1st Croatian Conference on Earthquake Engineering
1CroCEE
22-24 March 2021 Zagreb, Croatia

DOI: https://doi.org/10.5592/CO/1CroCEE.2021.10

Influence of panels on building behavior

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Abstract

Polyurethane panels are used for façade cladding and roofing, mainly, of industrial objects. They allow for a quick installation, and with that a reduction of the building cost. According to the current regulations in Macedonia, panels are only used as secondary load bearing elements, and not as elements that are in direct interaction with the rest of the load bearing construction.This work makes an analysis of the choice of the type of panel for a specific construction, the load bearing capabilities of the panels, as well as the approach of the stressed skin design method which analyses the panels as part of the primary load bearing construction. Based on the things listed above, a static design has been done on an object where the method of the modeling of the panels and the benefits of this type of analysis are displayed.

Key words: panels, steel construction, stressed skin design

1 Introduction

The current use of sandwich panels in the construction of industrial buildings demands a more sophisticated method of structural analysis, which will take into consideration their correlation with the load bearing structure itself.

Light sandwich panels used for roofing and facade cladding of modern industrial buildings are made of two metal sheets for cover (flat or with trapezoidal profile) and a light insulating core. In addition to their covering role. They also represent a very economical solution for increasing the stiffness of a roof plane. Moreover, when the roof diaphragm is used in correlation with façade bracing (or façade diaphragm), one can a get a maximally economical solution. In short: the diaphragm is analog to the web of an I beam and its role is to prevent shear deformation, while the outside elements of the diaphragm (the columns) are the flanges of the I beam.

One cannot deny that the load bearing structure will always be in interaction with the elements for cladding and roofing (in this case – the panels) and thus, they will play a significant role in the overall behavior of the building. Because of this interaction, the calculations of the stresses and the deformations in the load bearing structure, calculated only on the basis of the primary load bearing elements, are rather unrealistic, and significantly different from the real ones. Moreover, if one takes into calculation the properties of the façade cladding and roofing of the object, one can predict the true behavior of the building, thus significantly cut down on the material for it.

2 Application of panels in design of steel structures – characteristics and design principles

2.1 Choice of type of panels

The thermic, acoustic and structural requirements of the object dictate the type of panels for façade cladding and roofing. Based on these requirements, one can choose between single sheet steel plate or sandwich panels. The sandwich panels, as mentioned above, are made of two single sheets of either steel or aluminum with insulation of mineral wool or polyurethane between them.

The benefit of the polyurethane over mineral wool is that the polyurethane has quite higher thermal insulating capabilities. When two typical panels with thickness of 10 cm are compared, with either mineral wool or polyurethane, based on their thermal conductivity U (w/m^{2}K), typical polyurethane panel has a value of U = 0,226 W/m^{2}K and is 1,86 times better thermal insulator than the typical 10 cm thick mineral wool panel which has a U = 0,422 W/m^{2}K. To achieve the same thermal insulation with mineral wool, as one can with polyurethane, a thickness of 18cm is needed (U = 0,227 W/m^{2}K).

The situation displayed above, if the thermal conductivity is key, leads to an increase of the loads on the structure since the polyurethane panel of 10cm thickness has a weight of 12,77kg/m^2, while the 10cm mineral wool one has a weight of 23,43 kg/m^2; and if one needs to achieve the same U value with the 18cm mineral wool panel, this increases the weight to 36,08 kg/m^2. Certainly, a higher weight of the panels will lead to bigger section of the load bearing structure, thus making it more expensive. However, if there are requirements for fire resistance of the panels, the performance of the mineral wool panels are second to none.

2.2 Load bearing capabilities of panels and their role in the load bearing capabilities of the overall structure

Panels are mostly analysed in terms of how they transfer the outside loads (eg. wind and snow) to the main structure. They are treated as secondary elements to transfer these loads, while maintaining their deformations within the allowable limits.

Permitting this approach for calculating steel structures is aimed towards the main load bearing structure and the stiffeners placed on it, with the aim to reduce the structures deflection in horizontal, longitudinal and latitudinal direction. Before the arrival of personal computers and sophisticated programs for structural and dynamic analysis of structures, the calculation of these stiffeners was based on semi empirical formulas which determine the active load which each one transfers. One also must take into consideration the fact that there was an unclear Figure for the load distribution in certain planes. This was also connected to the experiential placement of the stiffeners (such as bracing), and which sometimes are displaced or totally removed due to functional requirements. Also, the calculation approach of the main load bearing structure, where the loads are transferred from on to another element (this especially applies to the wind load over the façade sub structure, and then to the columns) is ambiguous. Namely, the load bearing capabilities of the façade panels they have in their plane, was completely ignored (and which is evidently significant). To be exact, even at a glance of a hall with steel structure and cladding of panels, one can conclude that the cladding (as shell elements) plays a greater role in stiffening the structure when compared to classical vertical bracing, and in that way it reduces the deflection / deformations of the structure. Therefore, if there are less deformations, there will be less stress in the elements, and thus their load bearing capabilities will increase.

Based on the above written, if the panels are treated as primary load bearing elements, one can rationalize the amount of steel used in the construction process. According to the statements in the previous paragraph, key rationalization of steel structures involves the inclusion of the panels from the roof and façade in the load bearing capabilities of the structure i.e. the panels should be treated as primary load bearing elements. Today, with the possibilities structural design software offers, this is possible. The final purpose of this being the of reduction of classical stiffening elements (bracing) or completely removing them from the building system. This will consequently result in reducing the weight of the structure, simplifying the installation process and finally resulting in a more financially economic build. Naturally, to begin with this approach, we need to have a design model which focus on the properties of the panels (its stiffness and torsional stability).

2.3 Codes for design with panels as primary load bearing elements

The use of roof and façade panels as primary load bearing elements of a structure is allowed with EUROCODE 3 as stressed skin design. On a global level, this principle for design was introduced by E. R. Bryan, and as a result of his work the European recommendations for stress skin design are developed to be finally embodied into EUROCODE 3. Still, even with EUROCODE 3 doesnt strictly define a procedure which will have a binding character, but it is up to the designer if the load bearing capabilities of the panels will be used. Still, in Appendix A.7, all the conditions that need to be met if an engineer wants to use the panels in the calculation are defined:

- The use made of sheeting, in addition to its primary purpose, is limited to the formation of shear diaphragms to resist structural displacement in the plane of that sheeting
- The diaphragms have longitudinal edge members to carry flange forces arising from diaphragm action
- The diaphragm forces in the plane of a roof or floor are transmitted to the foundations by means of braced frames, further stressed-skin diaphragms, or other methods of sway resistance
- Suitable structural connections are used to transmit diaphragm forces to the main steel framework and to going the edge members acting as flanges.
- The sheeting is treated as a structural component that cannot be removed without proper consideration
- The project specification, including the calculations and drawings, draws attention to the fact that the building is designed to utilize stressed skin action
- In sheeting with the corrugation oriented in the longitudinal direction of the of the roof the flange forces due to diaphragm action may be taken up by the sheeting
- Stressed skin design may be used predominantly in low-rise buildings, or in the floors and facades of high-rise buildings
- Stress skin diaphragms may be used predominantly to resist wind loads, snow loads, other loads that are applied through the sheeting itself. They may also be used to resist small transient loads, such as surge from light overhead cranes or hoists on runway beams, but may not be used to resist permanent external loads, such as those from plant.

Also, the conditions that the diaphragm needs to meet are defined:

- In a profiled steel sheet diaphragm, both ends of the sheets should be attached to the supporting members by means of self-tapping screws, cartridge fired pins, welding, bolts or other fasteners of a type that will not work loose in service, pull alit, or fail in shear before causing tearing of the sheeting. All such fasteners should be fixed directly through the sheeting into the supporting member, for example through the troughs of profiled sheets, unless special measures are taken to ensure that the connections effectively transmit the forces assumed in the design.

- The seams between adjacent sheets should be fastened by rivets, self-drilling screws, welds, or other fasteners of a type that will not work loose in service, pull out, or fail in shear before causing tearing of the sheeting. The spacing of such fasteners should not exceed 500 mm.
- The distances from all fasteners to the edges and ends of the sheets should be adequate to prevent premature tearing of the sheets.
- Small randomly arranged openings, up to 3 % of the relevant area, may be introduced without special calculation, provided that the total number of fasteners is not reduced. Openings up to 15 % of the relevant area (the area of the surface of the diaphragm taken into account for the calculations) may be introduced if justified by detailed calculations. Areas that contain larger openings should be split into smaller areas, each with full diaphragm action.
- All sheeting that also forms part of a stressed-skin diaphragm should first be designed for its primary purpose in bending. To ensure that any deterioration of the sheeting would be apparent in bending before the resistance to stressed skin action is affected, it should then be verified that the shear stress due to diaphragm action does not exceed $0{,}25.f_{yb}/\gamma_{M1}$.
- The shear resistance of a stressed-skin diaphragm should be based on the least tearing strength of the seam fasteners or the sheet-to-member fasteners parallel to the corrugations or, for diaphragms fastened only to longitudinal edge members, the end sheet-to-member fasteners. The calculated shear resistance for any other type of failure should exceed this minimum value by at least the following:
  - for failure of the sheet-to-purlin fasteners under combined shear and wind uplift, by at least 40 %
  - for any other type of failure, by at least 25 %.

3 Role of panels in roof covering and façade cladding in the overall deformability and load bearing of the structure

Based on the before stated, it is obvious that the shortcomings of the usual approaches towards the calculation of the steel structures are the following:
- leaving out the load bearing capabilities of the cladding
- bigger deflections, and with that – bigger forces

Because of these shortcomings, one gets bigger profiles for the steel elements than the ones that are necessary.
To display these differences in the behavior of structures designed in a classical manner, compared to structures designed with the cladding as primary load bearing elements, an analysis of the deflections of a two-span steel hall is done in two separate models. In this analysis, only the deflections of the structures from wind load in Y direction will be displayed. The data will be obtained from two mathematical models. One without roof panels and on with roof panels in the mathematical model.

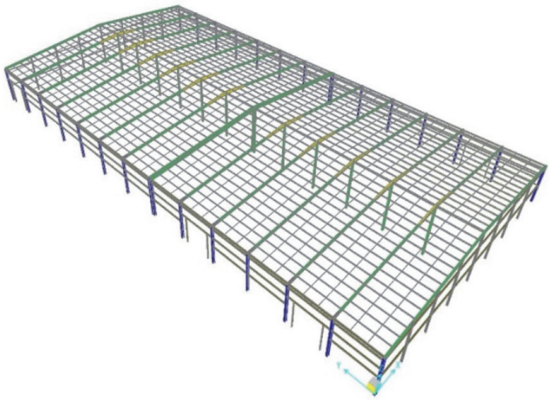

Figure 1. Isometric view of structure of hall

The building, in X direction is made of 2 modules of 20,0 m, in Y direction of 6 modules of 6 m; axial dilatation of 0,4 m; 7 modules of 6,0 m thus comprising a whole of 40,0 m x 78,4 m i.e. 3136 m^2. The gable of the building is on the 40,0 m wide side and forms a symmetrical roof.

3.1 Model 1: classically designed hall

The mathematical model of the structure is designed as a spatial system made of "frame" elements and surface "area" elements in the program package SAP2000.12. This program is used to do the structural and dynamic analysis of the building. Regarding the input data, needed for a proper analysis, the structure is loaded in accordance to the current regulations for loads for these types of buildings. In accordance to this, the building has been loaded with the following loads:

- Dead weight calculated directly from the software
- Permanent load G+ = 0,50 kN/m^2 (load of panels, installations)
- Snow load S = 0,75 kN/m^2
- Wind load W_0=0,7 kN/m^2 (II zone, exposed, H < 10 m).
- Seismic load through a respective spectrum.

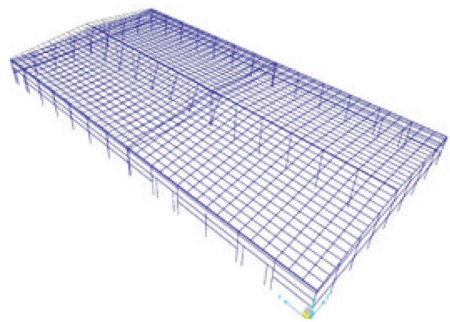

Figure 2. Mode 1 of Model 1

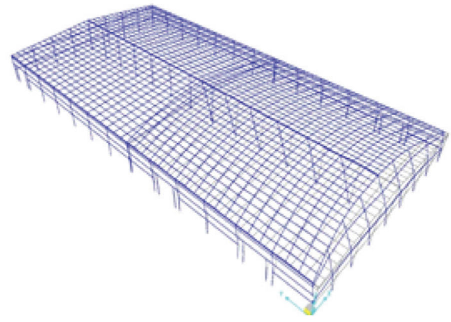

Figure 3. Mode 2 of Model 1

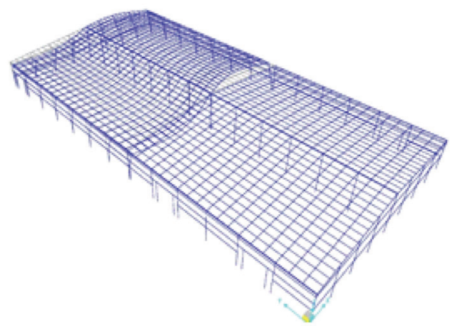

Figure 4. Mode 3 of Model 1

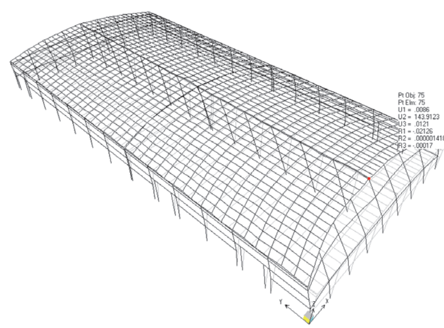

Figure 5. Deflection in Y direction from seismic load, on a model without roof and wall panels

3.2 Model 2: mathematical model with roof panels

Model 2 is actually Model 1 upgraded with the modeling of roof panels. The panels in the mathematical model are presented as fictive elements with circular cross section of 1mm, with which the model in on the side of safety (the stiffness of the panels is neglected, and they are analyzed as if they are acting as tension elements). The elements themselves are connected to the rest of the structure in a manner that will be done in reality: with self-tapping screws on every purlin on every 1000 mm (which is the width of the panel). What has been neglected from the real situation is that the panels are modeled as 20m elements (which is unreal due to the standard transport size). The reason this is done is to avoid the longitudinal connections of the panels with elements which would be placed on a distance of 250 mm.

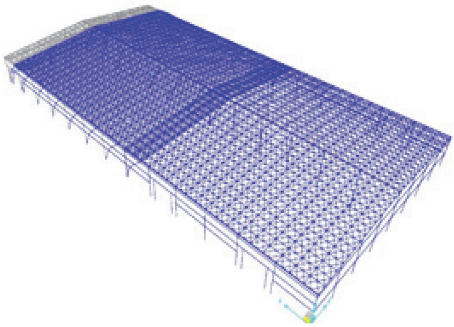

Figure 6. Mode 1 of Model 2

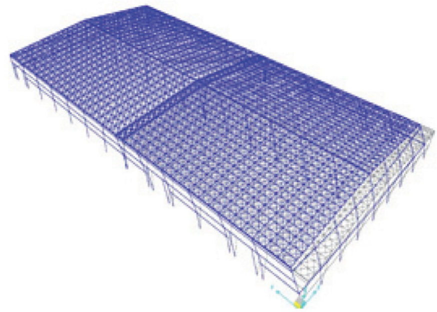

Figure 7. Mode 2 of Model 2

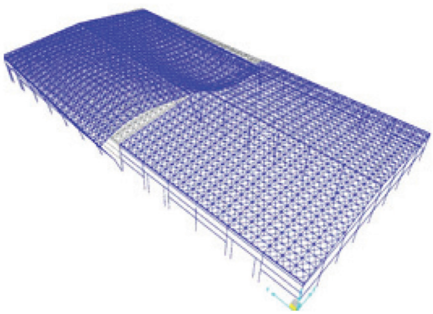

Figure 8. Mode 3 of Model 2

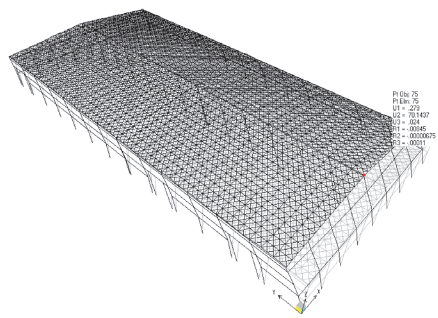

Figure 9. Deflection in Y direction from seismic load, on a model with roof and without wall panels

3.3 Analysis of results

Table 1. Modes, frequencies and deflections

	Model 1: Withouth panels		Model 2: With roof panels	
	T	f	T	f
Mode 1	2.12435	0.47073	1.57789	0.63376
Mode 2	2.04580	0.48881	1.52325	0.65649
Mode 3	1.51031	0.66211	0.87155	1.14738
	X - axis	Y - axis	X - axis	Y - axis
Deflection	12.837	59.155	8.970	28.317

4 Conclusion

As the results show (59 mm for Model 1, and 28mm for Model 2), one can conclude that by adding the roof panel in the structural analysis of the model, the horizontal deflection decreases by 50 %. Furthermore, one can safely claim that these values are not unrealistic, but are in line with the real situation of the structure. If the panels, with their respective stiffness are included in the mathematical model than the deflection will be even smaller than the one displayed. And if both roof and façade panels are included in the mathematical model as shell elements with their respective stiffness, the cross sections of the columns and beams would significantly decrease.

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