Original Paper

2 DIMENSIONAL ANALYSIS OF SEISMIC CRACKING IN CONCRETE GRAVITY DAMS

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This paper deals with seismic cracking of concrete gravity dams. First, the nonlinear tensile behavior of concrete is represented by the smeared crack model. The solution method of dynamic equation is discussed and improved to be consistent with the smeared crack model. Then, the seismic cracking of Koyna Dam is reproduced, to demonstrate the validation of such a nonlinear analysis on cracking in concrete gravity dams during strong earthquakes. Finally, the effect of hydrodynamic pressure inside cracks on the cracking in dam body is investigated and the calculation shows that hydrodynamic pressure inside cracks tends to increase the length of cracking.

Key words: crack, dynamic equation, concrete gravity dam, hydrodynamic pressure

1. INTRODUCTION

Cracking of concrete is one of the most important factors in the safety evaluation of concrete gravity dams because it will threaten the integrity of dams. Only a few concrete gravity dams have experienced structural cracking during earthquakes in the past,[1] but the fact could not give us the confidence regarding the safety of concrete gravity dams since dams have rarely experienced very intensive earthquake excitations. Considering the severe damage caused by the near-field ground motion in the 1995 Hyogo-ken Nanbu earthquake, the dam safety related to concrete cracking during such earthquakes must be evaluated carefully.

Over the last two decades, considerable work has been performed in the nonlinear analysis of concrete gravity dams and emphasis has been placed on the cracking of concrete. Generally, two types of model have been used for the representation of cracks: one is the smeared crack model,[2-4] and the other is the discrete crack model.[5,6] The discrete crack model is thought to be appropriate for unreinforced concrete structures,[5] but keeping cracks between elements will lead to the continuous change of finite element topology, which is very troublesome. On the other hand, the change of finite element topology will introduce some error in the distribution of stress and might lead to unreasonable results. So the widely used model in the cracking analysis of concrete gravity dam is the smeared crack model because of its computational convenience, although it has some width of band and can not represent the cracking of concrete explicitly.

This paper deals with seismic cracking of concrete gravity dams in two dimensions, using the smeared crack model. A numerical procedure for the dynamic cracking analysis of concrete structures is presented, and applied to the analysis of the earthquake damage to Koyna Dam. The effect of hydrodynamic pressure inside cracks on the cracking in dam body is investigated.

2. SMEARED CRACK MODEL OF CONCRETE

2.1 Smeared crack model

(1) Crack initiation and propagation

The initiation and propagation of cracking are based on the strength criterion. The principal stress of an element is checked in terms of a bilinear failure criterion as shown in Fig. 1(c), in which f_t and f_c are the uniaxial tensile strength and uniaxial compressive strength of material, respectively. If the failure criterion is met, cracking takes place in the element in the direction normal to the maximum principal stress.

(2) Constitutive relationship after cracking

Before cracking, concrete is modeled as an isotropic material whose constitutive matrix is

$$D=\begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix}=\frac{E}{1-\nu^2}\begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \frac{1-\nu}{2} \end{bmatrix} \quad (1)$$

in which E is Young's modulus and ν is Poisson's ratio.

Because uncracked concrete is considered to be isotropic, the constitutive matrix D is also applicable in the principal stress coordinate system. After cracking, the stiffness of the concrete normal to the crack is reduced to zero and the isotropic concrete model is replaced by an orthotropic model capable of shear transfer across the crack. Accordingly, the matrix D in the principal stress coordinate system