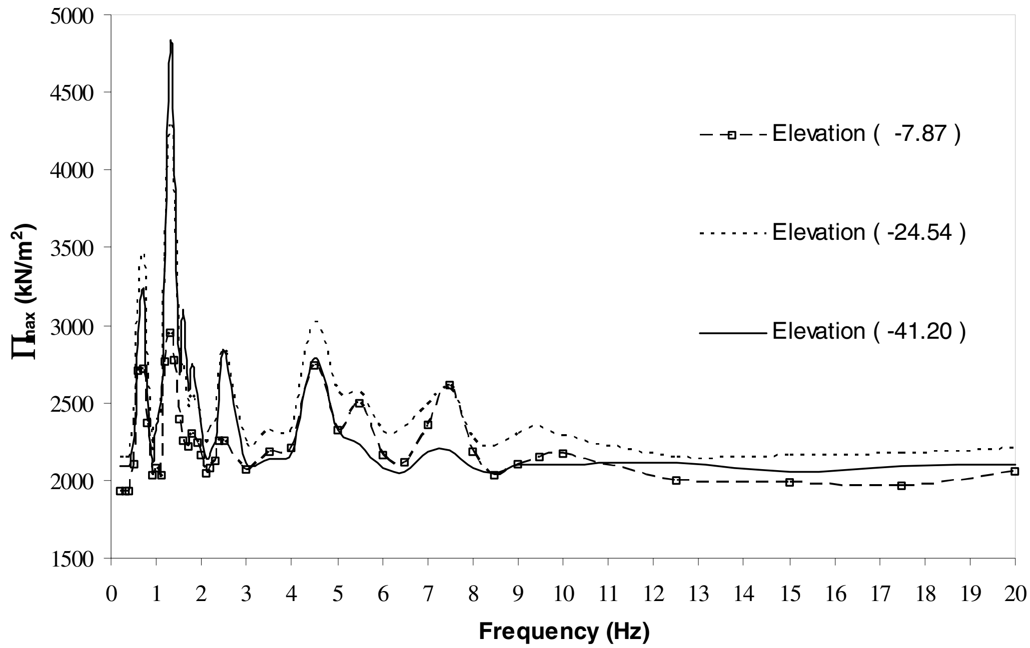

Fig. 3 Variation of maximum value of shear stress versus frequency at three elevations of wall

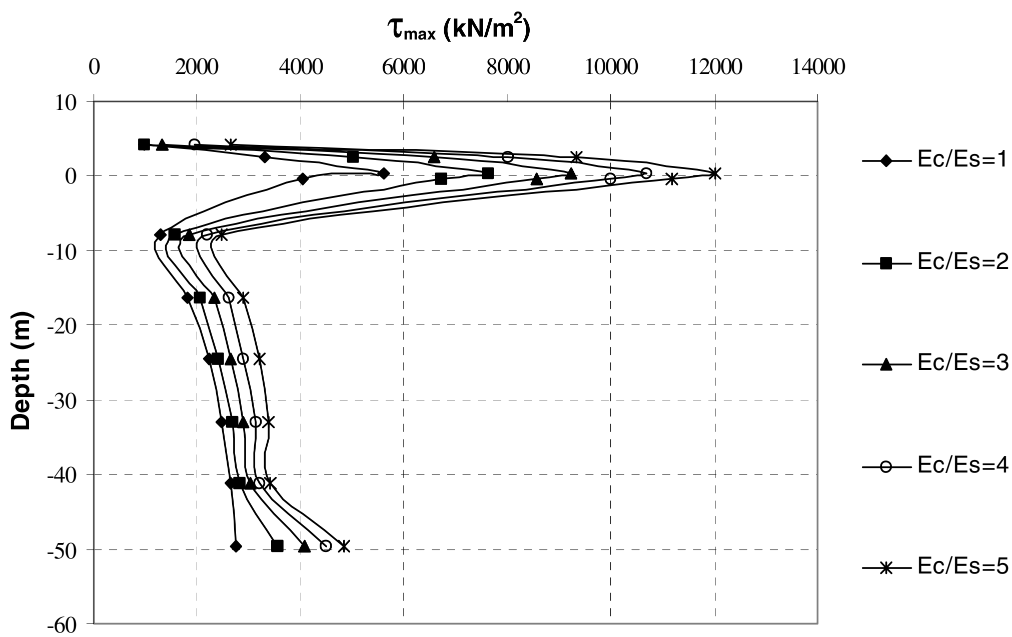

Fig. 4 Variation of maximum value of maximum shear stress at wall at frequency of 1.3 Hz for different ratios of elasticity modulus of wall material to elasticity modulus of adjacent soil of wall.

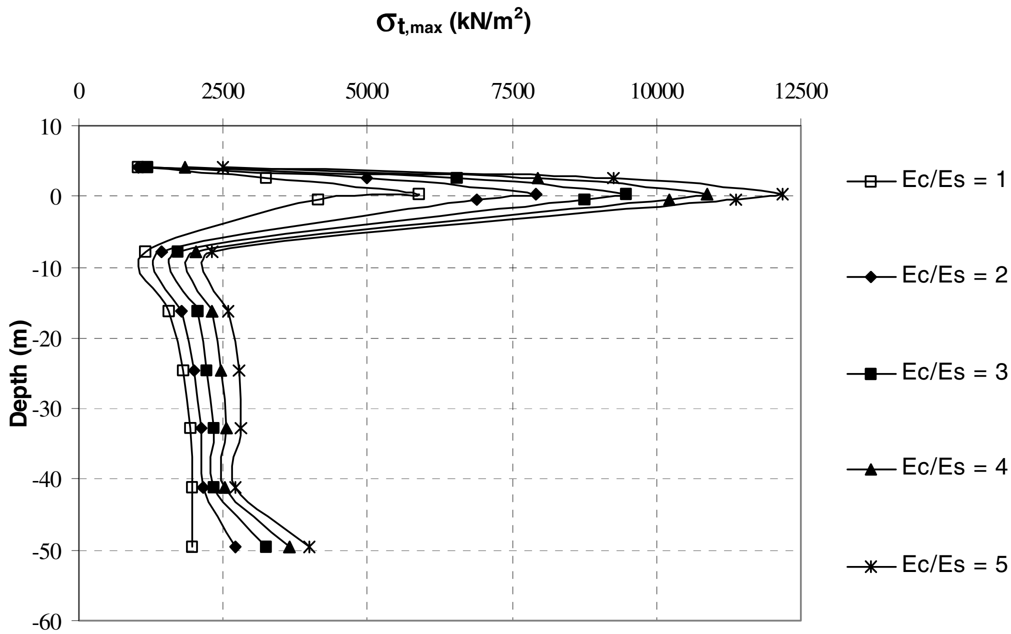

Fig. 5 Variation of maximum value of maximum tensile stress of wall at frequency of 1.3 Hz for different ratio of elasticity modules of wall materials to elasticity modules of adjacent soil of wall.

CONCLUSIONS

The behavior of plastic concrete cut off walls in earth-dams at the end of construction was investigated using finite element methods. The dam was subjected to shear waves due to earthquake loading. The results show that an increase in the wall material stiffness led to increasing the stresses generated in the wall. The maximum value of stresses was induced in the wall at the ground surface. Such stresses may lead to the damage of the cut off wall. Therefore, it is recommended that special provisions such as gradual increase in wall width or reinforcement the wall around the ground surface be taken into consideration while designing the cut off wall.

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