EXPANDING THE FUNCTIONAL ABILITIES OF MECHANICS ADD-IN FOR MS EXCEL WITH EXAMPLES IN THE FIELD OF STATICS

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ABSTRACT. MS Excel is one of the most popular products for storing, processing and visualising data in a tabular form. Apart from the wide range of around 500 in-built functions, MS Excel provides the opportunity for creating custom tools, which can be used for solving engineering tasks. This article presents the developed additional functions and macros to the Mechanics add-in. A planar and a space truss task have been solved numerically, as well as a sizing task of bodies with different Young's modulus in tension-compression.

Keywords: MS Excel, modelling, add-in, bar truss, Young's modulus

РАЗШИРЯВАНЕ ФУНКЦИОНАЛНИТЕ ВЪЗМОЖНОСТИ НА ADD-IN MECHANICS ЗА MS EXCEL С ПРИМЕРИ ОТ ОБЛАСТТА НА СТАТИКАТА

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РЕЗЮМЕ. MS Excel е един от най-популярните продукти за съхраняване, обработка и графично представяне на информация в табличен вид. Освен богатият набор от около 500 вградени функции, MS Excel дава възможност за създаване на потребителски инструменти, които могат да се използват при решаване на инженерни задачи. Настоящата статия представя разработените допълнителни функции и макроси към add-ins Mechanics. Числено са решени равнинна и пространствена задачи от статика на ставно-прътови конструкции, както и задача за оразмеряване на тела с различни модули на опън и натиск.

Ключови думи: MS Excel, моделиране, add-in, ставно-прътови конструкции, модул на Юнг

Introduction

MS Excel is one of the most popular products for storing, processing and visualising data in a tabular form. With its wide range of around 500 in-built functions as well as plenty of add-ins, MS Excel provides opportunities for solving a variety of engineering tasks. However, it does not have in-built modules for direct solving of tasks from the field of statics. Because of the widespread use of MS Excel, including in the field of teaching, two years ago add-in Mechanics was developed (Trifonova, 2017). It can be used for modelling some types of mechanical constructions. This module was developed in the Visual Basic for Application language and can be applied for solving some tasks of the mechanics curriculum.

The current article has the purpose of supplementing the add-in Mechanics with examples about the statics of a space truss, as well as an example about the sizing of bodies with different Young's modulus in tension-compression.

Engineering tasks

Space truss

A space truss is a construction of rods which are considered weightless. Load force is only applied on the joints so the *method of joints* can be used to solve for the unknown forces acting on members of a truss. When the whole construction is in equilibrium any isolated joint is in equilibrium as well. For each isolated joint, all forces acting on it are typed in, so that equilibrium equations for each joint can be written out:

$$\sum_{i=1}^{n} X_i = 0\,;\sum_{i=1}^{n} Y_i = 0\,;\sum_{i=1}^{n} Z_i = 0\,. \qquad (1)$$

Force components

For determining the equilibrium equations, two types of expressions are used: for a rod lying in the XZ plane and for a rod lying in the plane described by the rectangle OO_1B_1B in a cuboid with side lengths a, b and c. (Fig.1).

For rods lying in the XZ plane of the cuboid in Figure 1, the angle α_1 is the angle between the X-axis and the rod. Accordingly, the following expressions are valid for the components of the S_1-rod:

$$S_{2x} = S_2 \cos\alpha_2 \cos\beta,\ S_{2y} = S_2 \cos\alpha_2 \sin\beta$$
$$S_{2z} = S_2 \sin\alpha_2 \qquad (2)$$

where

$$\cos\alpha_1 = \frac{a}{\sqrt{a^2+c^2}}\,;\ \sin\alpha_1 = \frac{c}{\sqrt{a^2+c^2}}\,.$$

The equations are similar for a rod lying in the YZ-plane.

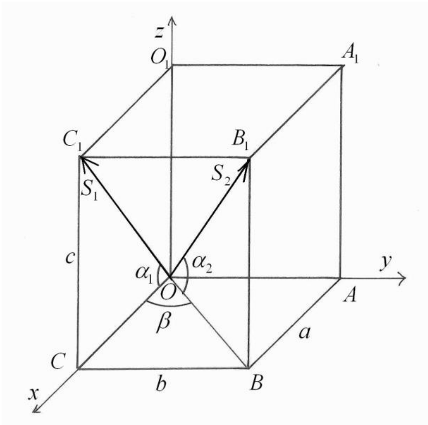

Fig. 1. Forces on the rods *S1* and *S2*

When the rod lies in the OO_1B_1B-plane of the cuboid, *double projection* is applied. Then, the force components are described as follows:

$$S_{2x} = S_2 \cos\alpha_2 \cos\beta,\ S_{2y} = S_2 \cos\alpha_2 \sin\beta$$
$$S_{2z} = S_2 \sin\alpha_2 \quad (3)$$

where

$$\cos\alpha_2 = \frac{\sqrt{a^2+b^2}}{\sqrt{a^2+b^2+c^2}};\sin\alpha_2 = \frac{c}{\sqrt{a^2+b^2+c^2}};$$
$$\sin\beta = \frac{b}{\sqrt{a^2+b^2}};\cos\beta = \frac{a}{\sqrt{a^2+b^2}}.$$

Here α_2 is the angle between the S_2-rod and the XY-plane, and β is the angle between the rod's projection on the XY-plane and the X-axis. The expressions (3) are also valid, if the rod lies in the AA_1C_1C-plane of the cuboid.

Analogous equations (2) are applied in (Stoyanov, 2012), and similar to equations (3) – in (Stoyanov, 2016). In these studies the matrix form of the equations is presented.

This method can be applied for teaching students at technical universities.

Algorithm for solving space and plane truss tasks

The classic algorithm for solving statically determined space and plane truss tasks goes as follows (Bachvarov et al., 1990):

- The joints of the described truss are analysed.
- Expressions (2) or (3) are applied for determining the components of the forces in the rods as well as for solving for the external reacting forces acting on the truss structure.
- The equilibrium equations (1) are written out in their analytical form for every joint.
- If there are multiple forces acting on a single joint, the forces need to be added in order to determine the equilibrium equations of the net force in the joint.
- The equilibrium equations with the components of the force in each joint are written out in a matrix form and solved.
- Through solving the matrix equation the unknown forces in the rods and supports are calculated.

The current article uses the matrix method suggested by (Stoyanov, 2012; 2016) rather than the classic one.

Dimensions of the cross section of bodies

Apart from truss constructions, expressions (2) and (3) can be applied on reduction of a force system and for equilibrium of a rigid body (Bachvarov et al., 1990). In order for the body to be in equilibrium, the net force vector and the net moment vector of the system of active (external) forces and reactions on the rigid body have to equal zero. After determining the external forces for every part of the body, the equations for the internal forces are written out. These forces are used for determining the tensions and the dimensions of the cross section of the body.

In most cases, real bodies are modelled as homogeneous and isotropic with identical Young's modulus. There are materials for which the Young's modulus is significantly different for tensile and for compressive forces. Therefore, analytical expressions for the stresses are developed, according to the art of the force: concentrated moment (Trifonova-Genova, 2014) and concentrated force (Trifonova-Genova, 2019). These stresses aren't equal in the zones of tension and compression. This requires a description of the stages that pass to determine the cross-sectional dimensions.

Algorithm for determining the dimension of the cross section of the body with different Young's Modulus in tension-compression

- The maximum moment, the admissible stresses of tension and compression, the Young's modulus of tension and compression and the relationship between the height and width of the cross section of the beam are set;
- The mean value of the admissible stress that corresponds to the material with the identical modulus in tension and compression is calculated;
- From the strength condition, the width is selected and the height of the cross section is determined;
- The height of the tensile zone is calculated by the stress equation in both zones (Trifonova-Genova, 2014);
- The moments of inertia are determined and the maximum values of the stresses in the two zones are calculated;
- The resulting maximum stresses are compared to the permitted tensile and compressive stresses. If they are smaller than the permissible stresses, then the section sizes are final;
- If the maximum stresses are greater than the permissible ones, the width should be increased and the height needs to be calculated. Go to *determine the height of the tensile zone.*

Numerical examples

The added functionality in add-in Mechanics is expressed by adding three macros: Truss2, Truss3 и Beam. The purpose of the first two is solving plane and space truss tasks, respectively. The third macro is used for calculating the size of bodies with different Young's modulus for tensile and compressive stress.

In order to better illustrate the work with the three macros, three example tasks have been solved.

A. Truss2

First, the following data have to be entered in a new sheet in MS Excel, starting from cell A1 and using different lines:

- Number of joints;
- For each joint in one line type in 3 values: x and y-coordinates of the joint as well as 0 or 1 depending on whether it is a support (0) or not (1);
- Number of rods;
- For each rod in one line type in 2 values, which are the numbers of the joints on both sides of the rod;
- Number of forces;
- For each force type in 3 values: number of the joint in which the force is applied and the projections of the force on the axes.

On Figure 2 a part of the input data for Truss2 is given. The values correspond to the example in Figure 3, which is borrowed from Stoyanov (2012).

	A	B	C
1	7		
2	0	0	0
3	3	5	1
4	6	0	1
5	9	6	1
6	12	0	1
7	15	6	1
8	18	0	0
9	11		
10	1	2	
21	3		
22	2	8	-50
23	4	0	-70
24	6	0	-90

Fig. 2. Part of the input data for Truss2

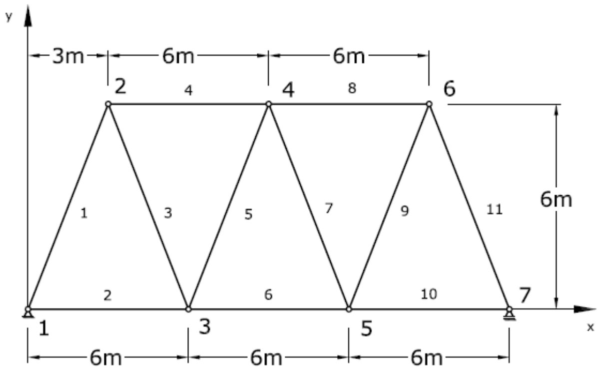

Fig. 3. A plane truss

Solving the task involves generating and solving a matrix equation of the type

$$A \cdot X = B, \tag{4}$$

where matrix A and the column vector B are generated automatically from the input data of the task. The column vector B contains the projections of the external forces and the matrix A results from the incidence matrix of the construction (Stoyanov, 2012).

Apart from visualising the resulting column vector X, the programme can also visualise the values of the elements of A and B from (4), if the user wants to track and check the solution.

Figure 4 shows the resulting values of the solution. The values of the stresses in the rods are within the range E1:E11, and the values of the elements of the matrices A and B are given in ranges G1:Q11 and S1:S11, which the programme calculates in the process of solving the task.

	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	-99.5526		-0.447	0	0.447	1	0	0	0	0	0	0	0		-8
2	52.5000		-0.894	0	-0.894	0	0	0	0	0	0	0	0		50
3	43.6242		0	-1	-0.447	0	0.447	1	0	0	0	0	0		0
4	-72.0000		0	0	0.894	0	0.894	0	0	0	0	0	0		0
5	-43.6242		0	0	0	-1	-0.447	0	0.447	1	0	0	0		0
6	91.5000		0	0	0	0	-0.894	0	-0.894	0	0	0	0		70
7	-34.6756		0	0	0	0	0	-1	-0.447	0	0.447	1	0		0
8	-76.0000		0	0	0	0	0	0	0.894	0	0.894	0	0		0
9	34.6756		0	0	0	0	0	0	0	-1	-0.447	0	0.447		0
10	60.5000		0	0	0	0	0	0	0	0	-0.894	0	-0.894		90
11	-135.3468		0	0	0	0	0	0	0	0	0	-1	-0.447		0

Fig. 4. Solution of the task in Fig. 3, calculated with macro Truss2

B. Truss3

The input data is entered the same way as in Truss2.

The macro is tested with the example shown in Figure 5, which is borrowed from Stoyanov (2016).

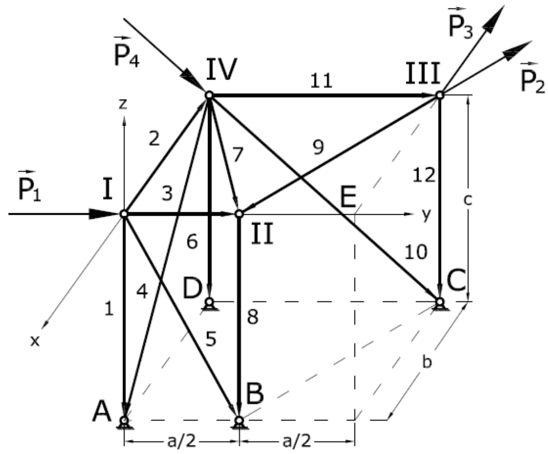

Fig. 5. A space truss

As a result of the calculations, the following values are generated (the transposed vector X is shown).

1	201.207	9.092E-15	43.836	94.833	-217.975	-95.572	-81.893	0	51.893	-24.068	-13.889	0

C. Beam

The geometry of the structure for the third example is shown in Figure 6.

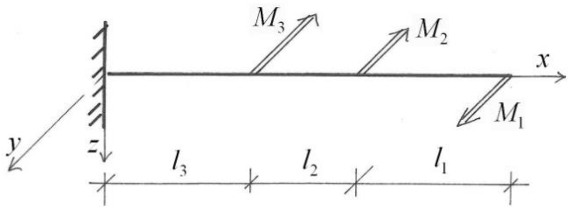

Fig. 6. The cantilever beam

In order for the macro to work, the following values are typed in the first line in a new sheet in MS Excel:

- Maximum moment as an algebraic sum of the given moments;

- Permissible tensile stress and permissible compression stress;
- Young's modulus for tension and for compression;
- Ratio height to width of the cross section;

For this example, the following values have been entered:

	A	B	C	D	E	F
1	10	160	240	9.327E+04	1.2436E+05	1.5

The results from the above shown data are as follows:

- Maximum tensile stress: σ_τ = 160 MPa;
- Maximum compression stress: σ_c = 179.5 MPa;

This result took three iterations to calculate.

As seen from the results, the distribution of the normal stresses is not symmetrical.

Conclusion

Advantages of solving the given tasks using add-in Mechanics:

- The time consuming process of solving a system of equations is overcome;
- In contrast to the manual solution, no joint with two unknown forces in the rods has to be chosen;
- The possibility of making mistakes in the calculations is eliminated;

The advantages of using computer calculations become clearer when analysing trusses with multiple rods and many forces in the joints, or when multiple iterations are needed for calculating the stress in cross sections.

In order to properly work with add-in Mechanics, no special knowledge about MS Excel is needed. Basic skills in working with the product, which are taught at school, are sufficient.

The developed programme can be used for teaching as part of the mechanics curriculum.

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