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APPLICATION OF SMEARED CRACK MODELS ON PLAIN CONCRETE DAM STRUCTURES

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1. Introduction

The cracking behavior of concrete gravity dams has been studied over the last decade. Smeared crack analysis, using the traditional tensile strength based crack propagation criterion [1], have long been criticized for mesh dependent response predictions [2]. The strain softening crack band constitutive model, derived on the basis of fracture energy conservation principle, is a significant achievement in finite element analysis of concrete fracture problems. However, the direction of fracture propagation has not been rigorously addressed in the crack band model. In this study, a crack band model embedded in a fixed crack concept is adopted. The main objective of this paper is to examine the failure behavior of plain concrete dams using smeared crack models. In this study two dimensional cracking behavior of mass concrete dams subjected to static loading was investigated. Two models of plain concrete structures were used as an numerical simulation.

2. Constitutive Equations

A constitutive equation for fracture process zone (FPZ) as shown in Figure 1 is selected to nonlinear model and time independent fracture.

$$\sigma = \zeta(\nu) = b\left[a + (\nu + \nu^*)^{\frac{1}{2}}\right]\exp\left[-c(\nu + \nu^*)^{\frac{1}{2}}\right] \quad \text{.......(1)}$$

in which : a,b,c and ν^* are decided uniquely by:

$$\sigma = \zeta(0) = f_{(t)} \quad \text{.......(1.a)}; \int_0^\infty \sigma d\nu = G_f \quad \text{.......(1.b)}$$

$$\frac{d\sigma}{d\nu}\Big|_{\nu=0} = H_0 \quad \text{.......(1.c)}; \sigma = \zeta(-\nu^*) = \alpha f_t \quad \text{.......(1.d)}$$

where f_t, G_f and H_0 are : tensile strength, fracture energy and initial slope of $\sigma-\nu$ curve. α is a constant value of 0.5~0.9. If the hardening effect of concrete before strength in the fracture process zone is considered, then $H_0 \rightarrow +\infty$ and $\nu^* = 0$. The relationship between the crack displacement ν and the fracturing strain ε can be expressed as:

$$d\nu = d\varepsilon_f h \quad \text{.......(2)}$$

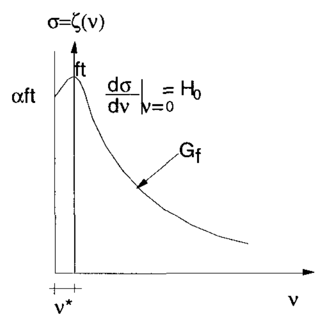

Fig.1. $\sigma - \nu$ curve

The relation between the local and global stress increment can be related by using the transformation matrix T(θ).

$$\Delta\sigma_{nt} = T(-\theta)^T \Delta\sigma, T(\theta) = \begin{vmatrix} c^2 & s^2 & cs \\ s^2 & c^2 & -cs \\ -2cs & 2cs & c^2 - s^2 \end{vmatrix} \quad \text{.......(3)}$$

where c= cos θ, s= sin θ, and θ is the angle between the global coordinate axes and the axes alighted with the direction of cracking. Detail explanation of transformation matrix and relation between the local fracture and global total strain reported in reference 3. This constitutive equations has been tested by using three point bending and four point shear beam. All complete report was presented in reference 3.

3. Numerical Studies and Results

3.1. Dam Model 1

Two scaled down 1:40 model on concrete gravity dam were tested by Carpinteri et.al [4] under lateral loading. Both models had a horizontal notch on the upstream face at 1/4 of the height. The notch/depth ratio was 0.1 to 0.2. The material properties of the model dam was reported to be E=35,700 MPa; ν=0.1; σ_a=3.6 MPa; and G_f = 184 N/m. The density of the material is assumed to be 2,400 kg/m^3. In this study, only the second model is analyzed and the prediction responses are compared with the experimental result of Carpinteri et.al [4] . A plane stress finite element model of the 30 cm thick dam model, and the applied loads are shown in Figure 2. The crack mouth opening displacement (CMOD) was used as a control parameter to adjust the applied load. Smeared crack models provide very close predictions of the ultimate resistance of the structure. The CMOD predicted by smeared crack model are relatively high. Refinement of the FEM mesh does not influence the CMOD response in smeared crack analysis, however, fictitious in nature since the

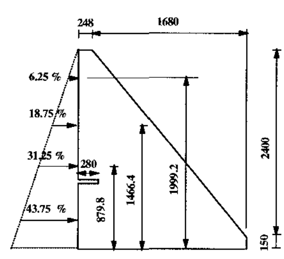

Fig.2.Geometry of Dam Model 1

geometric discontinuity is not explicitly represented in the FEM model. The continuity of displacement field, inherent in smeared fracture analysis, has enabled to predict long stretches of the post failure response, as shown in Figure 3. Crack pattern and mesh deformation were shown in Figure 4 and 5 respectively.

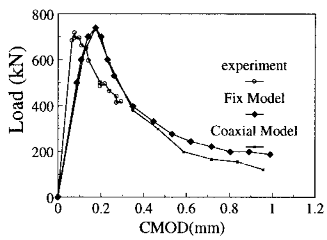

Fig.3. Load-CMOD Curve

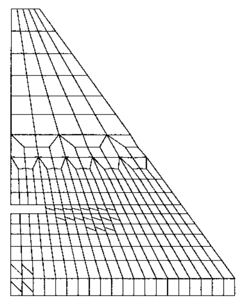

Fig.4. Crack Pattern Dam Model1

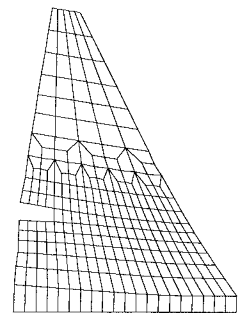

Fig.5. Mesh deformation of Model1

3.2. Dam Model 2.

A plane stress FEM mesh model of dam, subjected to loads due to a reservoir overflow is shown in Figure 6 used as dam model 2. The dam was subjected to self weight and full reservoir hydrostatic load in addition to overflow load In analysis, the top horizontal displacement on the upstream face was selected as the control parameter. Cracking at that point was reported to be most critical to the ultimate structure resistance. FEM analysis of the structure resistance to a reservoir overflow versus the horizontal displacement at the top of the dam are presented in Figure 7. It was shown that the prediction response is very sensitive to dimension of d. When increased the value of d=22 m, it was shown that predicted a significantly higher structural resistance. From numerical analysis, it is found that the structural resistance increases initially and then drops suddenly for a brief instance. This particular part didn't mention by previous investigators. The structural resistance again start to increase, and ultimately stabilizes at a level higher than the initial hump in the resistance curve. The crack profiles obtained for different initial notch depths are also similar. It was shown that the pattern for increasing the first part was similar with plasticity model, and the second part was similar with LEFM model. On the part of structural resistance suddenly drop, it is still needs more deeply study.

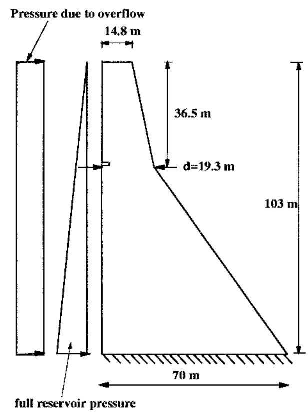

Fig.6. Geometry of Model 2

4. Conclusions

- It was shown that both of smeared crack model provide very close predictions of the ultimate resistance of the structures. Refinement of the FEM mesh does not influence the CMOD.
- It is clearly depicted that the structural resistance increases initially and then drop suddenly for a brief instance. The structural resistance again starts to increase, and ultimately stabilizes at a level higher than the initial lump in the resistance curve.

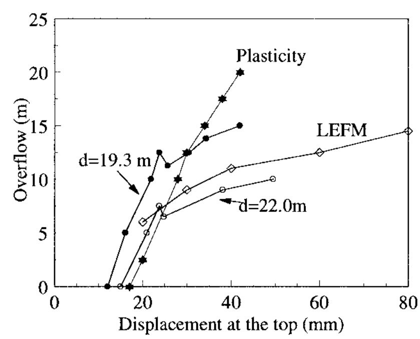

Fig.7. Structural resistance to reservoir overflow

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