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Analysis of Stress Fields on Supporting Elements of Structures with Different Geometry of Holes

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Abstract This article deals with two methods of evaluating stress fields. Those are: photoelasticimetry and the finite element method (FEM). Stress analysis of castellated beams, with different geometry of holes in the vertical portion of the beam-web was performed by photoelasticimetry and the finite element method. The results obtained using experimental analysis and numerical modelling were evaluated and compared.

Keywords: *photoelasticimetry, finite element method, castellated beam*

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1. Introduction

Castellated beams are known as an effective alternative to conventional rolled sections. They are made of rolled sections by dimensional cutting the web and by welding the separated part of the cellular beam. By this method we have got beam with holes in the middle of the web with higher bending stiffness than those made with normal rolled section, while weight and final price are low [1]. Cellular beams are divided according to the hole geometry - cellular beam with hexagonal holes, with circular holes (in contrast to beam with hexagonal openings has problem with lower resistance in shear) and beams ANGELINA, shape of the holes is achieved by sinusoidal trajectory of cutting [2]. Authors of this article have already dealt with similar issues [3], influence of the connection between the two parts of the castellated beam with the hexagonal holes for the distribution of stress fields. The production process of castellated beams consists of the following steps:

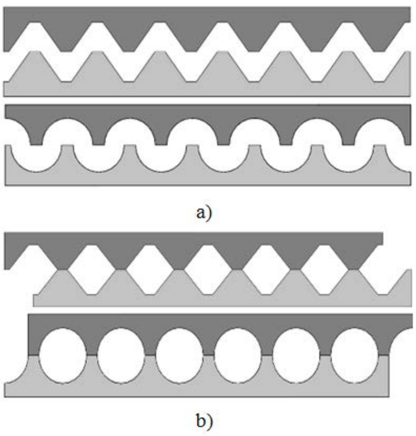

Figure 1. The process for producing castellated beam

a) Production of beam parts by separation cuts (Figure 1a).
b) Connecting profiles in the top part of cutting beam together by welding (Figure 1b) [1].

In Figure 2 is shown cutting process with double cut when we made beam with circular holes.

Figure 2. Flame cutting of rolled sections for circular holes

Cellular beams allow new architectural possibilities. Because of their high flexibility and aesthetics, they can be applied inter alia in different types of installations, pipelines, and lighting systems as well.

Cellular beams are designed to have maximum bending resistance with minimum weight and price. They are used for roofs (Figure 3), walls or reconstruction of buildings. Diameter of the holes is up to 80% of the height of the beam [4].

Figure 3. Construction of roofs using castellated beams

2. Experimental Stress Analysis by Using Optical Methods

Photoelasticimetry is an optical method suitable for a relatively fast full-field stress analysis even in shape-complex models. The authors studied the influence of the shape of the hole on stress analysis in the plane model in case of stress analysis around small holes by PhotoStress method. The results can also be used for quantification of residual stresses [5].

For experimental stress analysis using transmission photoelasticity were made models from photosensitive material PSM-1 with different geometry of the holes according to Figure 4. In order to prevent creation of residual stresses in the photosensitive material by improper cutting technology, water jet cutting was used [6].

Figure 4. Beam models made from photosensitive material PSM-1

For stress analysis the part of vertical beam - web was chosen. The aim was to perform stress analysis of the lightweight beams. The effect of changing hole geometry on the distribution of stress fields for free connection both parts of beam. Weight of burden acting on the top side of the beam is shown in Figure 5. The magnitude of force was 11,25 N.

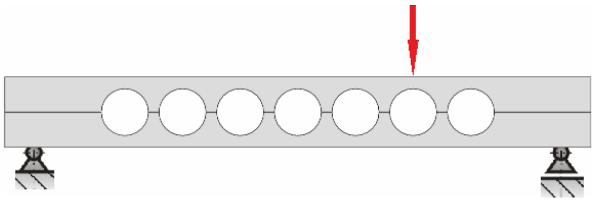

Figure 5. Place where load acted on castellated beam

Thus produced samples were loaded, and the stresses generated in the peripheral fibers were evaluated by polariscope model 060.

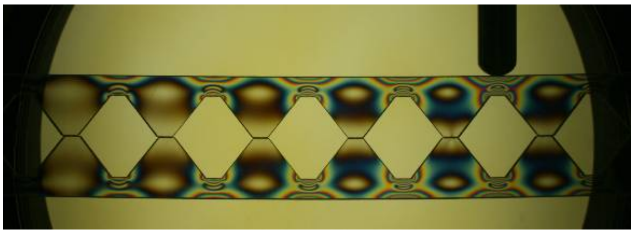

Figure 6. Isochromatic fringes on the loaded model

If the model from the photosensitive material is subjected to loading, change level of stresses lead to optical effect, which is showed as isochromatic fringes in polariscope, (Figure 6) [6].

The observed fringes order is proportional to the difference in principal stresses. This dependence can be expressed by equation (1)

$$\sigma_x - \sigma_y = \frac{N \cdot C}{t}, \tag{1}$$

where: N – fringe order
C – optical stress constant of material
t – thickness of model
σ_x, σ_y – principal stresses.

In our case, the stresses on the edge have been determined, where one of the stresses is zero, so we can use equation (2)

$$\sigma = \frac{N \cdot C}{t}. \tag{2}$$

In the peripheral fibers it was necessary to determine the fringe order value with compensator (Figure 7) [7].

Figure 7. Compensator model 067

The fringe order N can be determined by dividing value on the scale of compensator with sensitivity of compensator *d* = 48.

$$N = \frac{value\ on\ the\ scale\ of\ compensator}{d}. \tag{3}$$

For determination of fringes order it is necessary the axis of compensator turn in order to be parallel with the algebraically greatest principal stresses [7]. In (Figure 8) is shown the position for evaluated fringes on the top of the beam. On the beginning of the measuring the digital index was set to zero.

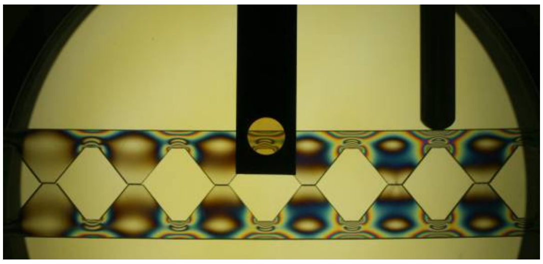

Figure 8. Setting of compensator for evaluating fringes order in the investigated area – the upper part of the beam

After setting the compensator in a suitable position, we investigated the edge of the beam through a window of compensator (Figure 9, Figure 10) and by turning of the control knob anti-clockwise we introduced birefringence in the light path.

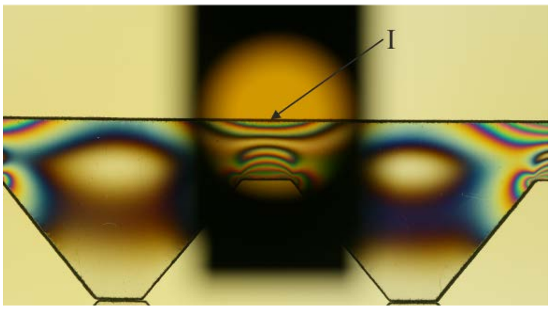

Figure 9. Detail view of the process of counting the fringes order in the investigated area, hexagonal holes - the upper silk in place I

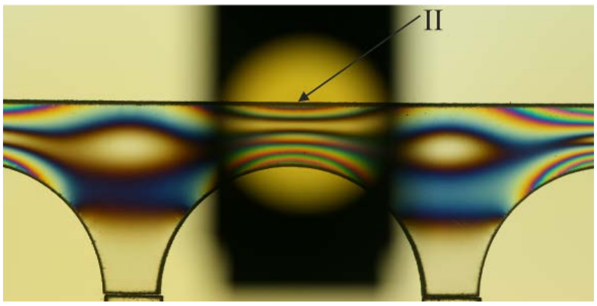

Figure 10. Detail view of the process of counting the fringes order in the investigated area, circular holes - the upper silk in place II

We continued to turn until we received the black fringe on the edge of the beam. Subtraction values obtained with compensator (Figure 11) for single variants we fit to the equation (3), then into the relation (2) for calculation of the stresses.

Figure 11. Value on compensator in place I

The same procedure was used for evaluating of bottom part of the loaded beam, but unlike the previous case, the compensator was set to the horizontal position (Figure 12).

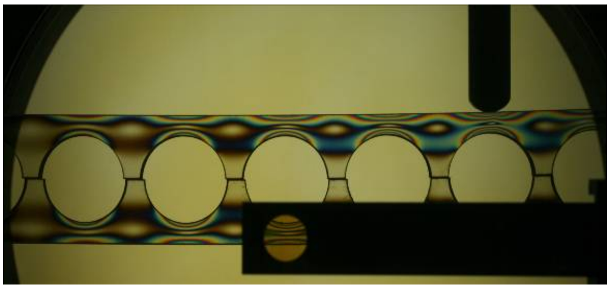

Figure 12. Setting of compensator for evaluating fringes order in the investigated areas – the bottom part of the beam

Then we were turning knob until we received a black fringe on the edge (Figure 13 and Figure 14). We recorded the value from the compensator for hexagonal holes. By using these numerical values, we received stress value at bottom fibers of the beams (tensile stress).

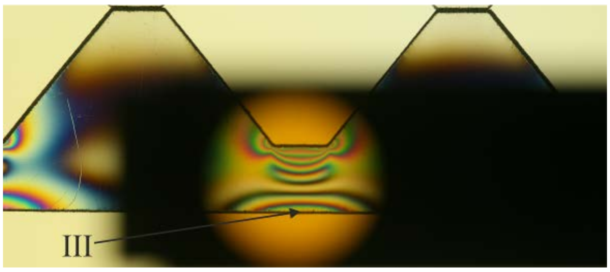

Figure 13. Detail view of the process of counting the fringes order in the investigated area, hexagonal holes - the bottom silk in part III

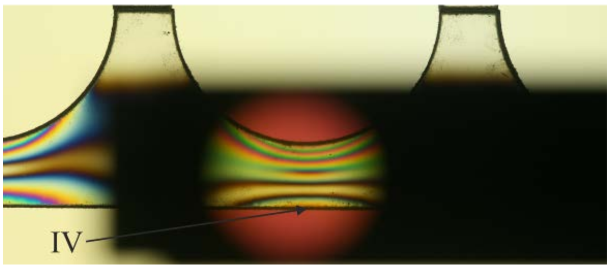

Figure 14. Detail view of the process of counting the fringes order in the investigated area, circular holes - the bottom silk in part IV

Way of subtraction was identical as for top silks (Figure 15). After induct number values we pinpointed the size normal stresses sx in bottom silks cellular beams.

Values for the stress in investigated points of castellated beams were verified by finite element method.

3. Stress Analysis of Castellated Beams by the Finite Element Method

For creating of CAD model SolidWorks was used [8]. Design of models (Figure 15) was based on the model parallelism of cellular beams used in the constructions.

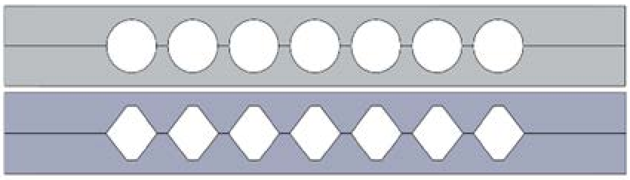

Figure 15. Models with different geometry of holes

In design process of beams, it had to be taken into account the size of the light-sensitive plates, which were used for making of physical models used in experimental measurements. Model dimensions are: length 498 mm, height 60 mm, width 6.25 mm.

Models were first meshed using automatically generated mesh. SolidWorks creates mesh with tetrahedral 3D solid elements for all solid components in the parts folder. Tetrahedral elements are suitable for bulky objects.

By using simple mesh sensitivity controls in SolidWorks we can determine whether the mesh is suitable for our simulation, and will not affect the results.

It was found out that it is necessary to refine the mesh, in order to eliminate errors in the results. By refining the mesh, we got to the final mesh, with the length of the element 0.1 mm and with aspect ratio 1.5. On Figure 16 are given meshed models with refine mesh in the surrounding of holes.

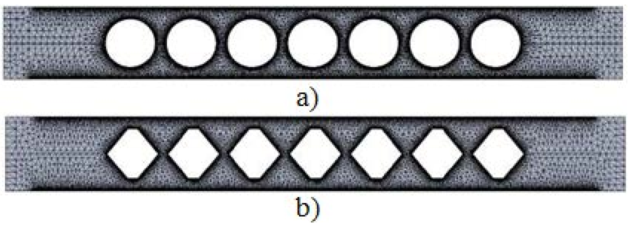

Figure 16. Mesh of cellular beams

Number of elements and nodes for analyzed beams with circular and hexagonal holes using automatically generated mesh and refined mesh is mentioned in Table 1.

Table 1. Number of elements and nodes for various types of investigated beams

Type of beam	Number of elements	Number of nodes
Beam with circular holes - refined mesh	605738	1040084
Beam witch hexagonal holes - refined mesh	600191	1028784
Beam with circular holes - auto. generated mesh	16818	30516
Beam witch hexagonal holes - auto. generated mesh	14632	27069

After completion of mesh optimization process, the boundary conditions were applied and the simulation was run. Thus meshed beams were checked for the effects of errors which affect the value of stress in the investigated areas. It was showed that effect of error on beams with refined mesh at the investigated points were equal zero.

The evaluation process of the results was the same as in the model provided with an automatically generated mesh so it will be possible to compare the stress values normal stresses Sx of the peripheral fibers. In this case, it was a static analysis. We defined material properties of PSM-1, loading F = 11.25 N.

In Figure 17 and Figure 18 are shown places where values of stress were evaluated. Results are given in Table 2.

It was concluded that the results obtained from the FEM analysis with fine mesh in the surrounding of holes and those from experimental models are in good agreement. Comparison of the measured stresses in the center of the beam on the upper and bottom parts of the beams has shown that the values of the stress in investigate parts was find out that in the case cellular beam with circular holes are values of stresses higher about 9%.

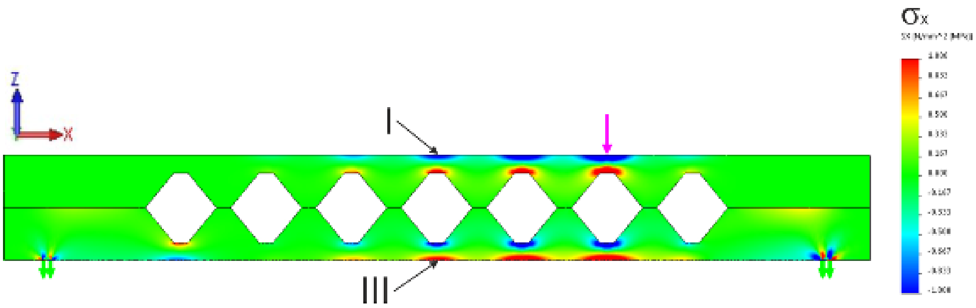

Figure 17. Field of normal stresses σ_x for beam with hexagonal holes

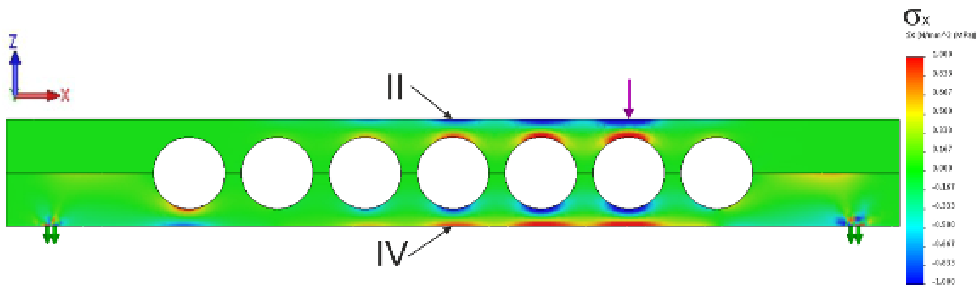

Figure 18. Field of normal stresses σ_x for beam with circular holes

Table 2. Comparison of recorded values

Model	Location of measuring	Stress value in investigated areas [MPa]			Variance in values between exp. and numerical model [%]	
		Numerical modelling		Experimental model	Percentage difference between FEM automat. and exp. model	Percentage difference between FEM refined and exp. model
		FEM model with auto. generated mesh	FEM model with refined mesh	Model from photosensitive material		
Unattended parts hexagonal holes	Point I	1,094	1,167	1,181	7,95	1,19
	Point III	1,161	1,237	1,257	8,27	1,62
Unattended parts circular holes	Point II	1,166	1,277	1,282	9,94	0,39
	Point IV	1,256	1,351	1,357	8,04	0,44

4. Conclusion

Nowadays, numerical modelling is widely used in design process of different types of machine and constructions. It should be borne in mind that wrong boundary condition definition can affect the results. Analysis of the stress in cellular beams with hexagonal and circular holes, using numerical modelling and experimental measurements was accomplished. We can conclude that the differences between these methods are small and the results show very good agreement. Photoelasticimetry may be a useful tool in addressing the issues of optimizing the shape, size or distance between the holes and in reduction of stress magnitude in critical areas. Authors of the paper used the results obtained by the experimental measurement to analyze stresses around the holes in order to quantify the residual stresses in the steel structures.

Acknowledgements

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References

[1] Prelamované nosníky směrnica 11. [Online] Available: http://www.novingrosty.cz/assets/prolamovane_nosniky_smernice.pdf cit. 21.10.2017.

[2] Angelina beams: A new generation of castellated beams [Online] Available: http://www.constructalia.com cit. 19.10.2017.

[3] Pástor, M., Bocko, J., Kula T., Roszkos. C. S. Possibilities of Optimizing the Shape and Geometry of Castellated Beams Using Numerical and Experimental Modelling., American Journal of Mechanical Engineering, 4 (7), pp.357-362. 2016.

[4] ACB Cellular beams: The intelligent solution for long spans [Online] Available: http://www.constructalia.com cit. 20.10.2017.

[5] Cárdenas-Garcia, J. F., Hashemi, J., Durelli, A. J. The practical use of the hole method in photoelasticity, Mechanical Research Communications, Vol. 22, No. 3, pp. 239-244, 1995.

[6] Pástor, M., Trebuňa, F. Application of transmission Photoelasticimety for Stress Concentration Analyses in Construction Supporting Parts, Applied Mechanics and Materials, Vol. 611, pp. 443-449, 2014.

[7] Trebuňa, F., Šimčák, F., Frankovský, P., Huňady, R., Pástor, M. Využitie optických metód v experimentálnej mechanike 1, Košice, 2014, ISBN 978-80-553-1863-9, pp. 392.

[8] Jančo, R. FEM Approach of Solution of Beams on Elastic Foundation. In. Applied Mechanics 2011, 13th Conference Proceeding, Brno, Czech Republic, pp. 71-74.