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The Behaviour of Cold-Formed stiffened Channels Using ANSYS

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Abstract In this study, the behavior of cold-formed channels with flange lips and web stiffener steel sections evaluated using the developed technical means. The effect of lateral restraints of purlins of cold-formed sigma sections provided by the roof sheeting is investigated. Finite element analysis software ANSYS is incorporated for calculation to fulfill the accuracy, quickness, and easiness. Uniformly distributed loads are applied on the upper flange of the purlins downward. Connection of roof sheeting to the purlin provided lateral restraints to the purlins. ANSYS software provided a high ability for simulating the model of connection roof sheeting to the purlins. The support type cleat is used to connect purlin to the main beams or the main structure. During the analysis, three types of buckling; local, distortion, and lateral torsion are expected to be explored or at least one of them.The extensive work has been conducted before this study on cold-formed steel purlins and purlin sheeting systems are still few. So the case require many investigations using many and different (various) means to predict the precise response of connecting roof sheeting to purlins. The geometric and material non-linear analyses have performed using ANSYS. In addition, a comparison between the angles of the web stiffeners has conducted. The aim was to evaluate the effect of the lateral restraints on the purlins, and to obtain a new optimal cross-section. During the comparison, the area of the cross-section kept the same for all the elements to obtain the same mass.

Keywords: Sigma- purlins-Cold-formed -lateral restraints- nonlinearity.

سلوك العناصر المعدنية ذات المقطع على شكل مجرى المشكلة على البارد بإستخدام برنامج الانسيس

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الملخص في هذه الدراسة، تم التطرق الى تقييم سلوك العناصر ذا ت المقطع نوع الساقية (المجرى) المشكلة على البارد المضاف اليها السنة عند اجنحتها والانواع المعمول بها تعرجات عند جسدها وذلك بإستخدام الوسائط التقنية الحديثة. في هذه الانواع وخصوصاً النوع الذي به تعرجات بالجسد تم دراسة تأثير التقييد الجانبي الناتج عن اتصالها بالاسقف. تم استخدام طريقة العناصر الصغيرة جداً والمتناهية في الصغر عن طريق برنامج الانسيس والذي يوفر الدقة والسرعة والسهولة في انجاز الشغل. تم تسليط أحمال موزعة بشكل منتظم على الجزء العلوي من الجناح في الاتجاه الى الاسفل. السوفت وير المستخدم وهو برنامج الانسيس له المقدرة العالية في امكانية عمل نماذج تمكن من دراسة اتصال السقف والمتمثل في الصفائح المعدنية بالكمرات الثانوية. تم استخدام نوع يسمى كليت لتثبيت الكمرات الثانوية بالكمرات الرئيسية او بالمنشأ الرئيسي. خلال التحليل الانشائي هناك ثلاث انماط من الانبعاج قد تواجه سلوك المنشأ او على الاقل أحدها: وهي الانبعاج الموضعي، والانبعاج الكلي، الانبعاج الفتلي الجانبي. رغم الابحاث السابقة التي عملت ولكن مازال هذا الموضوع يتطلب الكثير من الفحوصات لتقييم تأثير التقييدات التي توفرها صفائح السقف للمدادات. ان التحليل الهندسي واللاخطي تم انجازه بواسطة برنامج الانسيس. اضافة الى ذلك تم عمل مقارنة بين زوايا التعرجات المعمولة لتقوية الجسد. أن الهدف من دراسة هو لتقييم تأثير التقييدات الجانبية للمدادات ولعرض واستخلاص مقطع مثالي جديد. تم في خلال المقارنة تثبيت مساحة المقاطع المعدنية لتكون الكتلة ثابتة لجميع العناصر.

الكلمات المفتاحية: المدادات – الكمرات الثانوية – التعرجات –الالسنة– التقييد الجانبي– التشكيل على البارد– اللاخطية.

Introduction

Demand of using cold-formed steel structures has increased significantly due to their properties over other materials such as concrete, hot rolled steel, and wood. Cold-formed steel beams used widely in residential, industrial, and commercial buildings.

This study is concerned with using some cold-formed cross-sections for purlins. Cold-formed steel sections have wide flexibility of cross-sectional profiles and sizes available to designers (Tran & Li, 2006). Although some cold-formed members are simple to manufacture, other, more complex, are required to fulfil many structural requirements, for instance, to reduce the weight and cost of constructions and to provide stability. Purlins are structural elements which link roof sheeting to structural frames or trusses, and transfer the loads from roof to the main structure. Purlins are usually connected to the structural frame at the web using bolts and a support angle welded or bolted to the frame or with bottom flange. Connecting of roof sheeting to purlins provides restraints to purlins laterally and rotationally (Chu, et al., 2004 & 2005; Katnam, et al., 2006 & 2007; Vieira, et al., 2010). Buckling is considered critical phenomenon in various cold formed cross-sections for majority of load cases before achieving yield point (Cherry 1996; Chu, et al., 2004; Kankanamge, and Mahendran, 2009; Kolcu, et al., 2010)

This study considers the analysis of a cold formed steel section loaded in bending about its major axis (Al Nageim and MacGinley, 2005; Ambrose, 1997; Feng and Wang, 2004 & 2005).

The purlins have been analysed using ANSYS to predict the values of pure bending stresses and the combination of bending and warping torsion stresses as well as displacements (Gotluru, et al., 2000). The results from a finite element analysis are not compared to the results predicted by Simple Engineers theory of Bending because the different kind of supports (Ballio and Mazolani, 1983; Beale, et al, 2001; Gere & Timoshenko, 1987).

The concentration was on adding lips and stiffeners to the plain channel (Grey and Moen 2011), (Davies, 1987).

The considered model in this study is as illustrated in Figures 1 and 2. The dimensions as scheduled in Table 1.

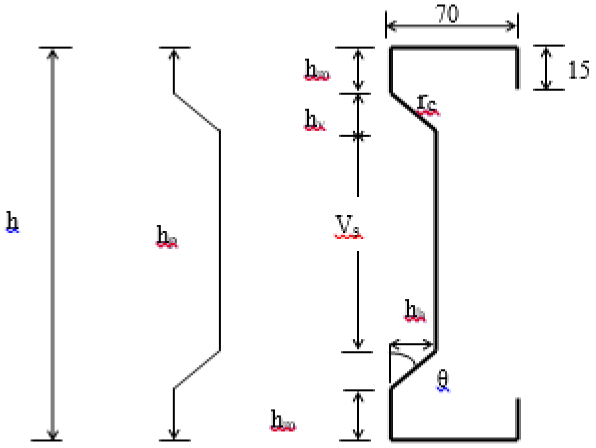

Figure 1 shape of the cross-section

Table 1 Dimensions of sigma cross-section (mm), h_m = 30mm

Specimen Type	Angle degree	h_h mm	h_v mm	r_c mm	v_s mm	h mm
		28	104.50	108.19	8.49	277.49
	15	25	93.30	96.59	31.68	278.28
		20	74.64	77.27	70.32	279.6
		30	51.96	60.0	104.86	268.78
Single Lip	30	25	43.301	50.0	124.86	271.46
		20	34.64	40.0	144.86	274.14
		30	30	42.43	140	260
	45	25	25	35.36	154.14	264.14
		20	20	28.28	168.3	268.3

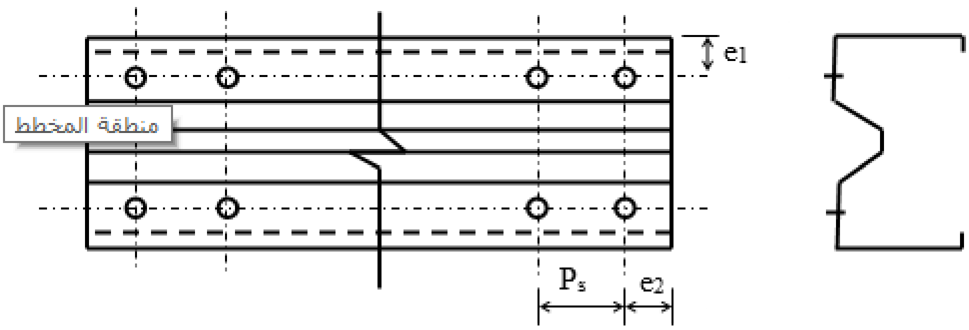

Figure 2 *support type, p = 100 mm, e_1 = 20 mm, e_2 = 25 mm, and V_s = various*

However, since the lack of the accuracy because of the approximation of the equations to simplify the calculation, the finite element analysis software ANSYS (commercial finite element package) is used with good efficiency for precision, quickness, and easiness. The method based on stiffness method is

also used widely to analyze cold-formed steel sections.
The analysis conducted to evaluate the mode buckling of the purlins of the three types of buckling, local, distortion, and lateral-torsion expected during the analysis. However, lateral restraints increase purlin buckling strength and play a major role in increasing the stresses (katnam, et al., 2007). To Estimate the lateral restraints provided by the roof sheeting to the attached purlins, non - linear analysis is used. The screws may be applied through crests or through troughs. The boundary conditions in figure 2 are employed. Downward loads are applied to the model to evaluate the behavior of the sections under the uniformly distributed loading case. Cleat is a type of support used widely as support to prevent lateral and longitudinal movement of the purlins ends.
Applying downward loads on the upper flange cause the flange under compression, and it is more susceptible to buckling while the free flange is under tension.
The issue of numerical modeling of the lateral restraints in cold-formed steel purlins connected to roof sheeting is not convincingly solved for design yet (katnam, et al., 2007). The problem has been studied by Vieira, et al. (2008, 2010), Katnam, et al. (2007), and still need more investigations to obtain models to simulate the real cases with precise and easy methods. Lateral restraints considered as rigid, whereas rotational restraints are always assumed to be flexible (Katnam, et al., 2007).
In the study, two methodologies have been taken into consideration which are restrained and unrestrained sections to demonstrate the effect of lateral restraints. The direct strength method is used to estimate the type of buckling.
When the purlin restrained, local buckling and distortional buckling are more expected after the analysis. However, if the beams are not adequately restrained laterally at sufficient intervals, lateral-torsional buckling may occur (kankanamge and Mahendran, 2009).
Finite element analysis for the beam was conducted using the spans (3 and 6 m) and cross-section dimensions as illustrated in table1.

Table 2. Mechanical properties adopted from Vieiera (2008)

ELMENT	Yield Strength f_y **(MPa)**	Ultimate Strength f_u **(MPa)**	Modulus of Elasticity E **(MPa)**
Purlin	390	500	203000

If the purlins tend to twist, the longitudinal stresses increase due to partially restrained warping torsion. The stresses are added to conventional bending stresses and they have a significant impact on cross-section strength and stability. The value of $\frac{L}{120}$ (L is the span of the purlin) was taken as the limit for the vertical displacements (Vieira, et al. 2010).

Finite element model

ANSYS is used to analyze the cold-formed steel sections with a good efficiency.
A finite element model is presented to predict the lateral restraints provided by single skin roof sheeting to the attached cold-formed steel purlins. Connecting the roof sheeting to the purlin reduced the probability of occurrence of lateral buckling for the sections.
ANSYS is a commercial finite element package based on stiffness method. The_modals have simulated using ANSYS. Shall181 is selected for the sections to analyze to obtain buckling modes.
The constitutive multilinear elastic-plastic model with isotropic hardening and the von Mises yield criterion are adopted for by using ANSYS. The stress-strain curve was limited to two sections, the first corresponding to a linear elastic model considering the modulus of elasticity of the steel (E); the second following a straight line up to the point equivalent to the tensile strength. The nonlinear system was solved using the full version of the Newton-Raphson incremental-iterative method, which updates the tangent stiffness matrix at each iteration. Vieira, et al. (2008) have emphasised that the Stress Stiffness tool should be used concomitantly. They added, it should be noted that in some models where convergence was difficult, the system solved using the full unsymmetrical Newton-Raphson method. The load should be applied incrementally with the ANSYS Automatic Load Stepping tool and the convergence criterion, in terms of displacements, should be used. They added the Line-Search tool is employed to improve the convergence of the model and incremental-iterative processes are limited to being convergent for the solution of the system of nonlinear equations starting from practically any initial solution. Hence, the Line-Search tool is used to reach an estimated solution outside the radius of convergence of the Newton-Raphson method. The method consists of multiplying the displacement increment vector by a factor determined by the minimization of the system's energy (Vieira, et al., 2008).
A cleat supported cold-formed steel lipped and stiffened channel under uniformly distributed loads was modeled in order to investigate the behavior of the purlins under lateral restraints provided by roof-sheeting. Shell elements with the size of 6 mm* 7 mm for lip, 15 mm*20 mm for flange, 10 mm*12 mm for web were used in the elastic buckling and non-linear analysis of the sections.
The boundary conditions were achieved by applying special conditions as illustrated in figure (2) for sigma beam.
Eigen value buckling analysis is also performed to obtain approximately the failure load of the section by using the frequency of the first mode (2.7645*10 = 27.645 kN/m).

Results and Discussion

3.1. Lateral restraint

As it has been mentioned, lateral restraints provided by roof sheeting are taken into consideration. Accordingly, a model has been simulated using ANSYS assuming the following restraint combinations:

- Sections without lateral restraints
- Sections with lateral restraints
- Effect of anti-sag ties

The lateral restraint is applied by assuming horizontally restraints to some node at the upper flange at distances as between the rivets which fits the roof sheeting to the purlins. In the this study, the distances are assumed to be 175 mm longitudinally starting with 25 mm from the end and ended with the same distance (25 mm). The anti-sag ties are applied once at the bottom of the web with 20 mm from the bottom flange, and once at the middle of the web.

First, a comparison between lipped channel and sigma sections has been conducted and the following diagrams obtained to illustrate the important of the sigma sections. The comparison has shown that whenever the load is increased the difference in displacements increases. During this investigation the percentage of difference has reached 70 %.

3.2. Variation of the Angles

The aim of this section is to investigate the effect of variation of the web stiffener angles. That using stiffeners in the web reduce the buckling phenomenon and consequently increase the strength of the structural element. The previous practical used cross-section which is produced by Kingspan Company is 45 degree of the web stiffener with 25 mm horizontal component according to the handbook of the company and its website. It has been found that increase of the angle decrease the probability of buckling occurrence for unrestrained elements. However, decrease of the angles decrease the probability of the buckling and increase the strength of the elements.

In this evaluation, a plate with length 454.86 mm, the thickness 2 mm, and area with 949.72 mm^2 has taken to fold it to different sigma cross-sections. Different angles have been taken for the web stiffener such as 15, 30, and 45 degree, with single lip. The flange width is fixed to 70 mm, and the lip is fixed to 15 mm. Upper and bottom h_m is taken 30 mm.

An additional properties and dimensions have illustrated in (Table 1)

The elements have the same mass. The comparison has carried out for unrestrained sections and when the sections are restrained by roof sheeting. The following details show the both cases.

3.3. Unrestrained sections with span length 3 m

Taking into consideration the three different angles, the span length is 3 m, the following details are drowned. Comparing between the displacements of angle 15 and angle 30, the angle 30 was less displacements with approximately maximum difference percentage 13 % and 34%, for vertical and horizontal displacements, respectively. However, comparing between angle 30 and angle 45, the displacements of angle 45 are lower with approximately 3 % and 9 %, for vertical and horizontal displacements, respectively. The comparisons have been shown graphically in figures 3 and 4.

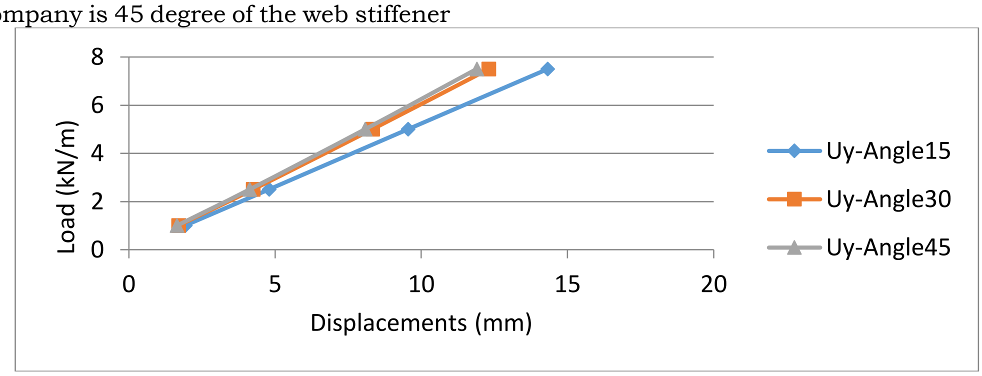

Figure 3 *vertical displacements of unrestrained sigma with angles 15, 30, 45.*

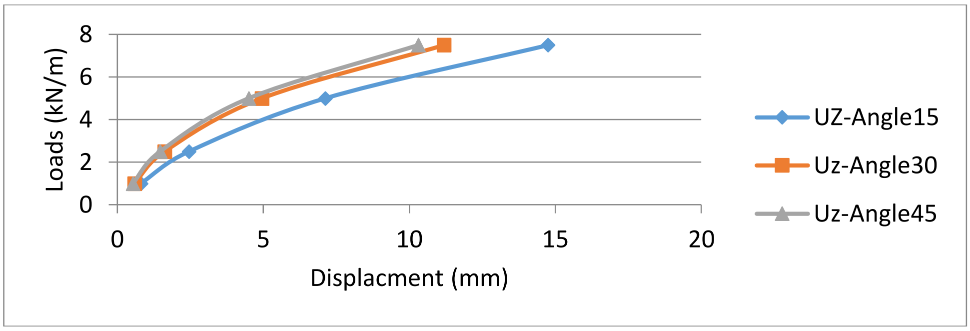

Figure 4 *horizontal displacements of unrestrained sigma with angles 15, 30, 45.*

3.4. Restrained sections with 3 m span length

However, for the restrained sections (the span is 3 m) and the distance between the screws is 175 mm. It was observed that the load strength of the sections was increased and the section with angle 15 showed increase in the first load (1 kN/m). While for all the other values of load greater than 1 kN/m, it showed less vertical displacements. The percentage at first selected load which is 1 kN/m between angle 15 and angle 45 (the least displacement at the considered load value) of vertical displacements was approximately 6 % maximum. The other values of loads were selected starting from 2.5 kN/m to the failure load. The failure load for angle 15 was approximately 30 kN/m, and the failure loads for angles 30 and 45 were between 25 and 30 kN/m. The angle 15 was found to be the least displacement. Comparing angle 15 with 30 the approximately maximum difference percentage of vertical displacements was 24 %. The comparison between angle 30 and angle 45 showed that angle 30 was less vertical displacement with maximum percentage 18% as shown in figure 5.

The comparison of the horizontal displacements of the sections illustrates that angle 45 was least horizontal displacements at the load values from 1 to 7.5 kN/m with maximum displacement 18 % between angle 45 and angle 30, and 68 % between angle 45 and angle 15. At the load 7.5 kN/m the angle 30 shows less displacement with approximately 11% and 16 % comparing with angle 15 and angle 45, respectively. Then for the loads above 7.5 kN/m angle 15 is a less displacement with approximately 69 % and 77 % comparing with angles 30 and 45, respectively as illustrated in figure 6.

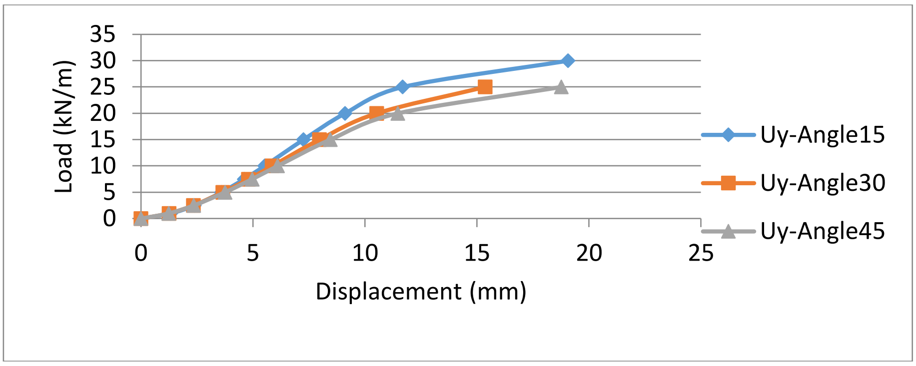

Figure 5 *vertical displacements of restrained sigma with angles 15, 30, 45.*

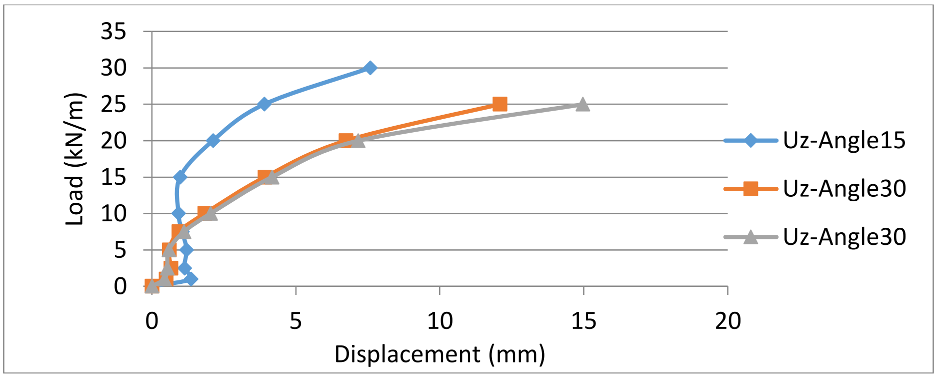

Figure-6 *horizontal displacements of restrained sigma with angles 15, 30, 45.*

3.5. Unrestrained section for span length 6 m

Taking into consideration the three different angles, with span length was 6 m, the following details were drowned. Section with angle 45 was less vertical and horizontal displacements. Comparing of the vertical displacement of the three angles, the displacement of angle 45 was less than angle 30 ones with approximately 28 %. Also the displacement of angle 45 was less the angle 15 with approximately 6%. Moreover, it has been observed that, the difference of the displacement between angle 30 and angle 15 is 23 %. The comparisons have been shown graphically in figures 7. Also when comparing the horizontal displacement of the three angles, the least displacement was angle 45. The maximum difference between angle 45 and angle 15 was 49 %. Whereas the maximum difference between angle 45 and 30 is 18 %.

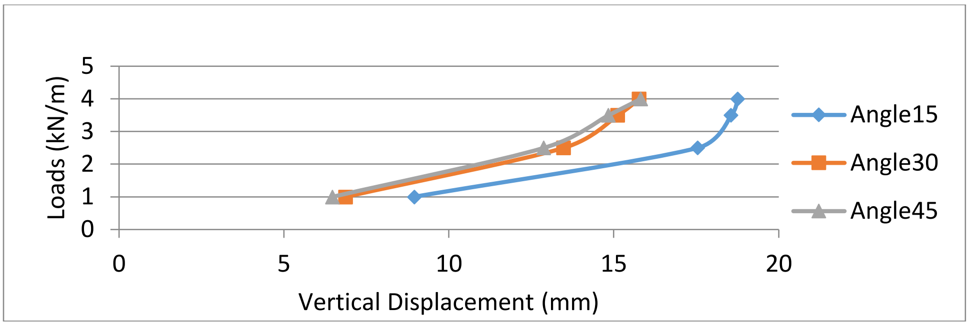

Figure 7 *vertical displacements of unrestrained sigma with angles 15, 30, 45.*

3.6. Restrained sections with span length 6 m

However, the following comparison is conducted using 6 m span length with applying restraints on the upper flange each 175 mm longitudinally. The relevant diagrams for the three angles show that angle 15 was generally the least vertical displacement during the three values of the loads as shown in figure 8. For applying load 1 kN/m, the least vertical displacement was angle 30, 15, and 45, respectively. Angle 30 is less displacement than angle 15 with approximately 1.5 %. Also angle 30 was less than angle 45 with 3 %.

However, at the load 5 and 10 kN/m, the maximum observed vertical displacement is approximately 18 % between angle 15 and angle 45, and 9 % between angle 15 and angle 30.

Investigating the lateral displacement, it has been found that imposing loads 1 and 5 kN/m showed less displacements for angles 45, 30, and 15, respectively. The maximum percentage between angle 45 and angle 15 was 90 %, and between angle 45 and angle 30 was 80 %. However, when the load 10 kN/m was imposed, angle 15 was the least lateral displacements. The difference between angle 15 and angle 45 was approximately 81 %. Meanwhile, the difference between angle 15 and 30 is the same 81 % (these values will be reduced using the anti-sag ties).

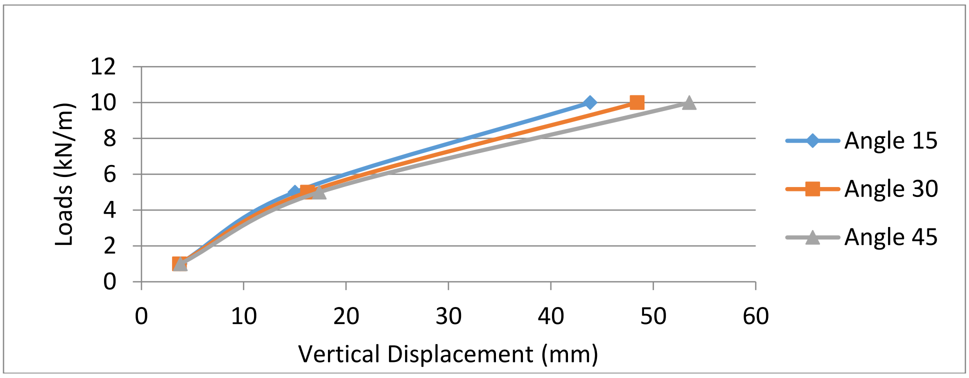

Figure 8 *vertical displacements of restrained sigma with angles 15, 30, 45.*

Evaluating of the stresses for restrained sections shows that the angle 15 was the least stresses. Comparing the stresses for the three angles, starting with longitudinally stresses, Figure 9, angle 15 is less stresses than angle 30 and 45 with 16 % and 20 %, respectively.

Also for vertical stresses, Figure 10, angle 15 is less stresses than angle 30 and 45 with approximately 23 %, and 28 %, respectively.

For the laterally stresses are considered, angle 15 is less stresses than 30 and angle 45 with 30 % and 38 %, respectively.

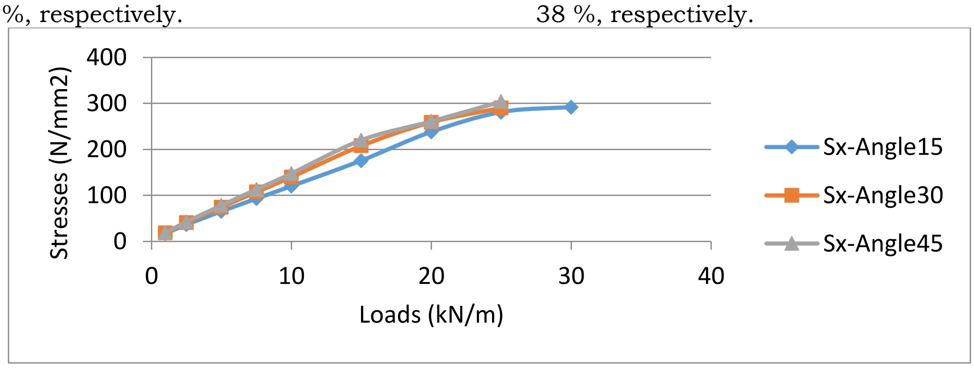

Figure 9 *stresses of restrained sigma with angles 15, 30, 45 in longitudinal direction.*

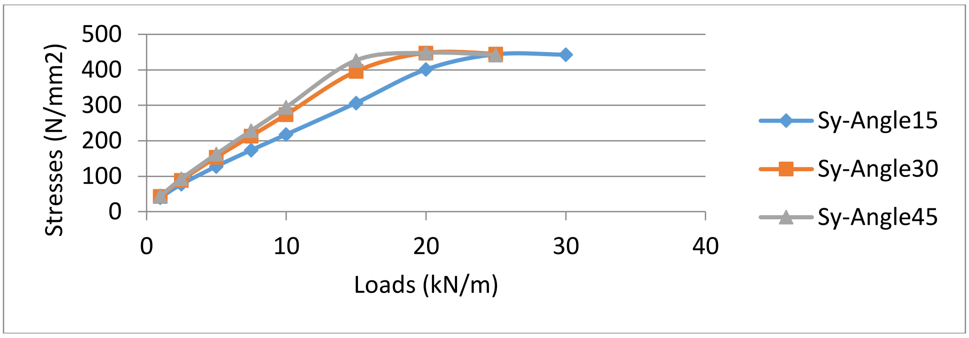

Figure 10 *stresses of restrained sigma with angles 15, 30, 45 in vertical direction.*

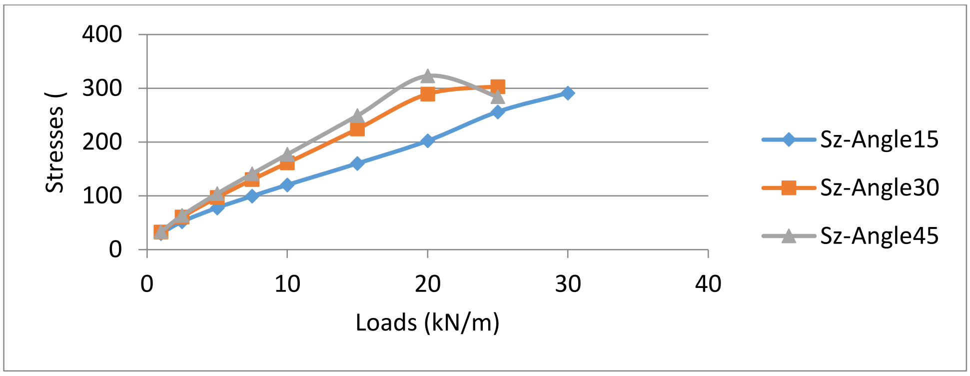

Figure 11 *stresses of restrained sigma with angles 15, 30, 45 in horizontal direction.*

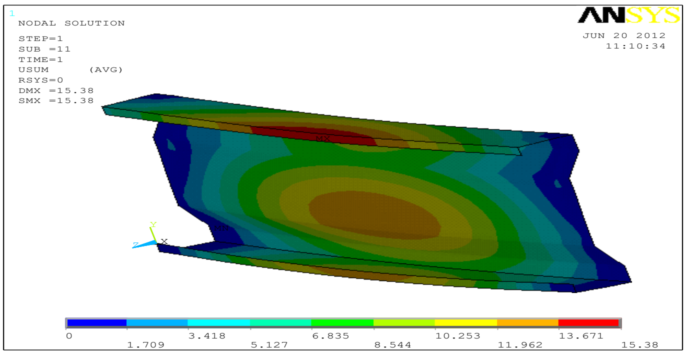

Figure 12 the distribution of the displacement of restrained sigma and the critical locations

Conclusion

Geometric study has been conducted for comparing between different cross-section, on the change of angles and web depth, and span length taking into consideration the effects of the parameters on the displacements and stresses. The intention was to obtain new optimal cross-section. The study was conducted using ANSYS. ANSYS provides a good opportunity to analyze the models that are needed for an evaluation and investigation which resembles a real case. ANSYS software has the ability to evaluate cross-sections with any shape by using shell elements, for instance, adding lips and stiffeners.

The elements with length 3 m was found to be susceptible to distortional buckling, and the elements with 6 m length was affected by lateral torsional buckling. The lateral restraints provided by roof sheeting to the purlins with channel sections under uniformly distributed loads has been provided to illustrate their important role in realistic use of the purlin.

The implementation of a non-linearity has been found essential in the simulation of obtaining a good agreement of the real case of the structural members.

The requirements of boundary conditions have been discovered to be rather different than the application of normal supports in theoretical equations.

Sigma with angle 15 was found the best cross-section through applying the loads downwards and using lateral restraints. Sigma 45 was found the best for unrestrained sections. It is recommended for practical use to reduce the angle value directing to angle 45 passing through angle 30. So, in case of using lateral restraints, angle 30 is better than angle 45.

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