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STATIC ANALYSIS OF RECTANGULAR PLATES

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ARTICLE INFO	ABSTRACT
Article history: Received: 2024-11-26 Received in revised form: 2024-11-26 Accepted: 2024-12-03 Available online *Keywords: Von-Mises stress, deflection, strain, safety factor, plate*	*In the article, a static analysis of plates made of AISI 1020 steel with different cross-sectional dimensions was performed. The cross-sectional dimensions of the plates are 300x150x15 and 400x200x15 mm, respectively. 3D solid models of the plates were drawn in the Solidworks program. A static analysis of the plates was performed using the Solidworks simulation application. The plates were rigidly fixed on both sides (Fixed Geometry fastening type was selected), and a load of 100,000 N was applied along the surface. A fine mesh of 2.46 mm and 0.43 mm was selected for the plates. As a result of the static analysis, the values of Von-Mises stress, strain, deformation and safety factor distributed along the surface of the plates were obtained. The obtained results were analyzed. The plates showed a difference of 6% in stress, 43% in deflection, 2% in strain, and 44% in safety factor.*

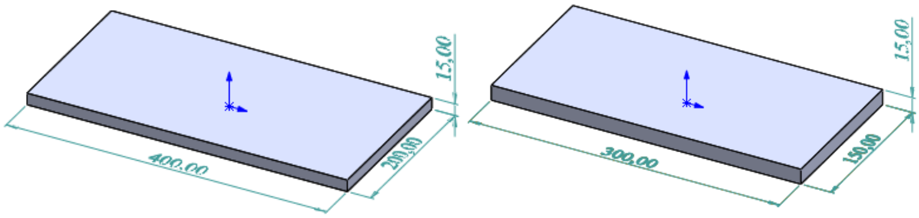
5. Introduction

Plates are considered to be metal construction parts whose thickness is very small compared to other dimensions. Plates are widely used in various types of engineering structures. Some examples are parts in vehicles (cars, airplanes, helicopters, armored vehicles, buses, railway vehicles, etc.), rocket and missile systems, modern bridges, dam and canal covers. In addition, plates are even parts used in very high-tech space and aviation industries.

Plates can be analyzed by the equations of elasticity theory. The exact solution of the differential equations of some plates can be obtained only under certain boundary and loading conditions. With the development of computer technology, numerical solution methods have become widespread. There are methods such as finite difference, boundary element and finite elements for solving plate problems. Among the numerical solution methods, the finite element method is used more than other methods. Examples of analytical methods include the Navier and Levy methods [1-3].

The static analysis of an isotropic rectangular plate is given in [4]. Here, the optimal values of the plate thickness are obtained for various boundary conditions and load values. E. Reissner developed a plate theory that takes into account the deformations caused by shear forces [5]. The problems of rectangular plates simply supported on two opposite sides and free on the other side were solved by Levy [2- 11].

The purpose of plate theory is to calculate static and dynamic parameters such as stress, deformation and vibration in a plate under no load or under load. Thus, it is possible to obtain the static load-bearing properties of a plate. Reducing the weight of the structural parts used and increasing the operational efficiency are important problems facing engineers. For this purpose, accurate engineering reports are of great importance. In the presented article, a static analysis of plates with different cross-sectional dimensions was carried out using the finite element method using Solidworks simulation (Figure 1).



N1 N2

Fig. 1 Plates with different cross-sectional dimensions.

According to the applied load value, the Von-Mises stress, total deflection and deformation, distributed values of stress, deflection and deformation along the x, y, z axes, and safety factor were obtained. The results of the static analysis are presented in the form of tables and graphs.

2. Materials and methods

2.1. Design of boards and selection of materials

The dimensions of the boards used in the article are as follows:

Plates 1 (N1): Length L=400mm; width b=200mm; thickness d=15mm.

Plates 2 (N2): Length L=300mm; width b=150mm; thickness d=15mm.

The boards were drawn using the design application Solidworks. For this, a 2D drawing of the boards was first drawn, then converted into a 3D solid model (Figure 2).

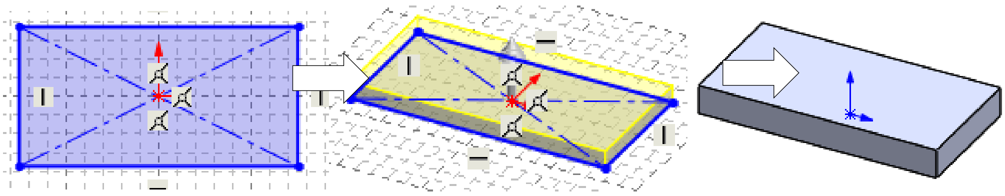


Fig. 2 Steps for drawing a 3D solid model of a plate.

It is assumed that the plates are made of AISI 1020 steel (St20 according to GOST). AISI 1020 steel has the following mechanical properties:

Modulus of elasticity: 200000N/mm2;

Poisson's ratio: 0.29;

Modulus of elasticity in shear: 77000N/mm2;

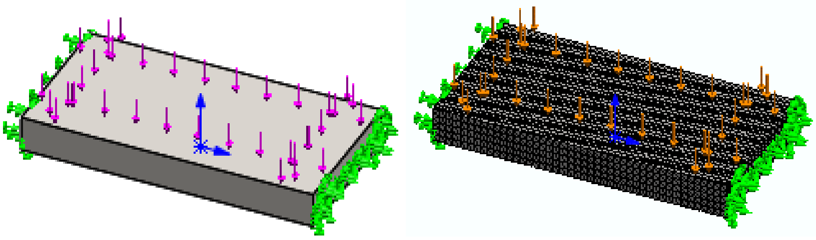
Density: 7900kg/m3;

Strength limit: 420.507N/mm2;

Yield limit: 351.571N/mm2.

2.2. Static analysis of the plate

In this paper, the simulation application in Solidworks was used to analyze the bending behavior of the plates under static load. Both sides of the plates were fixed ("Fixed Geometry"). A force of 100000N was applied to the other top surface. Isotropic AISI 1020 steel material was selected from the model library as the material. Mesh is one of the main elements of the simulation process in finite element analysis (FEA). Mesh plays an important role in the engineering simulation process. Creating a high-quality mesh is one of the most important factors to be considered to ensure the accuracy of the simulation. A fine-grained mesh was selected. The mesh parameters are 2.86mm and 0.143mm (Figure 3).

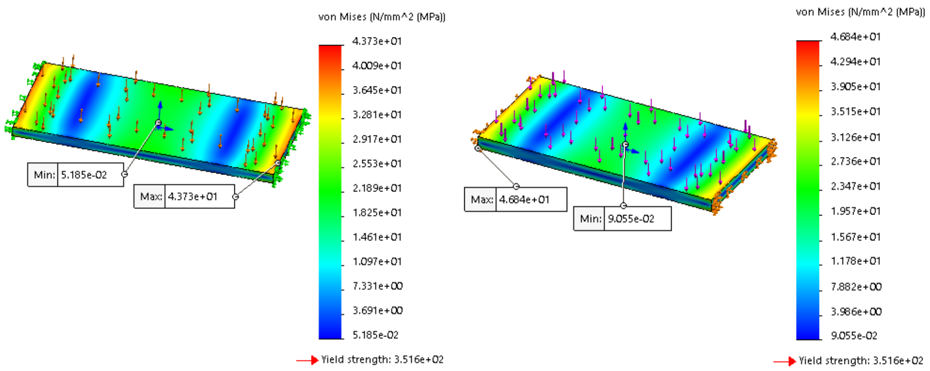


a) b)

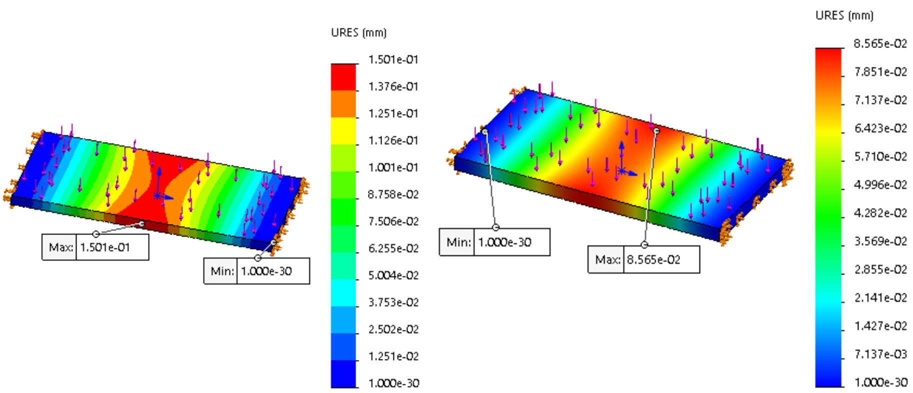
Fig. 3 Static analysis of a plate using the finite element method.

a) boundary conditions, b) application of the mesh property.

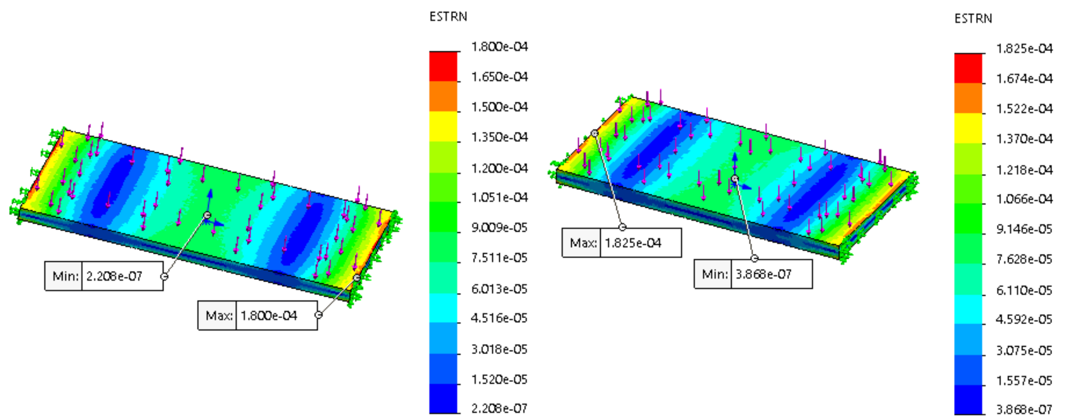
In the analysis, the maximum Von-Mises, normal stresses, maximum deflection and relative deformation safety factors were obtained. The values of the mentioned parameters distributed over the plate model are given in Figure 4.



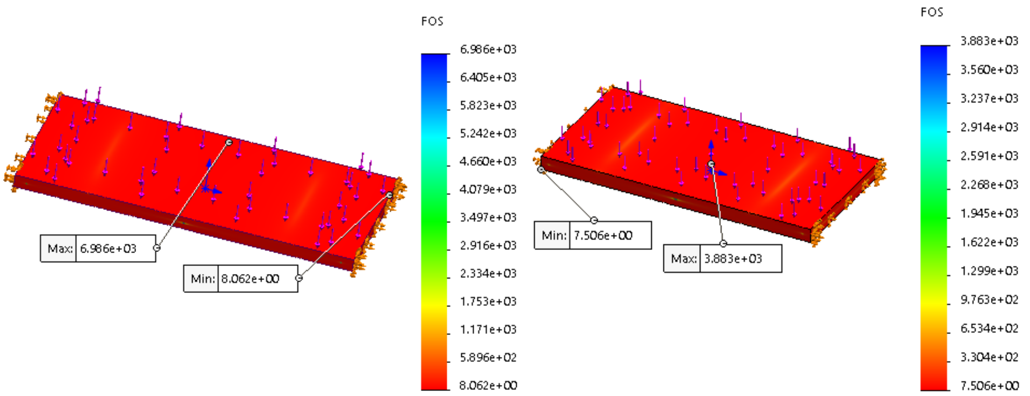
N1 N2 a)



N1 N2 b)



N1 N2 c)



N1 N2 d)

Fig. 4 Values obtained as a result of static analysis: a) Distributed values of von Mises stress; b) Distributed values of yield; c) Distributed values of deformation; d) Distributed values of safety factor.

3. Static analysis results

The values obtained as a result of static loading of two different plates are given in Table 1 and Figure 4. It is a theory that states that failure will occur as a result of triaxial stress. It was developed by Richard Von-Mises. The Von-Mises stress is calculated by the following expression:

$$\sigma_{von-Mises} = \sqrt{\frac{1}{2}\left[\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_x - \sigma_z\right)^2 + \left(\sigma_y - \sigma_z\right)^2\right] + 3\left(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2\right)} \quad (1)$$

Here σ_x, σ_y və σ_z – are the normal stresses along the corresponding axes, and τ_{xy}, τ_{yz} və τ_{zx} – are the tangential stresses.

The maximum and minimum Von-Mises stresses in the plates subjected to bending were observed in sample 1. These values were 43,73N/mm^2 and 0,05 N/mm^2, respectively. In plate N2, they ranged from 46.84N/mm^2 to 0.09 N/mm^2. Sample 2 had the maximum stress value. The difference between the stress values in plates N1 and N2 was 6%.

In plate N1, the stress values along the x axis were 56.18N/mm^2 and 9,29 N/mm^2, along the y axis were 22,95N/mm^2 and 3,79N/mm^2, and along the z axis were 22,95N/mm^2 and 3,79 N/mm^2.

The stress values along the x-axis in plate N2 were 60.19N/mm^2 and 0.132N/mm^2, along the y-axis 25,28N/mm^2 and 0,05N/mm^2, and along the z-axis 25,28N/mm^2 and 4,26 N/mm^2. The maximum stress difference between plates N1 and N2 was 7% along the x-axis and 9% along the y and z axes.

Table 1. Values of von Mises stress and normal stress obtained along the corresponding axes (x, y, z).

Won mises stress, N/mm^2		Normal stress, N/mm^2					
		X-axis		Y-axis		Z-axis	
№1	№2	№1	№2	№1	№2	№1	№2
43,73	46,84	56,18	60,19	22,95	25,28	22,95	25,28
40,09	42,94	46,80	51,61	19,12	21,08	19,12	21,08
36,45	39,05	37,42	41,31	15,29	16,87	15,29	16,87
32,81	35,15	28,05	31,02	11,46	12,67	11,46	12,67
29,17	31,26	18,67	20,72	7,62	8,46	7,62	84,64
25,53	27,36	9,29	10,43	3,79	4,26	3,79	4,26
21,89	23,47	-0,08	0,132	-0,03	0,05	-0,035	0,05
18,25	19,57	-9,45	-10,16	-3,86	-4,15	-3,86	-4,15
14,61	15,67	-18,84	-20,46	-7,69	-8,35	-7,69	-8,35
10,97	11,78	-28,21	-30,75	-11,52	-12,56	-11,52	-12,56
7,331	7,88	-37,59	-41,05	-15,35	-16,77	-15,35	-16,77
3,691	3,98	-46,97	-51,34	-19,18	-20,97	-19,18	-20,97
0,05	0,09	-56,34	-61,64	-23,01	-25,18	-23,01	-25,18

The values of the wear along the surface of the N1 and N2 plates are given in Table 2 and Figure 2b. The total wear value varied between 0.15mm and 1x10-30 on the N1 plate. On the N2 plate, it was between 0.085mm and 1x10-30. As can be seen, the wear value on the N1 and N2 plates was 43% higher than that on the N2 plate.

The maximum values of the deflection in plate N1 were 0,0085mm on the x axis, 0,0001mm on the y axis, and 0,0020mm on the z axis. In plate N2, they were 0,0064mm, 0,00008mm, and 0,0015mm, respectively. The maximum deflection difference was observed on the x axis. This difference was 0,0021mm.

The values of the distribution of the relative deformation values along the surface of the plates are given in Figure 5c. The total deformation values were in the range of 1,8x10-4 and 0,0022x10-4 for plate N1, and 1,82x10-4 and 0,0038x10-4 for plate N2. The total deformation difference between the plates is 2%. In plate N1, the maximum deformation was 2,17x10-4 along the x axis, 8,3x10-5 along the y axis, and 5,23x10-5 along the z axis. In plate N2, it was 2,18x10-4, 8,20x10-5, and 4,66x10-5, respectively. The deformation difference between the plates was 10% along the z axis.

The distribution of the safety factor values is given in Figure 3d. The safety factor is calculated as the ratio of the ultimate stress to the applied working stress for brittle materials.

$$n = \frac{\sigma_h}{\sigma} \quad (2)$$

Here $n -$ is the safety factor, $\sigma_h -$ is the ultimate stress, and $\sigma -$ is the applied stress.

For plastic materials, it is calculated as the ratio of the yield strength to the applied stress.

Table 2. Values of total deflection and deflection along the corresponding axes (x, y, z).

Total deflection, mm		Deflection, mm					
		X axis		Y axis		Z axis	
№1	№2	№1	№2	№1	№2	№1	№2
0,15	0,085	0,0085	0,0064	0,0001	0,00008	0,0020	0,0015
0,14	0,078	0,0071	0,0053	-0,0124	-0,0070	0,0017	0,0013
0,12	0,071	0,0056	0,0042	-0,0249	-0,0142	0,0013	0,0010
0,11	0,064	0,0042	0,0032	-0,0374	-0,0215	0,0010	0,0008
0,10	0,057	0,0028	0,0021	-0,0499	-0,0285	0,0007	0,0005
0,087	0,050	0,0014	0,0010	-0,0624	-0,0356	0,0003	0,0003
0,075	0,042	$1{,}6x10^{-7}$	$1{,}22x10^{-7}$	-0,0750	-0,0427	$3{,}4x10^{-7}$	$-8{,}85x10^{-8}$
0,062	0,035	-0,0014	-0,0010	-0,0875	-0,0450	-0,0003	-0,0003
0,050	0,028	-0,0028	-0,0021	-0,1000	-0,0570	-0,0007	-0,0005
0,037	0,021	-0,0042	-0,0031	-0,1126	-0,0641	-0,0010	-0,0008
0,025	0,014	-0,0056	-0,0042	-0,1251	-0,0713	-0,0013	-0,0010
0,125	0,007	-0,0071	-0,0053	-0,1376	-0,0780	-0,0017	-0,0013
$1x10^{-30}$	$1x10^{-30}$	-0,0085	-0,0063	-0,1501	-0,0856	-0,0020	-0,0015

Təhlükəsizlik əmsalının qiyməti konstruksiya hissələrinin istismar vəziyyətinə görə dəyişir. Bu əmsal konstrukiya hissələrinin normal şəraitdə lazım olduğundan daha möhkəm, dayanıqlı olması üçün nəzərdə tutulub. Bu, onların fövqəladə hallar, əlavə yüklər, həddən artıq istifadə və ya köhnəlmə nəticəsində yaranan deqradasiya kimi ekstremal şəraitdə belə işləməyə davam etmə ehtimalını artırır. Cari istifadə üçün əlavə təhlükəsizliyi təmin etməklə konstruksiya hissələrinin funksionallığını qoruyur. Əmlakın, işçilərin və maşınların zədələnməsinin qarşısını alır. Məmuldan istifadə zamanı baş verə biləcək gözlənilməz risklərdən müdafiəni təmin edir. Məmulun sıradan çıxma ehtimalını azaldır. Təhlükəzilik əmsalı nə qədər çox olarsa məmul və ya konstruksiya hissəsi bi o qədər təhlükəsiz hesab olunur. N1 lövhəsi üçün təhlükəzislik əmsalının qiyməti 6986 və 8, N2 lövhəsi üçün isə 3883 və 7,5 aralığında dəyişir. Tətbiq olunan qüvvəyə görə təhlükəszlik əmsalları arasında 44% fərq var.

4. Conclusions and Discussions

The ranges of stress, deflection, strain and safety factor values were determined for two plates with different cross-sectional dimensions. For both plates, the maximum value of Von-Mises stress was obtained at the attachment surfaces of the plates, and the minimum values were obtained at the center point.

As the area of the plates increased, a decrease in stresses was observed. A 6% increase in stress was observed for a change in the area of 525000mm2.

The maximum value of deflection was observed at the center of both plates. The deflection value decreased equally from the center of the plates to the edges. The deflection value decreased proportionally with the decrease in the area of the plate. The deflection value decreased by 43%, corresponding to a 44% decrease in the area.

The maximum values of deformation were obtained at points close to the attachment surfaces of the plates, and the minimum values were obtained at the center. An equal distribution of deformation was observed in the tension and compression regions.

The maximum value of the safety factor was at the center of the plates, and the minimum value was at the attachment points. The value of the safety factor decreased with increasing area. Thus, for a 44% increase in area, the safety factor decreased by 44%.

The results obtained in the article can be used in the stability reports of plates used in various fields.

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