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Comparison of a load bearing capacity for composite sandwich plywood plates

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Abstract. **This article shows numerical investigations of composite sandwich plywood plates with birch plywood faces and a core of straight and curved plywood honeycomb-type ribs in comparison to standard plywood plates and other core type plates.**

This shape of core ribs provides several improvements for these plates in manufacturing process as well as mechanical properties.

The influence of core element shapes on stiffness in longitudinal direction of a plate is insignificant although it is possible to vary with stiffness in transverse direction of these plates by changing form of plate's ribs. The results are describable as specific strength or stiffness (stiffness to mass or strength to mass ratio etc.) in both directions.

The various results depending on chosen variables (according to strength-stiffness criteria) plywood composite macrostructure is obtained for one span plate with uniformly distributed loading. The results show that it is possible to reduce material consumption causing reduction in stiffness but in general increasing stiffness to weight ratio for about 30% or even more if it is possible to increase height of a plate more than maximum standard plywood plate.

All thicknesses of elements are chosen according to plywood supplier assortment.

A various thicknesses of plywood sheets (0/90/0+90/0·n) are taken for straight ribs as well as various plates coverings for waved part of ribs the 3 layer plywood was taken (90/0/90) or (0/90/0) due to simplification of manufacturing process.

For all parts of plate were Birch plywood plates used, as well as reference plywood were Standard Birch plywood plates chosen.

Keywords: **Composite plywood plates, sandwich structures.**

I INTRODUCTION

It is actual as much as possible to use renewable resources and one of these is wood. Although they are environment friendly materials by increasing demand we should plan how we could save even more materials by using them rationally where they are used in greater amounts.

The consumption of wood products is increasing last few decades although the sawn wood production is decreasing [1]. The wood based panels become more significant in constructions as well as other wood based structural elements. Plywood is one of the most common wood based secondary (transformed) used materials and its consumption (and production) is increasing over past decades especially in area of Asia [2], [3].

Although the use of material in plywood structure is improved some problem still remains. The normal stresses in middle part through plate's thickness are low (Fig. 1) so the material is not rationally used. It is possible to reduce material in middle layer of a plate to make traditional "sandwich" core material. The faces' materials have the main influence on plates stiffness while the core material to the shear properties.

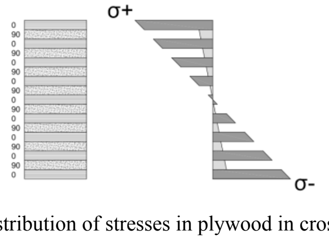

Fig. 1. Distribution of stresses in plywood in cross section (methodology of calculations according to LVS ENV 14272)

We cannot reduce this material unreasonable due to shear stresses that should take the middle part of a plate, like it is in "traditional" sandwich structures (Fig. 2).

If the plates are subjected to bending it is not allowable to unreasonable reduction of material as the shear stresses (τ) increases.

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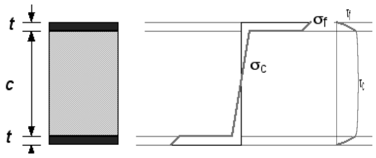


Fig. 2. Stress distribution in sandwich structures (faces with high stiffness and core with low stiffness) [4]

It is experienced that the bearing capacity for all parts (faces and core) is solved in previous research by using different materials or cross sections for each part of a plate. Although the problem with serviceability limit state still remains (it is the determinant for these plates) as it is taken for this research main problem to be solved.

II RESEARCH OBJECT

In recent doctoral thesis [5] [6] the idea of honeycomb-type sandwich plates are already provided, but with low level depth of detail. And used plates are complicated for manufacturing of curved hollow ribs. So the new type of plates [7] [8] is provided with thin curved rib parts and multiple thicknesses for straight rib parts and faces of plates. (Fig. 3) These plates require more complicated manufacturing since there are different layers to assembly, but this process should be mechanized to make it simpler, efficient and safer. Thereby for high amount of manufacturing these plates could be established in building, mechanical and furniture engineering.

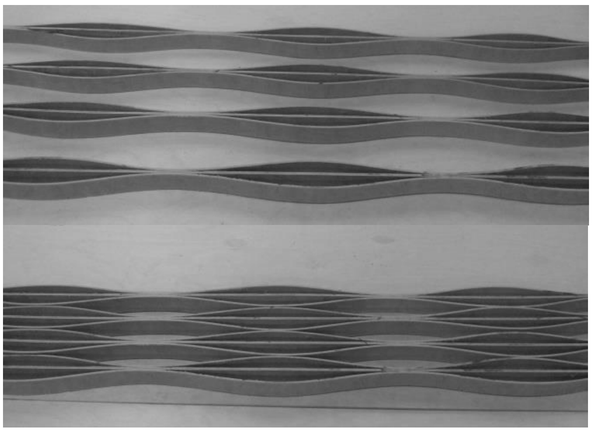


Fig. 3. Assembly of composite plywood plate with cell-type core. Bottom only one face layer shown.

The main advantages for such plates are ability to save material and energy due to improved stiffness properties, improved stability, increased shear strength and simplified technology comparing to plates with straight rib core.

The influence of geometrical parameters was previously investigated [9] so in this paper the case study was presented.

The most influence of stiffness has the height of a plate (h), so it was chosen as one of changeable parameters to see the plate's properties at various heights.

All these problems could be reduced by using such plates with previously mentioned new type of core layer.

The geometry of ribs allows to improve properties in other direction (transversal to the longitudinal direction) of a plate when we the deflection of both directions of a plate should be improved.

III RESEARCH METHODOLOGY

These plates could be compared to standard plywood plates as they can carry load in longitudinal and transversal directions and they provide good properties in both directions. The dominant for this type plates is the serviceability limit state therefore it is taken as a major problem in this paper.

For the case study the plate with dimensions of 2.1 m span in longitudinal direction and 1.1 m span in transversal direction was chosen. Although it is proved that dimensions and other geometrical parameters make influence on plate's stiffness and specific stiffness [9].

The research is based on bending behavior of these plates. Main results will show the comparison of stiffness, specific stiffness (stiffness-to-Weight) or load bearing capacity of these plates.

For large displacements non-linear calculations are required but they are not described here. The maximal service load was calculated to assume that

The plates were loaded with uniformly distributed load which is the most common loading type. For calculation and extrapolation the load with intensity of 1 kN/m^2 was used.

As the height of the plate is considerable larger than the span of a plate the influence of shear deformation is not separated from bending deformation.

A. *Used symbols for research*

Table I

The mainly used symbols

	Symbol	Units
Span of a plate	L	m
Width of a plate	B	m
Height of a plate	h_{plate}	m
Service Load	SL	kN; kN/m^2;
Ultimate Load	UL	kN; kN/m^2;
Dead Weight	DW	kg

B. *Stiffness in longitudinal direction*

For these plates most common limitation is 1/200 of a span, so all the serviceability loads and conditions were calculated with this limitation. And the different plates compared with achieved results for this limitation.

As it was proved earlier [9] the influence on stiffness and specific stiffness in longitudinal direction is not dependent on width of a plate.

C. Stresses

Bending stresses were analyzed in three parts of a plate. Longitudinal stresses in faces of a plate (σ_l; σ_t), longitudinal stresses in all parts of a rib.

The factors for determination of design plywood bending strength are taken according to EN 1995-1-1 [10] with the characteristic values from Riga ply supplier catalogue [11]

$$f_{m,d} = \frac{k_{mod}}{\gamma_M} f_{m,k}$$

k_{mod} – is a modification factor taking into account the effect of the duration of load and moisture content (for plywood in 1 or 2 class - 0.6)
γ_M – is the partial factor for a material property (for plywood - 1,2)
$f_{m,k}$ – is the characteristic value of bending load-carrying capacity; (for 3 ply 4mm plywood - 52 MPa in tension)

D. Used material and FEM data

Material properties applied for birch plywood of one ply sheet Fig. 4 [12] are summarized in Table 1. It is assumed that the ply has the same properties as sawn wood material.

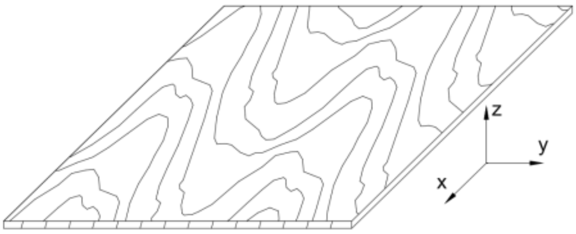


Fig. 4. Three principal axes of wood with respect to grain direction and growth rings. (x – longitudinal; y – tangential; z – radial) [13]

As these plates could be used as interior and exterior elements they should provide water-resistant properties according to EN 636 and EN 314 Class 2 (for internal use as structural component in humid conditions) the same class 2 according to EN 1995-1-1 [10].

The index at E shows the property in corresponding direction, for the Poisson's ratio the first index shows the extension direction as the second shows contraction's direction.

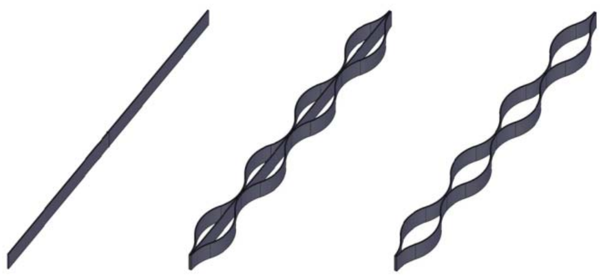
Plywood stacking sequence has been modelled assuming that each layer is perpendicular to the upper and lower one, as plywood consists of an odd number of plies. In this paper three layers plywood was taken for all parts of a plate with total thickness of one plywood sheet of 4.0 mm. It has been assumed that each ply has same thickness of 1.27 mm and transversal isotropic material properties (see Table II.). For waved ribs constant thickness was taken and various thickness of straight rib, from 3 layer to 15 layer according to standard birch plywood (Latvijas Finieris 2005).

Table II

Properties of birch wood

	Symbol	Value
Modulus of elasticity in longitudinal direction [GPa]	E_x	16.4
Modulus of elasticity in tangential direction [GPa]	E_y	0.68
Modulus of elasticity radial direction[GPa]	E_z	0.68
Poisson ratio xy	μ_{xy}	0.04
Poisson ratio yz	μ_{yz}	0.81
Poisson ratio xz	μ_{xz}	0.043
Shear modulus in xy plane [GPa]	G_{xy}	0.89
Shear modulus in yz plane [GPa]	G_{xz}	0.23
Shear modulus in xz plane [GPa]	G_{yz}	1.54
Density [kg/m^3]	ρ	715

Three types of ribbed plates were analyzed and compared to standard plywood and to plates with straight ribs [14]. With only straight ribs (Fig. 5 A); straight ribs and curved ribs (Fig. 5 B); and only with curved ribs (Fig. 5 C); For direction of curved ribs orientation same direction as the plates longitudinal direction was taken (∥) or transversal to plates longitudinal direction but in direction of plates height (⊥). For the symbols the first index shows the type of the rib (whether or not with straight rib part) while the second index shows the orientation of curved rib part. the detailed explanation is summarized in Table III.



A - **r** B - $\tilde{\mathbf{r}}_I$ C - $\tilde{\mathbf{r}}_{II}$

Fig. 5. Three types of ribs analyzed (A – flat rib; B – flat and curved rib; C – only curved rib)

Table III

Symbols of plates

	Reference in Fig. 5 Fig. 8	Symbol
Standard plywood		**PW**
Only straight ribs*	A	**r**
Straight ribs* and waved ribs* (outer layers fiber direction same as panel and rib longitudinal direction)	B	$\tilde{\mathbf{r}}_{I,\parallel}$
Straight ribs* and waved ribs* (outer layers fiber direction transversal to panel and rib longitudinal direction)	B	$\tilde{\mathbf{r}}_{I,\perp}$
Only waved ribs* (outer layers fiber direction transversal to panel and rib longitudinal direction)	C	$\tilde{\mathbf{r}}_{II,\parallel}$
Only waved ribs* (outer layers fiber direction same as panel and rib longitudinal direction)	C	$\tilde{\mathbf{r}}_{II,\perp}$
* Thickness for each rib part 4mm		

IV RESULTS

In this paper the both limit states are analyzed although as mentioned before for such type structures in the mostly cases the decisive is the serviceability limit state so the main results were achieved for it. The results were obtained for one span plate

For comparison specific values (bearing capacity to weight) were used so the influence is dependent not only from mechanical properties but also from dead weight changes (Fig. 6) If we compare only the dead weight, it is seen that material consumption for increasing plate's height similar for ribbed plates (about 15%) while for plywood it increases for about 67 % when the height is increased from 3 cm to 5 cm.

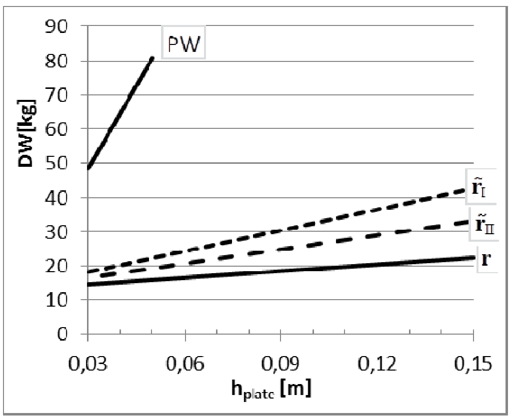


Fig. 6. Dead Weight (DW) comparison for different type of plates. (Symbolical meaning see Table III).

A. Serviceability limit state

For these plates most common limitation is 1/200 of a span, so all the calculations were done at this level and was assumed that material is loaded in linear stage of a material. The results show that Service Load is increased for the I type of plates as there is more material in core layer Fig. 7.

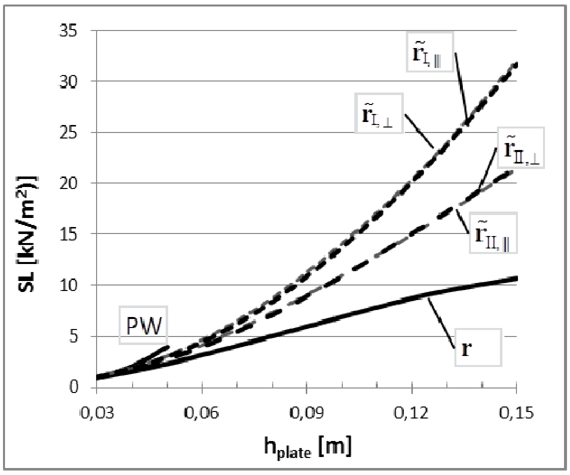


Fig. 7. Maximal Service Load (SL) for different type of plates. (Symbolical meaning see Table III).

Although by comparing Service Load to dead weight results show similar properties.

These results were summarized in Fig. 9 for each height that was analysed. It is seen that by lower height of a plate the straight ribs has larger specific stiffness as the SL_{max}/DW is larger. Although by increasing height of a plate the advantages of cell type plates becomes more significant.

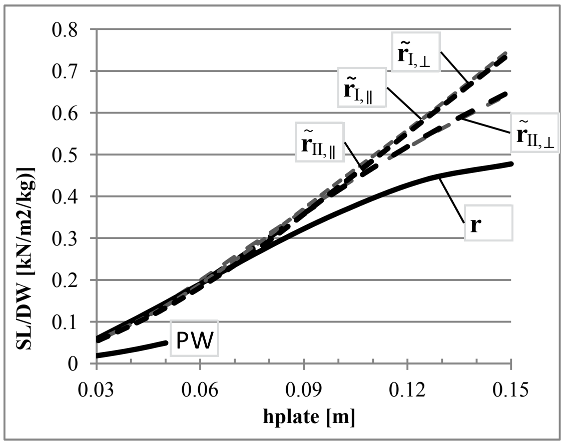


Fig. 8. Maximal Service Load (SL) to Dead weight (DW) for different type of plates. (Symbolical meaning see Table III).

By comparing plywood and ribbed structures it is achieved that dead weight decreases for 70% in average while the stiffness decreases for 30 % in average. So it was analysed 35 mm plate and compared to 35mm plywood. And as a result it was achieved that for achieving the stiffness that has the 35 mm we should increase height of a plate to 45mm Fig. 10 and Fig. 11.

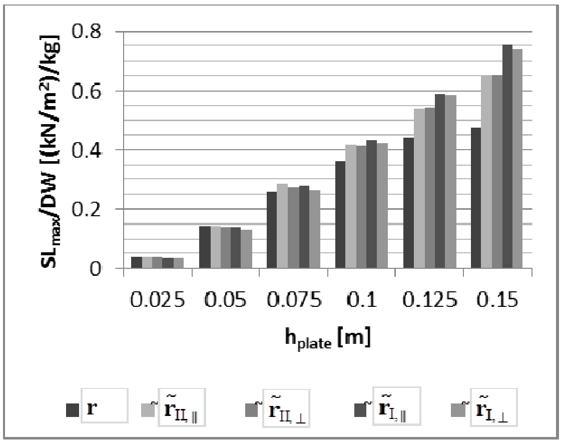


Fig. 9. Maximal Service Load (SL) to Dead weight (DW) for different type of plates. (Symbolical meaning see Table III).

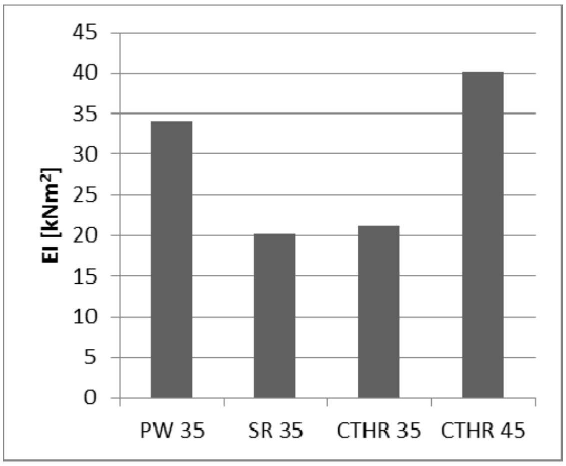


Fig. 10. Comparison of stiffness for different plates. (Symbolical meaning see Table III).

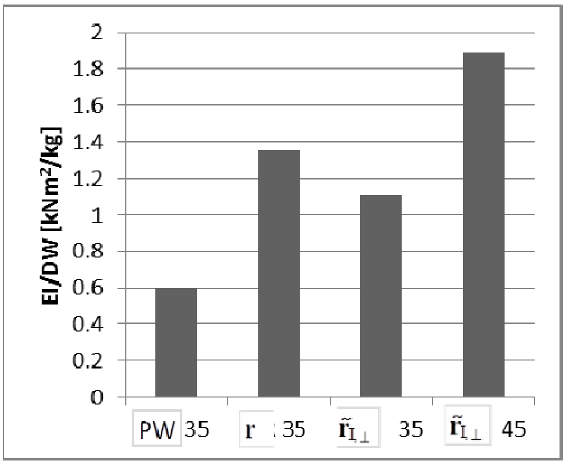


Fig. 11. Comparison of stiffness-to-mass ratio for different plates. (Symbolical meaning see Table III).

Comparing cell-type ribs to straight ribs provides easier technology and resists to local deformations that occurs with thin faces of plate.

B. Ultimate limit state

For the comparison of stresses for the same plate dimensions normal stresses in plate's faces were analyzed.

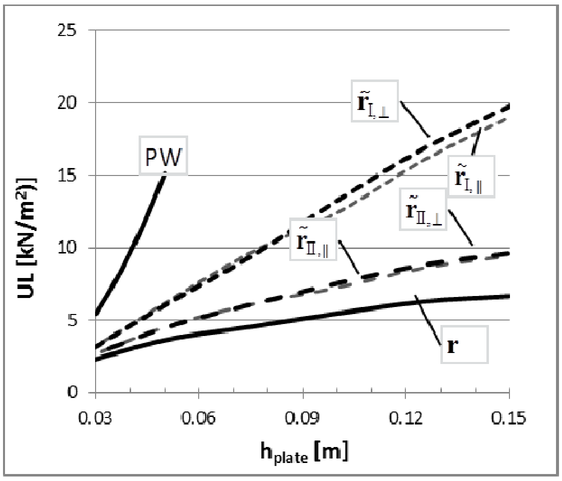


Fig. 12. Maximal Ultimate Load (UL) for different type of plates. (Symbolical meaning see Table III).

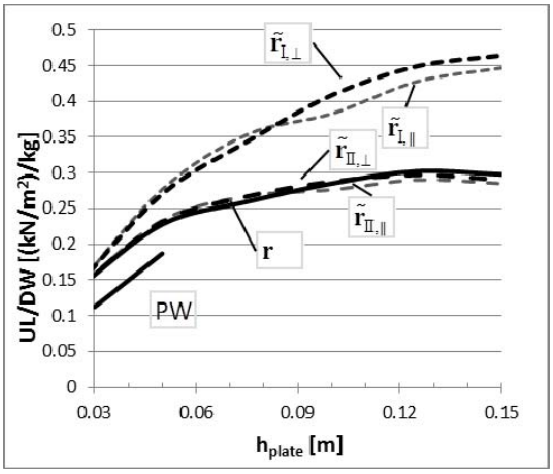


Fig. 13. Maximal Ultimate Load (UL) to mass for different type of plates. (Symbolical meaning see Table III).

We can see that also for Ultimate load the highest strength from ribbed plates show I type plates (Fig. 12) only plywood shows highest strength. That still remains for the UL/DW ratio only here Standard plywood shows the lowest ratio comparing to other plates Fig. 13.

By increasing height of a plate more than 10 cm 1/200 the shear stresses and deformation should be taken into account as they become more determinant. Therefore by increasing plates height the orientation of waved ribs' outer layers transversal to plates longitudinal axis are more sufficient, although it reaches maximum at some point where the increase of plate's covering is needed due to overloaded plate's skins.

The stress-deformation plot is seen in Fig. 14. It is seen that straight ribs show the highest stress-deformation ratio.

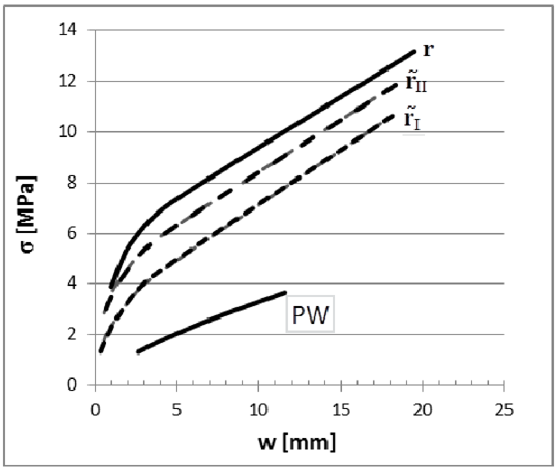


Fig. 14. Stress-deformation plots for different type of plates. (Symbolical meaning see Table III).

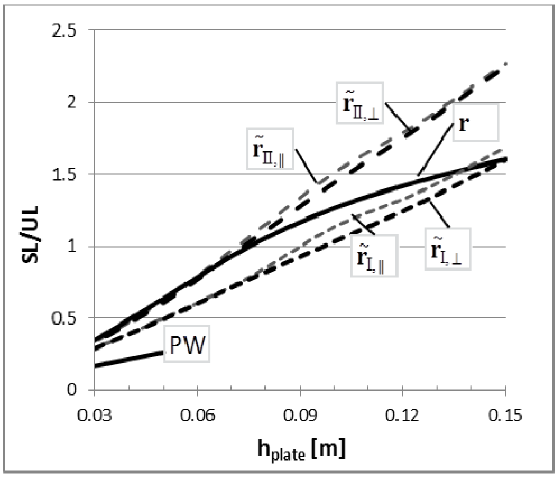


Fig. 15. Service Load-to-Ultimate Load ratio depending on the Height of a plate (Symbolical meaning see Table III).

In Fig. 15 we can see how much is used material in comparing both limit states (SL and UL). It is seen that it is different for different type of plates. For plates with straight ribs up to plate's height h_{plate} 7cm it is similar to II type plates but by increasing the height more we achieve that the determinant becomes the Ultimate Limit State becomes determinant for design. The similar trend could be seen for I type of plates although this point where the Ultimate Limit State becomes determinant is at larger plate's height.

By using this chart it is possible to optimize and choose geometrical parameters of the plate for required load to fill the maximum load conditions in both limit state SL/UL ratio equal to 1. Where it is needed could be varied by thickness of plate's faces or the straight rib.

V FUTURE RESERACH

A physical tests should be done for such plates and improved technology of gluing process that provides possibility to ensure pressure 5-15 kg/cm^2 (70-150 psi) like it is used for glued wood structures [15].

The bending properties in transversal direction should be detailed analyzed as they can show more advantages to plates with only straight ribs.

The use of other materials could be considered at some parts of a plate.

VI CONCLUSIONS

By using such plates it is possible to equal the bearing capacity for Ultimate limit state and Serviceability limit state so that the material is used for the same level in both of the Limit states.

Provided type of plates shows improved bending properties that allows to decrease material consumption for 70% at 30% of stiffness decrease that gives possibility to increase stiffness-to-weight ratio for up to 100% by keeping all requirements.

Where it is possible to increase plate's height for 30% the improvement in stiffness reaches up to 100% and keep increasing by even more increase of height.

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