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Comparison of Discrete and Smeared Cracks in the Dynamic Analysis of Concrete Gravity Dam

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Abstract: There are cracks in structures that can cause structural defects or reduce their useful life. Among the structures that examining cracks and their safety are of importance are concrete dams. There are two main methods to investigate the occurrence of cracks and how to develop it: the discrete and smeared cracks methods. In this paper, we review and compare the two methods. The results show that the discrete crack method requires more time to be analyzed and meshing in the model is changed by opening the cracks. But smeared crack method is easier and it requires less time to be analyzed.
Keywords: dam, discrete crack, smeared crack, dynamic analysis

I. INTRODUCTION

Detection of structural defects in the industry has always been a priority. Defects may occur progressively such as reducing the hardness and resistance as a result of crack growth [1]. To detect the damage, it is necessary to examine the effects of it. According to the theory of structure, static and dynamic response of any structure is related to its hardness; as a result, any sudden change in the hardness will be accompanied by a change in the static and dynamic response of the structure. This allows you to determine the structural damage by examining changes in response of the structure before and after its creation. Structural health monitoring methods are subject to extensive researches that have already been carried out [2]. Dimarogonas has modeled the crack as local flexibility as the primary idea and has obtained the hardness through tests [3]. In this study, we examined and predicted the crack in concrete gravity dams in two smeared and discrete crack methods and the results of the two methods have been compared. To perform the nonlinear analysis, we need the energy required to form the crack, the ability to absorb energy and the impact of dimension to determine the compressive and tensile strength of the concrete specimens [4]. Chopra et al., (1972) as the first step have examined the seismic behavior and prediction of the cracks in the dam using a linear elastic analysis. In this study, Koena concrete gravity dams in India and Pine Flat in the United States were studied regardless of the interaction of Lake and Koena earthquake-based foundation in 1967 [5]. Zohouei (2004) has introduced a numerical model to simulate the behavior of roller compacted dam concrete in which the stress-strain relations is modeled with multi-layered structure for describing the elastic and elastoplastic behavior. As a practical example, the finite element model of Langtan dam with four different mix designs of RCC with different mechanical properties in different parts of the body was analyzed [6].
In this paper, we modeled the crack and how to expand it in concrete gravity dams using the finite elements method. To implement the finite element method, the commercial software ABAQUS is used.

II. MATERIALS AND METHODS

Interaction of dam – lake is a coupled problem of two differential equations of order 2 that is expressed by the following equations:

$$[M]\{\ddot{U}\}+[C]\{\dot{U}\}+[K]\{U\}=[f_1]-[M]\{\ddot{U}_g\}+[Q]\{P\}=\{F_1\}+[Q]\{P\} \quad (1)$$

$$[G]\{\ddot{P}\}+[C']\{\dot{P}\}+[K']\{P\}=\{F_2\}-\rho[Q]^T\{\ddot{U}\} \quad (2)$$

Where [M], [C] and [K] are respectively the matrices of mass, damping and stiffness of structure, [K'], [C'], [G] are respectively the matrices of mass, damping and stiffness of the lake and {U}, {P} are respectively the hydrodynamic pressure and displacement vectors, and $\{\ddot{U}\}$ is the ground acceleration, $\{F_1\}$ is body and hydrostatic force vector and $\{F_2\}$ is the component of force caused by the acceleration in the boundaries of dam - lake and lake - foundation [8].

A. Boundary conditions

1) Foundation is considered as rigid.
2) Pressure of reservoir level is zero and the effect of surface waves is neglected [7].

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3) The length of the reservoir is considered 3 times more than the dam height.

To model the dam and reservoir, the Jagin dam is considered. This dam is type RCC with a height of 78 M.

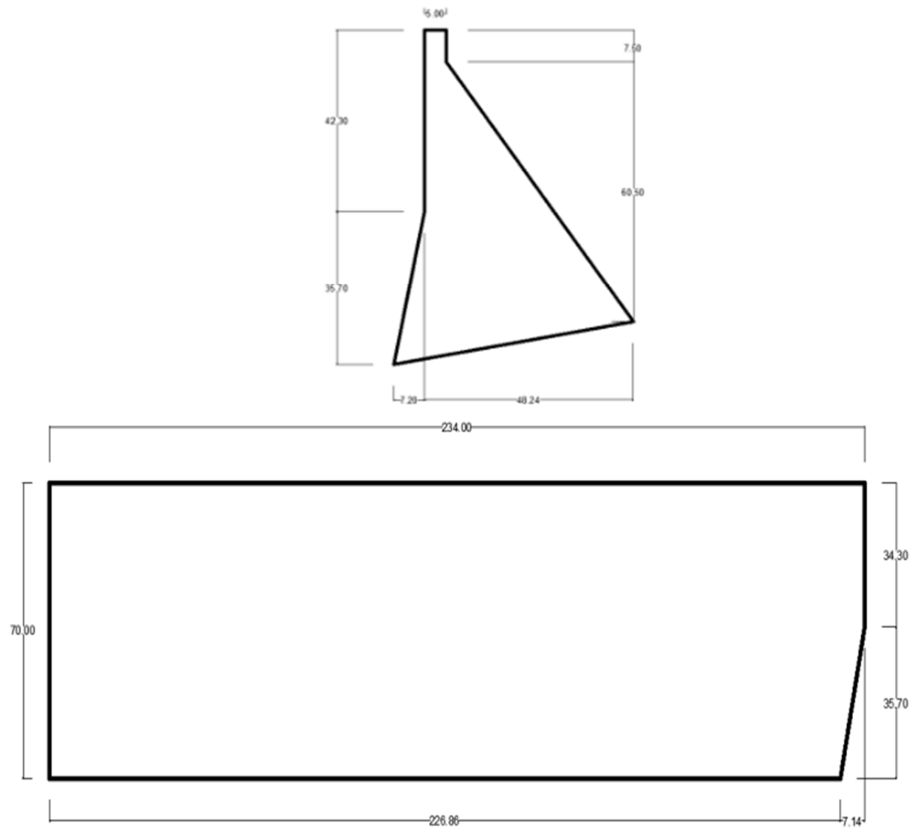

Fig. 1 Geometry of the dam and reservoir

B. Material properties

TABLE I
CONCRETE PROPERTIES

Tensile stress of failure	Ultimate compressive stress	Compressive yield stress	Angle of concrete cracking	Density	Poisson's ratio	Young's modulus
σ_{t0}= 1.7 MPa	σ_{cu}= 24.1 MPa	σ_{c0}= 13.0 MPa	ψ= 36.31o	ρ= 2453 kg / m3	ν= 0.2	E = 21027 MPa

TABLE IIIII FLUID PROPERTIES

Density	Poisson's ratio	Bulk modulus
ρ= 1000 kg / m 3	ν= 0	k = 2.23*109 N/m2

C. Earth movement

To review and dynamic analysis of the dam, Koena earthquake acceleration record December 11, 1967 is used.

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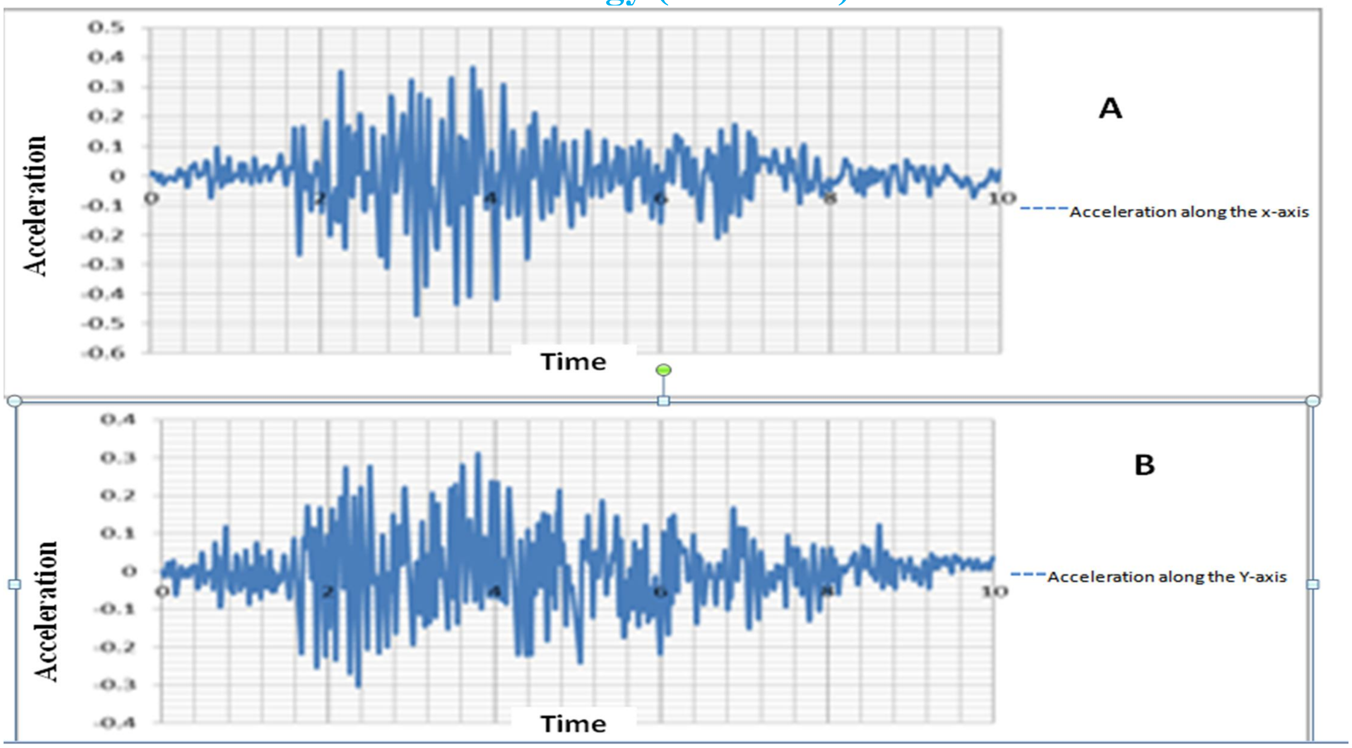

Fig. 2 Koena acceleration (A) Horizontal, and (B) Vertical

D. Meshing

Meshing of the dam and reservoir set is done using eight-node tetrahedral elements, that 735 elements type CPS8R elements are used to model the dam and 4,000 elements type AC2D8 are used to model the fluid.

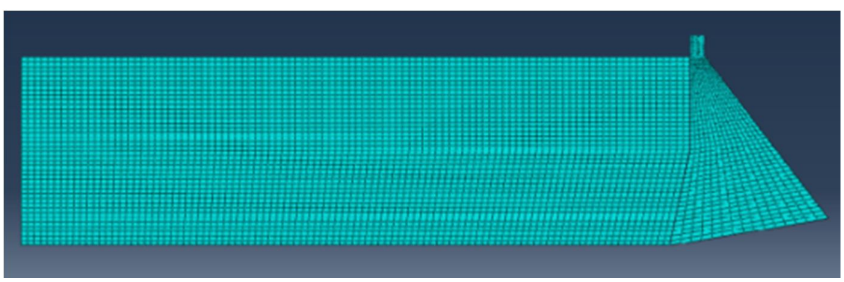

Fig. 3 Dam and reservoir meshing

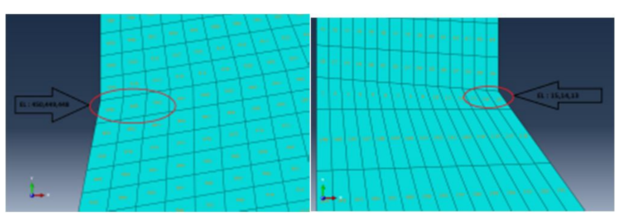

Fig. 4 Elements numbers 450, 449 and 448 in dam upstream, elements numbers 15, 14 and 13 in dam downstream

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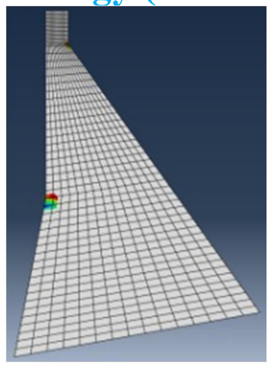

Fig. 5 Growth of cracks in the dam body at 4.85 second, the water level in the reservoir 70 M, smeared crack method

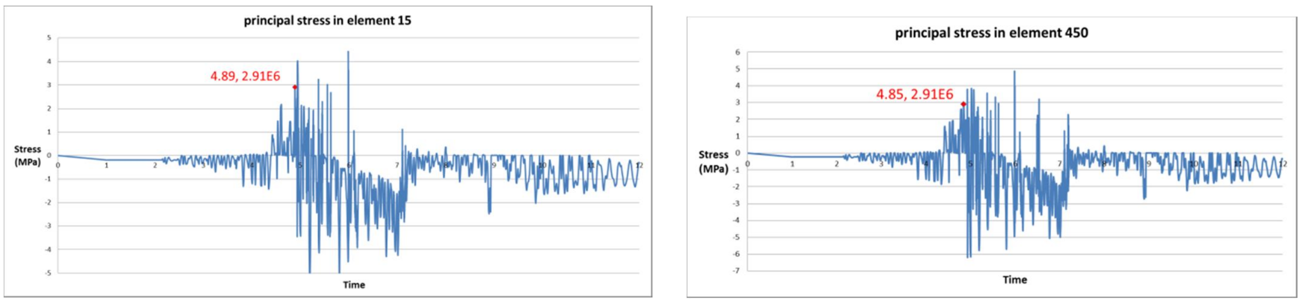

Fig. 6 The main stress in element 15 of the downstream of the dam, the main stress in element 450 in dam upstream, smeared crack method

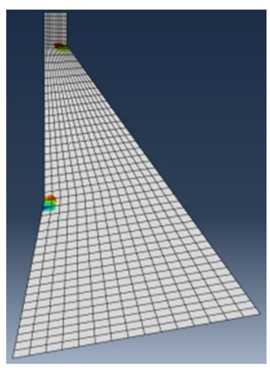

Fig. 7 Growth of crack in dam body at 4.89 second, the water level in the reservoir 70 M, smeared crack method

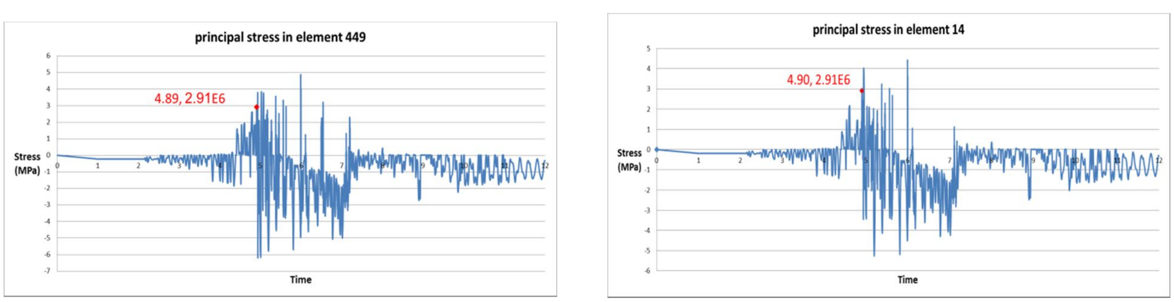

Fig. 8 The main stress in element 14 in downstream of the dam, the main stress in element 449 at the dam upstream, smeared crack method

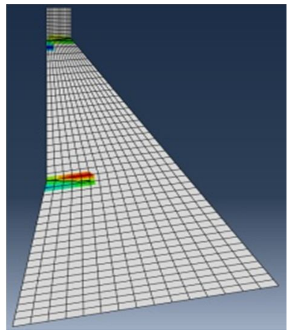

Fig. 9 Growth of crack in the dam body at 5.02 second, water level in the reservoir 70 M, smeared crack method

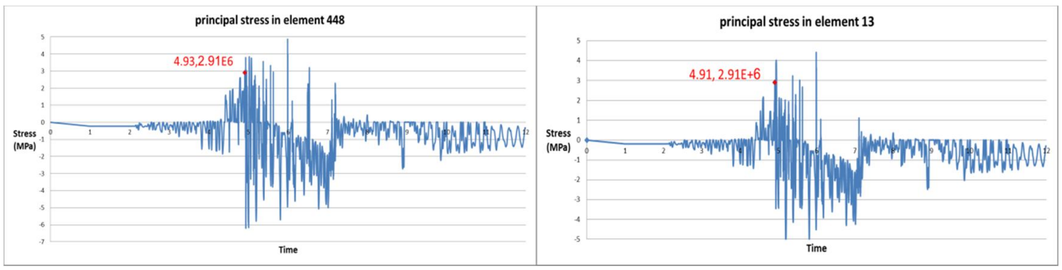

Fig. 10 The main stress in element 13 of dam downstream, the main stress in element 448 in the upstream of the dam, smeared crack method

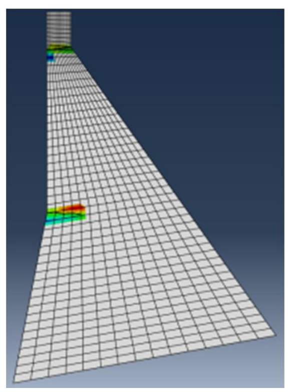

Fig. 11 Growth of crack in the dam at 5.17 second, water level in the reservoir 70 M, smeared crack method

TABLE IVVVI THE TIME OF STUDIED ELEMENT CRACKING, SMEARED CRACK METHOD

448	449	450	15	14	13	**Number of elements**
4.93	4.89	4.85	4.89	4.90	4.91	**Crack growth time (S)**

TABLE VIIV TIME OF CRACKING STUDIED ELEMENTS

Location	**Crack growth start**	**Crack growth end**
Upstream	4.85S	5.17 S
Downstream	4.89S	5.02 S

III. RESULTS OF THE ANALYSIS BY DISCRETE CRACK APPROACH

To investigate the discrete crack, we create a crack with a length of 50 Cm and horizontal in the local dam upstream which is obtained in smeared crack method and the dam began to crack and we analyze the model under seismic loading.

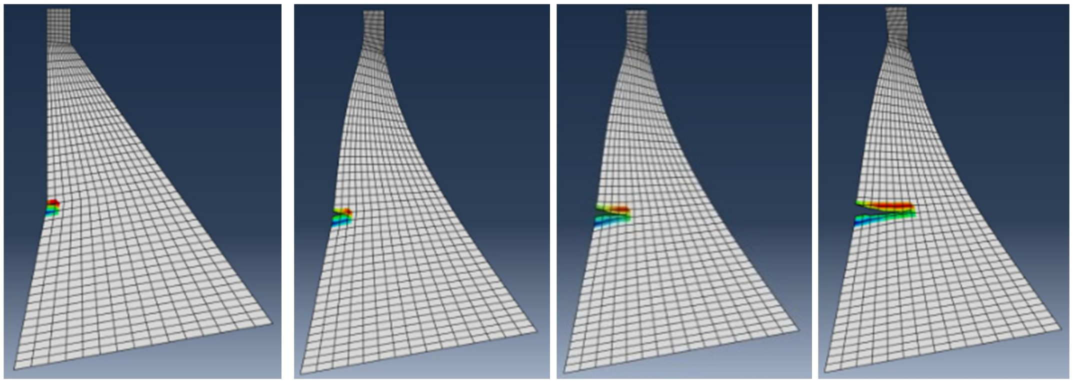

Fig. 12 Time 4.63second, time 4.88 Second, time 5.03 Second, time 5.16 Second, the water level in the reservoir 70 M, discrete crack method

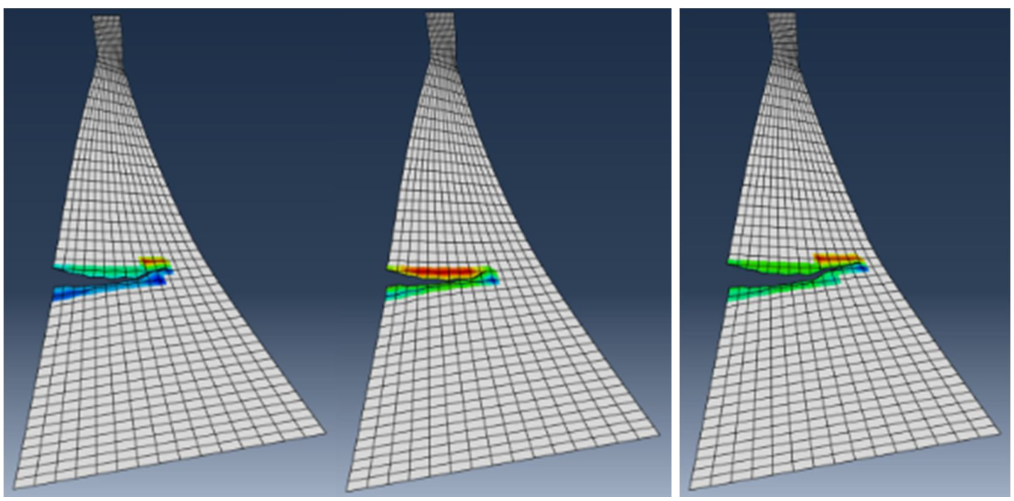

Fig. 13 Time 5:24 second, time 5.32 Second, time 5.41 Second, the water level in the reservoir 70 M, discrete crack method

IV. CONCLUSIONS

Tensile stress distribution in the range of inelastic behavior can adequately predict the areas prone to crack.

The results of the nonlinear dynamic analysis of Jagin concrete dam show that the tensile cracks occur at 4.85 s in location of change in the slope of the body in the upstream in the middle range and also close to the crown at the downstream level. These cracks began earlier in the upper part but in this zone they have slower progress than downstream. According to the obtained results, the crack in upstream grows until 5.17 seconds, but in the downstream it is stopped in 5.02 seconds. Crack analysis in smeared crack method occupies 5 G of the computer memory and takes about 10 hours to complete. Crack analysis in discrete crack method occupies 18 G of the memory of the computer and it takes about 140 hours to be completed. The advantage of discrete crack is the real display of crack and its openings. The disadvantage of this method is that it is very time-consuming and computationally expensive due to frequent changes in the network of finite elements. In comparison with discrete crack method, the smeared crack method is simple and is economical in terms of time and computational costs. The smeared crack method can be used to predict the areas prone to cracking. These methods have no need to field studies, and can be applied given the behavior of materials as well as by considering the boundary conditions in accordance with reality. In contrast to model the crack using discrete crack method, we need field studies and the inspection of the dam body to identify the size and dimensions of existing cracks and model them properly in the software. Also the two discrete and smeared crack methods can be used as supplement for each other, so that using smeared crack method, the dam is modelled in the software and obtain the areas prone to cracking and according to the field inspections if there are cracks in these areas should be measured and then they can be modelled using discrete crack method.

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