DE GRUYTER OPEN

International Conference KNOWLEDGE-BASED ORGANIZATION
Vol. XXI No 3 2015

STRUCTURAL EFFICIENCY OF COLD-FORMED STEEL PURLINS

Vlad CUCU, Daniel CONSTANTIN; Dan-Ilie BULIGA

Military Technical Academy, Bucharest, Romania,
cucuvlad@gmail.com

Abstract: *Cold-formed steel structures represents an alternative to classic buildings made of hot rolled steel profiles which bring a lot of savings based on advanced calculations and also some practical measures in order to provide optimum strength and weight ratio.*
Due to these advantages, cold-formed steel structures are used in more technical fields including automotive industry, storage industry, military sheltering and of course building industry.
The paper is focused on the economic impact of using lightweight members for the main applications of these structures – roof structures and cladding support. The comparison will be made between classic system with hot formed purlins and advanced lightweight purlins made of cold-formed steel elements, in the same practical situation.

Keywords: cold-formed, lightweight, buckling

1. Introduction

In order to prove the structural efficiency of cold-formed steel structures, will be studied the most used situation – members subjected only to bending and shear force as secondary structural roof members as purlins and side rails to support the roof sheeting and the vertical claddings of low to medium rise buildings. Is very important to specify that the efficiency of the system, reaches higher levels for low to medium standard spans (5-7.50 m), for longer spans the classic solution (hot rolled) is more efficient but without taking into consideration trusses (which can be also made of cold-formed steel elements).

Cold-forming process uses high strength steel with yield strength ranges from 280 to 450 N/mm^2 in comparison with hot rolled technology which uses in the most of cases steel grades as S235 and S355 with yield strength of 235 and 355 N/mm^2.

The design rules on section capacities for cold formed steel sections can be found in various codes of practice [1-2], because are used different approaches of capacity in comparison with hot rolled steel members.

For achieving the performance of cold-formed steel sections, special attention should be paid against losing the stability of the members which are more slender compared to hot-rolled, because of their wall thickness (ranging from 1.2 to 3 mm).

2. Practical use of steel purlins

Purlins are used as secondary roof members which must support the cladding against the action of the wind and the snow load. The most used shapes of steel purlins are C and Z sections for cold-formed solution and IPE (European I beam) and UPN (European standard channels) as hot rolled Euro Profiles.

In practice there are different configurations depending on the degree of continuity as *single span, double span, multi-span with sleeves* and *multi-span with overlaps.*

DOI: 10.1515/kbo-2015-0137

When using hot-rolled steel purlins only first 3 configurations are available because the overlapping is not possible regarding the section shape and its thickness. In comparison the 4th configuration is the most popular used in case of cold-formed members because of its advantages as high level of continuity between members, ease of transportation and effective stacking.

For a long member with intermediate supports it is known that best results are obtained when using a continuous beam instead of using simply supported beam because the large mid span moment for simply supported beam would be reduced due to negative end moments. Now, since we design for the maximum bending moment value (which would be lesser in continuous beams), it would ultimately be more economical than a simply supported span. For a particular section, the load carrying capacity would be large for a continuous beam. Also the scope for redundancy is an important feature in continuous beams which helps to ensure safety in conditions of large loading or settlement of supports.

2.1. Basic configurations in achieving the continuity of the beam

Once the purlin configuration is chosen, a special attention should be paid regarding the continuity connection between individuals beams because the moment transfer between members depends on the degree of continuity achieved using various connection elements.

For hot rolled solution the continuity can be achieved by using steel cleats beyond the maximum bending moment zone, so the connection will be made in a safe area.

In comparison with hot-rolled purlins, those made of cold-formed sections must be connected on the joint area not along the span because there are developing important internal forces and they are subjected of losing the stability – so the connection between inferior rafter and continuous purlins provide an extra support for the beam. Also the load carrying capacity of these purlin systems depend on the steel grades, the restraints provided by roof sheeting and intermediate bracing connections in order to ensure a shorter buckling length.

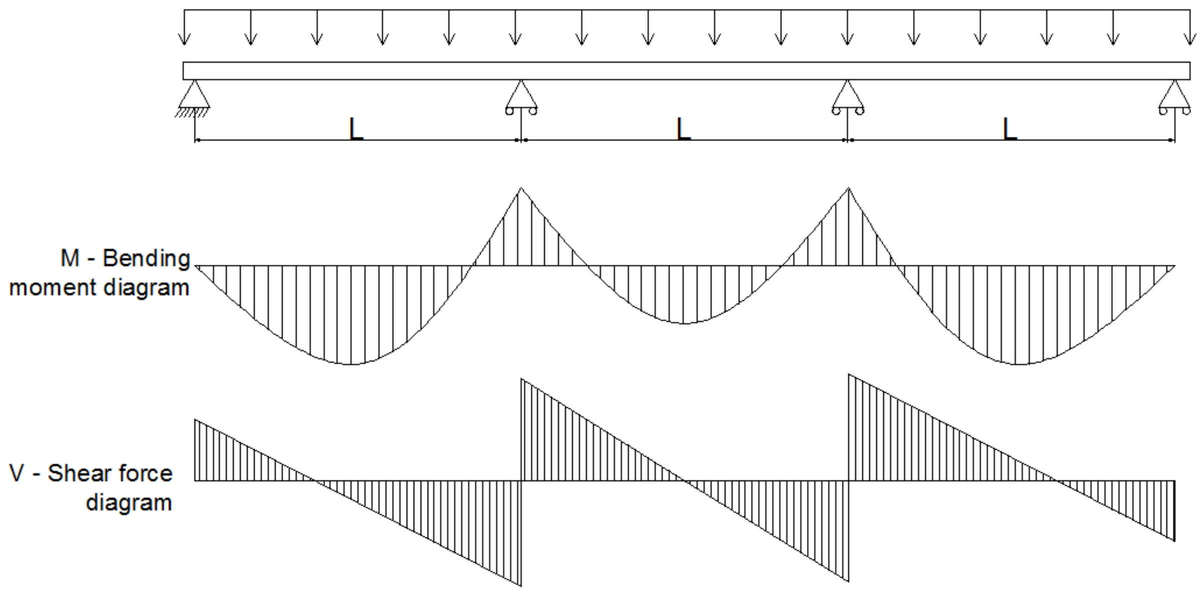
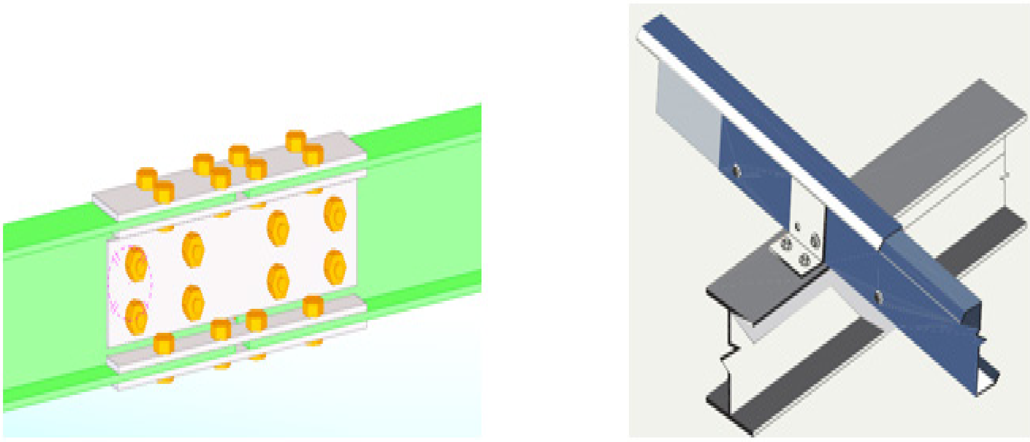


Figure 1: Continuous beam and efforts diagrams

In case of using hot-rolled profiles no sheeting interaction is needed, the cladding will be take into account only as a load, in comparison with cold-formed purlins where

this interaction provides additional stability and intermediate lateral supports which decrease the buckling length of the purlins.
The continuity joint between beams can be made by using steel cleats and gussets in case of hot-rolled and cleats or only bolts for lapping cold-formed purlins as in the pictures below.

For the same snow load of **1** kN/m^2 and a dead-load from sheeting of **0.4** kN/m^2 of roof we will have a design load of about **2** kN/m^2 (considering the Ultimate Limit State combination of actions).
Materials used:
IPE 120 – S355 grade with a yield strength of 355 N/mm2, (f_{yk}=355 N/mm^2);



b)

Figure 2:Continuity joints; a) Hot-rolled; b) Cold-formed

3. Practical design situation

In order to make a fair comparison we consider a continuous beam with 4 equal spans of 6.00 m, in first case this is made of an IPE 120 and in the second case we consider a cold-formed steel section Z200x1.5 shape.
The roof elements are disposed as in the picture below

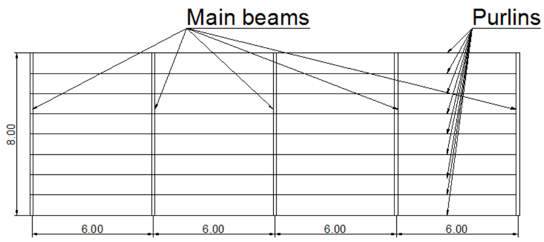


Figure 3: Roof disposal plan

The advantage of hot-rolled is that we can dispose fewer continuous beam in order to cover the same roof area (the distance between purlins can be greater than the cold-formed solution).

Z200x1.5mm – S350 (f_{yk}=350 N/mm2)
Both steels have the Elastic Modulus E_s=210 kN/mm^2.

3.1. Hot-rolled purlins

Distance between purlins 2.00 m
Tributary load distributed for 1 m of purlin – 4 kN/m.
Self-weight of the purlin – 0.104 kN/m.
The design of purlins was made by using a finite element calculation program. In this case all members were discretized as linear elements with the same Elastic Modulus along the continuous beam.

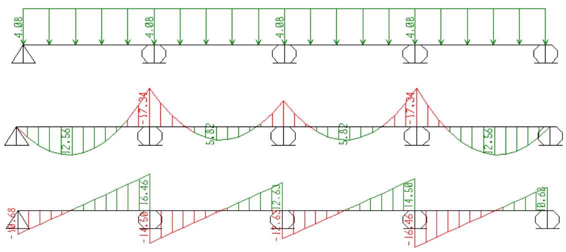


Figure 4: Design load assignment, bending moment and shear force diagram

Checks made for safety use of purlins:
Against maximum bending moment using the equation:

$$\sigma = \frac{M_{max}}{W_{el}}$$

where M_{max} (17.4 kNm) is the maximum bending moment, W_{el} (52960 mm^4) is the elastic strength modulus and σ is the unitary tension stress.
In this case the tensile stress σ is about 328 N/mm^2;
Against maximum shear force using the equations:

$$\frac{\tau_{Ed}}{f_y/(\sqrt{3})} \leq 1 \quad \text{and} \quad \tau_{Ed} = \frac{V_{Ed}}{A_w}$$

Where τ_{Ed} is tangential tension, V_{Ed} is the design shear force (16.50 kN) and A_w is the shear web area (472.50 mm^2)
τ_{Ed}=34.92 N/mm^2

$$\frac{34.92}{350/(\sqrt{3})} = 0.172 \leq 1$$

Regarding its sections properties, is a section class 1 (which can form a plastic hinge with the rotation capacity required from plastic analysis without reduction of the resistance).
Conclusion – the section correctly designed.

3.2. Cold-formed purlins

Distance between purlins 1.00 m
Tributary load distributed for 1 m of purlin – 2 kN/m.
Self-weight of the purlin – 0.044 kN/m.
In this case all members were discretized as linear elements with different Elastic Modulus along the continuous beam as in the scheme below:
According to [3], the level of continuity in lapped connections against bending depends on not only the load levels and the lap length to section depth ratios, but also the lap length to span ratios. The widely adopted assumption of '*doubled strength and stiffness'* in lapped connections is not correct at all.
Based on research of prof. K.F. Chung, the stiffness of the overlapping varies from 80% to 140% comparing to a single profile. The design with finite element method should take into account different rigidities for various sectors of the continuous beam and also *the overlapping scheme.*
Flexural rigidity reaches maximum level of 140% when the overlapping length gets higher than six times the height of the element section (for overlapping sections E=1.4 E_s).
Because the element is cold-formed from thin sheet of steel it is a Class 4 profile according to Eurocode 3 (cross-sections are those in which local buckling will occur before the attainment of yield stress in one or more parts of the cross-section).
Checks made for safety use of purlins:
Against maximum bending moment using the equation:

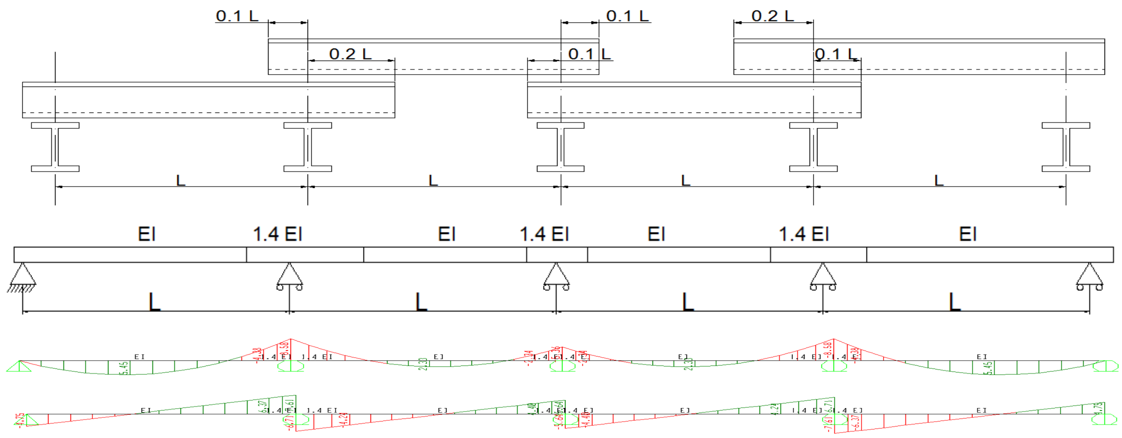


Figure 5: Overlapping scheme for cold-formed steel purlins; Distribution of flexural rigidities; Bending moment and shear force diagram

$$\frac{M_{\max}}{M_{b,Rd}} \leq 1 \quad \text{and} \quad M_{b,Rd} = \chi_{LT} W_{eff,y} \frac{f_y}{\gamma_{M1}}$$

where M_{max} is the maximum bending moment (negative and positive), W_{eff} is the effective strength modulus, obtained for the effective section taking into account the section geometry and its slenderness; f_y is yield strength of material (350N/mm^2) and χ_{LT} is reduction factor because of buckling.

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^2 - \bar{\lambda}_{LT}^2}}$$

$$\phi_{LT} = 0.5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - 0.2\right) + \bar{\lambda}_{LT}^2\right]$$

$$\bar{\lambda}_{LT} = \left[\frac{W_{eff} \cdot f_{yb}}{M_{cr}}\right]^{0.5}$$

α_{LT} is a coefficient that characterizes the level of section imperfections (0.21 in this case)

λ_{LT} is relative slenderness of the section

Φ_{LT} is the global imperfection regarding the deviation from the vertical axis

$M_{max, negative}$=8.58 kNm

$M_{max, positive}$=5.45 kNm

$M_{b,Rd, negative}$=9.25 kNm

$M_{b,Rd, positive}$=6.03 kNm

Against maximum shear force using the equations:

The shear capacity of the web will be the minimum value between $V_{b,Rd}$ and $V_{pl,Rd.}$

Where $V_{b,Rd}$ is the critical shear capacity of the section, $V_{pl,Rd}$ is the plastic shear capacity of the section, t is the thickness of profile (2mm),h_w – height of the web, f_{bv} is the critical shear stress , Φ is the angle between web and flanges - 90°, and γ_M material safety factor = 1.

$$V_{b,Rd} = \frac{\frac{h_w}{\sin\phi} \cdot t \cdot f_{bv}}{\gamma_{M1}} \qquad V_{pl,Rd} = \frac{\frac{h_w}{\sin\phi} \cdot t \cdot \frac{f_y}{\sqrt{3}}}{\gamma_{M0}}$$

In both cases the shear capacity of the section is up to 120kN, higher than the shear design force, about 6 kN.

4. Results of theoretical investigation

Based on the current configurations taken into account, we can concise that the lightweight purlin system is more efficient than the classic hot-rolled system.

For the designed situation the entire quantity of steel can be summarized in the table 1.

The differences between the studied situations is only 9% if using S355 and 26% if using S235 steel grade for hot-rolled purlins, but this advance could be major if instead S350 we use high strength steel S450 for cold-forming. Also the lightweight of the aggregate can bring another reduction for the main beams that will be lightweight in this situation. So on, other reductions

Table 1 Summary of steel consumption

	Theoretical situations			Efficiency of cold-formed against hot-rolled	
	Hot-rolled IPE 120 S355 grade	Hot-rolled IPE 140 S235 grade	Cold-formed Z200x1.5 S350 grade	Z200 vs IPE 120	Z200 vs IPE 140
Total length (including overlaps) [m]	120	120	259	9%	26%
Total weight [kg]	1248	1548	1139	-	-

The ratios between maximum bending moment and the capacity moment are 0.92 and 0.90 so the section is well chosen regarding the capacity against bending.

will be important regarding the columns and the foundations.

The total amounts of material reductions will overpass that 9%, being rational in this way to choose lightweight members instead of using hot-formed steel sections.

4. Conclusions

Depending on the level of actions, geometry of the structure (span, height, seismicity of the zone), weather conditions and other operating conditions the designer can choose between using cold-formed steel elements or hot-rolled ones in order to achieve the optimum level of material uses and embedded energy in fabrication, transport and fitting.

Acknowledgements

This paper has been financially supported within the project entitled "Horizon 2020 - Doctoral and Postdoctoral Studies: Promoting the National Interest through Excellence, Competitiveness and Responsibility in the Field of Romanian Fundamental and Applied Scientific Research", contract number POSDRU/159/1.5/S/140106. This project is co-financed by European Social Fund through Sectoral Operational Programme for Human Resources Development 2007- 2013. Investing in people!

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