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Probe of Crack Initiate at the Toe of Concrete Gravity Dam using Numerical Analysis

M. S. Salimi, H. Kiamanesh, and N. Hedayat

***Abstract*—**In this survey the process of crack propagation at the toe of concrete gravity dam is investigated by applying principals and criteria of linear elastic fracture mechanic. Simulating process of earthquake conditions for three models of dam with different geometrical condition, in empty reservoir under plain stress is calculated through special fracture mechanic software FRANNC2D [1] for determining fracture mechanic criteria. The outcomes showed that in spite of the primary expectations, the simultaneous existence of fillet in both toe and heel area (model 3), the rate of maximum principal stress has not been decreased; however, even the maximum principal stress has increased, so it caused stress intensity factors increase which is undesirable. On the other hand, the dam with heel fillet has shown the best attitude and it is because of items like decreasing the rates of maximum and minimum principal stresses and also is related to decreasing the rates of stress intensity factors for 1st & 2nd modes of the model.

***Keywords*—**Stress intensity factor, concrete gravity dam, numerical analysis, geometry of toe.

I. INTRODUCTION

SINCE in both constructing and exploiting time of the dam, because of some states like, arid continent, the reservoir of the dam is in water shortage (almost empty), hence the situation that the state of the dam in empty reservoir which is investigated under the earthquake condition is very probable and considerable Since one of the main problem in designing and building dams is lack of information of initiating crack points and the itinerary of crack propagate in Connecting foundation to dam body areas, hence; in this survey by using numerical analysis, the geometry of connecting area of foundation to dam body, the stress concentrating point and variability of stress intensity factors during crack propagation have been studied exactly. Worthy to say, because of the smaller size of fracture process zone at the crack tip with respect to the structure size the assumption of linear elastic fracture mechanics were used in this survey [2], [3], [4]. The first study on size effect due to localization of cracks was done by Bazant and then provided the simple formula of the size effect which explains the effect of semi brittle fracture of stable crack growth and provided the possibility of fracture parameters measurement by using maximum loading experiments[5], [6]. The strip crack model based cohesive crack model provided by Bazant & Oh which show the size effect perfectly. This model is used as original model of concrete fracture in industry [7]. Saouma & Milner have done some surveys to show the unconservativity of classic survey analysis based on allowable stress and comparing it with mechanic fracture analysis method [2].In Galvez surveys, analysis method based on principals and criteria of fracture mechanic, the length of critical propagated crack in the base of the dam is show highly [3]. Plizzari found implicit analysis equation for determining stress intensity factors in large gravity dams by assuming the existence of horizontal crack in connection zone to the foundation [4]. Rahimian & Amini analyzed the crack growth in Litian buttress dam by using smeared crack model. The result showed that the main factor of crack initiate in buttress 10/11 Litian dam, is because of variation of temperature and also the lack of crack growth by increasing temperature loading cycle shows that by existing static loading, the crack will not grow [8]. Lohrasbi & Atar nejad analyzed crack growth in a concrete gravity dam by applying discrete crack model. The result showed that there is an acceptable adoption between receiving loads and the rate of crack opening. In conclusion by exercising the receiving load as load factor, some useful data in designing new dams or redesigning the built dams in compare with stress attitude and stability is gained [9]. Madandost, Lashte neshaei & hatami analyzed the effect of reservoir water level in achieving earthquake forces in concrete gravity dams. Conclusion showed that crack in the heel of the dam propagates toward the upstream of the dam by increasing loading frequency [10]. Vothuqi far, Adl parvar & shamsaei analyzed seismic analysis in concrete gravity dam having crack by applying mixed method finite volume- finite element. The result showed that by using finite volume- finite element and boundary element compound in proportion to finite element method more accurate result can be gained [11].

II. DAM DESCRIPTION

For analyzing the problem, a dam with 80 m height, 60 m width, and the 5 m crest length have been considered; also different parts of dam like crest, body and foundation were built with the same materials. For the dam concrete, an isotropic and elastic behavior was assumed and also the material properties adopted are given in TABLE I.

M.S. Salimi is with Civil Engineering Department, Dezful Branch, Islamic Azad University, Dezful, Iran (e-mail: salimi.family.mss@gmail.com)

H. Kiamanesh is with Civil Engineering Department, Dezful Branch, Islamic Azad University, Dezful, Iran (e-mail: doctor_kiamanesh@yahoo.com).

N. Hedayat is with Civil Engineering Department, Dezful Branch, Islamic Azad University, Dezful, Iran (corresponding author to provide phone:+989166443227;e-mail: n.hedayat@yahoo.com).

TABLE I
MATERIAL PROPERTIES

Elasticity module (Mpa)	24000
Poison`s ratio	0.15
Density(kg/m^3)	2400

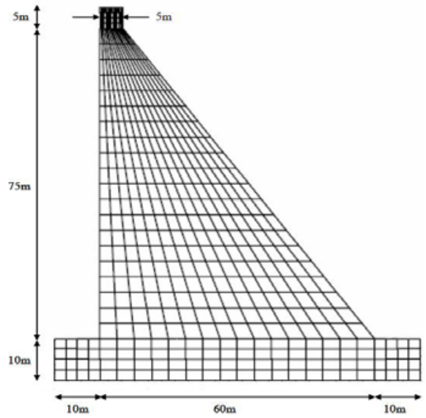

Fig. 1 Sample of finite element (model 1)

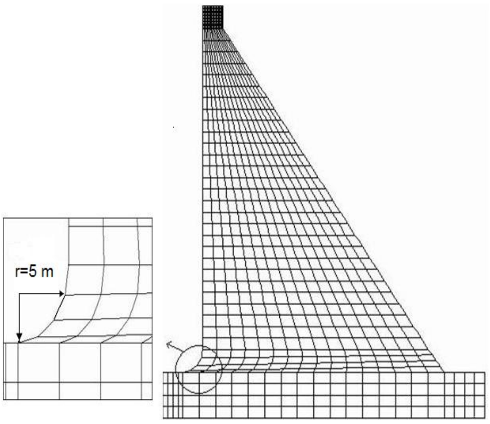

Fig. 2 Sample of dam with heel fillet (model 2)

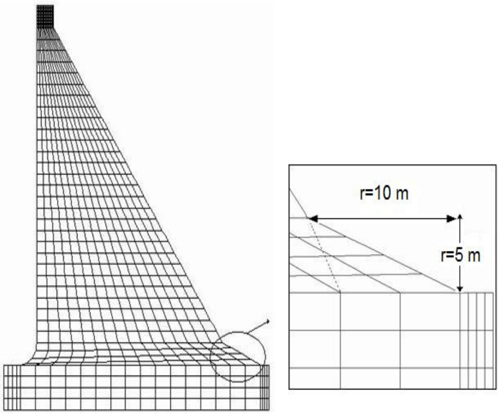

Fig. 3 Sample of dam with fillet in both toe and heel (model3)

In Fig (1), Fig (2) and Fig (3) respectively the view of finite element model of dam with right angle and heel fillet geometry with 5 m radius and toe fillet geometry with their scale have been shown.

III. NUMERICAL ANALYSIS & CONCLUSION

In this survey modeling for earthquake in empty reservoir state has been done for three different geometrical models. The dynamic response of models under the horizontal and vertical accelerations (a_h=0.3g & a_v=0.15g) has been studied. After determining material properties, fixity process and acting out some other necessary steps, the inertial forces due to earthquake acceleration have been applied in which the horizontal component in the worst condition is toward upstream and it`s vertical component is considered to the top.

Since the initial crack does not propagate after applying vertical earthquake acceleration, hence, in this survey once the impact of horizontal acceleration, also once the impact of both vertical and horizontal acceleration just for comparing, have been applied.

The uncracked body cross section under applied forces has been analyzed because of investigating of the variety of maximum principal stress. By exploring the procedure of maximum principal stress variation can be found, the possibility of crack propagate is stronger in those areas where are under more tension. Hence in the following figures, maximum principal stress contour for dam with recalled geometries and accelerations has been shown. It is noticed that because of similarities in results, using of minimum principal stress contours have been ignored.

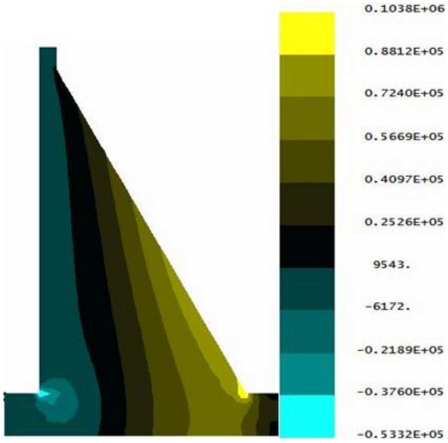

Fig. 4 Maximum principal stress for model 1, (a_h=0.3g)

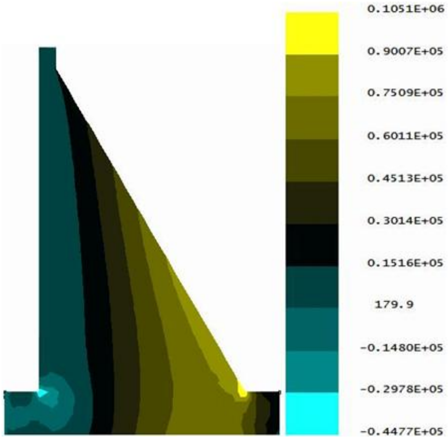

Fig. 5 Maximum principal stress for model 1, (a_h=0.3g & a_v=0.15g)

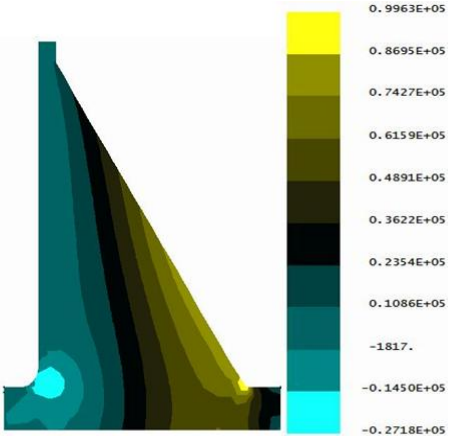

Fig. 6 Maximum principal stress for model 2, (a_h=0.3g)

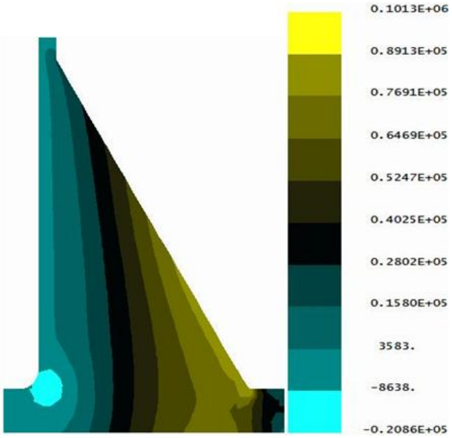

Fig. 7 Maximum principal stress for model 2, (a_h=0.3g & a_v=0.15g)

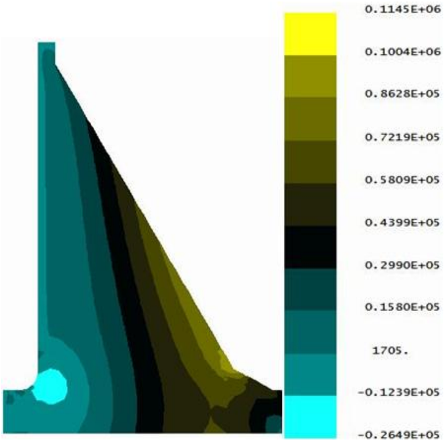

Fig. 8 Maximum principal stress for model 3, (a_h=0.3g)

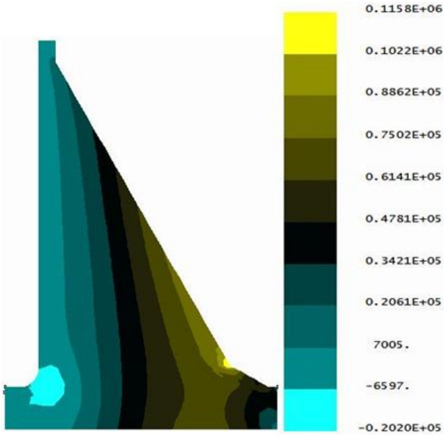

Fig. 9 Maximum principal stress for model 3, (a_h=0.3g & a_v=0.15g)

For modeling crack propagation, one tiny crack is necessary to be initiated. This horizontal tiny crack was placed at the downstream face of the dam, where the body slopes changed. Then the initiated crack with initial length of 2 m in several steps of 2 m increment at each step according to following figures, in vertical direction to maximum circumferential stress propagates. Worthy to say the crack increment in each step and amount of that are determined by trial and error and also adopting parameters like structure geometry of dam and the rate of stress.

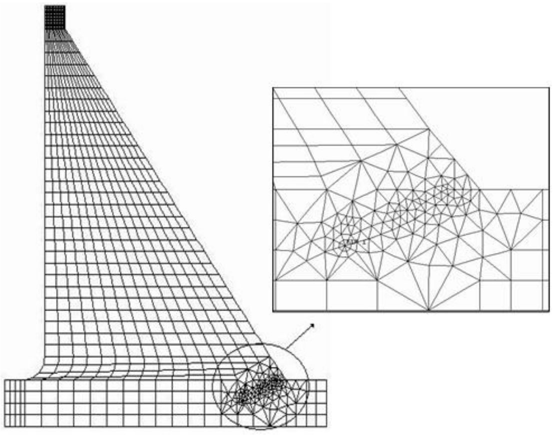

Fig. 10 Trajectory of crack growth for model 2, (a_h=0.3g)

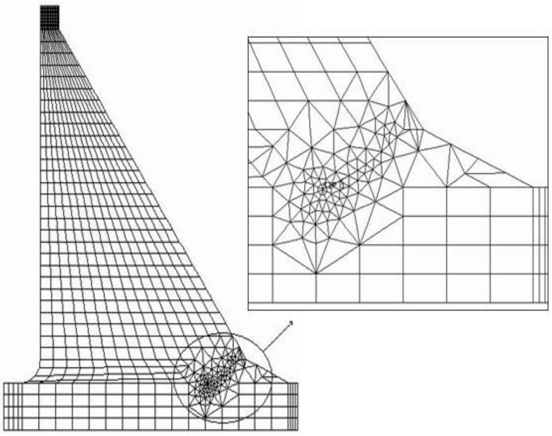

Fig. 11 Trajectory of crack growth for model 3, (a_h=0.3g)

As the crack propagation trajectory for other cases are identical with the direction of crack shown in figures above, hence it is ignored to repeat here.

According to Fig (12) & Fig (13) respectively stress intensity factors variation in first mode with crack length for different model of dams with impact of horizontal earthquake acceleration and simultaneous impact of both horizontal and vertical earthquake accelerations have been shown. Model (1) shows the dam with sample geometry (toe and heel with the sharp tip), model (2) shows the dam with heel fillet, model (3) shows the dam with simultaneous fillet in both toe and heel.

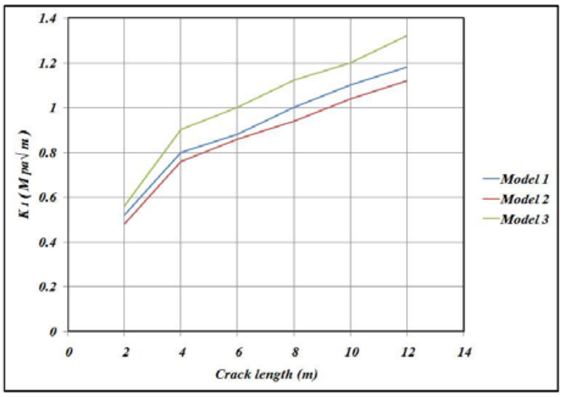

Fig. 12 Variation of (k $_I$), (a_h=0.3g)

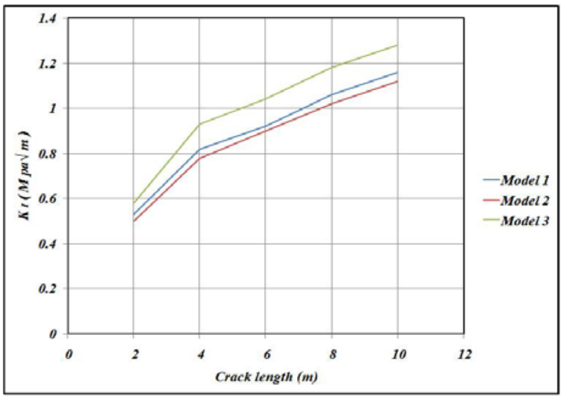

Fig. 13 Variation of (k $_I$), (a_h=0.3g & a_v=0.15g)

According to Fig (12) & Fig (13) the rates of stress intensity factor for first mode (kI) for the dam with heel fillet (model 2) is less than (kI) rates for other models which is desirable and causes crack delay. On the other hand (kI) rates for the dam with simultaneous fillet in both toe and heel (model 3) is more than (kI) rates for other model which is undesirable. This question may be asked, haven`t we gained any desirable answer for (model 3), which has simultaneous fillet in both toe and heel yet? The answer of this question needs more investigations.

The rising in curves in Fig. (12) & Fig. (13) is due to mixed mode fracture impacts, so there are signs of mixed mode fracture impact until the crack length gets to fracture zone (Crack length$\approx$4 m). As crack tends to get to purity mode 1, in this area the amount of (k_I) increased more and it keeps on to 4 m length. When the crack length gets to 4 m, crack is approximately under mode 1 loading and the amount of (k_I) increases with lower slope.Fig. (14) & Fig. (15) show the variation of stress intensity factors for the seconnd mode (k_{II})

with crack length for different model of dams with impact of horizontal earthquake acceleration and simultaneous impact of both horizontal and vertical earthquake accelerations have been shown.

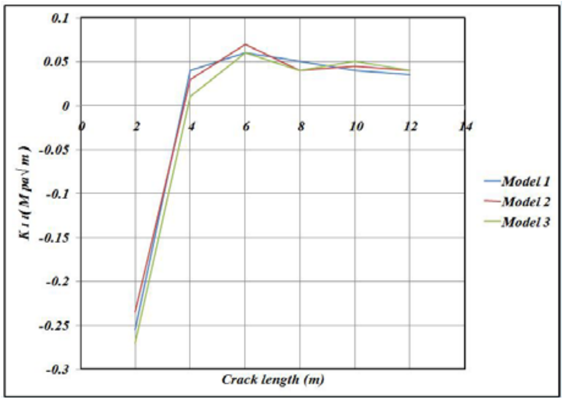

Fig. 14 Variation of (k $_{II}$), (a_h=0.3g)

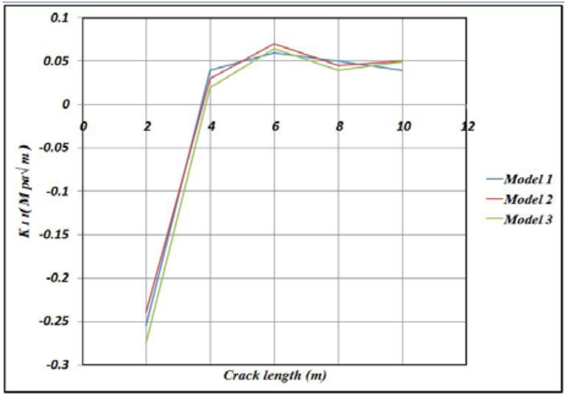

Fig. 15 Variation of (k $_{II}$), (a_h=0.3g & a_v=0.15g)

As it is appeared in Figs. (14) & Fig. (15) with respect to Fig. (12) & Fig. (13), the rates of (k_{II}) is less than those of (k_I), at the beginning of crack propagation because of mixed mode effect the rates of (k_{II}) is more in absolute value and also these rates decrease little by little by increasing crack length and as the crack propagate trajectory gets to a steady rate, the rates of (k_{II}) oscillates in steady amount which are 0.05 Mpa√m in above figures.

As it is shown in Figs. (12), Fig. (13), Fig. (14) & Fig. (15), and also the figures that relates to maximum principal stress contour, for the dam with heel fillet (model 2), the rates of tensional stresses are least in comparison with other models which is desirable. So the rates of (k_I) with respect to other models decrease which this subject delays the crack propagation. So for safety design and also reducing investment (model 2) can be considered.

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