STRENGTHENING OF THE TRAPEZOIDAL SHEET METAL TR 150/280 WITH AN OSB PLATE

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Summary: *Trapezoidal sheet metal is used in contemporary building practice mostly as a roofing of industrial objects. The sheet metal is mounted over purlins, and thermal insulation and final roof cladding is spread over the metal sheets. Increase of the purlin distance requires increase of strength and stiffness of the sheet metal. This can be achieved by selecting of sheets with greater thickness or depth. Instead of this, the sheet metal can be strengthened by making composite structure with other sheet or with plates made of different material. In the paper, the case without composite action between sheet metal and OSB plate, and the case with full shear connection are analyzed. Sheet metal strength with and without strengthening was determined using FEM analysis.*

Keywords: *Trapezoidal sheet metal, OSB plate, strengthening, FEM*

1. INTRODUCTION

During the design of the industrial buildings in modern practice, in most cases is used trapezoidal steel sheet as a roofing. In order to overcome larger span and thus reduce the number of purlins, it is necessary to increase strength of the cross section. It is achieved by increase of the section depth or by increase of the sheet thickness. The sheet with the max. depth in Serbia is TR 150/280, and it is currently manufactured in two factories (Pankomerc Požega [1] and INM Arilje [2]), while in Europe, it is manufactured in several factories. Sheet thickness ranges from 0.5 to 1.5 mm.

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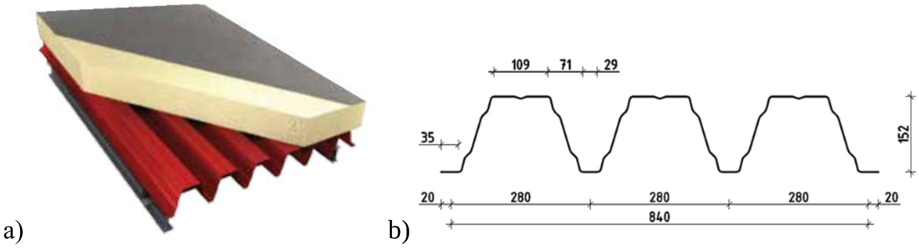

Fig. 1. Trapezoidal sheet 150/280; a) detail of the ceiling of modern industrial objects (TR sheet, thermal insulation and roof cladding) [1], b) geometry.

Plates made on wood base for lightweight ceilings are used mostly in the USA [3]. They are mounted so that the plates are set over lightweight girders made of thin-walled cold-formed steel profiles and join by self-tapping screws. During the design of such structures, it is assumed that the profile and the plate are not joined firmly, but the plate is rested freely on the profiles. By examining of such ceilings [4], it was concluded that the screws transmit the shear to a large degree, and the ceiling has significantly higher strength and stiffness, because it behaves like composite structure.
The problem that occurs at trapezoidal sheets is orthotropy. Because of that, the sheet is behaving as a one-way slab, while the strength in the perpendicular direction is negligible. During the acting of a concentrated load on the sheet, only the loaded web is activated. At two-way slabs, the stress distribution in the slab is much more favourable. Ahmed et. al. [5] used plates made of chopped wood with binder based on cement, with thickness of 16 mm, for composite action with the sheet. The plates are joined by self-tapping screws. The concentrated load is in this case spread on surrounding webs, whereby a considerably higher strength is achieved. Besides the improving of the properties during the acting of the concentrated load, a much better behaviour of the girder during acting of distributed load is also evident [6]. A similar investigation was conducted by Awang and Wan Badaruzzaman [7], who used Prima*flex* plates 9 mm thick instead of the cement plates. The Prima*flex* plates are made of a mixture of cellulose fibers, Portland cement, and fine sand. They are resistant on atmospheric influences and fire.
Plywood is made by cross gluing of veneer, so it has good properties in both directions. Because of that, it is suitable for strengthening of trapezoidal sheets. Li et. al. [8] have been examined girders made of two plywoods 10 i 25 mm thick, joined by cold-formed C profiles 1 mm thick. Strength depletion arose at all models due to the buckling of the steel profiles. In case that the composite girder sheet-wood is applied as a final roof cladding, it is more favourable that the plate is set under the sheet. Islam et. al. [9] have examined simply supported beams made by composite action of a plywood 12 mm thick and roof sheet 0.56 mm thick. Since the support reactions are transferred through the plywood, the sheet buckling does not arise at the supports, but failure ocurrs due to the strength depletion of the section in the midspan. Strength is increased more than 50 % regarding the strength of the sheet without strengthening.

Fig. 2. Bending test of a roof sheet with plywood under [9]

Beside the cement and Prima*flex* plates, steel profiles can be coupled with other products based on wood, too. Research was conducted on composite beams made of steel cold-formed C profiles and plates based on wood, like chipboard [10, 11, 12]. Profile depth was varied ranging from 220÷300 mm, and the profile thickness ranging from 1÷3 mm. The wooden plate was 38 mm thick and 600 mm wide. Self-tapping screws were used as fasteners. The theory of elastic coupling was used for describing of the behaviour of the girder. Wooden plates have limited dimensions, smaller than girder span, and they must be spliced. In the splicing zones, discontinuities occur, and because of that, the plate is not activated in its full capacity, which requires special consideration. The depletion of strength occurs in all models due to buckling of the steel profiles.
All previous examinations were done on beam models, because it was assumed that the slab has much higher stiffness in the girder span direction, and that it transfers the load in one direction. The slab girders are most common in practice for this type of structures. Becuse that, the examinations of the slabs made of thin-walled C profiles coupled with an OSB plate above were done [13]. The samples with dimensions at base 2400×4800 mm were made. The profile thickness was 1.6 mm, and depth 305 mm. The thickness of the OSB was varied (12÷18 mm), as well as the gage of the fasteners (100÷300 mm).
Coupling of the open and deep thin-walled profiles and plates based on wood can produce high structural strength. Due to the large depth and small thickness of the C profile, the failure occurs mostly due to the buckling of the profiles at the supports or in the midspan [12], while at the same time the stress in the wooden plate within elastic range. In order to avoid buckling, transversal stiffening can be provided.

Fig. 3. Composite plate made of cold-formed C profiles - workmanship and testing [13]

Trapezoidal sheets have smaller depth than C profiles, so buckling is less prominent. Due to the large distance between the C profiles in the tested girders, a smaller plate width is activated, and the average axial force in the plate is decreased. Webs of the trapezoidal sheet are set at smaller mutual distance than the C profiles are. Because of that, the stresses in the webs are lower, and the axial force in wooden plate is more even.
In this paper trapezoidal sheet TR 150/280, 1 mm thick, was analyzed. First, an analysis of the sheet without strengthening was conducted, and then an analysis with strengthening by an OSB plate. The strengthening is performed in two ways: by setting the OSB plate over the sheet, without fastening, and with fastening. The plate used was OSB/3, 15 mm thick, which is the most common on Serbian market.

2. STRENGTH OF THE SHEET TR 150/280

The strength analysis was done using software FEMAP with NX NASTRAN. The model consists of two supports with a width equal to a purlin, trapezoidal sheet, and fasteners (screws) (Fig. 4). Bottom flanges of the sheet lie on the supports over 80 mm width. Between the sheet and the support plates, a contact region was modelled. The supports and the sheet are modelled using the PLATE FE [14], and the screws using BEAM FE. The screw diameter was 5 mm. The support is translatory restrained on one end, and free on the other, which corresponds to a simply supported beam.

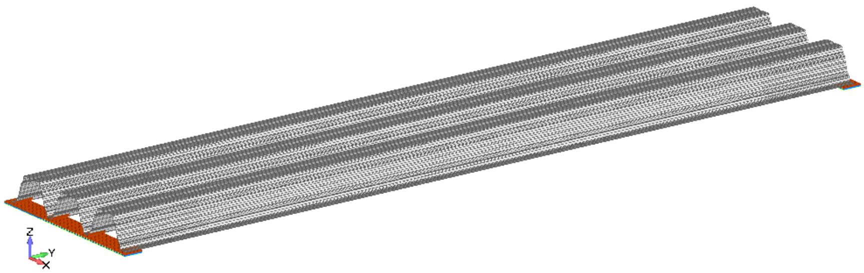

Fig. 4. FE model of the trapezoidal sheet with supports

Assumed steel material is S235. The material model is bilinear, with the modulus of elasticity E=210 GPa, yield point f_y=235 MPa, and plasticity modulus E_p=1% E. The FE mesh has higher density in the support zones, at length of 400 mm. In the support zones the FE size is 10 mm, and in the rest of the model is 20 mm. The load is applied on the top flanges of the sheet, with intensity that corresponds to the surface load of 10 kN/m^2 over the total covering surface (Fig. 6). The analysis was conducted with material and geometric nonlinearity (Advanced Nonlinear Static [14]). The load was applied incrementally, in 50 steps.
In order to reduce the model, an optimization was performed, using symmetry. One fourth of the model was used, with correspondent boundary conditions (Fig. 5). Analysis confirmed that the optimized model behaved identically as the whole model, so it was adopted for the further analysis.

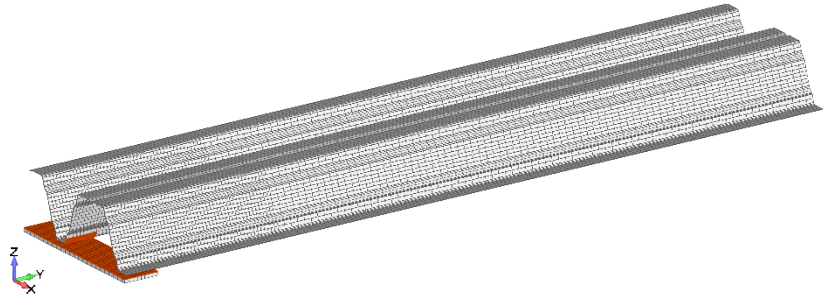

Fig. 5. Model of 1/4 of the trapezoidal sheet TR 150/280 – a double symmetry

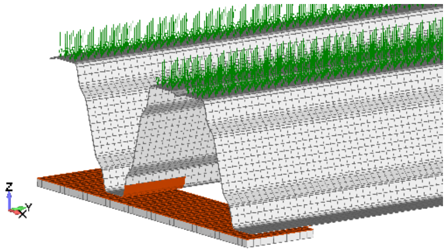

Fig. 6. Support details, contact regions, load

Analysis results for the max. load, and for the sheet without strengthening, are presented in Fig. 7. Stress concentrations occur in the support zones, and failure arises due to buckling at load of 6.925 kN/m^2.

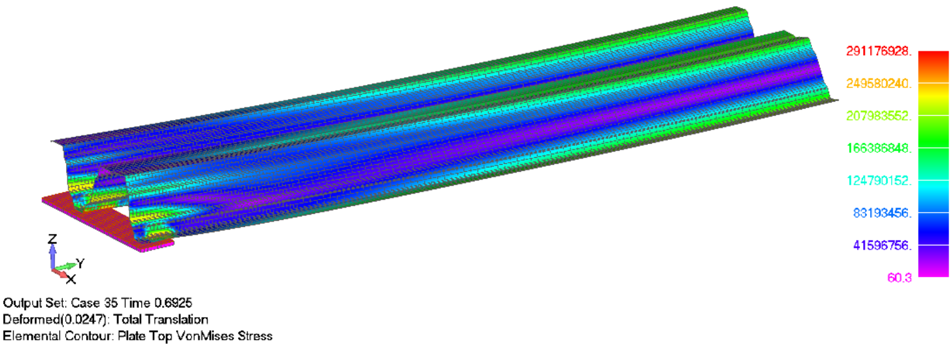

Fig. 7. Results. Ultimate load: 6.925 kN/m2, Total translation: 24.7 mm,
Von Mises stress: 291 MPa

3. STRENGTHENING USING OSB PLATE

The model of trapezoidal sheet with strenghtening was made by adding a 15 mm thick OSB plate (Oriented Strand Board) (Figure 8). The width of the plate is 840 mm, which corresponds to the covering width of the sheet. The board is modeled using the PLATE type FE. Between the upper flanges of the sheet and the bottom of the board, a contact is modeled in the same way as the contact between sheet and supports. The load with value of 10 kN/m^2 is applied to the OSB plate.

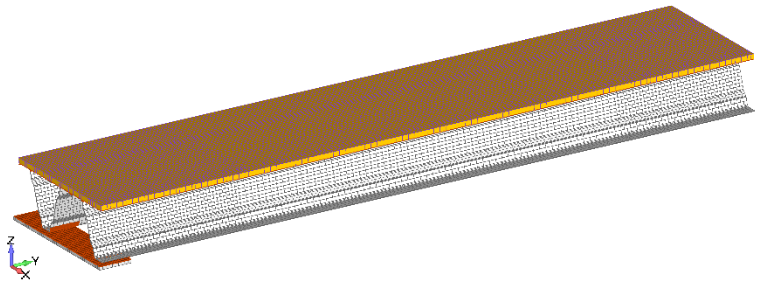

Fig. 8. FE model of the trapezoidal sheet TR 150/280 with OSB/3 plate

In the literature [15, 16, 17], the OSB characteristics are given by various authors. The mechanical properties of the plates were adopted from the Standard Eurocode (EN 12369) [18] as relevant. The OSB plate is anisotropic. However, in order to simplify the structure, an isotropic model was adopted. For both directions the characteristics given for the direction 0^0 are adopted. Because the stresses in OSB material are under limited values (Table 1 and Table 2), only elastic behavior is manifested. Therefore, a simple linear model was adopted.
Two models were created. On the first OSB board is added over the sheet without fixing. The connection was made only by contact. In the other case, the connection between the sheet metal and the OSB plate was achieved connection with 5 mm diameter screws, which are set in six rows (on each flange two), at a longitudinal distance of 100 mm. This arrangement should model the rigid connection of the sheet and OSB. The screws are modeled with BEAM finite elements.

Table 1. Mechanical properties of OSB/3

Property	Direction – angle [^{0}]	Value
Thickness [mm]	/	10÷18 (in this paper 15)
Bending strength [MPa]	0 / 90	16.4 / 8.2
Compression strength [MPa]	0 / 90	15.4 / 12.7
Mean stiffness (bending) [MPa]	0 / 90	4930 / 1980
Mean stiffness (compression) [MPa]	0 / 90	3800 / 3000

Geometric and material non-linear analysis were conducted and the results on the following contours were obtained. It can be noticed that stress concentrations occur in support areas, as well as in sheet metal without strengthening.

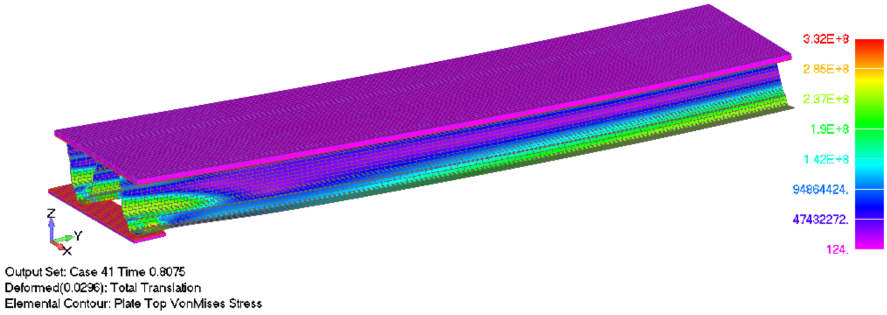

Fig. 9. Results. TR 150/280 + OSB (without connectors). Ultimate load: 8.075 kN/m2, Total translation: 29.6 mm, Von Mises stress: 332 MPa

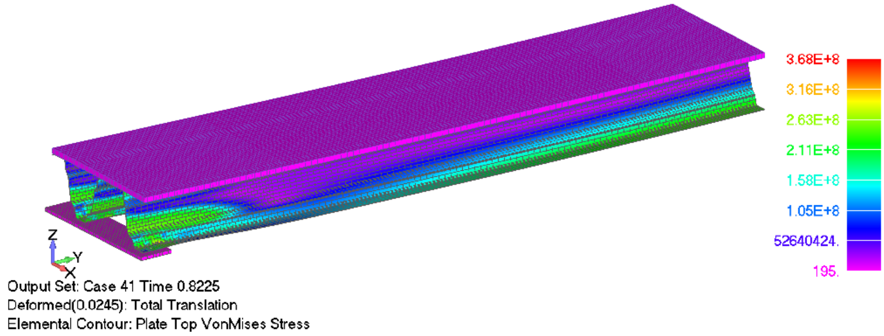

Fig. 10. Results. TR 150/280+OSB (with connectors). Ultimate load: 8.225 kN/m2, Total translation: 24.5 mm, Von Mises stress: 368 MPa

For structures that are not coupled, there is a slip in the coupling zone in the support zones (Fig. 11a). Due to the fixing of OSB plate sheets, there is no slip, and the pressure in OSB plate appears. It is interesting that the load capacity is slightly increased by coupling, even though the bending capacity is higher. This is because the fracture does not occur due to bending, but because of the buckling of the sheet metal on the supports, as well as in the model without strengthening.

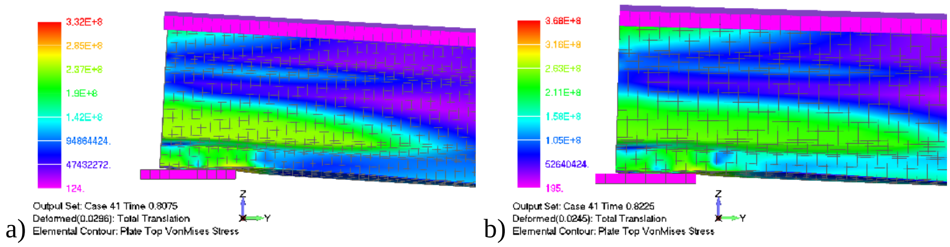

Fig. 11. Results. Ultimate load. a) Sliding in model with connectors (left – 1.36 mm), b) negligible sliding in model without connectors (right – 0.11 mm)

Table 2 shows the results for all analyzed models. The strength of the sheet strengthened with OSB plate is higher by an average of about 17% compared to the sheet without strengthening. In the diagram (Fig. 12), load-deflection curves for analyzed models are shown. Although, the carrying capacity of the coupled model is negligibly higher than the load capacity of the model without coupling, it is evident that the rigidity is higher by about 25% compared to the sheet metal without coupling, and about 30% compared to the sheet metal without strenghtening by OSB plate.

Table 2. FEA results

Model	p_{ult} [kN]	Strength increase [%]	Sheet stress [MPa]	Plate stress [MPa]	Sliding sheet-plate (at support) [mm]	z_{max} [mm]	L/z [-]
TR 150/280	6.925	-	291	-	-	24.7	162
TR 150/280 + OSB (without connectors)	8.075	16.6 %	332	1.47	1.36	27.6	145
TR 150/280 + OSB (with connectors)	8.225	18.8 %	368	4.12	0.11	22.5	178

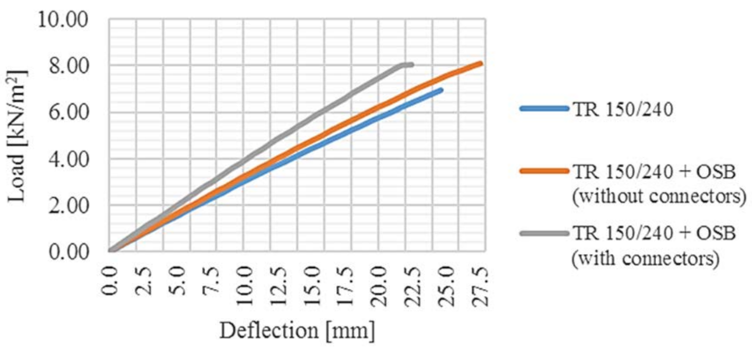

Fig. 12. Load vs. deflection diagrams, with and without strengthening

CONCLUSION

Coupling of an OSB plate and profiled sheets can be used for fabrication of lightweight ceilings or for strengthening of the existing roof structures of the industrial halls. The sheets with low depth can be strengthened. However, it is more favourable to strengthen the sheets with high depth like the TR 150/280. Regarding its depth, it already has relatively high strength. Setting an OSB plate over the sheet one also gets an even pad for laying floor or final roof cladding.

Significant increase of strength was noticed as by strengthening with OSB plate without coupling, as well as with coupling. Since bending strength was not governing at the analyzed models, the coupled and the uncoupled model differ insignificantly regarding their strength. Strength depletion arises due to buckling in the support regions, so those regions should be stiffened by inserting of wooden blocks or specially formed steel strips. Such solution is easy to apply during laboratory tests, but its application in practice is questionable because of large number of stiffenings that must be installed with precision.

Profiled sheets behave as an orthotropic plate. Setting an OSB plate over it and their mutual joining results with a plate with more favourable characteristics. Patch load that acts on a sheet without strengthening (e.g., a workman standing on the sheet) activates only a couple of webs in the immediate vicinity. If such load acts on an OSB plate set over the sheet, the plate distributes the load on the neighboring webs, so the stress state is more favourable.

Further investigations should determine behaviour of the uncoupled and coupled structure made of a profiled sheet and an OSB plate with various support width, span, and sheet and plate thickness. In addition, the possibility of strengthening of the support regions should be examined, which would lead to the more efficient use of the cross section across the girder length. This would give the design engineer much more extensive possibilities for roofs and ceilings, as well as for eventual sanations of the existing ones.

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ОЈАЧАЊЕ ТРАПЕЗНОГ ЛИМА ТР 150/280 ПОМОЋУ ОСБ ПЛОЧЕ

Резиме: *Трапезни лимови се у савременој грађевинској пракси користе најчешће за покривање индустријских објеката. При томе се преко рожњача постављају табле лимова, а преко њих термоизолација и завршна облога крова. Са повећањем размака између рожњача јавља се потреба за повећањем носивости и крутости лима. Већа носивост и крутост се може постићи усвајањем лима са већом дебљином или висином. Уместо тога, лим се може ојачати спрезањем са другим лимом или плочама од различитих материјала. У раду су анализирани случајеви када нема спрезања лима и ОСБ плоче, и случај када је остварено круто спрезање. Носивости лимова са и без ојачања су одређене помоћу МКЕ анализе.*

Кључне речи: *Трапезни лим, ОСБ плоча, ојачање, МКЕ*