SECTION 4 RESIDUAL LIFE ASSESSMENT FOR STRUCTURAL ELEMENTS

СЕКЦІЯ 4 ОЦІНЮВАННЯ ЗАЛИШКОВОГО РЕСУРСУ ЕЛЕМЕНТІВ КОНСТРУКЦІЙ

ADVANCED METHODS FOR RELIABILITY AND FRACTURE RISK ASSESSMENT OF STRUCTURAL ELEMENTS WITH CRACK-LIKE DEFECTS

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Abstract. Technical diagnostics and exploitation experience of critical structures and technological equipment showed that in different objects of industrial infrastructure the number of so-called “non-traditional” damaging increases. This type of damage is not predicted by the instructions or codes. This situation can be in heat-and-power generation plants; pipeline transport; chemical and medical industry; mechanical engineering.

In this work some advanced methods for reliability and fracture risk assessment of structural components with crack-like defects are presented. They are based on fracture mechanics approaches and the criteria for calculation of strength and durability of defected structural elements, in particular the criterion of threshold (safe) crack depth and the criterion of brittle catastrophic fracture, are involved.

In work [1] the criteria for the strength and durability assessment of defected structural elements are grounded. In particular, it has been done for the threshold (safe) crack depth and for the criterion of the brittle catastrophic fracture. The new criterion for assessment of the strength and reliability of structures with crack-like defects is proposed on the base of the concept “resistance of structural element to crack growth”, which is a characteristic of the variation rate of the stress intensity factor change at the crack tip during its development in a considered structural element. Based on the dependence of this parameter on the geometry of structural element, loading mode and the shape and location of crack-like defects, it is possible to assess the fracture risk of the structures or their components and also to formulate the procedure requirements for the technical diagnostics of structures during their operation.

This work presents two criteria for the critical depth of defects. First criterion is a_{fc}. In this case the assessment is carried out according to well-known criterion of brittle fracture mechanics [1, 5] $\Delta K_I \leq \Delta K_{fc}$, where ΔK_{fc} is a cyclic fracture toughness [5].

On this ground, the critical defect depth a_{fc} is attained when stress intensity factor is equal of the critical value: $K_I = K_{fc}$ and the criterion of the “critical” crack-like defects will be the condition: $a \leq a_{fc}(\Delta K_{fc})$.

Thus, all detected crack-like defects in structural elements with a depth about $a \approx a_{fc}$ can be considered critically dangerous, because the high probability of their unstable growth that could lead to catastrophic failure of objects.

It has been found that there is a defect size a_*, at which the variation rate of SIF K_I significantly increases. This defect size is considered a fundamental parameter for the assessment of strength and reliability of structural elements with crack-like defects. A defect for which the value of a_* is the lowest one was accepted as the most hazardous from the viewpoint of fracture risk. For many cases the value a_* is lower than the critical size of defect a_c. Therefore it can be concluded that a defect size within the range $a_* \le a \le a_c$ involves an increasing risk of fracture. In some cases this “red range” should be omitted under calculation of the residual durability of the defected structural component.

These relations have the following specific feature: One can always indicate a size of the defect $(a/t)*$ starting from which the rate of changes in the SIF K_I rapidly increases as shown in figure 1.

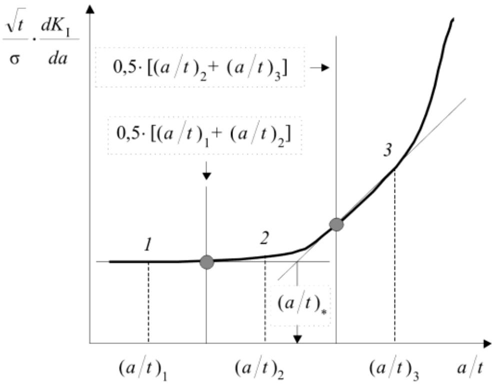


Fig.1 General schematic of determination the characteristic size of a crack like defect.

In this work a modification of this method was conducted with the following considerations.

1. The segment is divided in n parts.

2. n parts give a set of points.

3. A period from the minimum to the last point is considered to get a set of values roughly from a minimum to a maximum.

4. Assessment of the increments function at these points for further work with increments.

5. Determine the maximum increase. Of course it will be the last point of the curve. According to the characteristic point increment or take, depending on the value in accordance with: (for example, if the increase - 0.6, then the characteristic point - 0.5. if the increase - 300, then the characteristic point - 100. We call it $z*$

6. Three scenarios for the program were considered:

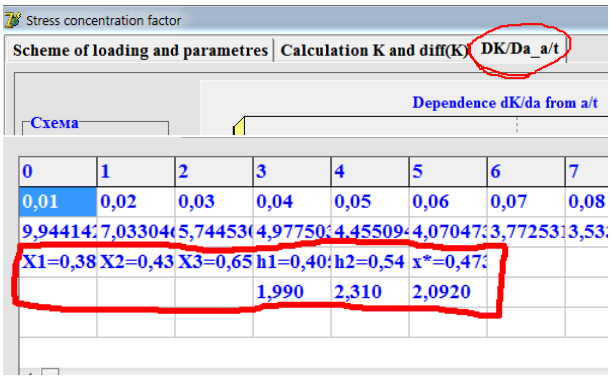
1) $(0.01 \cdot z*; 0.1 \cdot z*; z*)$ - in this case all such points exist in the target graph;

2) $(0.1 \cdot z*; z*; 0.5 \cdot (z* + \max))$ - if there is not $0.01 \cdot z*$;

3) $z*$; $0.5 \cdot (z* + \max)$; max) - if there is not $0.1 \cdot z*$.

7. Depending on the availability of these points, the program (fig. 2) selects one of the three options proposed by us.

8. The program (fig. 2) defines three points and continues working on the existing algorithm. The arguments of these points respectively designated as, and. After that point the arguments and held tangent to the graphics dependence. The point of intersection of the tangents took over.



0	1	2	3	4	5	6	7
0,01	0,02	0,03	0,04	0,05	0,06	0,07	0,08
9,94414	7,03304	5,74453	4,97750	4,45509	4,07047	3,77253	3,53
X1=0,38	X2=0,43	X3=0,65	h1=0,40	h2=0,54	x*=0,47		
			1,990	2,310	2,0920		

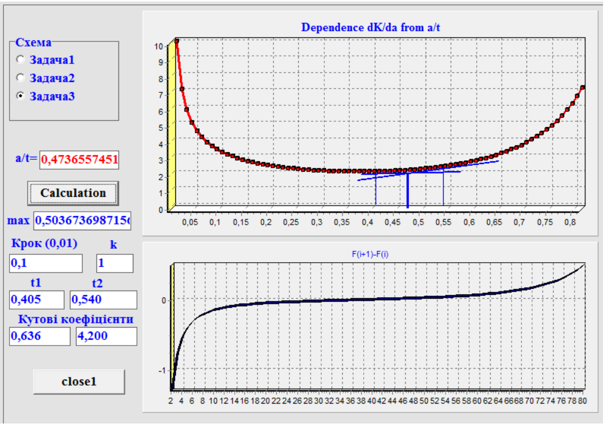


Схема: ○ Задача1 ○ Задача2 ● Задача3

a/t= 0,4736557451

max 0,503673698715

Крок (0,01): 0,1

k: 1

t1: 0,405

t2: 0,540

Кутові коефіцієнти: 0,636 4,200

Fig. 2. Main windows of program

Based on this calculation, defined $(a/t)^*$ values in different pipes with different defects (fig. 3) can be determined.

Moreover, the circumferential crack for which the value of the characteristic parameter $(a/2r)^*$ is minimal proves to be the most dangerous crack for round bars with cracks subjected to the action of uniaxial tension (fig. 3).

In pipes with external axial semielliptic cracks, as the ratio (a/c) decreases, the value of the characteristic parameter (a/t)* becomes lower, which reveals a decrease in strength (fig. 3). In other words, the elongated semielliptic cracks are more dangerous.

The comparison of three characteristic types of defects in the pipe wall under the action of internal pressure, i.e., of axial, circumferential, and elliptic cracks (fig. 3), that the external axial semielliptic crack is much more dangerous than the other types of cracks. Indeed, for this crack, the value of the characteristic parameter (a/t)* is very low, i.e., all defects of this type with $(a/t)^* = 0{,}199$ are potentially characterized by high levels of fracture hazard.

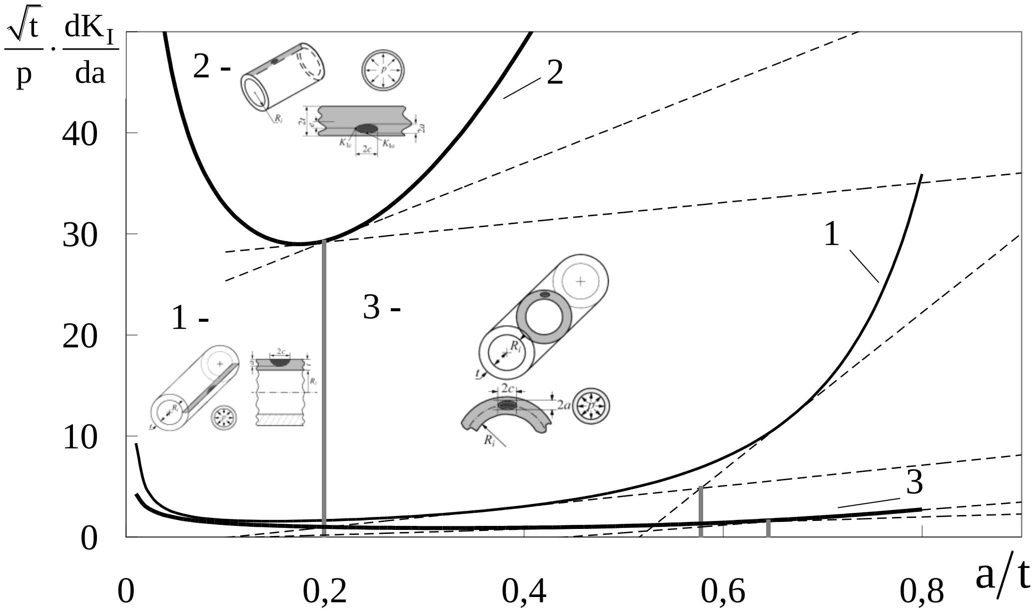


Fig. 2. Comparative assessment of the danger of an axial longitudinal semielliptic crack on the external surface of the pipe (1) and axial (2) or circumferential (3) elliptic cracks in the pipe wall under internal pressure and characteristic values $(a/t)^*$ for this cases: 1 - $(a/t)^* = 0{,}199$; $(a/t)^* = 0{,}578$; $(a/t)^* = 0{,}646$.

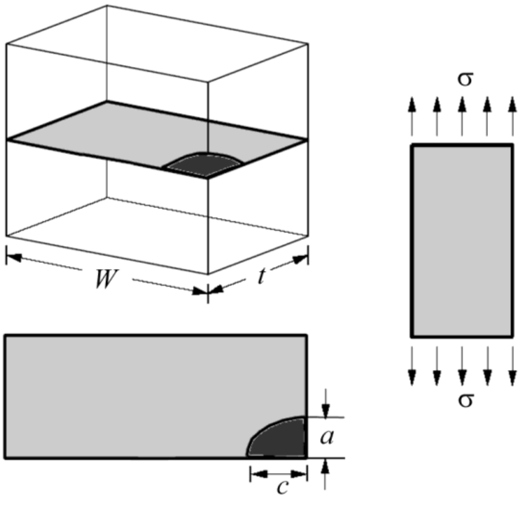


Fig. 2. DEFECT in plate from bone cement: Plate under tension with crack, quarterelliptical corner crack: W – length of plate; t – width of plate ; a – length of crack; $2c$ – width of crack; σ – ongoing efforts.

Table 2 show the length of the crack in the considered case, after reaching which may occur spontaneously its growth, which is likely to lead to the fracture of the object. Here are the values, which obtained with three different approaches to the calculation of critical crack length: the calculation of the mathematical model for SIF; the definition of the characteristic value of $(a/t)*$ for the same model using the original SIF. These three values chosen minimum, which also represented a critical crack length for this particular case. The situation is that for the same objects, but for other defects of form and geometry necessary to apply different criteria to determine whether an investigated parameter.

Table 2 Values of the a_{fc} in simulated body fluid with quarterelliptical corner crack of acrylic bone cements with different soaking time in SBF for 4 and 6 %

Defect I	DEAEA			DEAEM		
a/c=0.1	0 months	3 months	6 months	0 months	3 months	6 months
4	0.87775	0.88042	0.88487	0.86974	0.87775	0.88932
6	0.8822	0.88309	0.8911	0.8733	0.8822	0.88843
a/c=0.25	0 months	3 months	6 months	0 months	3 months	6 months
4	1.27 (a_*)	1.27 (a_*)	1.27 (a_*)	1.27 (a_*)	1.27 (a_*)	1.27 (a_*)
6	1.27 (a_*)	1.27 (a_*)	1.27 (a_*)	1.27 (a_*)	1.27 (a_*)	1.27 (a_*)
a/c=0.5	0 months	3 months	6 months	0 months	3 months	6 months
4	1.88615	1.94112	2.02477	1.74275	1.88615	2.12037
6	1.96502	1.97936	2.14905	1.81206	1.96502	2.0893
a/c=0.75	0 months	3 months	6 months	0 months	3 months	6 months
4	2.24054	2.32725	2.33	2.01629	2.24054	2.25
6	2.36612	2.38705	2.37	2.12094	2.36612	2.38

Note: a_* - by $(a/t)*$.

We propose a method for the evaluation of the serviceability and fracture hazard of structural elements with crack like defects according to the parameter of “crack-growth resistance of structural elements” characterizing the rate of changes in the stress intensity factor. We also estimate the efficiency of application of the proposed parameter $(a/t)*$ for the determination of the residual service life of defective structural elements under cyclic loads in working media.

This research used in following part of this work for another elements..

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