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The project and the numerical verification of the stations assumptions, to examine the influence of load on natural frequency of thin-walled panel

Projekt i weryfikacja numeryczna założeń stanowiska do badania wpływu obciążenia na częstości drgań własnych cienkościennego panelu

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Demonstrated is a description of a research station project, which allows to assess the influence of a load on natural frequency of a thin-walled panel. A FEM model, which allowed assessing the strength, but primarily the numerical verification of the research assumptions, has also been included.

KEYWORDS: thin-walled structure, natural frequency, tension field

It is not necessary to convince anybody about the importance of knowing the frequency and form of the vibrations of their own designed structures. The scientific literature is very abundant in articles and monographs [1–5] explaining dynamic phenomena appearing in the mechanisms of machines and devices during forced transformation through resonance zones. It is known how important the impact – both on the durability of the structure and the comfort of their use – is to provide adequate resonant characteristics. One of the best ways to protect technical objects from the negative effects of resonant phenomena is to ensure that the first natural frequency is high and extends beyond the frequency range. This design method should ensure an appropriate level of construction safety and an "acoustic climate". This is extremely important in thin-walled constructions, which very often work at loads similar to critical loads. This applies in particular to aircraft structures [6, 7] and motor vehicles [8–10].

During numerical analyses of thin-walled structures, described, among others, in [11, 12], a significant impact of the load on the natural vibration frequency of thin-walled panels was noticed. In particular, this applies to tangential loads causing the field of drawing [6, 13–15] in typical rectangular panels in which a thin-walled cover is attached to a relatively rigid frame. Therefore, it was considered useful to build a position that (after numerical verification of assumptions) will allow to examine the impact of tangential loads on the natural frequency of the cover sheets.

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Project assumptions

The basic condition was to use the existing chamber, in which the speaker is the source of forcing panel vibration (thin-walled structure), and for the vibration measurement a laser vibrometer was used (fig. 1).

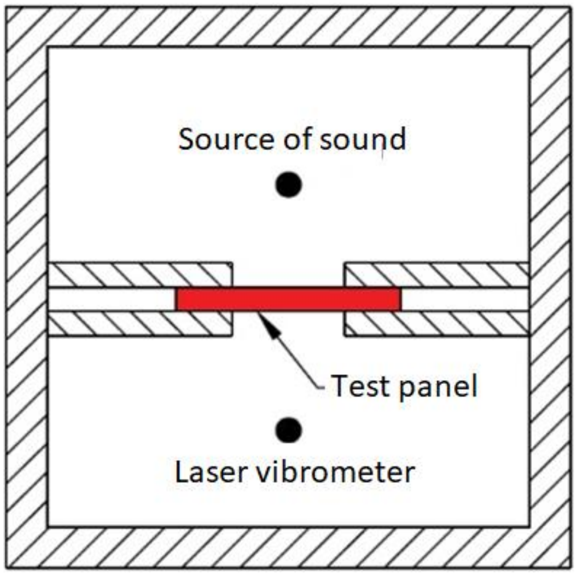

Fig. 1. Measurement scheme

In order to eliminate the influence of bending the frame elements on the buckling of the cover, it was decided that the stand would meet the assumptions of the classic half-shell model [6, 16], in which the frame elements are articulated and carry normal loads, and the thin-walled panel transfers cutting loads (fig. 2). It was also assumed that investigated structures will be tested for loads exceeding the critical loads, causing local loss of stability in the elastic range of the material.

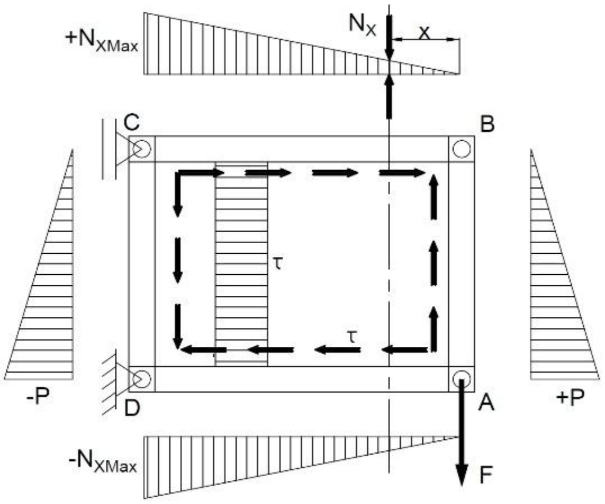

Fig. 2. Panel model – loads and boundary conditions

Design

Fastening elements (fig. 3), using, among others, bolt connections in corners and guides, ensure that the system works in accordance with fig. 2.

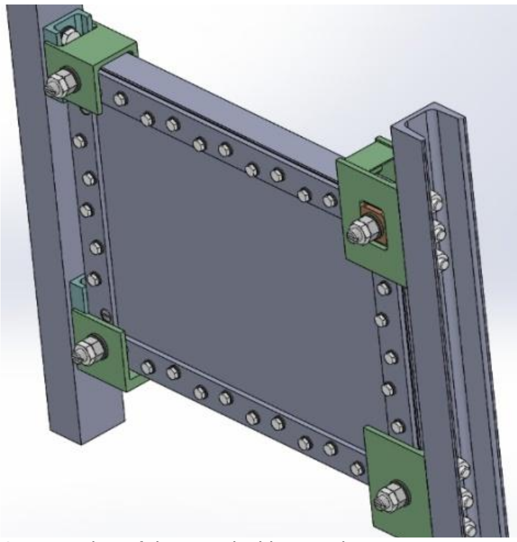

Fig. 3. Construction of the panel with restraints

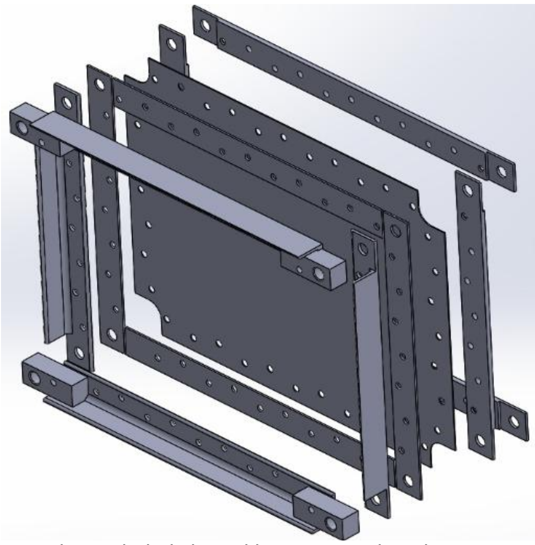

Fig. 4. Panel – exploded view without connecting elements

The skeleton of the panel consists of flat bars of two different thicknesses and isosceles angles (fig. 4). These parts are attached to the plate by means of threaded connections. In addition, in each corner there are reinforcements in the form of welded fasteners.

FEM Model

Most parts of the panel were made of quadrangular first-order shell elements (fig. 5). Only the connectors have been modeled as cubic first-order solid elements.

Fixed connections are implemented by tie-type bonds, i.e. nodes of neighboring elements have associated degrees of freedom. The bolts have been replaced by kinematic bonds.

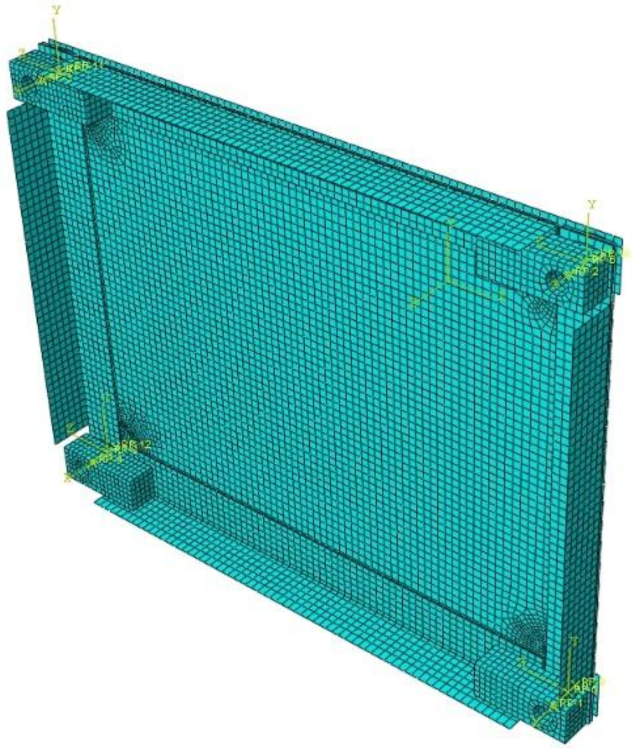

Fig. 5. FEM model

Finally, each bolt was replaced by three reference points (fig. 6) located on the straight line, which is the axis of rotation of the bolt. The individual reference points are connected by MPC Beam kinematic bonds with the surfaces of the corresponding openings in the frame elements. In addition, the Connector Hinge type is used between the reference points, i.e. only relative rotation is possible.

The boundary conditions were introduced as blockages of appropriate displacements and rotations at the central reference points, in accordance with the mode of operation of restraints. The load was also entered at the central reference point.

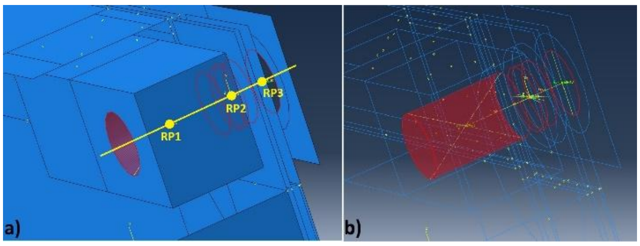

Fig. 6. Way of modeling the bolt connection in FEM

Results

The construction has been verified in terms of strength. Static non-linear analysis was carried out, including large deformations.

Stresses reduced in all elements of the structure do not exceed the permissible values. The plate can be observed concentration of stresses around the corners. The largest occurs in the C corner and according to the Huber-Mises-Hencky hypothesis is 319.8 MPa (fig. 7).

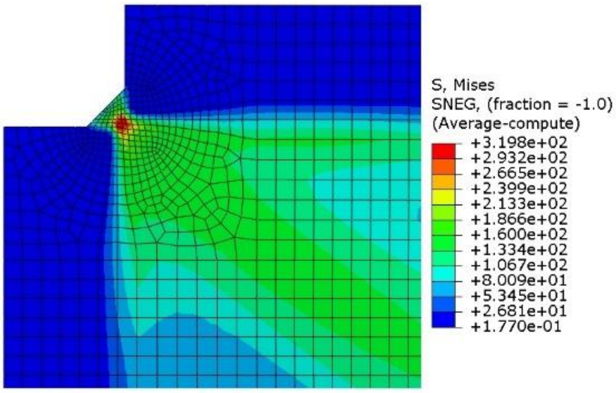

Fig. 7. Map of stresses reduced in MPa in the corner C of the slab

In the frame elements, the greatest reduced stresses occur around the bolt holes (fig. 8). The maximum stress according to the Huber-Mises-Hencky hypothesis was observed in the upper flat bar with a thickness of 5 mm; it is 98.9 MPa. The maximum deflection at the point of application of the force is 0.59 mm.

The map of displacements in the direction perpendicular to the plate was determined (fig. 9). Large deformations are caused by the creation of a field of pulls in the plate. Considering the displacement of the center point of the plate and the result of the analysis of critical forces, it can be noticed that a rapid increase in displacements occurs when the load value is close to the determined critical force of 3800.7 N (see fig. 11).

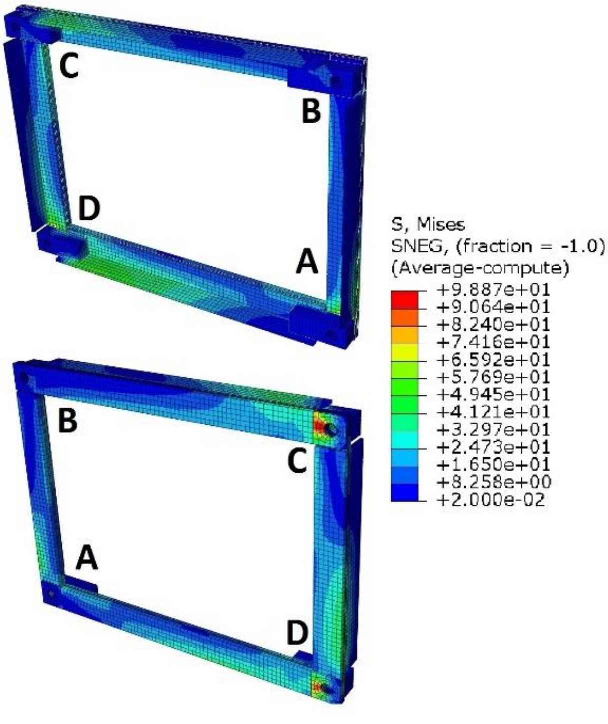

Fig. 8. Map of reduced stresses according to the Huber-Mises-Hencky hypothesis in the skeleton elements

An analysis of natural frequency of vibration without load was carried out. Its results are shown in fig. 10, and the corresponding frequency (in Hz) is: *a*) 119.62; *b*) 192.44; *c*) 287.86; *d*) 313.80; *e*) 356.05; *f*) 470.82.

In addition, the course of changes in natural frequency under load was determined (fig. 11). This was done as a cyclic analysis of two types of analyses, one after the other, in which the first one was a static stress-displacement analysis, and the second one – the analysis of natural frequency. The model was loaded with a given force increase, after which the value of natural vibrations was tested. The cycle was repeated until the final load value was reached.

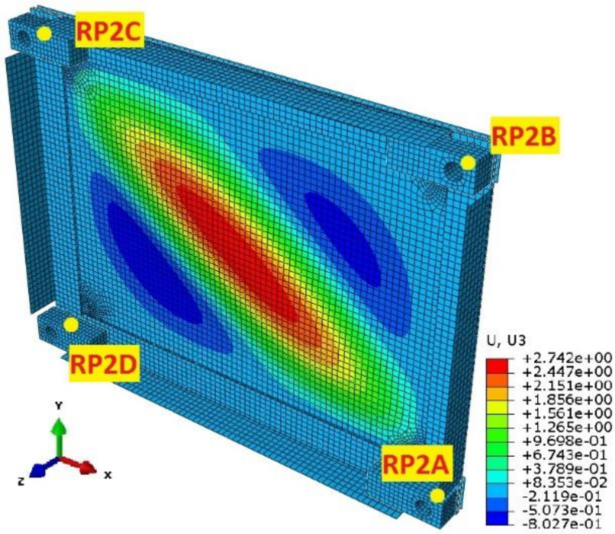

Fig. 9. Map of displacements in the direction perpendicular to the plate

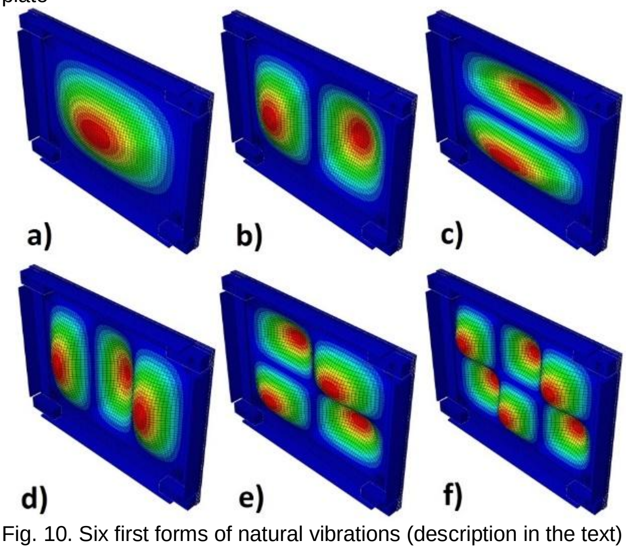

Fig. 10. Six first forms of natural vibrations (description in the text)

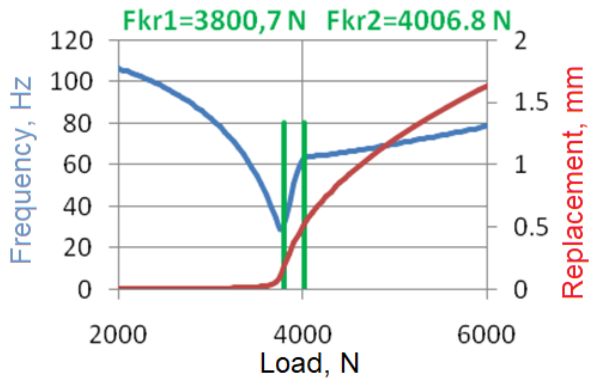

Fig. 11. Dependence of frequency and displacements on the load

The course of the natural frequency of vibration as a function of the load is shown in fig. 11. It can be observed that the value of vibration frequency until the loss of stability decreases, and after it is exceeded – it increases. The minimum value was around 29 Hz.

Conclusions

Numerical analyses have proved that the designed structure meets the assumptions. None of the elements have exceeded the permissible stresses, and frame elements provide adequate rigidity. Work simulations for the cover sheet with a thickness of 0.5 to 1 mm confirmed very significant influence of tangential load on the natural frequency. In all cases, for the load close to the critical value, there was a decrease in the natural frequency by over 70% in relation to the frequency of unloaded structure. This confirms the correctness of the assumptions and the necessity to carry out the experiment using real objects.

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