DETERMINING THE STRESSES IN A BUCKET KNIFE OF THE SRS 4000 BUCKET WHEEL EXCAVATOR

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ABSTRACT: The stresses in a specific knife of the bucket of the SRS 4000 bucket wheel excavator are examined in this article. The knife is modelled as a broken space frame. It is supported by four point rods and its two ends are fixed. Most of the frame lies in one plane. The load on the teeth of the knife is asymmetric. It is composed of two groups. The first group includes transverse forces and moments lying in the plane of the frame. The second load group is composed of forces lying in the plane and of moments perpendicular to it.

The final stage of the solution to plane and space frame is examined here. The frame is loaded by the first group of load which is significantly higher than the second one. The force method is used to determine the internal forces. In this work, the analytical expressions of coefficients in the basic equations for the method and stresses are given.

The final stage of solution described is illustrated by a numerical example. The values of coefficients in the basic equations of the method, the reactions of supports, the internal moments, and the dimensions of cross sections are calculated for a specific frame.

Key words: bucket knife, broken plane and space frame, stresses in a bucket knife.

ОПРЕДЕЛЯНЕ НАПРЕЖЕНИЯТА В НОЖ НА КОФА ЗА РОТОРЕН БАГЕР SRS 4000

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РЕЗЮМЕ: В статията се изследват напреженията в конкретен нож на кофа за роторен багер SRS 4000. Той е моделиран като начупена пространствена рамка. Тя е подпряна с четири пръта и запъната в двата края. По-голямата част от рамката лежи в една равнина. Натоварването върху зъбите на ножа е несиметрично. То се състои от две групи. Първата група включва напречни сили и моменти, лежащи в равнината на рамката. Втората група натоварване се състои от сили, лежащи в равнината, и моменти, перпендикулярни на нея.

Тук се разглежда заключителен етап на решение на равнинно-пространствена рамка. Тя е натоварена с първата група натоварване, което е значително по-голямо от втората група. За определяне на вътрешните сили се използва силов метод. В работата са дадени аналитичните изрази за коефициентите от основните уравнения на метода и напреженията.

Описаният заключителен етап на решението е илюстриран с числен пример. Стойностите на коефициентите в основните уравнения на метода, реакциите на връзките, вътрешните моменти и размерите на напречните сечения са изчислени за конкретна рамка.

Ключови думи: нож на кофа, начупена равнинно-пространствена рамка, напрежения в нож на кофа.

Introduction

The compartments of a knife on the bucket of the SRS 4000 excavator are studied with the classical method of forces (Dinev et al., 2016b). The computational scheme is chosen. The load on the teeth is composed in two types. The first includes transverse forces and moments lying in the plane part of the frame. In the second kind of load, the forces lie in the plane and the moments are perpendicular to them.

The first kind of load is settled in a manner satisfactory for the spatial broken frame. The two parts of algorithm of determining the stresses are described in Vutcheva et al. (2017, 2018). The numerical results for a specific knife on the bucket are inserted into these articles.

The main purpose of this work is to present the third final part of the algorithm. Using popular program tools, the values of stresses for a real knife will be determined.

Methods

1. Application of the problem

The frame is tilted at two ends (A_*, B_*) and is supported by four rods at points K , I , A_3, and C (Vutcheva et al., 2018) (Fig.1). The load consists of the bending forces (P_i^*) and the torsion moments (M_{yi} , M_{zi} , M_{xi}) applied in points A_i ($i = 1 \div 4$) (Dinev et al., 2016b).

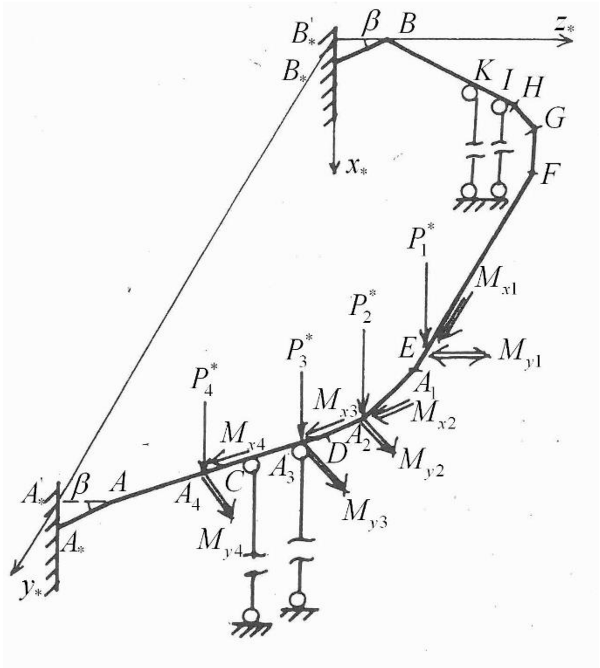

Fig. 1 Computational scheme

2. Internal forces

The frame is broken, planar and spatial. It is undetermined. For determining the reactions in the connections, a force method is used (Kisyov, 1978), (Valkov, 2011).

2.1. Reactions of supports

The reactions at points: B_*, K, I, A_3, and C are extracted and are noted with X_i $(i = 1 \div 7)$.The basic frame is obtained. It is tilted to point A. The basic equations of the method are given by Vutcheva et al. (2017):

$$\sum_{j=1}^{7} \delta_{ij} X_j = \Delta_i^P . \qquad (1)$$

$$\delta_{ij} = \sum_{k=1}^{3} \delta_{ij}^k \; ; \; \Delta_i^P = \sum_{k=1}^{3} \Delta_i^{P,k} \qquad (2)$$

where:

$$\delta_{ij}^1 = \sum_{k=1}^{m} \frac{1}{EJ_{y,k}} \int_0^{l_k} M_{yi} M_{yj} dz \; ;$$

$$\delta_{ij}^2 = \sum_{k=1}^{m} \frac{1}{GJ_{x,k}} \int_0^{l_k} M_{xi} M_{xj} dz \; ;$$

$$\delta_{ij}^3 = \sum_{k=1}^{m} \frac{1}{EJ_{z,k}} \int_0^{l_k} M_{zi} M_{zj} dz \; ;$$

$$\Delta_i^{P,1} = \sum_{k=1}^{m} \frac{1}{EJ_{y,k}} \int_0^{l_k} M_{yi} M_{yi}^P dz \; ;$$

$$\Delta_i^{P,2} = \sum_{k=1}^{m} \frac{1}{GJ_{x,k}} \int_0^{l_k} M_{xi} M_{xi}^P dz \; ;$$

$$\Delta_i^{P,3} = \sum_{k=1}^{m} \frac{1}{EJ_{z,k}} \int_0^{l_k} M_{zi} M_{zi}^P dz \; ;$$

m is the number of sections in frame;

l_k is the length of the section k, m;

M_{yi}, M_{zi} are the bending moments parallel to y and z, by unit of forces or moments, kNm;

M_{xi} is the torsion moment by unit force or moment, kNm;

M_{yi}^P, M_{zi}^P are the bending moments, by external load, parallel to y and z, kNm;

M_{xi}^P is the torsion moment by external load, kNm;

E is the Young’s modulus, MPa;

G is the shear modulus, MPa;

J_{yi}, J_{zi} are the moments of inertia parallel to y and z, m^4;

J_{xi} is the polar moment of inertia, m^4.

To determine the coefficients in (2), the ready tables in Trifonova-Genova et al. (2017) are used.

The system of linear equation (1) is solved with the Gaussian method. It is noted as a method of successful interruption of unknown reactions. The output system is transformed into a system with a triangular form. This process is called the right way. The solution of a new system is called the inverse way (Petrova-Deneva et al., 1977). Thus, the reactions of support are obtained. Using balance equations, the other reactions are determined.

2.2. Diagrams of internal forces

The values of moments in points of frames are obtained by:

$$M_x = M_{x,p}^{**} + \sum_{i=1}^{7} M_{xi} X_i \; ;$$

$$M_y = M_{y,p}^{**} + \sum_{i=1}^{7} M_{yi} X_i \; ; \qquad (3)$$

$$M_z = M_{z,p}^{**} + \sum_{i=1}^{7} M_{zi} X_i$$

In these expressions, $M_{x,P}^{**}$, $M_{y,P}^{**}$, and $M_{z,P}^{**}$ are moments in arbitrary sections by external loads;

M_{xi}, M_{yi}, and M_{zi} are moments by unit forces or moments in such sections.

3. Stresses in theknife

The values of moments in equation (3) allow determining dangerous points in the beam. The equivalent stresses are calculated for them by the third resistance theory:

$$\sigma_{eq,x,j}^{III} = \sqrt{\left(\sigma_{x,j}^{1}\right)^2 + \left(\sigma_{x,j}^{2}\right)^2 + 4\tau_{x,j}^{2}} , \quad (4)$$

where:

$$\sigma_{x,i}^{1} = \frac{\max\left|M_{y,j}\right|}{W_{y,j}} ; \ \sigma_{x,i}^{2} = \frac{\left|M_{z,j}\right|}{W_{z,j}} ; \ \tau_{x,i} = \frac{\left|M_{x,j}\right|}{W_{t,j}} ;$$

$$W_{y,j} = \frac{J_{yj}}{b_j} ; \ W_{z,j} = \frac{J_{zj}}{h} ; \ W_{t,j} = \frac{J_{tj}}{b_j} ; \ j = 1 \div m .$$

The moments of inertia for every section *j* of equation (4) are determined in Dinev et al. (2016b).

4. Numerical example

The frame in Fig. 1 has dimensions and load given in Dinev et al. (2016a). The values of the physical and mechanical characteristics of the cross section and the values of the moments in equation (2) can be seen in Vutcheva et al. (2017; 2018). The coefficients in such equations are given in Table 1 and Table 2:

Table 1. *Coefficients* $\delta_{ij}.10^{-6}$.

δ_{11}	δ_{12}	δ_{13}	δ_{14}
78.79	0.05	0.47	66.17
δ_{15}	δ_{16}	δ_{17}	δ_{22}
63.83	7.05	4.96	0.00
δ_{23}	δ_{24}	δ_{25}	δ_{26}
0.0	-0.05	-0.06	-0.02
δ_{27}	δ_{33}	δ_{34}	δ_{35}
-0.01	0.01	0.43	0.42
δ_{36}	δ_{37}	δ_{44}	δ_{45}
0.04	0.03	63.36	61.25
δ_{46}	δ_{47}	δ_{55}	δ_{56}
7.91	5.24	58.14	7.54
δ_{57}	δ_{66}	δ_{67}	δ_{77}
7.14	1.41	1.26	0.92

Table 2. *Coefficients:* $\Delta_i^P.10^{-6}$.

Δ_1^P	Δ_2^P	Δ_3^P	Δ_4^P
1 333.82	-4.32	8.01	849.73

Δ_5^P	Δ_6^P	Δ_7^P	
1 428.74	303.51	123.84	

After applying Gaussian method, the reactions of supports $B_y, M_{By}, M_{Bx}, K_y, I_y, A_{3y}$, and C_y are obtained and their values are given in Table 3.

Table 3. *Reactions of supports:* X_i .

X_1	X_2	X_3	X_4
257.08	-19 598.64	1 851.02	3.42

X_5	X_6	X_7	
-313.17	-120.34	373.29	

The moments of equation (3) are placed in Table 4:

Table 4. *Moments in frame, kNm.*

point	M_x	M_y	M_z
B_*	-1 851.02	-19 598.64	0
B	-1 851.02	-14 816.87	0
B	-7 505.40	-12 908.14	0
K	-7 505.89	-3 526.14	0
K	-7 758.32	-3 419.85	0
I	-7 478.46	355.94	0
I	-7 492.20	53.75	0
H	-4 492.01	-585.18	0
H	-7 313.77	1 737.49	0
G	-7 270.11	699.06	0
G	-5 839.15	4 471.13	0
F	-5 296.65	1 980.48	0
F	-3 103.48	903.42	0
A_1	-4 355.88	1 651.84	0
A_1	-4 197.28	1 639.75	0
E	-4 357.36	2 350.18	0
E	-3 611.71	2 919.15	0
A_2	-3 699.36	2 057.63	0
A_2	1 849.52	3 882.96	0
D	119.80	980.83	0
D	601.79	5 325.72	0
A_3	-783.02	5 359.52	0
A_3	-777.60	4 312.47	0
C	-880.59	4 058.33	0
C	-1053.87	3 385.80	0
A_4	-823.22	7 478.35	0
A_4	-570.59	8 095.59	0
A	-755.19	14 710.69	0
A	4 704.54	23 634.07	3 869.08
A_*	4 888.57	20 087.56	3 948.84

The sections are four kinds (m=4).

The widths and the resistance moments in such kind of (4) can be seen in Table 5:

Table 5. *Resistance moments*

i	b_i	W_{y_i}	W_{z_i}	W_{t_i}

		10^{-6}	10^{-6}	10^{-6}
dimensions	mm	m^3	m^3	m^3
1	448	268.8	2 007.04	207 246.69
2	438	262.8	1 918.44	186 821.50
3	429	257.4	1 840.41	175 978.76
4	456	273.6	2 070.36	218 846.40

The equivalent stresses in equation (4) are calculated in a section with a maximum bending moment. These stresses are greater than the admissible stress. This means that the width h=60mm of the cross section in insufficient. Then, for three earlier sections is selected h=105mm and for four sections – h=131mm. In that case, the analogous stresses are 178 MPa and 183 MPa.

4. Key findings

The algorithm described is applied for solving the sizes of the cross section in a specific planar and spatial frame. This is a generalisation of a known solution for a frame with a rectangular form in the plane.

The presented solution is for the load on the frame which includes transverse forces and moments lying in the plane.

Conclusion

The method for determining the stress state in a bucket knife is presented in this article. It includes a choice of computational scheme, the load on the teeth, and a method of solution (Dinev et al., 2016a). The computational scheme is in the form of a broken spatial frame. The load on the teeth is asymmetric and spatial. The space task is decomposed into two tasks: the planar and-spatial, and the planar. The former task is described in two earlier articles (Vutsheva et al., 2017; 2018) and in the present article. The latter task will be presented in a future work.

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