

COSMOS DESIGN STAR STUDY: THE TENSILE TESTS OF THE RECTANGULAR PLATE WITH STRESS CONCENTRATORS

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SUMMARY

The present paper analyse the tensile of the rectangular plate with stress concentrator, using the finite element software Cosmos Design Star [1], for different versions of the concentrators and plate modelling, respective: Solid Model, 2D Planar Model and Shell Model.

1. INTRODUCTION

The analyse will be made for a steel rectangular plate with Modulus of Elasticity $E=2.1 \times 10^5$ MPa, Poisson's Ratio $\nu=0.3$ and geometrical dimensions: height $h=40$ mm, width $b=6$ mm and length $l=100$ mm, figure no. 1; the axial force $P=6,000$ N is applied, for the following cases study:

- the plate analyse without concentrators – Solid Model;
- the plate analyse with concentrator in section 1 – Solid Model
- the plate analyse with concentrator in section 2 – Solid Model
- the plate analyse with concentrators in section 1 and 2 – Solid Model, 2D Planar Model and Shell Model.

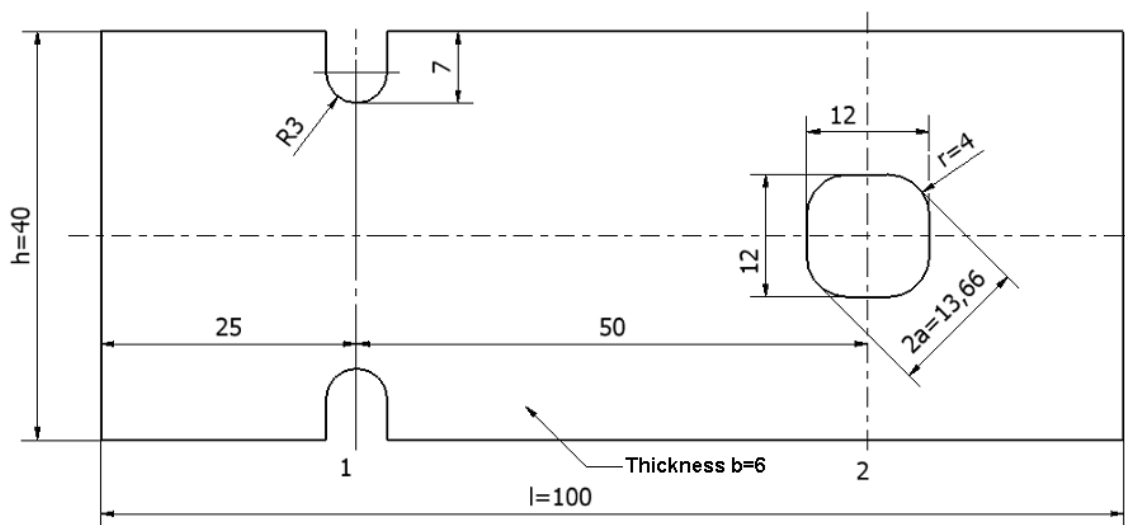


Figure no. 1. The plate and concentrators geometrical dimensions

2. THE STUDIES OBJECTIVES

Every study has the following objectives:

- to import in Cosmos Design Star the geometry generated in Autodesk Inventor [2];
- to generate a new linear stress analysis study;
- to select the material from Cosmos library;
- to apply the external loads and restraints;
- to mesh the model into finite elements;
- the study calculus;
- to visualize and interpret the results.

3. THEORETICAL CONSIDERATIONS

For the plate without concentrators the maximal stress and elongations formulas of the plate are:

$$\sigma = \frac{P}{A} = \frac{6000}{240} = 25 \text{ MPa} \quad [1]$$

$$\Delta l = \frac{P \cdot l}{E \cdot A} = \frac{6000 \cdot 100}{2.1 \cdot 10^5 \cdot 240} = 0.0119 \text{ mm} \quad [2]$$

where: $A = h \cdot b = 240 \text{ mm}^2$ is the transversal area of the plate.

For the plate with concentrator no. 1, the maximal stress and elongations formulas are:

$$\sigma_{n1} = \frac{P}{A_1} = \frac{P}{(h - 2 \cdot 7) \cdot b} = \frac{6000}{(40 - 2 \cdot 7) \cdot 6} = 38.46 \text{ MPa} \quad [3]$$

$$\sigma_{\max 1} = \alpha_{k1} \cdot \sigma_{n1} = 2.5 \cdot 38.46 = 96.15 \text{ MPa} \quad [4]$$

where: $A_1 = (h - 2 \cdot 7) \cdot b = 156 \text{ mm}^2$ is the transversal area of the plate in section 1 and $\alpha_{k1} = 2.5$ is concentrator coefficient for section 1.

For the plate with concentrator no. 2, the maximal stress and elongations formulas are:

$$\sigma_{n2} = \frac{P}{A_2} = \frac{P}{(h - 12) \cdot b} = \frac{6000}{(40 - 12) \cdot 6} = 35.71 \text{ MPa} \quad [5]$$

$$\alpha_{k2} = 1 + 2 \cdot \sqrt{\frac{a}{r}} = 1 + 2 \cdot \sqrt{\frac{4 + 2\sqrt{2}}{4}} = 3.613 \text{ mm} \quad [6]$$

$$\sigma_{\max 2} = \alpha_{k2} \cdot \sigma_{n2} = 3.613 \cdot 35.71 = 129 \text{ MPa} \quad [7]$$

where: $A_2 = (h - 12) \cdot b = 168 \text{ mm}^2$ is the transversal area of the plate in section 2 and $\alpha_{k2} = 3.613$ is concentrator coefficient for section 2.

4. THE GEOMETRY IMPORT IN COSMOS DESIGN STAR

After building the model in a CAD system and generating the proper file, the model will be imported into Design Star, where studies will be created, solve them, and visualize the results.

5. GENERATE A NEW LINEAR STRESS ANALYSIS STUDY

For a given geometry it is possible to generate multiple design studies. Design Studies offer the possibility to perform various types of studies on the model. Each study represents a what-if scenario and is defined by:

- analysis type and options;
- material(s);
- a set of loads and restraints;
- a mesh.

6. THE MATERIAL SELECTION FROM COSMOS LIBRARY

The plate material was selected from Cosmos library with the following properties: the Modulus of Elasticity $E=2.1 \times 10^5 \text{ N/mm}^2$ and Poisson's Ratio 0.28.

7. THE RESTRAINT AND LOAD

The plate will be fixed in the origin, with the length oriented in X direction. The fix restraint consist in no translation on X direction: $U_x=0$ and the force $P=6000 \text{ N}$ will be applied on the opposite face, figure no. 2.

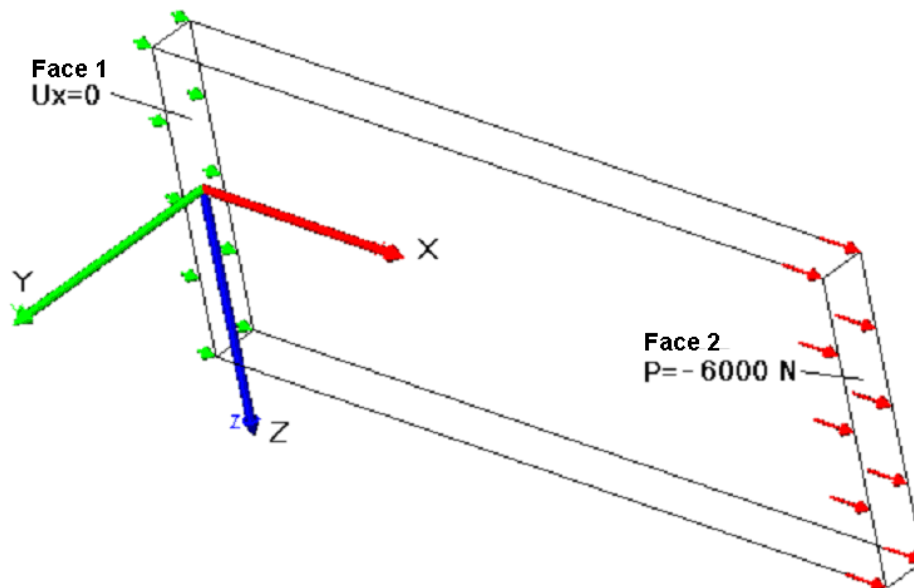


Figure no. 2. The restraint and load applied to the plate

8. THE MESH

Meshing is a very crucial step in design analysis. The automatic mesher generates a mesh based on a global element size and local mesh control specifications. Mesh control lets you specify different sizes of elements near vertices, edges, and faces. The program estimates a global element size for the model taking into consideration its volume, surface area, and other geometric details. The size of the generated mesh

(number of nodes and elements) depends on the geometry and dimensions of the model as well as the specified element order (draft or high quality), element size, mesh tolerance, mesh control, and contact specifications.

For the plate it is possible to generate the following types of elements: tetrahedral solid elements for meshing solid parts in a solid study and triangular shell elements for meshing shell study.

The following mesh options will be imposed: High Quality, the Standard Mesher Type, 4 Point Rule Jacobian Check, Automatic Transition and Smooth Surface for Mesh Control.

9. THE STUDY CALCULUS

Finite element analysis provides a reliable numerical technique for analyzing engineering designs. The process starts with the creation of a geometric model. Then, the program subdivides the model into small pieces of simple shapes (elements) connected at common points (nodes). Finite element analysis programs look at the model as a network of discrete interconnected elements. FEA assumes that the behaviour of each element varies in particular known fashions for various conditions. The finite element method predicts the behaviour of the model by manipulating the information obtained from all the elements making up the model.

10. THE RESULTS

The X stress variation is presented in figure no. 4. The maximal value is 25.126 MPa, and the distribution is approximately constant in X direction. The X elongation variation is presented in figure no. 5. The maximal value is 0.012 mm and the distribution is variable in X direction, from 0 to maximal value.

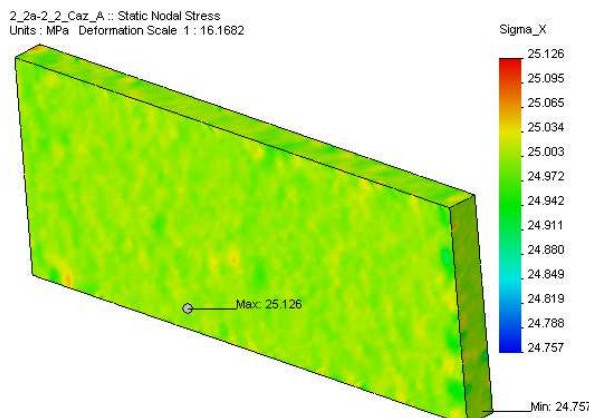


Figure no. 3. The X stress variation

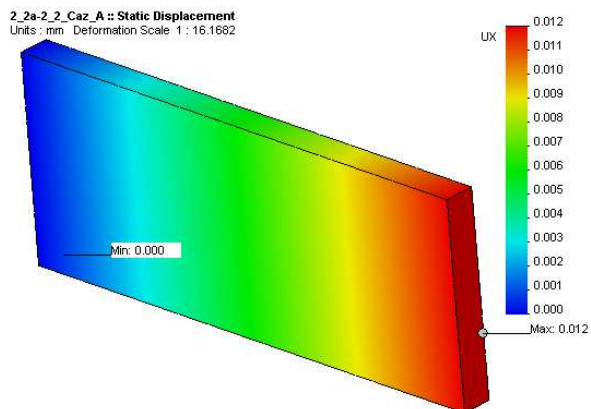


Figure no. 4. The X elongation variation

Results for the plate with no concentrators – Solid Model

11. THE PLATE ANALYSE WITH CONCENTRATOR IN SECTION 1 – SOLID MODEL

There will be followed the same steps like the anterior study, with the following modifications:

- the geometry will include the concentrator in section 1 ;

- there will be generate a new study;
- Mesh Type→ Solid;

The X stress variation is presented in figure no. 5. The maximal value is 112.1046 MPa. The maximal position is placed near the rounded curve. The X elongation variation is presented in figure no 6, with the maximal value 0.0132 mm.

2_2b-2_2_Caz_B :: Static Nodal Stress
Units : MPa Deformation Scale 1 : 297.203

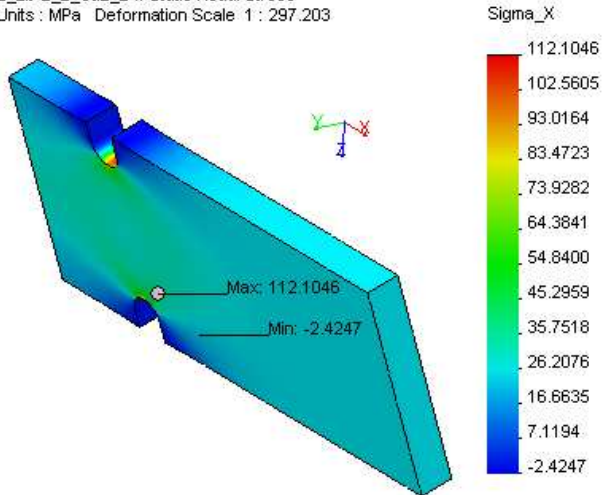


Figure no 5. The X stress variation

2_2b-2_2_Caz_B :: Static Displacement
Units : mm Deformation Scale 1 : 297.203

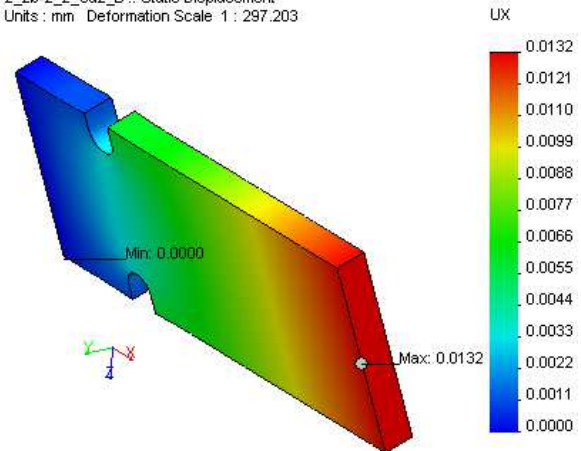


Figure no. 6. The X elongation variation

Results for the plate with concentrator in section 1 – Solid Model

12. THE PLATE ANALYSE WITH CONCENTRATOR IN SECTION 2 – SOLID MODEL

The new geometry will include the concentrator in section 2. The X stress variation is presented in figure no. 7. The maximal value is 83.0952 MPa. The maximal position is placed in section 2. The X elongation variation is presented in figure no. 8. The maximal value is 0.0137 mm.

2_2c-2_2_Caz_C :: Static Nodal Stress
Units : MPa Deformation Scale 1 : 22.7724

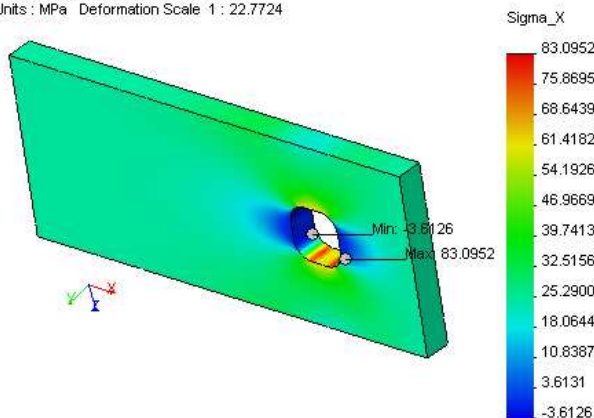


Figure no. 7. The X stress variation

2_2c-2_2_Caz_C :: Static Displacement
Units : mm Deformation Scale 1 : 22.7724

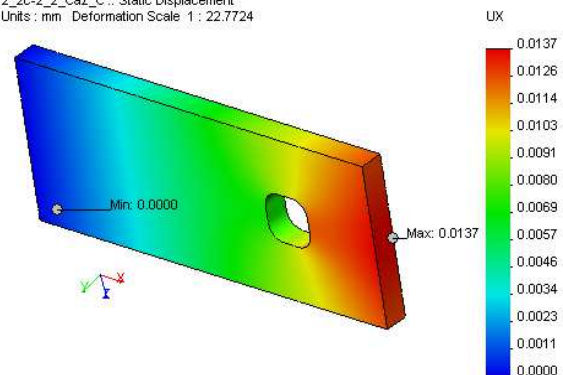


Figure no. 8. The X elongation variation

Results for the plate with concentrator in section 2 – Solid Model

13. THE PLATE ANALYSE WITH CONCENTRATORS IN SECTION 1 AND 2 – SOLID MODEL

The new geometry will include the concentrator in section 1 and 2. The X stress variation is presented in figure no. 9. The maximal value is 113.3243 MPa. The maximal position is placed near the rounded curve in section 1. The X elongation variation is presented in figure no. 10. The maximal value is 0.015 mm and the distribution is variable in X direction, from 0 to maximal value.

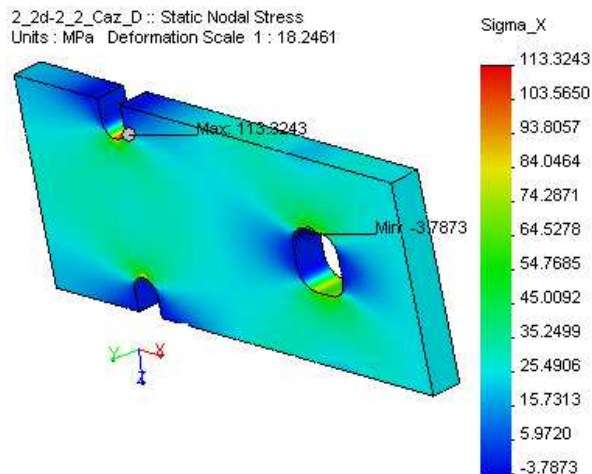


Figure no. 9. The X stress variation

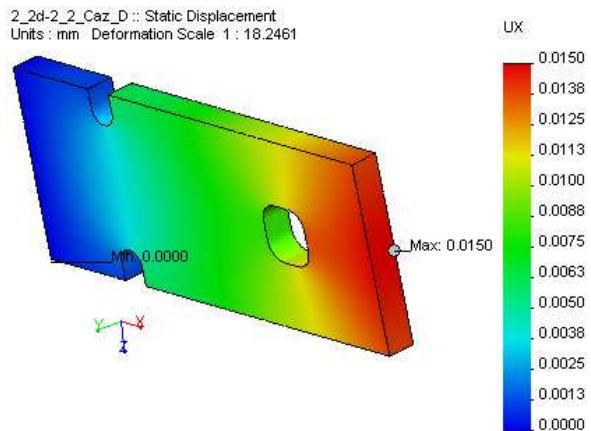


Figure no. 10. The X elongation variation

Results for the plate with concentrators in section 1 and 2 – Solid Model

14. THE PLATE ANALYSE WITH CONCENTRATORS IN SECTION 1 AND 2 – 2D PLANAR MODEL

Since the geometry and loads are disposed in the same plane the problem can be modelled in 2D Planar version. So, the problem is simplified from 3D to the 2D domain, the very small stress in Z direction been neglected.

14.1 2D Sketch of the Plate

The geometry will be generate in Cosmos Design Star in a new file, using the sketch tools of the software, figure no. 11.

14.2The 2D Planar Study

From the sketch will be generate a sheet as a source of the static analyse, with 2D Planar option for Mesh Type. Also will be specify the following options: mm in Units lists and value 6 mm for the sheet thickness.

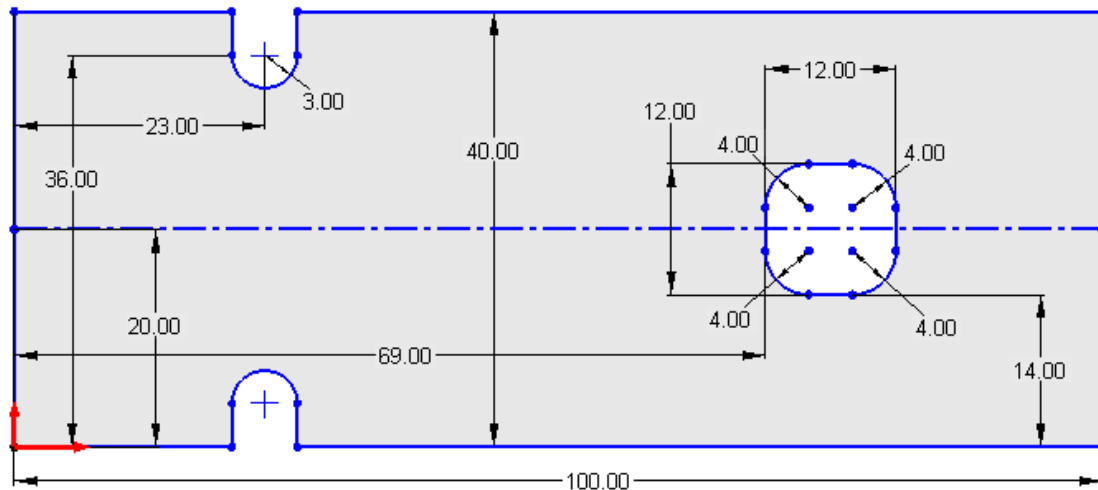


Figure no. 11. The 2D geometry of the plate with concentrators

14.3 Material Selection and Specify Restraints and Loads

There will be applied the same material, restraints and loads like the previous studies, with only difference that the loads will be applied on edges and not on the faces, see figure no. 12.

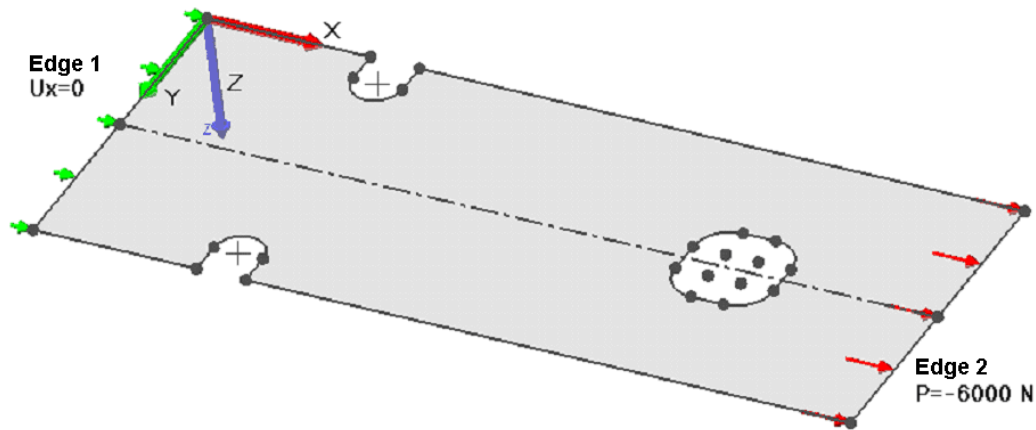


Figure no. 12. Restraints and loads applied on edges of the sheet

14.4 The Results

The X stress variation is presented in figure no. 13. The maximal value is 106.4486 MPa. The maximal position is placed near the rounded curve in section 1. The X elongation variation is presented in figure no. 14. The maximal value is 0.015 mm and the distribution is variable in X direction, from 0 to maximal value.

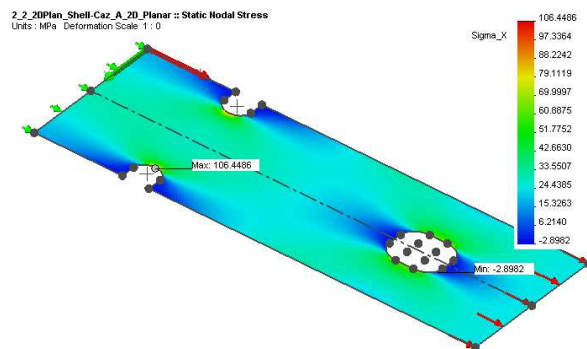


Figure no. 13. The X stress variation

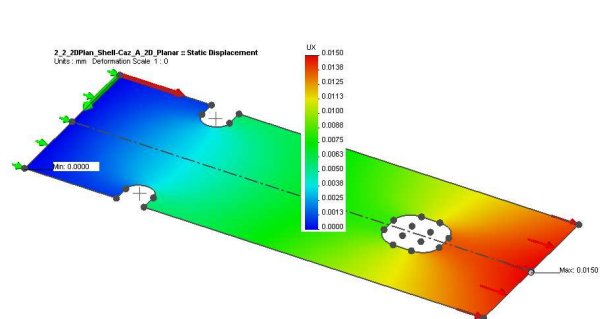


Figure no. 14. The X elongation variation

Results for the plate with concentrators in section 1 and 2 – 2D Planar Model

15. THE PLATE ANALYSE WITH CONCENTRATORS IN SECTION 1 AND 2 – SHELL MODEL

The same steps will be followed like the previous study, with difference: Mesh Type → Shell. The X stress variation is presented in figure no. 15. The maximal value is 100.482 MPa. The maximal position is placed near the rounded curve in section 1. The X elongation variation is presented in figure no. 16. The maximal value is 0.015 mm and the distribution is variable in X direction, from 0 to maximal value.

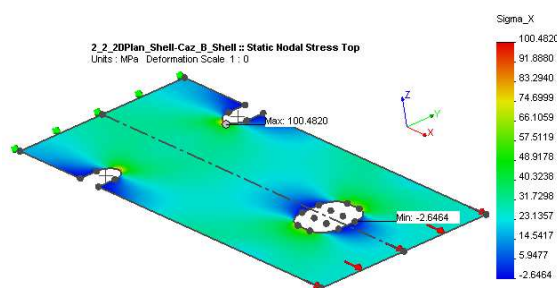


Figure no. 15. The X stress variation

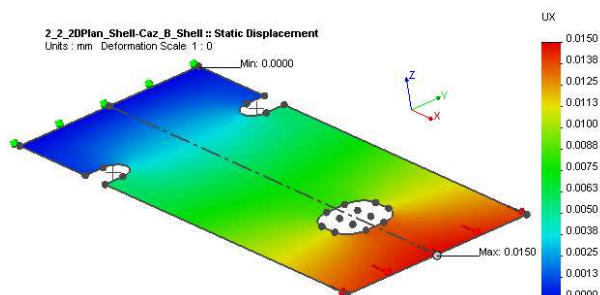


Figure no. 16. The X elongation variation

Results for the plate with concentrators in section 1 and 2 – Shell Model

16. CONCLUSIONS

The final comparative results and relative errors obtained by Cosmos Design Star software are presented in table no. 1.

For „a” case – Solid Model, the stress errors are neglectable; the errors grow up to 14 % for case „b” – Solid Model and to 35 % for case „c” – Solid Model.

For „d” case – Solid Model, „e” case – 2D Planar Model and „f” case – Shell Model, the errors are 13.83 %, 17.48 % and 22.11 % respectively, so the values are quite the same, but the maximal position stress value is not located in section 2 (like in analytical case) but in section 1 (for FEM calculus).

The elongation Δl for all cases („d”, „e”, „f”) is 0.0150 mm and the stress values are 113.3243 MPa, 106.4486 MPa, 100.48 MPa, this small differences correspond to the selected Mesh Type. If , for „f” case – Shell Model, the finite elements number increase from 8,834 to 21,074, which correspond to a fine mesh, the stress value grow to 104.7067 MPa, which is close up comparative to „e” case – 2D Planar Model. So the results are practically identical as value and location for the three cases.

The analytical and FEM results shows:

- the same values of the elongation and stress if concentrators are not presents.
- the differences for values and location of maximal stress for the plate with concentrators, with maximal 35 % relative errors, as a results of concentrator coefficients values, see relations [4] and [7].

Table no. 1. Comparative analytical and FEM results						
Case study	Parameter	Symbol	U/M	Analytical solution	FEM solution	Relative errors [%]
a) Plate with no concentrators solid model	Stress	σ	MPa	25	25.126	-0.50
	Elongation	Δl	mm	0.0119	0.012	-0.80
b) Plate with concentrator in section 1 solid model	Stress	σ	MPa	96.15	112.1046	-14.23
	Elongation	Δl	mm	-	0.0132	-
c) Plate with concentrator in section 2 solid model	Stress	σ	MPa	129	83.0952	35.61
	Elongation	Δl	mm	-	0.0137	-
d) Plate with concentrators in section 1+2 solid model	Stress	σ	MPa	129	113.3243	13.83
	Elongation	Δl	mm	-	0.0150	-
e) Plate with concentrators in section 1+2 2D Planar model	Stress	σ	MPa	129	106.4486	17.48
	Elongation	Δl	mm	-	0,0150	-
f) Plate with concentrators in section 1+2 Shell model	Stress 8,834 finite elements	σ	MPa	129	100.48	22.11
	Stress 21,074 finite elements	σ	MPa	129	104.7067	18.83
	Elongation	Δl	mm	-	0.0150	-

Table no. 2 show the finite elements and nodes numbers obtained by Cosmos Design Star mesher, for every studied case.

Table no 2. Finite Elements and Nodes Number generated by mesher				
Case study	Solid Model			
	a) Plate with no concentrators	b) Plate with concentrator in section 1	c) Plate with concentrator in section 2	d) Plate with concentrators in section 1+2
Finite Elements Number	49,597	48,245	50,170	48,397
Nodes Number	75,568	73,948	76,470	74,271
Case study	2D Planar Model		Shell Model	
	e) Plate with concentrators in section 1+2		f) Plate with concentrators in section 1+2	
Finite Elements Number	8,834		8,834	21,074
Nodes Number	18,052		18,052	42,730

17. REFERENCES

- [1] MĂNESCU T., NEDELCU D., Analiză structurală prin metoda elementului finit, Editura „Orizonturi Universitare” Timișoara, ISBN 973-638-217-6, 2005.
[2] NEDELCU D., Modelare parametrică prin Autodesk Inventor, Editura „Orizonturi Universitare” Timișoara, ISBN 973-638-116-1, 2004.

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