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CRACK ANALYSIS FOR SOME STRUCTURES SUBJECTED TO THERMAL AND DYNAMIC LOADS

Ngo Huong Nhu
Institute of Mechanics, VAST, 264 Doi can, Hanoi, Vietnam

Abstract. Numerical methods of crack analysis for some 2D-elasticity problems with thermal and dynamic loads are considered in this work. The general steps of the algorithm are presented. Some programs are written by Gibian languages in the codes Castem for crack analysis of different structures. Numerical illustrations are realized for the crack dam model, the plate with one and two cracks the plate with crack at the hole subjected to under variable tension of thermal loads . The influence of the temperature, dynamic loads or position of the crack on fracture parameters for these structures are investigated. The given programs may be useful for estimating the failure of dams, tunnels or other structures.

1. FINITE FORMULATION OF CRACK ANALYSIS FOR STRUCTURES SUBJECTED TO THERMAL, DYNAMIC LOADS

The main steps of crack analysis for some plates subjected to static load are presented in [1]. This part deals with the basis of solution for the problems with thermal and dynamic loads.

1.1. Thermal conduction problem

Thermal effect within an elastic solid produces heat transfer by conduction and this flow of thermal energy establishes a temperature field in material.

The equilibrium equation of heat flux in steady-state heat conduction has form [2]:

$$\int \overline{\Theta}'^T k \overline{\Theta}' dV = \int V \overline{\Theta} q^B dV + \int_S \overline{\Theta}^S q^S dS + \sum_{\overline{\Theta}^i} Q^i, \tag{1}$$

where $\overline{\Theta}'^T = \left[\frac{\partial\Theta}{\partial x}\ \frac{\partial\Theta}{\partial y}\ \frac{\partial\Theta}{\partial z}\right]$, $k = \begin{bmatrix} k_x & 0 & 0 \\ 0 & k_y & 0 \\ 0 & 0 & k_z \end{bmatrix}$; $k_x,\ k_y,\ k_z$ are anisotropy conductivity coefficients, Θ is a temperature function, $\overline{\Theta}$ expresses variation of Θ and it is virtual value. q^B represents the (heat) flux per unit of volume, q^s is the (heat) flux per unit of surface and Q^i are the heat, which is concentrated at the nodes. This equation represents that the quantities of ingoing and outgoing heat flux are equal.

Note that(1) is similar as the formula of virtual work in the elastic problem. The temperature $\Theta^{(m)}$ in m-th element may be expressed by vector of temperatures θ in the form:

$$\Theta^{(m)}(x,y,z) = H^{(m)}(x,y,z)\theta \quad \text{and} \quad \Theta'^{(m)}(x,y,z) = B^{(m)}(x,y,z)\theta,\ \theta^T = [\theta_1\ \theta_2 \ldots \theta_n],$$

where θ_i is temperature at i - node, $H^{(m)}$ and $B^{(m)}$ define temperatures and gradients of temperatures inside in the m- element depending on the node temperatures.

Substituting these expressions into, the equilibrium equation (1) yields

$$K\theta = Q \tag{2}$$

where $K = \sum_m \int_{V^{(m)}} B^{(m)T} k^{(m)} B^{(m)} dV^{(m)}$ is the conduction matrix; $Q = Q_B + Q_S + Q_C$ is the vector node heat, Q_C is the vector concentrated heat at nodes, and

$$Q_B = \sum_m \int_{V^{(m)}} H^{(m)T} q^{B^{(m)}} dV^{(m)}; \quad Q_S = \sum_m \int_{S^{(m)}} H^{S^{(m)}T} q^{S^{(m)}} dS^{(m)}. \tag{3}$$

1.2. Boundary condition for the thermal problem

Usually there are two types of thermal condition:

- The temperatures are given at some nodes i on the structure:

$$\theta_i(x, y, z) = \theta_i^{imp} \tag{4}$$

- The other important conditions are the convection and radiation, the values of q^s in (3) depend on the temperatures of body surface and ambient temperature. In linear case the condition is:

$$q^s = \lambda(\theta_e - \theta), \tag{5}$$

λ - convection constant, θ_e - given temperature of ambient. Then the heat flux going through the surface (3) has the form:

$$Q_S = \sum_m \int_{S^{(m)}} \lambda^{(m)} H^{S^{(m)}T} H^{S(m)} dS^{(m)} \theta_e - \sum_m \int_{S^{(m)}} \lambda^{(m)} H^{S^{(m)}T} H^{S(m)} dS^{(m)} \theta$$

So the problem of heat conduction leads to solving equation (2) with the unique temperature unknown θ and boundary condition (4), (5). It is equivalent to a static elastic problem with unknowns which are displacements.

The given temperature distribution in the structure generally induces the volumetric and stress changes. These effects are added to solving mechanical problem.

1.3. Thermo-mechanical problem

In many stress analysis problems, the structures are subjected to both mechanical and thermal loadings. Then, at first it needs to solve a thermal conduction problem to find a temperature field. Then thermal effects are involved to the mechanical problem as external nodal load by following:

The elastic behavior has the relationship between stresses and strains as:

$$\{\sigma\} = [D](\{\varepsilon\} - \{\varepsilon^0\});$$

D is an elasticity matrix containing material properties, $\{\varepsilon^0\}$ is an initial strain.

The strains due to thermal expansion are considered as an initial strain $\{\varepsilon^0\}$ in the body with components: $\varepsilon_{ij}^{(\theta)} = \alpha(\theta - \theta_0)\delta_{ij}$; where θ_0 is initial temperature, α is thermal expansion coefficient, δ_{ij} is Kronecker delta.

The thermal load vector then has form:

$$\{F\}^\theta = \int [B]^T [D] \left\{\varepsilon_{ij}^\theta\right\} dv.$$

Thermo-mechanical problem leads to solving a general mechanical problem by FEM:

$$K^* \{U\} = \{F\} + \left\{F^\theta\right\}, \tag{6}$$

where K^* stiffness matrix, {U},{F} - displacement and nodal force vectors. The obtained displacements are involved to analyze stresses at the crack point by the way in the following part.

1.4. Crack analysis with thermal and mechanical loads

When the solid has a crack, the stress-strain field at the tip of a crack can be characterized by stress intensity factor K or J-integral Rice, energy release rate G or Crack Opening Displacement (COD), for linear elastic behavior $G = J$. To receive K, J, G or COD for crack structures under thermal load, the first step is to solve a thermo-mechanical problem to have displacements $v(\beta)$. Then the stress intensity factor functions $K_I(r)$, $K_{II}(r)$ are calculated from displacements $v(\beta)$ with $\beta = \pi$ and β=0 at the sides of the crack as in [3]:

$$K_I = \frac{2\mu}{(\chi+1)}\sqrt{\frac{2\pi}{r}}v(\pi);\ K_{II} = \frac{2\mu}{(\chi+1)}\sqrt{\frac{2\pi}{r}}v(0); \quad \text{where } \chi = \frac{3-\nu}{1+\nu}.$$

The values K_I, K_{II} are given by extrapolation $K_I(r)$, $K_{II}(r)$ for the points r near to 0 . Here they are calculated by the mean of the displacements of three points, which are closest to the crack tip. The characteristics J- integral and G can be received from stress intensity factors K_I and K_{II} in mixed mode by [3]:

$$G = J = \frac{K_I^2 + K_{II}^2}{E'}; \quad E' = \frac{E}{1-\nu^2} \text{ – for the plane strain state.}$$

1.5. Crack analysis for structures subjected to dynamic load

When the external loads vary slowly with time, that means the ratio between exciting load frequency and the natural frequencies of the structures is less than 0.25, the inertia and damping effects can be neglected and the problem has quasi-static equation [6]:

$$K^* \{U(t)\} = \{F(t)\}.$$

At each moment $t = t_i$, $t_i = t_0 + i\Delta t$, $\Delta t = T/n$, n - time steps, this equation expresses a static problem with external load $F(t_i)$.

By the same procedure in part 1.4, the given components $v(t_i)$ of displacements $U(t_i)$ are employed in calculating of stress intensity factor K, J- integral for static cracks in elastic material subjected to time dependent loadings for each step of time t_i.

2. NUMERICAL CRACK ANALYSIS FOR SOME STRUCTURES

Based on all the above mentioned manners, using the different operators in Castem, some programs are established by Gibian languages to realize numerical crack analysis for 2D problems with thermal, dynamic loads as the crack dam model, the plate with one or two cracks and the plate with crack at hole.

The program RUPTEMFV is written for thermo mechanical problem to calculate crack characteristics for dam model under self-weight, variable hydraulic and thermal loads.

The code RUPBVFT lets crack analysis of plate with one crack under variable tension loading and temperature and RUPBVF2 for analysis of plate with two cracks.

The program RUPHOLVF is used for analysis crack at hole in the plate in variable tension.

The general main steps of all these programs are the same as in [1] but the involving temperature or variable loads requires some other steps relative to these problems.

Operators and steps in thermal analysis

When there is temperature change in the structure body, the first step in FEM is finding of the temperature distribution in the structure. There are some steps and special operators in Castem to find following thermal fields:

- The total conduction of whole structure material by using operator COND
- The heat flux of the given temperatures at the nodes or the line in the structure by operator DEPI.
- The heat flux can be caused by the convection of the structure with external ambient temperatures by operator CONV and find the total heat flux.

After that, using operator RESO to solve the thermal problem with total flux, total conduction to find temperature distribution.

The second step in the thermal analysis is finding of the temperature stresses field from temperature field by operator THET. These stresses are added to the external mechanical load and then process of analysis for the structures is realised as usually FEM.The given displacements in the region of the crack tips and in the structure is used for crack analysis.

Operators and steps in crack analysis with dynamic variable loads

- The first, the function of loading changing and the time steps must be involved to find the load at considered moment.
- After that, using procedure PASAPAS TAB_DYN to solve quasi-static problems with corresponding load to find displacement and stress fields for structure at each time step.
- Using the given displacement distribution and some procedures as 'OBJECTIF' = MOT 'J_DYNA' and SUPTAB. 'SOLUTION_PASAPAS' = TAB_DYN and G_THETA SUPTAB for crack analysis to find crack characteristics K, J, COD at i-th time step.

So, all characteristics at the crack tip in the structures at any time step can be received.

The following problems are considered as numerical illustration for above mentioned.

2.1. The crack dam model subjected to self-weight, hydraulic and thermal loads

Consider a model of gravity dam [4] with the height H=240 cm, the width w=200 cm, at H=60 cm in the upstream wall there is a notch with crack length a=20 cm (Fig. 2).The characteristics of material are: E= 35.700 Mpa, ν=0.2, thermal conductivity coefficient k=2 W/m.K^0, the thermal expansion coefficient α =9.e-6.

The thermal conditions are:

The value of temperature at the dam bottom T_b =18^{o}C.

At the upstream side the temperature T_1=20^{o}C, the convection factor in the face contacted with the water λ = 100 W/m^2.K^0; K^0-temperature unit in degrees Kelvin.

At the downstream side the temperature T_2 equal to 25^o C, 28^o C, 38^o C the convection factor in the face contacted with the air λ = 6 W/m^2.K^0 [5].

The hydraulic load was modeled by the force $F(y)$= 1000 KN, which was distributed into concentrated load at all points in the upstream side.

Using **RUPTEMFV** code, the received fracture mechanics parameters are shown in the Table 1. The temperature and stress fields are shown in the Figs. 1a and 1b.

The units in all tables in this work for crack characteristics are COD (mm); K (MPa.$\sqrt{\text{mm}}$); G (MPa. mm); σ (MPa).

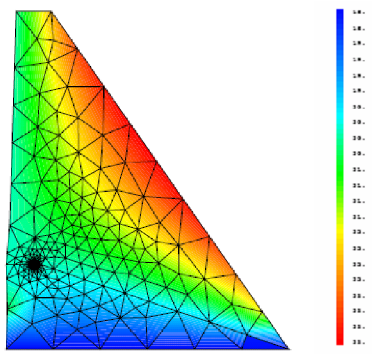

Fig. 1a. Temperature field

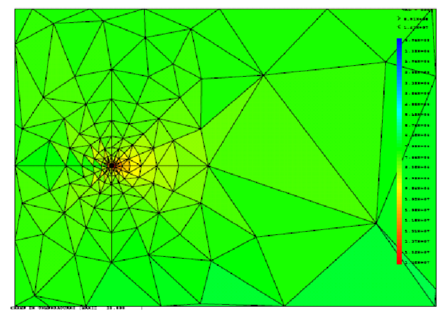

Fig. 1b. Stress field σ_{xx}

Table 1. The values of fracture mechanics parameters for crack dam model

Without or with thermal loading (N/Y)	**T1 (^{0}C)**	**T2 (^{0}C)**	**Tb (^{0}C)**	**COD**	**K$_I$**	**K$_{II}$**	**G**	σ_{xx} **max**
N				0.0306	0.5003	0.0625	7.2083	4.34
Y	20	25	18	0.1236	0.6983	-0.0256	22.625	14.0
Y	20	28	18	0.1198	0.6603	-0.0176	20.738	13.7
Y	20	38	18	0.1079	0.5332	-0.0524	15.143	13.4

Numerical results are given in Table 1 which shows that:

- The thermal effect has significant influence on the values COD, K_I and G. These values become greater compared with the case without the heat loading.

- When the gradients of temperature in the boundary sides ($T_2 - T_1$) increase the crack parameters COD, K_I, G decrease.

- The received calculated temperature values at the boundaries (Fig. 1a) coincide with boundary conditions (T_2=25^{0}C). In the case without thermal loads this code gives good agreement with results in [1, 4]. These show the correctness of the written code.

2.2. The crack dam model subjected to self-weight and variable hydraulic loading

Assume that the dam model subjected to self-weight and hydraulic loads $F(y)$ change on time in law $F(y) * f_i(t)$, i=1,2,...where f_i are multiplying factors of variable hydraulic loading. Time step is equal to 0.5 hour, the considered time is 3,5 hours.

In the 1$^{\text{st}}$ case the hydraulic loading change as linear function (Fig. 2b):

$$f_1(t) = \{1., 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8\};$$

In the 2nd case the hydraulic loading is changed as periodic function (Fig. 3b):

$$f_2(t) = \{1., 1.2, 1, 1.2, 1, 1.2, 1, 1.2\}.$$

The analysis is realized by the same code RUPTEMFV. The obtained results of deformation , graphic of $f_1(t)$ and calculated J-dyna are presented in Figs. 2a, 2b, 2c for the first load case and Figs. 3a, 3b, 3c for the second . The numerical results are shown in the Table 2.

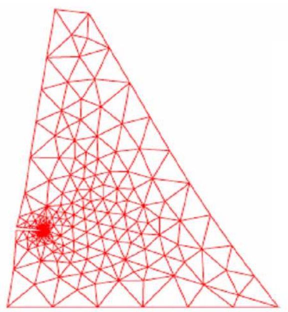

Fig. 2a. Deformation x1000 (step3)

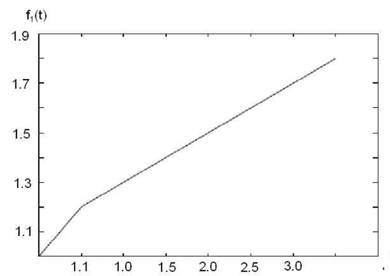

Fig. 2b. The factor load function $f_1(t)$

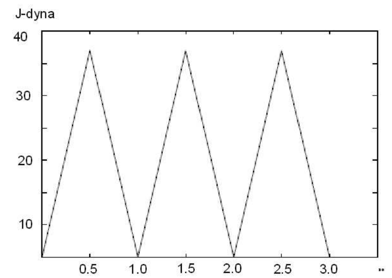

Fig. 2c. J-dyna as a function of the time t

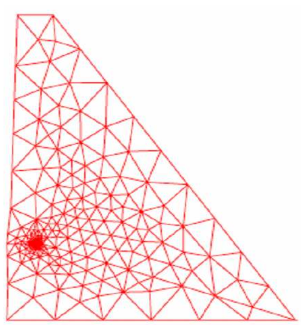

Fig. 3a. Deformation x1000 at 6-th step3

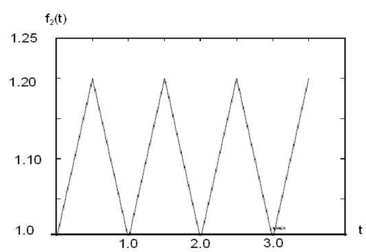

Fig. 3b. The factor load function $f_2(t)$ changes periodically

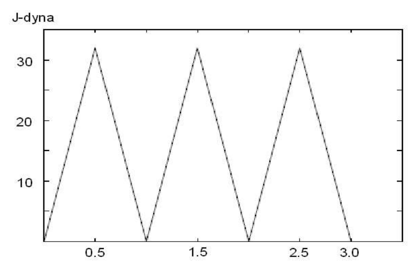

Fig. 23c. J-dyna as a function of the time t

Table 2. The values of crack characteristics of dam model for two load cases for dam model

Load	F1= F(y)*f1(t)			F2= F(y)*f2(t)		
Step times	J- DYNA	K(t)	COD (x e-2)	J- DYNA	K(t)	COD (x e-2)
1	3.20155 e1	1.07448	3.60510	3.20155e1	1.07448	3.60510
2	6.76778e-1	0.15562	0.51666	1.43879e-7	0.000072	1.164617e-4
3	3.85112e1	1.17845	3.94913	3.20070e1	1.074330	3.60477
4	1.88232e0	0.26053	0.86145	2.26238e-6	0.000285	6.5844e-4
5	4.55974e1	1.28229	4.29285	3.19900e1	1.07405	3.60412
6	3.69397e0	0.36497	1.20655	1.14861e-5	0.000643	1.48139e-3

Note that :

- The Figs. 2c, 3c show that when hydraulic load changes as linear or periodic function, the J-dyna gives the quasi-periodic or the periodic variable form

- The values COD for the linear changing of hydraulic load are larger than in the case of periodically changing (Table 2).

2.3. The crack plate subjected to tension variable loading $F(t)$

Consider the cracked plate of width w=104 mm and length h=40 mm. The length of fissure $2a$=24 mm. The crack is located at the middle of plate so the mesh is constructed for only half of the plate (Fig. 4b). The material characteristics of plate are E= 75.61 MPa, $\nu = 0.286$. The side DC and AB subjected dynamic tension loadings $F_i(t)$, i=1,2 in two cases.

- The loading is a linear function: $\{F_1(t_i)$, i=1, 7$\}$= (0.1e6N, 0.2e6N, 0.3e6N , 0.4e6N, 0.5e6N, 0.6e6 N, 0.7e6N) (Fig. 4a)

- The loading F_2(t) is a periodic variable as following: (0.4e6 N ,0.8e6N)x4 times (Fig. 5a).

The mechanical boundary conditions are: Displacements U_x =0 at the side AD and BC and displacements U_y =0 at the point P_5.

The calculation are realized for 7 steps time, each step is 0.5 year. The results in the case when $F_1(t)$ changes linearity are expressed in the Fig. 4b, 4c and for the periodic law $F_2(t)$ in the Fig. 5c, 5b and in the Table 3.

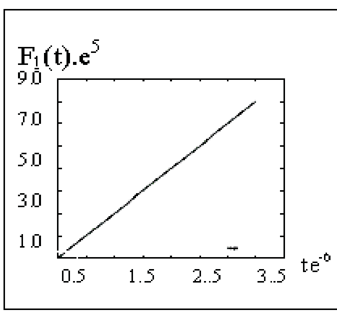

Fig. 4a. The graph of loading $F_1(t)$

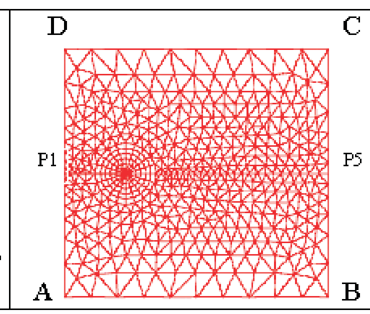

Fig. 4b. Deformation (x100) at 5-th step

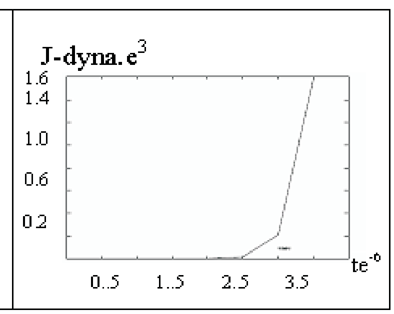

Fig. 4c. The graph of J-dyna of the time t

Clearly that for the plate in tension, independently of linear or periodic load changing, the function J-dyna in both load cases has no periodic form Figs. (4c, 5c). It is different between effects of tension and hydrostatic loads. The all values J, K_I, COD for the both loading cases are given in the Table 3.

So, for the periodically loads F_2 the all given crack characteristics values are greater.

2.4. The crack plate subjected to tension $F(t)$ varying linearly with time and constant thermal load

The calculating is realized for plate subjected the thermal conditions as followings:

At the side AD temperature has value T=40^{o}C. On the sides AB, BC, DC there are convections with ambient temperature T= 20^{o}C with convection factor λ = 6 W/m^2.K^0, the thermal conductivity coefficient of material is k=2 W/m.K^0, the thermal expansion

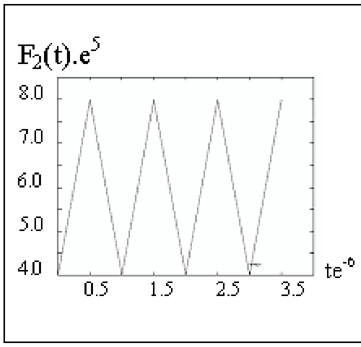

Fig. 5a. The graph of loading $F_2(t)$

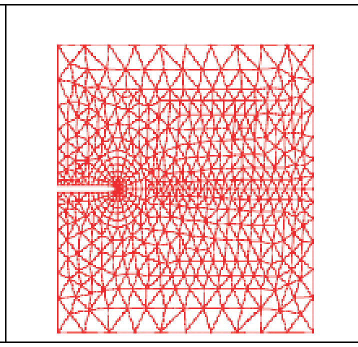

Fig. 5b. Deformation (x100) at 6-th step

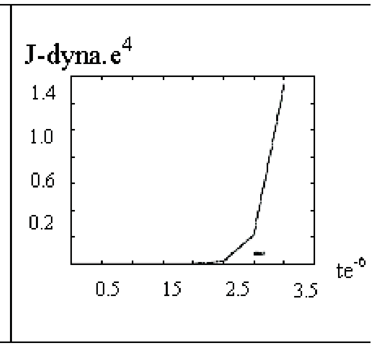

Fig. 5c. The graph of J-dyna of the time t

Table 3. The values of crack characteristics for plate with two load cases

Load	**F_1(t) changes linearly**			**F_2(t) changes periodically**		
Steps	J-DYNA	K_I(t)	COD (xe-4)	J-DYNA	K_I(t)	COD (xe-4)
1	1.21264e-7	3.1600	6.6016e-4	1.94022e-6	12.64	2.6406e-3
2	7.90816e-5	80.697	1.8036e-2	1.19944e-3	314.27	7.0385e-2
3	1.11545e-2	958.40	2.3309e-1	1.58538e-1	3613.2	8.8369e-1
4	5.98888e-1	7017.8	1.88808	7.84017	25409	6.91449
5	1.52006e1	35379	10.7168	1.79595e2	121610	37.6198
6	2.05092e2	129955	45.1972	2.10988e3	416820	150.461

coefficient α =1.e-5. The factor load for thermal load equal 10e-6.The results of analysis give thermal distribution in Fig. 6a and $J(t)$ and $K(t)$ in Fig. 6b, 6c

Table 4. The values of crack characteristics when $F_1(t)$ changes linearly with and without thermal load

Cases	**with thermal load**			**without thermal load**		
Steps	J- DYNA	K_I(t)	COD (xe-4)	J-DYNA	K_I(t)	COD (xe-4)
1	1.21603e-8	1.0187	2.0664e-4	1.21264e-7	3.1600	6.6016e-4
2	1.06728e-5	29.646	6.8258e-3	7.90816e-5	80.697	1.8036e-2
3	1.80513e-3	385.54	9.5674e-2	1.11545e-2	958.40	2.3309e-1
4	1.16508e-1	3097.4	8.4122e-1	5.98888e-1	7017.8	1.88808
5	3.61452	17252	5.21759	1.52006e1	35379	10.7168

The results show that:

- When thermal load exists, the values J, K, COD became smaller compared with the case it does not exit (Table 4)

- The given temperatures of analysis are: 40^{o}C; 34.288^{o}C; 29.576^{o}C; 26.181^{o}C; 20.023^{o}C at the corresponding points in the middle line of plate P_1, P_6, P_3, P_7, P_5 so calculating results coincide with boundary conditions on the AD and CB (Fig. 6a) so the code RUP-BVFT is reliable.

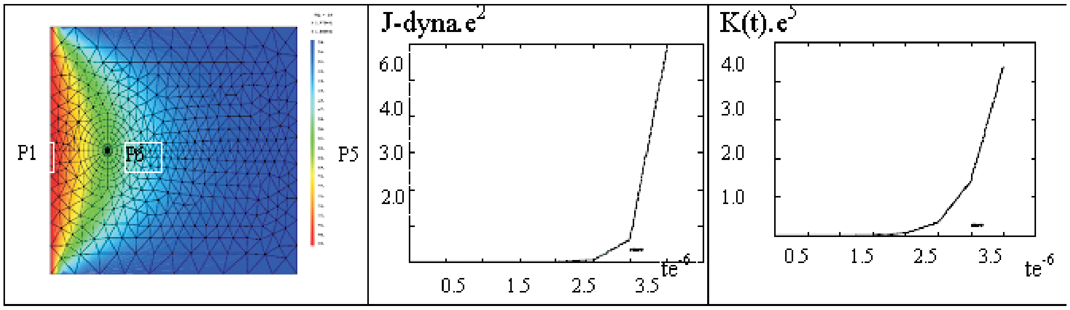

Fig. 6a. Temperature field *Fig. 6b.* J-dyna *Fig. 6c.* $K(t)$

2.5. The plate having two cracks subjected to tension load $F(t)$ varying linearly with time

In this part, the plate of above mentioned dimensions under linear loading is considered for cases: The plate has only one crack (Fig. 7a) and the plate has two cracks (Fig. 7b, 7c) with the lengths a_1=12 mm and a_2=8 mm. The mechanical boundary conditions are: Displacements U_x =0 at the side AD and CB and displacements U_y =0 at the point B_1. The influence of second crack on the first is investigated by code RUPBVF2.

2.5.1. *The influence of positions of the cracks*

Consider plate with two cracks. The first crack is located at the distance h_1=30 mm, the second crack is located in two ways

a) The second cracks lies at h_2=7 mm from bottom of the plate (Fig. 7b)

b) The second crack is located at the distance h_2= 10 mm (Fig. 7c).

The results of analysis at 4-th step time give the different deformations in the Figs. 7b, 7c. If COD$_1$, J$_1$, K$_1$ are denoted for the first crack and COD$_2$, J$_2$, K$_2$ for the second, the crack characteristics in each case for each crack are presented in the Table 5.

Table 5. The values of COD and J for two cracks

Cases	**h_1=30 mm, h_2=7 mm**			**h_1=30 mm, h_2=10 mm**		
Steps	COD1 (xe-3)	COD2 (xe-3)	J2	COD1 (xe-3)	COD2 (xe-3)	J2
1	1.1239e-2	8.6608e-2	1.6758e-1	1.12496e-2	6.95413e-2	3.4544e-3
2	1.1782e-1	1.04137	1.71478e1	1.78262e-1	8.36894e-1	5.8529e-1
3	1.3128	5.70472	3.26458e2	1.31286	4.58749	2.22252e1
4	5.89818	18.7309	2.08197e3	5.89834	15.0793	3.11415e2
5	18.0338	41.9681	6.80607e3	18.0350	33.8195	1.93761e3
6	40.2281	72.3401	1.77129e4	40.2281	58.275	6.56825e3

The Table 5 shows that:

- When h_2 is smaller (7 mm< 10 mm) that means the crack nearest the boundary loading, the crack characteristics for second crack have greater values and the failure can be arisen early.

- The calculated values COD_2 of second crack is larger than COD_1 of the first crack (Table 5). This is a good coincidence with visual deformation results in Fig. 7b, 7c.

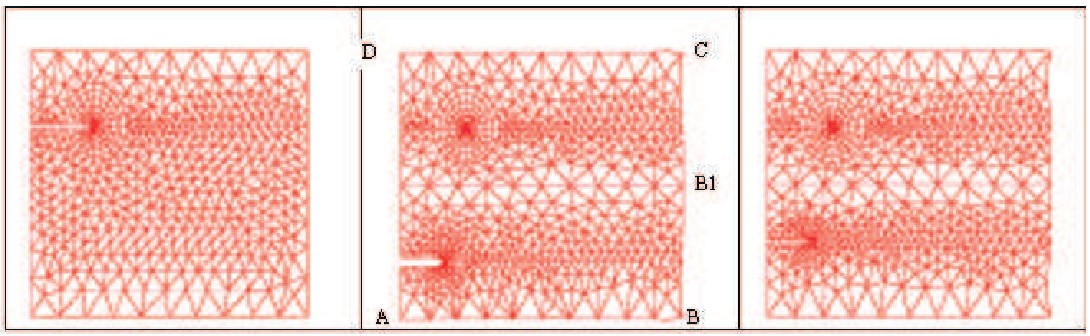

Fig. 7a. The deformation with one crack

Fig. 7b. The deformation when h_2=7 mm

Fig. 7c. The deformation when h_2=10 000 mm

2.5.2. *The influence of second crack existence on the characteristics of the first crack*

Now consider how characteristics of the first crack change when second crack arises. The plate with only one crack (Fig. 7a) and the plate with two cracks are analyzed (Fig. 7b) The results for first crack are shown in the Table 6.

Table 6. The values of crack characteristics for the first crack

Load	**The plate has one crack**			**The plate has two cracks, h_2=7 mm**		
Steps	J1	K_I(t)	COD (xe-4)	J1	K1(t)	COD1 (xe-4)
1	9.29264e-3	874.76	1.7946e-1	3.46248e-3	533.97	1.1239e-1
2	1.50229e0	1112.2	2.68346	6.39327e-1	7255.7	1.78261
3	4.73728e1	62458	18.4155	2.38601e1	44326	13.128
4	4.97271e2	2.02356e5	76.4394	3.02318e2	1.57780e5	58.9818
5	2.29517e3	4.34738e5	215.156	1.65627e3	3.69305e5	180.338
6	6.74956e3	7.45517e5	444.492	5.29698e3	6.60441e5	402.281

The results shows:

- When second crack exists all characteristics of the first crack become smaller.

- The calculating also gives that: characteristics J_1, K_1 (Table 6), and COD_1(Table 5) for the first crack are almost the same in both case h_2=7 mm and h_2=10 mm that means the positions of second crack has a little influence on the characteristics of the first crack.

The code and results of this part let investigate the complex problems with many cracks as estimating of plate failure or development of cracks.

2.5.3. *The problem for the crack at hole in the plate under dynamic load*

A rectangular plate of width and length $2w$=250 mm, $2h$=200 mm respectively, E= 140 Mpa , ν =0.1 is considered . The plate has a hole with radius R= 30 mm and the center at C(125, 10) (Fig. 8). The crack point lies at the hole at point P_{11} (x=150 mm, y=20 mm). The length of crack a = 50 mm. The crack inclined at angle 45^0 to the axis $0x$. The boundary conditions are: U_x=0, U_y=0 at P_0, U_y=0 at P_2.

On opposite sides LG and CD, the plate is subjected to dynamic tension uniform load varying linearly with time: 4000 N, 5000 N, 6000 N, 7000 N, 8000 N, 9000 N, 10000 N, 11000 N and cyclically changing as: 4000 N, 8000 N, 4000 N, 8000 N, 4000 N, 8000 N, 4000 N, 8000 N.

Using the code RUPHOLVF, the values of the J-dyna in both load cases are received in 6 time steps, each of which equals 0.5 hours and are shown in the Table 7 and in the graph form (Fig. 8b, 8c).

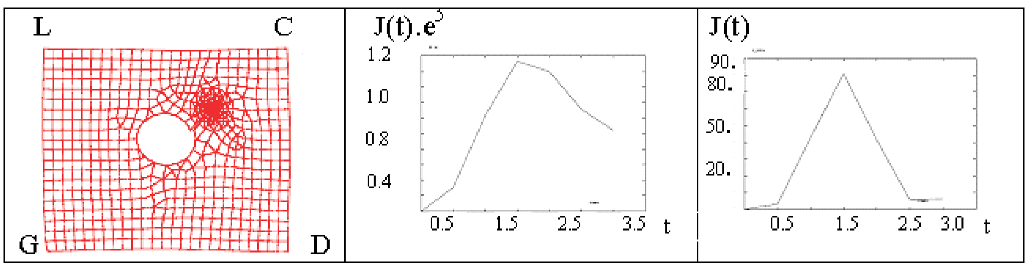

Fig. 8a. The deformation (x 500) of the plate under linear tension at 4^{th}-step

Fig. 8b. J-dyna function in the case of linear tension

Fig. 8c. J-dyna function in the case of cyclic tension

Table 7. The values of crack characteristics for plate with the crack at hole

Load	**Tension load changes linearly**		**Tension load changes cyclically**	
Steps	J- DYNA	$K_I(t)$	J- DYNA	$K_I(t)$
1	1.64748	15264	2.92886	20351
2	2.69189e1	61699	4.27133e1	77719
3	6.59936e1	96605	8.10499e1	107059
4	5.73176e1	90031	4.14790e1	76588
5	3.05805e1	65761	5.60815	28162
6	1.91673e1	52063	6.12952	29441

3. CONCLUSION

The main steps and algorithm of crack analysis for structures subjected thermal and dynamic loads are presented. Some codes are written based on the languages Gibian and operators in Castem. The codes are checked and used to solve many 2D problems with complex geometry forms and loads: the crack dam model under dynamic hydrostatic load, the crack plate with various tension, the plate with one and two cracks , the plate with crack at hole. By using these codes, the integral J, Stress Intensity factors K_I and Crack Opening Displacement are received at any time step with any changing load law, involved thermal effect. The methods and given codes can be useful for practical problems to estimate the failure of the structures.

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PHÂN TÍCH VẾT NỨT CHỊU TẢI TRỌNG NHIỆT VÀ ĐỘNG

Phương pháp tính toán số và thuật toán phân tích vết nứt cho bài toán 2D đàn hồi chịu tải trọng động và tải nhiệt được đề cập trong bài báo. Một số chương trình được lập trên cơ sở ngôn ngữ Gibian và các toán tử của Castem đã giải được cho nhiều kết cấu khác nhau. Các tính toán số minh hoạ được thực hiện cho mô hình đập nứt chịu tải thuỷ tĩnh thay đổi, tải nhiệt và trọng lượng bản thân, bản với một vết nứt, hai vết nứt chịu lực kéo biến thiên theo thời gian, bản có nứt ở mép lỗ. ảnh hưởng của nhiệt độ, dạng tải trọng động và vị trí nứt đến các thông số đặc trưng cho vết nứt của các kết cấu được nghiên cứu và đánh giá. Các chương trình và phương pháp tính có thể ứng dụng được cho các bài toán thực tế.