2021

IX INTERNATIONAL SCIENTIFIC CONFERENCE

TECHNICS. TECHNOLOGIES. EDUCATION. SAFETY

07 - 10 JUNE 2021, BOROVETS, BULGARIA

ISSN 2535-0315 (Print)
ISSN 2535-0323 (Online)

VOLUME I

- TECHNOLOGY. MECHANICS AND ANALYSIS OF ELEMENTS.
- TRANSPORT TECHNOLOGIES. MANAGEMENT AND LOGISTICS. SECURITY AND ECOLOGY.

ORGANIZERS
SCIENTIFIC -TECHNICAL UNION OF MECHANICAL ENGINEERING
"VASIL LEVSKI" NATIONAL MILITARY UNIVERSITY

INTERNATIONAL SCIENTIFIC CONFERENCE

TECHNICS. TECHNOLOGIES. EDUCATION. SAFETY. 2021

PROCEEDINGS

YEAR V,
ISSN 2535-0315(Print),
ISSN 2535-0323 (Online)
ISSUE 1 (11),
BOROVETS, BULGARIA 2021

VOLUME 1

- TECHNOLOGY. MECHANICS AND ANALYSIS OF ELEMENTS.
- TRANSPORT TECHNOLOGIES. MANAGEMENT AND LOGISTICS. SECURITY AND ECOLOGY.

07-10.06.2021
BOROVETS, BULGARIA
www.techtos.net

Publisher: Scientific technical union of mechanical engineering “Industry - 4.0”

C O N T E N T S

Determining stress intensity factors of mode I for the crack in rectangular cross-section of thin-walled beam

Mykola Pidgurskyi, Mykola Stashkiv, Ivan Pidgurskyi
Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine
E-mail: pidhurskyy@gmail.com, stashkiv.mykola@gmail.com, ipidhurskyy@gmail.com

Abstract. *A fracture mechanical behavior of thin-walled elements with through-thickness crack is researched. General analytical methods to determine stress intensity factors (SIF) in such elements are presented. The methods are based on the assessments of nominal stresses in the process of crack growth (first method) and change of inertia moment in defective section (second method). Correction functions are obtained for the central crack under bending for rectangular cross-section of thin-walled beams.*
KEYWORD*: THIN-WALLED BEAM, RECTANGULAR CROSS-SECTION, BENDING, CRACK, STRESS INTENSITY FACTOR.*

1. Introduction

An important area of calculation is the prediction of the durability of machines and structures with fatigue cracks, using the methods of fatigue failure mechanics. These methods find practical application in mechanical engineering and construction, in relation to structural elements that are subject to time-variable loadings, and the period of operation of which after formation of the crack is important to assess the residual life of the machine or structure.

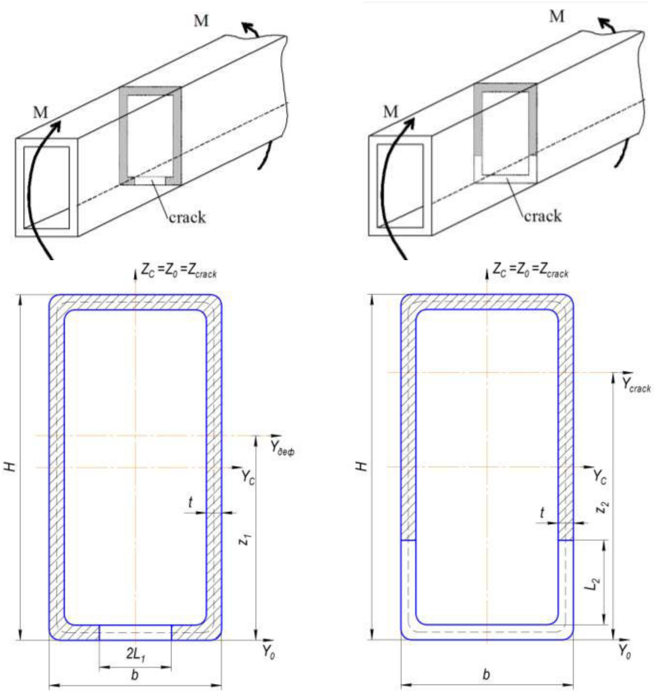
One of the promising areas of reducing the metal content and cost of load-bearing frame systems is the use of closed roll-welded profiles. Analysis of the operation of such structures in mobile machines, as well as in buildings shows that one of the main types of their load is cyclic bending loads with variable amplitude. Such loads in profiles fatigue contribute to cracks formation. Within linear fracture mechanics of materials, the study of the stress-strain state (SSS) of structural elements with crack is reduced to determining the stress intensity factor (SIF).

2. Theoretical Foundation

Analysis of methods for determining SIF for geometrically complex structural elements is given in [1, 2]. It is noted that such problems that take into account the real load and the geometry of the structure are quite complex in mathematical terms. To solve such problems analytical methods [2, 4], finite element method [1, 3, 6, 7], as well as computational and experimental methods [8] are used for each individual case of calculation; methods of the theory of thin-walled beams [9] or approximate engineering methods [10, 11] constituting an acceptable simplification of problems and transforming them into typical calculation schemes for which solutions are already known, and formulas for calculating of SIF are given in reference books [12, 13].

Following the analysis the approximate value of the SIF for a symmetrical through-thickness crack in a thin-walled rectangular element [10] is determined. The authors propose the following mathematical model of symmetrical crack development. The crack growth in the element is divided into several stages (Fig. 1): the propagation of a semi-elliptical crack in the horizontal wall, which gradually turns into a through-thickness crack, which develops along the horizontal wall (Fig. 1, a) (in this case SSS around the crack is close to the state, which occurs during tensile loading of a strip with a central crack, therefore we consider uniaxial tension of the strip with width equal to the length of the horizontal wall); crack propagation in the side walls (Fig. 1, b) (in this case SSS around the crack is close to the state that occurs during bending of a strip with an edge crack, so we consider bending of the strip with a thickness equal to the total thickness of the side walls). Thus, the development of a through-thickness crack in a closed profile is considered as two separate, unrelated tasks. In fact, the SIF is equal zero at the beginning of crack development in the side walls, and the influence of the previous stage of crack development on the next one is not estimated. The approximate SIF values are obtained, which allow to predict the crack size and to establish the allowable sizes of defects for the case of a symmetrical crack in the frame elements.

In this regard, we will consider the definition of SIF for closed roll-welded profiles using the following methods: method of nominal stresses (the problem is to determine σ_{nom} in a complex profile with a crack) and method of the change of inertia moment in the defective profile with the crack developing in it based on dependences [8]. Using these methods, solutions to the problem of determining the SIF in open profiles with a crack are obtained, which coincide well with the results of experimental tests [14, 15]. In addition, the use of these methods allows creating a mathematical model of the defect in a thin-walled element, taking into account the influence of the previous stage of crack growth on the next one.



a) b)

Fig. 1. *Load scheme and Stages of a symmetrical crack growth in a closed rectangular profile:*
a - in a horizontal wall; b - in vertical walls.

3. Methods of calculation

Method of calculation SIF using nominal stresses.

A central crack with length $2L_1$ develops in the closed rectangular profile in the lower edge.

The nominal stresses at the crack tip will be determined by the change in the inertia moment and in the coordinates of the center of mass of the net section of the rectangular profile. The change of vertical coordinate *Z* will have a significant effect, while the coordinate *Y* of the center of mass does not affect the nominal stresses, because it is a central crack.

For the first stage of crack development, the nominal stresses are determined by the dependences:

$$\sigma_1 = \frac{M\left(z_1 - t/2\right)}{I_{Y1}}, \qquad (1)$$

$$z_1 = \frac{(b - 2t - 2L_1)t\,\frac{t}{2} + (b - 2t)t\left(H - \frac{t}{2}\right) + 2\left((H - 2t)t\,\frac{H}{2}\right)}{(b - 2t - 2L_1)t + (b - 2t)t + 2t(H - 2t)}, \qquad (2)$$

$$I_{Y1} = \frac{(b-2t-2L_1)t^3}{12} + (b-2t-2L_1)t\left(z_1-\frac{t}{2}\right)^2 + \frac{(b-2t)t^3}{12} + (b-2t)t\left(H-z_1-\frac{t}{2}\right)^2 + 2\left(\frac{t(H-2t)^3}{12} + t\{H-2t\}\left(z_1-\frac{H}{2}\right)^2\right), \quad (3)$$

where z_1 – the distance from the lower edge of the profile (Y_0 axis) to the center of mass of the net section (running axis Y_{def}), m;

I_{Y1} – inertia moment of the cross section of a closed profile with a crack, m^4.

The other symbols are shown in Fig. 1.

When determining SIF, the problem is to load strip (using tension) weakened by a central crack of length $2L_1$ [12, 13]:

$$K_I^t = \sigma_1(1-\varepsilon_1)\sqrt{\pi L_1}\cdot\left(1+0.128\varepsilon_1-0.288\varepsilon_1^2+1.525\varepsilon_1^3\right), \quad (4)$$

where $\varepsilon_1 = \frac{2L_1 t}{2(H-2t)t+2(b-2t)t} = \frac{L_1}{(H-2t)+(b-2t)}$ – the ratio of the crack area to the gross cross-sectional area of the profile.

Substituting the dependences (1-3) in (4) and performing the transformation we obtain:

$$K_I^{(1)} = M\frac{H}{2}\frac{1}{I_Y}\sqrt{\pi L_1}F_1(\varepsilon_1), \quad (5)$$

where $L_1 = \varepsilon_1((H-2t)+(b-2t))$ – is determined by ε_1;

$M\frac{H}{2}\frac{1}{I_Y} = \sigma$ – nominal stresses in section of the profile without defects, MPa;

I_Y - the moment of inertia of the closed rectangular profile without defects, m^4:

$$I_Y = 2\left(\frac{(b-2t)t^3}{12} + (b-2t)t\left(\frac{H}{2}-\frac{t}{2}\right)^2\right) + 2\frac{t(H-2t)^3}{12}. \quad (6)$$

For similar reasons for the second stage (Fig. 1, b) nominal stresses are determined by the dependences:

$$\sigma_2 = \frac{M(z_2-\delta_1-L2)}{I_{Y2}}, \quad (7)$$

$$z_2 = \frac{(b-2t)t\left(H-\frac{t}{2}\right)+2\left((H-2t-L_2)t\cdot\left(H-\left(\frac{H-2t-L_2}{2}+t\right)\right)\right)}{(b-2t)t+2((H-2t-L_2)t)}, \quad (8)$$

$$I_{Y2} = \frac{(b-2t)t^3}{12} + (b-2t)t\left(H-z_2-\frac{t}{2}\right)^2 + 2\left(\frac{t(H-2t-L_2)^3}{12}\right) + 2(t(H-2t-L_2))\left(z_2-\left(H-\left(\frac{H-2t-L_2}{2}+t\right)\right)\right)^2. \quad (9)$$

When determining the SIF for a crack propagating in the wall of the profile, the problem is to bend the strip weakened by the edge crack L_2 [12, 13]:

$$K_I^b = \sigma_2(1-\varepsilon_1)^2\sqrt{\pi\left(L_2+\frac{b-2t}{2}\right)} \times \left(1.122-1.40\varepsilon_2+7.33\varepsilon_2^2-13.08\varepsilon_2^3+14\varepsilon_2^4\right), \quad (10)$$

where

$$\varepsilon_2 = \frac{L_2+\frac{b-2t}{2}}{(H-2t)+(b-2t)}. \quad (11)$$

Substituting dependences (7-9) in (10) and performing the transformation we obtain:

$$K_I^{(2)} = M\frac{H}{2}\frac{1}{I_Y}\sqrt{\pi\left(L_2+\frac{b-2t}{2}\right)}F_2(\varepsilon_2), \quad (12)$$

where L_2 is determined from dependence (11).

To approximate the correction functions $F_1(\varepsilon_1)$ (first stage) and $F_2(\varepsilon_2)$ (second stage) and obtain a generalized function $F_{1,2}^{(\sigma)}$, consider the assortment of bent welded profiles according to ДСТУ Б В.2.6-8-95 [16]. As it was shown in calculations, roll-welded profiles can be divided into three groups according to the ratio of height and width of their cross section: rectangular profiles with aspect ratio of 2:1, with ratio (1,375…1,475):1 and square profiles. Correction functions $F_{1,2}^{(\sigma)}$ are approximated by generalized curves:

– for rectangular profiles with an aspect ratio of 2:1:

$$\begin{aligned} F_{1,2}^{(\sigma)} = {} & 1+4.131\varepsilon-508.952\varepsilon^2+29523.311\varepsilon^3-864650.909\varepsilon^4+ \\ & +1.561\cdot10^7\varepsilon^5-1.891\cdot10^8\varepsilon^6+1.609\cdot10^9\varepsilon^7-9.902\cdot10^9\varepsilon^8+ \\ & +4.509\cdot10^{10}\varepsilon^9-1.540\cdot10^{11}\varepsilon^{10}+3.972\cdot10^{11}\varepsilon^{11}- \\ & -7.746\cdot10^{11}\varepsilon^{12}+1.134\cdot10^{12}\varepsilon^{13}-1.226\cdot10^{12}\varepsilon^{14}+ \\ & +9.483\cdot10^{11}\varepsilon^{15}-4.966\cdot10^{11}\varepsilon^{16}+1.576\cdot10^{11}\varepsilon^{17}-2.290\cdot10^{10}\varepsilon^{18} \end{aligned} \quad (13)$$

(the error of $F_{1,2}^{(\sigma)}$ when $0<\varepsilon\le0.55$ does not exceed 2% for profiles with a height of 63–250 mm in the whole range of their thicknesses);

– for rectangular profiles with aspect ratio (1,375…1,475):1:

$$\begin{aligned} F_{1,2}^{(\sigma)} = {} & 0.671+17.404\varepsilon-257.773\varepsilon^2+2009.491\varepsilon^3-7759.120\varepsilon^4+ \\ & +14052.424\varepsilon^5-7366.370\varepsilon^6-8583.184\varepsilon^7+8859.089\varepsilon^8 \end{aligned} \quad (14)$$

(the error of $F_{1,2}^{(\sigma)}$ when $0<\varepsilon\le0.6$ does not exceed 4% for profiles with a height of 63–250 mm in the whole range of their thicknesses);

– for square profiles:

$$\begin{aligned} F_{1,2}^{(\sigma)} = {} & 0.975+4.249\varepsilon-121.681\varepsilon^2+1686.699\varepsilon^3-9730.664\varepsilon^4+ \\ & +27366.606\varepsilon^5-37796.230\varepsilon^6+22037.075\varepsilon^7-2292.681\varepsilon^8 \end{aligned} \quad (15)$$

(the error of $F_{1,2}^{(\sigma)}$ when $0<\varepsilon\le0.6$ does not exceed 10% for profiles with a height of 63–200 mm in the whole range of their thicknesses).

Generalized correction functions $F_{1,2}^{(\sigma)}$ for roll-welded profiles are presented in Fig. 2.

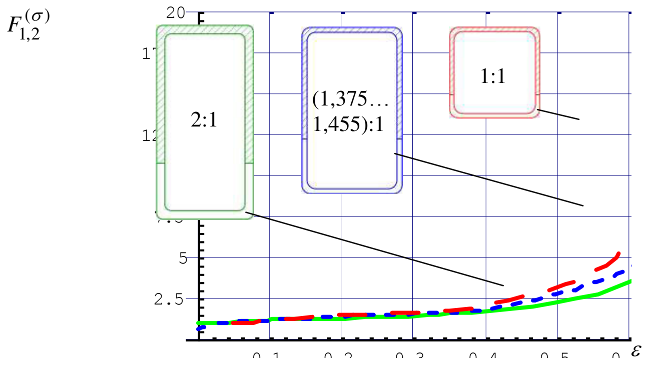


Fig. 2. *Generalized correction functions $F_{1,2}^{(\sigma)}$ for a series of standard rectangular profiles*

The expression to determine the SIF for a crack with length $0<L<\left(\frac{b}{2}+H\right)$ will look like:

$$K_I^{(\sigma)} = M\frac{H}{2}\frac{1}{I_Y}\sqrt{\pi\cdot L}\cdot F_{1,2}^{(\sigma)}. \quad (16)$$

Method of calculation using the change of the inertia moment

Considering the energy parameters during crack propagation, namely the rate of energy release during crack propagation and making transition from energy to force characteristics - Irwin's criterion, the dependence of SIF for cracks developing in simple beam samples are obtained [8].

$$K_I = M\sqrt{\frac{1}{t}\left(\frac{1}{I_{Ydef}} - \frac{1}{I_Y}\right)}, \quad (17)$$

where M – bending moment, N·m;
t – thickness of beam, m;
I_{Ydef}, I_Y – inertia moments of beams with and without defect respectively, m^4.

Consider the determination of SIF for a crack that develops in a thin-walled closed profile. With the development of a crack in the lower edge of a closed profile (first stage) (Fig. 1, a), the inertia moment of the defective profile is determined by the dependences (1-3), and the defect-free profile is defined by formula (6).

Then SIF during the development of crack in the edge of a closed profile is determined by the formula:

$$K_I^{(1)} = M\sqrt{\frac{1}{t}\left(\frac{1}{I_{Y1}} - \frac{1}{I_Y}\right)}. \quad (18)$$

Transforming SIF expression into standard form we obtain next dependence:

$$K_I^{(1M)} = \sigma\sqrt{\pi L_1}F_{1M} = M\frac{H}{2}\frac{1}{I_Y}\sqrt{\pi L_1}F_{1M}. \quad (19)$$

Similarly, for the second stage, the inertia moment of the defective profile will be determined by the dependences (7-9), and the SIF for the crack:

$$K_I^{(2)} = M\sqrt{\frac{1}{t}\left(\frac{1}{I_{Y2}} - \frac{1}{I_Y}\right)}. \quad (20)$$

Transforming SIF expression into standard form we obtain next dependence:

$$K_I^{(2M)} = M\frac{H}{2}\frac{1}{I_Y}\sqrt{\pi\left(L_2 + \frac{b-2t}{2}\right)}F_{2M}. \quad (21)$$

The expression to determine the SIF for a crack with length $0 < L < (b/2 + H)$ will look like:

$$K_I^{(M)} = M\frac{H}{2}\frac{1}{I_Y}\sqrt{\pi \cdot L} \cdot F_{1,2}^{(M)}. \quad (22)$$

Expressions of functions F_{1M} and F_{2M} are not given due to their cumbersomeness.

Defining the correction functions F_{1M} and F_{2M} for a series of standard profiles, we find generalized functions $F_{1,2}^{(M)}$ similarly to the one described above. Therefore,

– for rectangular profiles with an aspect ratio of 2:1:

$$\begin{aligned}F_{1,2}^{(M)} &= 0.877 - 8.567\varepsilon + 211.646\varepsilon^2 + 4755.803\varepsilon^3 - 310552.056\varepsilon^4 + \\ &+ 6.829\cdot10^6\varepsilon^5 - 8.767\cdot10^7\varepsilon^6 + 7.515\cdot10^8\varepsilon^7 - 4.572\cdot10^9\varepsilon^8 + \\ &+ 2.043\cdot10^{10}\varepsilon^9 - 6.833\cdot10^{10}\varepsilon^{10} + 1.727\cdot10^{11}\varepsilon^{11} - 3.305\cdot10^{11}\varepsilon^{12} + \\ &+ 4.754\cdot10^{11}\varepsilon^{13} - 5.055\cdot10^{11}\varepsilon^{14} + 3.852\cdot10^{11}\varepsilon^{15} - \\ &- 1.989\cdot10^{11}\varepsilon^{16} + 6.230\cdot10^{10}\varepsilon^{17} - 8.931\cdot10^9\varepsilon^{18}\end{aligned} \quad (23)$$

(the error of $F_{1,2}^{(M)}$ when $0 < \varepsilon \le 0.6$ does not exceed 6% for profiles with a height of 63–250 mm in the whole range of their thicknesses);

– for rectangular profiles with an aspect ratio (1,375…1,475):1:

$$\begin{aligned}F_{1,2}^{(M)} &= 0.598 + 11.516\varepsilon - 71.371\varepsilon^2 - 5574.037\varepsilon^3 + 115501.304\varepsilon^4 + \\ &+ 13100.877\varepsilon^5 - 2.681\cdot10^7\varepsilon^6 + 4.341\cdot10^8\varepsilon^7 - 3.791\cdot10^9\varepsilon^8 + \\ &+ 2.177\cdot10^{10}\varepsilon^9 - 8.819\cdot10^{10}\varepsilon^{10} + 2.603\cdot10^{11}\varepsilon^{11} - 5.674\cdot10^{11}\varepsilon^{12} + \\ &+ 9.140\cdot10^{11}\varepsilon^{13} - 1.075\cdot10^{12}\varepsilon^{14} + 8.970\cdot10^{11}\varepsilon^{15} - \\ &- 5.035\cdot10^{11}\varepsilon^{16} + 1.705\cdot10^{11}\varepsilon^{17} - 2.630\cdot10^{10}\varepsilon^{18};\end{aligned} \quad (24)$$

(the error of $F_{1,2}^{(M)}$ when $0 < \varepsilon \le 0.6$ does not exceed 7% for profiles with a height of 63–250 mm in the whole range of their thicknesses);

– for square profiles:

$$\begin{aligned}F_{1,2}^{(M)} &= 0.206 + 20.20\varepsilon + 654.38\varepsilon^2 - 34866.31\varepsilon^3 + 387097.794\varepsilon^4 + \\ &+ 4.590\cdot10^6\varepsilon^5 - 1.775\cdot10^8\varepsilon^6 + 2.397\cdot10^9\varepsilon^7 - 1.959\cdot10^{10}\varepsilon^8 + \\ &+ 1.096\cdot10^{11}\varepsilon^9 - 4.42\cdot10^{11}\varepsilon^{10} + 1.314\cdot10^{12}\varepsilon^{11} - 2.912\cdot10^{12}\varepsilon^{12} + \\ &+ 4.801\cdot10^{12}\varepsilon^{13} - 5.807\cdot10^{12}\varepsilon^{14} + 5.006\cdot10^{12}\varepsilon^{15} - \\ &- 2.911\cdot10^{12}\varepsilon^{16} + 1.023\cdot10^{12}\varepsilon^{17} - 1.643\cdot10^{11}\varepsilon^{18}.\end{aligned} \quad (25)$$

(the error of $F_{1,2}^{(M)}$ when $0 < \varepsilon \le 0.5$ does not exceed 8% for profiles with a height of 70–200 mm in the whole range of their thicknesses; – for square profiles with cross-section area 63×63 mm the error is 9.7 %).

Generalized correction functions $F_{1,2}^{(M)}$ for roll-welded profiles which are obtained using the change of inertia moment of the defective and defect-free section are presented in Fig. 3.

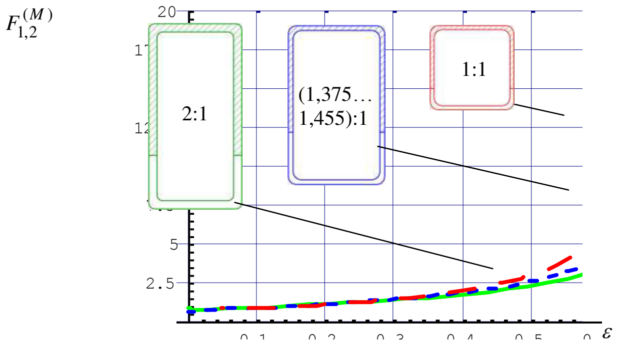


Fig. 3. *Generalized correction functions $F_{1,2}^{(M)}$ for a series of rectangular thin-walled profiles*

For comparison the generalized correction functions $F_{1,2}^{(\sigma)}$ and $F_{1,2}^{(M)}$ for a series of standard rectangular box profiles are given (Fig. 4), which are obtained by two methods: using nominal stresses and using the change of inertia moment of the defective element. The analysis shows that for all three groups of thin-walled roll-welded profiles there is a satisfactory agreement between the correction functions defined by the proposed methods. While $0 < \varepsilon \le 0.6$ the error does not exceed 2% for rectangular profiles with an aspect ratio of 2:1, 4% - with an aspect ratio of (1,375…1,455):1 and 8,5% for square profiles. It should be noted that in all cases $F_{1,2}^{(\sigma)}$ is greater than $F_{1,2}^{(M)}$.

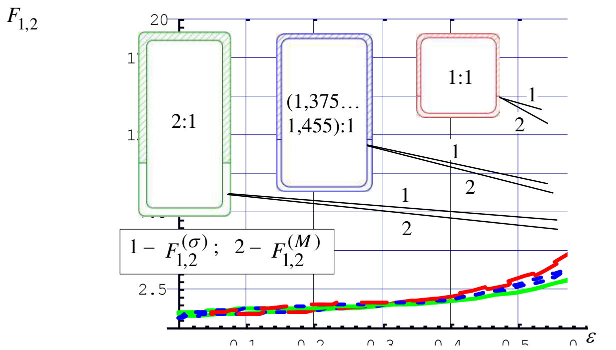


Fig. 4. *Generalized functions $F_{1,2}^{(\sigma)}$ and $F_{1,2}^{(M)}$ for standard roll-welded box profiles with a crack*

The analysis of correction functions shows that it is possible to determine the general correction functions $F_{1,2}^{(\sigma)}$ and $F_{1,2}^{(M)}$ for all assortment of roll-welded closed profiles when $0 < \varepsilon \le 0.4$:

$$F^{(\sigma)} = 0.939 + 3.734\varepsilon - 14.115\varepsilon^2 + 35.856\varepsilon^3 - 21.447\varepsilon^4, \quad (26)$$

$$F^{(M)} = 0.769 + 1.219\varepsilon - 0.047\varepsilon^2 + 18.606\varepsilon^3 - 21.929\varepsilon^4. \quad (27)$$

The correction functions (26) and (27) are substituted into the expressions for determining the SIF (16) and (22), respectively.

To correctly compare the results of the SIF calculation using nominal stresses and using the change of inertia moment with the data of other authors (Fig. 5) we move from the relative parameter ε to the absolute parameter such as the actual crack length L, m. The results of SIF for a square thin-walled pipe 140x140x5 mm with a central crack (Fig. 1, a) for the case of pure bending at the value of initial stresses equal to 109 MPa were compared.

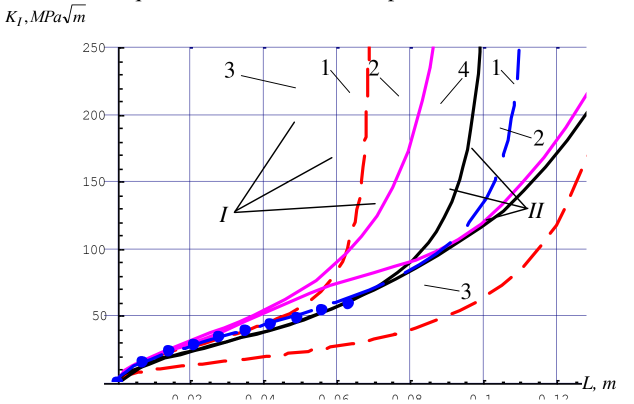


Fig. 5. *Comparison of theoretical and experimental SIF values for central cracks in bars with square section 140 × 140 × 5 mm:*
• • • - FEM data [3]; 1 - calculation using nominal stresses;
2 - calculation using the change of inertia moment;
3 - calculation using [10]; 4 - calculation using [3];
I - the stage of crack development in the horizontal wall;
II – the stage of crack development in the vertical wall.

The discrepancy between the results of the calculation of SIF by different methods was defined as

$$\Delta(K_{I(i)}) = \left| \frac{K_{I(base)} - K_{I(i)}}{K_{I(base)}} \right| \cdot 100\% \qquad (28)$$

where the initial SIF $K_{I(base)}$ is the results of the analytical calculation of SIF for the central crack in the wall of a square thin-walled pipe, obtained in [3].

The results of the calculation of the discrepancy $\Delta(K_{I(i)})$ between the SIF values $K_{I(base)}$ using basic method, SIF values obtained in [1] and by the authors of this article (formulas 16 and 22) for a square thin-walled pipe 140 × 140 × 5 mm are presented in table 1.

Table 1 *- Results of SIF calculation obtained by different methods for a crack in a thin-walled square pipe 140 × 140 × 5 mm*

ε [3]	0.05	0.1	0.15	0.2	0.25	0.3
L, мм	7	14	21	28	35	42
K_I [3]	15.44	22.48	28.39	33.89	39.28	44.74
$K_{I\,exp}$ [3]	15.91	23.14	28.92	33.98	39.04	43.38
$\Delta(K_{I\,exp})$, % [3]	**3,04**	**2,94**	**1,87**	**0,27**	**0,61**	**3,04**
K_I [10]	8.3	11.25	13.53	15.63	17.76	20.02
$\Delta(K_I)$, % [10]	**46,24**	**49,96**	**52,34**	**53,88**	**54,79**	**55,25**
$K_I^{(\sigma)}$	16.64	23.87	30.33	37.52	45.67	54.29
$\Delta(K_I^{(\sigma)})$, %	**7,77**	**6,18**	**6,83**	**10,71**	**16,27**	**21,35**
$K_I^{(M)}$	12.36	19.53	23.73	29.48	34.72	39.35
$\Delta(K_I^{(M)})$, %	**19,95**	**13,12**	**16,41**	**13,01**	**11,61**	**12,05**

Continuation of ***Table 1***

ε [3]	0.35	0.4	0.45	0.5	0.6	0.7
L, мм	49	56	63	70	84	98
K_I [3]	50.44	56.53	63.22	70.79	90.49	125.53
$K_{I\,exp}$ [3]	48.44	54.22	59.28	–	–	–
$\Delta(K_{I\,exp})$, % [3]	**3,97**	**4,09**	**6,23**	–	–	–
K_I [10]	22.52	25.36	28.66	32.55	43.02	59.59
$\Delta(K_I)$, % [10]	**55,35**	**55,14**	**54,67**	**54,02**	**52,46**	**52,53**
$K_I^{(\sigma)}$	62.62	70.06	76.4	81.95	94.18	115.45
$\Delta(K_I^{(\sigma)})$, %	**24,15**	**23,93**	**20,85**	**15,76**	**4,08**	**8,03**
$K_I^{(M)}$	45.34	52.77	60.49	68.53	89.11	113.05
$\Delta(K_I^{(M)})$, %	**10,11**	**6,65**	**4,32**	**3,19**	**1,53**	**9,94**

It should be noted that the engineering calculation of the SIF by formula (16) (nominal stress method) at the initial stage of development of the central crack (when $\varepsilon \le 0.2$) has a good agreement with the basic method. When $0.2 < \varepsilon \le 0.7$ a method based on the change of inertia moments (formula 22) has greater accuracy.

4. Conclusions

Using approximate methods in engineering such as nominal stresses method and method based on the changes of inertia moment in the defective cross-section the correction functions for determining the SIF for the central crack during bending of roll-welded thin-walled closed profiles are determined. The obtained results are compared with known theoretical and experimental data. The obtained results are the basis for further construction of mathematical models for the determination of SIF in corner cracks of roll-welded box profiles.

5. References

1. Longgang Tian, Leiting Dong, Sharada Bhavanam, Nam Phan, S. N. Atluri. Mixed-mode fracture & non-planar fatigue analyses of cracked I-beams, using a 3D SGBEM–FEM Alternating Method / Theoretical and Applied Fracture Mechanics. 74 (1), 2014, p. 188-199.
2. Yue, F.; Wu, Z. Fracture Mechanical Analysis of Thin-Walled Cylindrical Shells with Cracks. Metals 2021, №11, 592, p. 26.
3. Xie, Y.J. & Wang, X.H. & Lin, Y.C. Stress intensity factors for cracked rectangular cross-section thin-walled tubes. Eng. Fract. Mech. V. 71, I. 11 (2004). p. 1501–1513.
4. Dotti, Franco & Cortínez, Víctor (2013). Mode I stress intensity factor for cracked thin-walled open beams. Engineering Fracture Mechanics, 110. p. 249-257.
5. Dotti, Franco & Cortínez, Víctor & Reguera, Florencia (2013). Mode I stress intensity factor for cracked thin-walled composite beams. Theoretical and Applied Fracture Mechanics. Volumes 67–68. p. 38-45.
6. Pawar, Pravin & Ballav, Raj & Kumar, Amaresh (2016). Finite element method analysis of stress intensity factor in I channel section. Journal of Production Engineering, 19. p. 103-107.
7. Álvarez, Morán & Seitl, Stanislav & Miarka, Petr (2020). Numerical study of universal beam (I section) under bending load with crack. / Conference: Engineering Mechanics, p.54-57.
8. Kienzler R., Hermann G. An Elementary Theory of Defective Beams // Acta Mecanica, 1986. V. 62. p. 37-46.
9. Gjelsvik, A. (1981) The Theory of Thin Walled Beams. J. Appl. Mech. Jun 1982, 49(2), p. 248.
10. Андрейкив А.Е., Дарчук А.И. Усталостное разрушение и долговечность конструкций. - К.: Наук. думка, 1992. - 184 с.
11. Jelena M. Djoković, Ružica R. Nikolić, and Jan Bujnak. Working Life of the I-beam with a Crack. Procedia Engineering, vol. 111, 2015. P. 142-148.
12. Механика разрушения и прочность материалов / Под ред. Панасюка В.В. - Т.2: Коэффициенты интенсивности напряжений в телах с трещинами. - К.: Наук. думка, 1988. - 620 с.
13. Справочник по коэффициентам интенсивности напряжений / Под ред. Мураками Ю. – М.: Мир, 1990. – Т. 1, 2. – 1016 с.
14. Пидгурский Н. Прогнозирование и обеспечение усталостной надежности несущих конструкций мобильных машин // Пидгурский Н., Рыбак Т., Сташкив Н., Попович П. / Международнен конгрес «Машиностротелни технологии» International congress "Mechanical engineering technologies'04". Volume 6. Varna, 2004. – С.139–142.
15. Підгурський М., Сташків М. Методи визначення КІН для дефектних елементів відкритого профілю // Вісник ТДТУ, 2006. – Т. 11. - № 2. – С. 92 –108.
16. ДСТУ Б В.2.6-8-95 (ГОСТ 30245-94) Будівельні конструкції. Профілі сталеві гнуті замкнуті зварні квадратні і прямокутні для будівельних конструкцій. Технічні умови. 1995. – 19 с.