The Effect of Adding Stiffeners and Lips to Cold-Formed Steel C Sections

*Mohamed I Iswisi

Abstract: This study is concerned with the use of cold formed steel channel sections as purlins in metal roofed buildings. This section type represents the mono-symmetric case. Uniformly distributed loads both in the downward as well as the upward direction will be considered. In all cases beams will be considered as simply supported.

Cold-formed channel sections are widely used as cross-section of structural members, such as purlins to support roof sheeting. Connecting of roof sheeting to purlins provides restraints to purlins laterally and rotationally.

The restraints to purlins may reduce the critical load or increase the strength of the sections. In this study the effect of lateral and rotational restraints needs to be investigated taking into consideration local, distortional, and lateral torsional buckling for detached and connected purlins as well as changing of geometry of the members. Achieving this requires determining of appropriate lateral linear spring of stiffness *K* and rotational spring stiffness *CD* (British standard Institution, 2009). Buckling is considered critical phenomena in various cold formed cross-sections for majority of load cases before achieving yield point.

The results obtained from Theoretical equations will be compared with those obtained from finite element analysis using ANSYS (release 12) for various dimensions of the purlins. The boundary conditions, which are used for the finite element members, need special consideration depending on the shell type, for instance, shell 43.

The purlins have been analysed using theoretical equations and ANSYS to predict the values of pure bending stresses and the combination of bending and warping torsion stresses as well as displacements.

Keywords: Channels Cold-formed lips steel stiffeners.

1. Introduction

This study is concerned with using some cold-formed cross-section 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. 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).

* Lecturer at Sebha University-Libya

Buckling is considered critical phenomena 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 theoretical equations and 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 compared to the results predicted by Simple Engineers theory of Bending (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)

2. Calculation of Deflection and Stresses

2.1 Plane channel sections

The Analysis of a Simple Cold Formed Channel Section Loaded at the Shear Centre using ANSYS Software is conducted.

The section considered is a plain, unlipped channel with the following dimensions as shown in Fig 1.

Length 3000 mm

Web depth 150 mm

Flange width 65 mm

Thickness 1.5 mm,

The load applied is uniformly distributed along the length.

Finite Element Analysis

The analysis is conducted using ANSYS software using the shell element type elastic shell43.

In order to prevent torsion, the load must be applied through the shear centre of the section (Gere & Timoshenko, 1987; Gotluru, et al 2000). For the section under consideration, the shear centre is outside the section, as illustrated below.

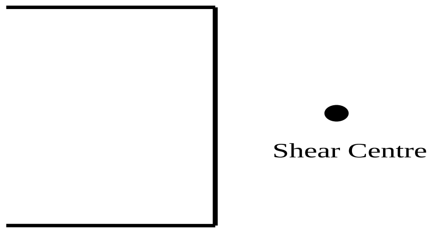


Fig. 1. The imagination position of the shear centre

The position of the shear centre can be calculated theoretically to be 22.426 mm from the centre of the web.

In order to simulate this load in ANSYS, the following idealization was used:

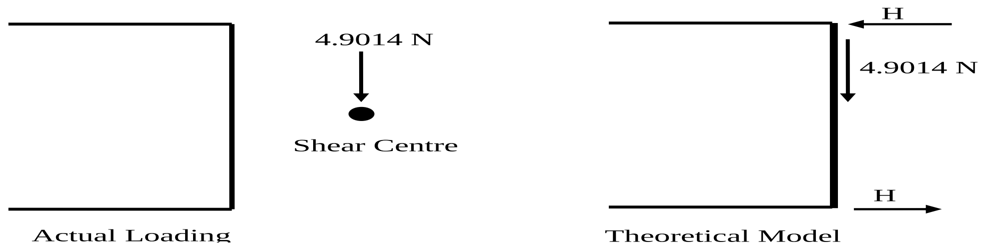


Fig. 2. Actual and theoretical loads

The section could be considered to be loaded by vertical load equal to 4.9014 N at the middle point of the web and together with two equal and opposite loads applied to the top and bottom flanges to counteract the torsion caused by the eccentricity from the shear centre of the vertical load.

The value of these horizontal loads can be calculated theoretically using the eccentricity from the shear centre.

$$i.e. \quad H = \frac{Vertical\ Load\ x\ Eccentricity\ from\ Shear\ Centre}{Section\ Depth}$$

$$H = \frac{4.9014\ x\ 22.426}{150} = 0.733\ N$$

Alternatively the value of the horizontal force can be evaluated using ANSYS by initially restraining the flanges from horizontal movement as below.

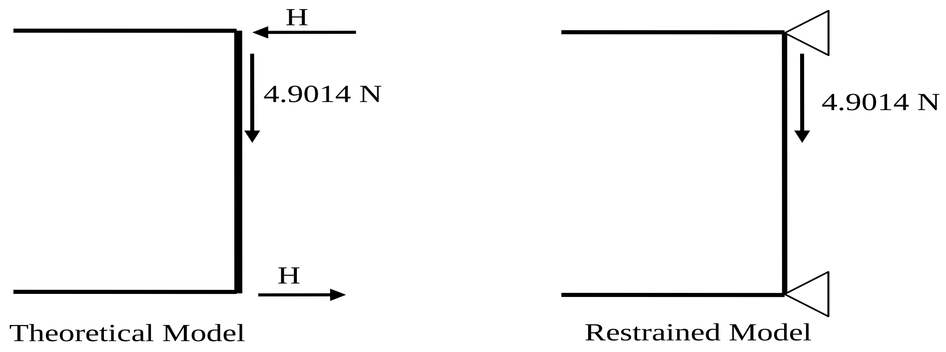


Fig. 3. Theoretical and Ansys model

The reactions at the horizontal ‘supports’ can be output from ANSYS. Ignoring a slight discrepancy at the ends, the value of these ‘reactions’ is 0.76692 N. These reactions could therefore be replaced by horizontal loads of 0.76692 N.

This compares with the value calculated above of 0.733 N.

These two methods of calculating the required horizontal loads that must be applied to prevent torsion therefore give agreement within 4.5%.

Applying the above loads the stresses and displacements at the seven points on the element can be calculated as illustrated in figure 4. These are shown in Tables 1 and 2.

It has been found that for using shell 181 the percentage of error of the displacements are less than when use shell 43, however, for stresses is vice-versa.the supports for shell43 is *UX*, *UY*, *UZ* at one end and *UY*, *UZ* at the second end. And *RotX* at all the ends

The results when the loads above applied on the nodes mentioned with supports (*Ux*, *Uy*, *Uz*, *Rot X*, fixed at one end, and *Uy*, *Uz*, *Rot X*, fixed at the second end) at the mid-length of the web and vertical load at the same node but along the member, it has been found that the displacement and the stresses approximately the same as the same those obtained from theoretical equations

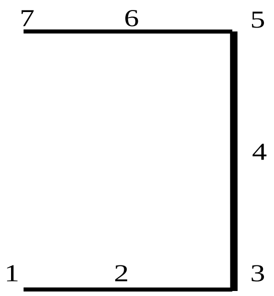
The equations used to calculate the stresses and deflections are based on Simple Engineers Theory of Bending.

Model validation and Results

The stresses and displacements calculated at mid span by both the above methods are compared in the table below:

Table 1: Comparison of deflection and stresses plane channel section

Element	load	Nodes	δ Theory	δ Ansys	Error %	σ Theory	σ Ansys	Error %
E_1 3000*150*65*1.5	q_1	1				-5.617	-5.48	2.43
		2				-5.617	-5.49	2.26
		3				-5.617	-5.51	1.9
		4	0.35	0.3483	0.29	0	0	0
		5				5.617	5.51	1.9
		6				5.617	5.49	2.26
		7				5.617	5.48	2.43



Nodes	Distance Z	Distance Y
1	-49.35	-75
2	-16.85	-75
3	+15.65	-75

Fig. 4. Nodal Location

The ANSYS analysis used for table 1 used the Shell 43 element, with a mesh spacing of at flanges (16.25 mm* 50 mm) and at web (15 mm * 50 mm)

6.1 Mesh Sensitivity Study.

The investigation of the mesh sensitivity show that the size of the elements affects the results in somehow, but the percentage of the error does not exceed 0.4 %. Supports *UX* and *UY* fixed at one end and *UY* fixed at the second end. Uz is fixed at the nodes (where the web and flange are connected) along the member.

It has been found, the element is not very sensitive to the mesh element, that the percentage of the difference does not exceed 0.4 %, also for the distributions of stresses for the same element and the same cases of loading is shown in figure 5. It has been found, the element is not very sensitive to the mesh element, that the percentage of the difference does not exceed 0.3 %.

Table 2: Division of section parts to elements

case	σ_1	σ_2	σ_3	σ_4	σ_5	σ_6	σ_7	σ_8	σ_9
a	- 5.4703	- 5.4999	-	-	0	-	-	5.4999	5.4703
b	-5.501	- 5.5086	- 5.5211	- 3.2773	0	3.2773	5.5211	5.5086	5.501
c	- 5.4852	- 5.4934	- 5.5122	- 3.2683	0	3.2683	5.5122	5.4934	5.4852
d	- 5.4874	- 5.4981	- 5.5133	- 3.2689	0	3.2689	5.5133	5.4981	5.4874

Table 3: Displacements of the three cases

Plane channel	Case	Flange		web		Element along the length
		size, mm	elemnt	size,mm	element	
L = 3000	A	65*100	1	75*100	2	30
h = 150	b	16.25*50	4	15*50	10	60
b_f =65	c	8.125*50	8	7.5*50	20	60
t = 1.5 in mm	d	8.125*25	8	7.5*25	20	120

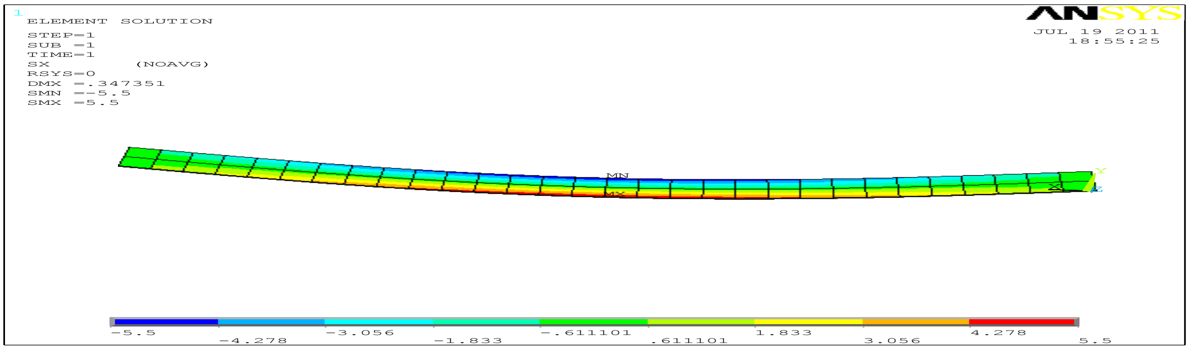


Fig. 5. Distribution of stresses using Ansys model

It can be shown that the deflection and stresses have quite a similar values when using simple engineering theory of bending, but the percentage varies according to the position of point. It should be noticed that the deflections and stresses increase whenever the loads increase. It has been noticed from tables 5, 6 and 7 that the increase of thicknes from 1.5 mm to 2.5 mm of the section 150-65-1.5 reduces the deflection with 40% and also increase the flange width to 100 mm decrease the deflection to 46%. Whereas, increase the web depth from 150 mm to 250 mm decrease the deflection with 67% with reasonable cross section area.

Comparing the three elements, the values of stresses of the element 250-65-1.5 are less than others with 58% to the element 150-65-1.5. That indicates, the increase of web depth is better than increasing of thickness and flange width. However, the increase of the web depth should be limited to avoid buckling.

Table 4: Displacement and stresses of Channel section.

Element	load	Nodes	Distance Z	Distance Y	δ Theory	δ Ansys	Error %	σ Theory	σ Ansys	Error %
3000*150*65*1.5 Calculation at mid span Channel	q_1	1	-49.35	-75				-5.617	-5.51	1.9
		2	-16.85	-75				-5.617	-5.53	1.55
		3	+15.65	-75				-5.617	-5.53	1.55
		4	0	0	0.35	0.349	0.29	0	0	0
		5	+15.65	+75				5.617	5.53	1.55
		6	-16.85	+75				5.617	5.53	1.55
	q_2	1	-49.35	-75				-13.07	-12.81	1.97
		2	-16.85	-75				-13.07	-12.86	1.59
		3	+15.65	-75				-13.07	-12.86	1.59
		4	0	0	0.817	0.814	0.37	0	0	0
		5	+15.65	+75				13.07	-12.86	1.59
		6	-16.85	+75				13.07	-12.86	1.59
	q_3	1	-49.35	-75				-20.52	-20.12	1.94
		2	-16.85	-75				-20.52	-20.19	1.6
		3	+15.65	-75				-20.52	-20.19	1.6
		4	0	0	1.28	1.277	0.23	0	0	0
		5	+15.65	+75				20.52	-20.19	1.6
		6	-16.85	+75				20.52	-20.19	1.6
	q_4	1	-49.35	-75				-57.77	-56.64	1.96
		2	-16.85	-75				-57.77	-56.84	1.61
		3	+15.65	-75				-57.77	-56.84	1.61
		4	0	0	3.61	3.598	0.33	0	0	0
		5	+15.65	+75				57.77	56.84	1.61
		6	-16.85	+75				57.77	56.84	1.61

1.1.**Lipped channels**

The element taking for this section is

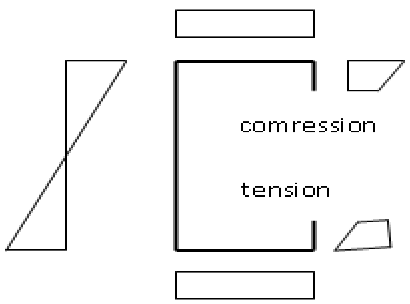


Fig. 6. Stress distribution of lipped channel section.

Table 5: Displacement and stresses of lipped channel section.

load	Element	Nodes	Distance Z	Distance Y	δ Theo.	δ_{usum} Ansys		σ Theo.	σ Ansys	%
Lip	L=3000 h=150 Bf=65 t=1.5 c=20	1	+65	-55				3.53	3.37	4.5
		2	+65	-75				4.8	4.73	1.5
q_1 Calculation at mid span SHELL43		3	+32.5	-75						
		4	0	-75				4.8	4.73	1.5
		5	0	0	0.30	0.30	0	0	0	0
		6	0	+75				-4.8	-4.73	1.5
		7	+32.5	+75						
		8	+65	+75				-4.8	-4.73	1.5
		9	+65	+55				-3.53	-3.37	4.5
	L=3000 h=130 Bf=65 t=1.5 c=20 Ansys	1	+65	-45				-4.02	-3.82	5
		2	+65	-65				-5.80	-5.69	1.9
		3	+32.5	-65						
		4	0	-65				-5.80	-5.63	1.9
		5	0	0	0.42	0.41	2.4	0	0	0
		6	0	+65				5.8	5.63	1.9
		7	+32.5	+65						
		8	+65	+65				5.8	5.64	1.9
		9	+65	+45				4.02	-4.29	5
	L=3000 h=110 Bf=65 t=1.5 c=20	1	+65	-35				-4.58	-4.32	5.7
		2	+65	-55				-7.2	-7.03	2.4
		3	+32.5	-55						
		4	0	-55				-7.2	-7.03	2.4
		5	0	0	0.613	0.60	2.1	0	0	0
		6	0	+55				7.2	7.03	2.4
		7	+32.5	+55						
		8	+65	+55				7.2	7.03	2.4
		9	+65	+35				4.58	4.32	5.7

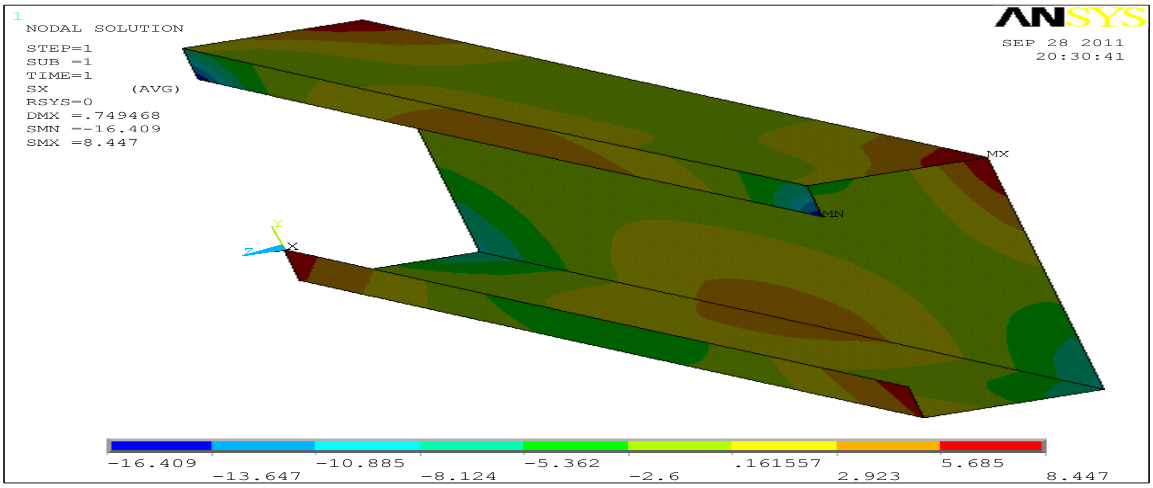


Fig. 7. Stress distribution of lipped channel section using ANSYS.

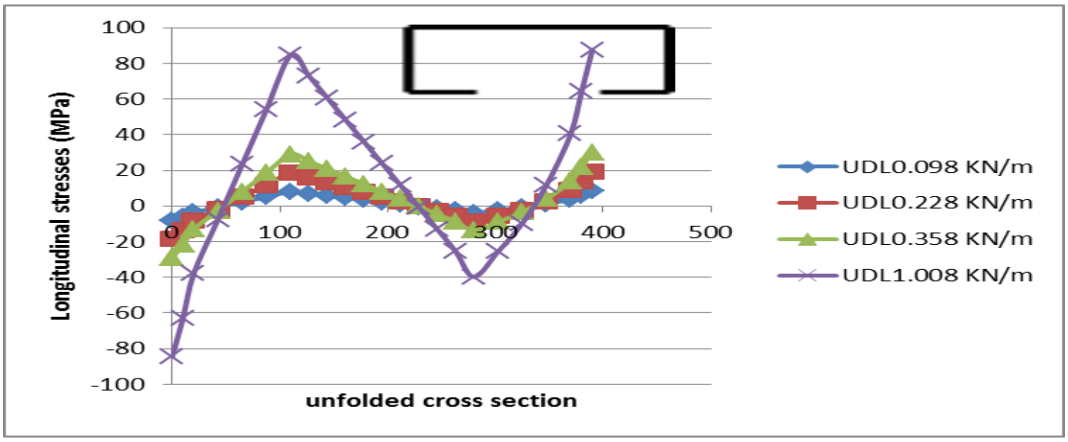


Fig. 8. Stress distribution for various uniform loads on lipped channel section.

1.2. **Web stiffeners**

A stiffened channel sections with using angle 45 degree element was used and supported at the both two ends. The element with dimensions 3000 mm span length, 150 mm web depth, 65 mm flange width, and 1.5 mm thickness. Uniformly distributed load, equal to 0.098, has been applied on the upper flange downwards (using pressure 0.0015). It has been analysis the element using ANSYS. Fig. 9 shows the maximum deflection and the distribution of stresses on the section.

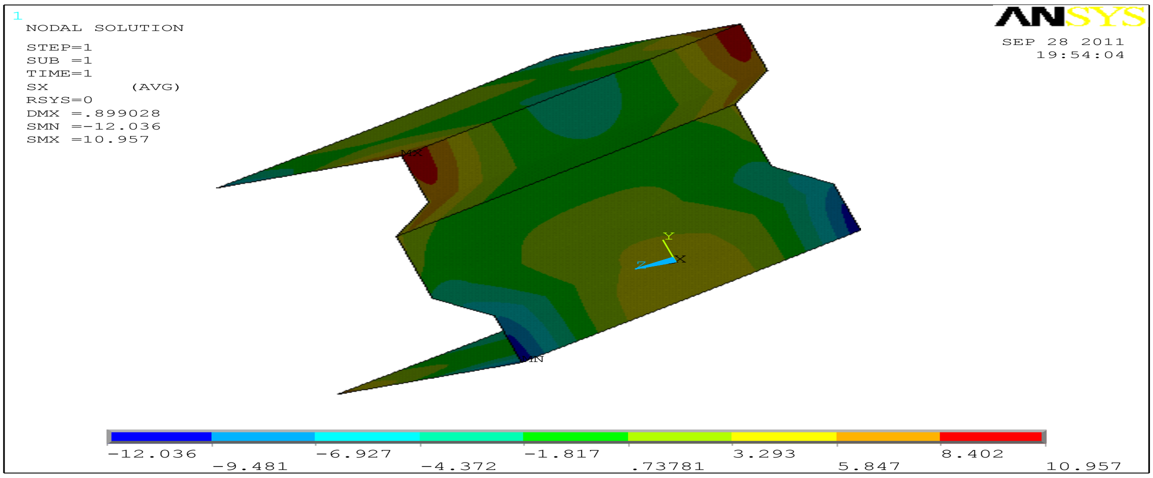


Fig. 9. Stress distribution of stiffened channel section using ANSYS.

Conclusion

1. The above tables illustrates that for this particular section under this level of loading, the ANSYS modelling proposal is valid, agreeing with Simple Engineers Theory of Bending within 3%

2. Longitudinal bending and warping torsion displacement and stresses have been studied in this work.

3. It has been analyzed the channel sections using two different methods; theoretical equations and finite element method to obtain the displacement and stresses of the sections under uniformly distributed loads.. It has been found that the stresses are relatively complex due to the presence of bending and warping torsion.

4. It has been concentrated, when comparing between different cross-section, on the change of web depth, thickness, and flange width taking into consideration the effects of local, distortion, and lateral-torsional buckling and also the lateral and rotational restraints provided by roof sheeting to the purlins with channel sections under uniformly distributed loads.

5. Conducting laboratory investigations is essential for purlins when doing a model to simulate the real case. It is also important to evaluate the analysis using finite element method by using ANSYS program.

6. The main advantage and ability of ANSYS program to compose the roof model is quick and easy. ANSYS provides a good opportunity to analysis the models that are needed for

evaluation and investigation which resemble a real case. ANSYS software has ability to evaluate cross-sections with any shape by using shell elements, for instance, adding lips and stiffeners.

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

8. It has been noticed that, the increase of web depth is better than increasing of thickness and flange width. However, the increase of the web depth should be limited to avoid buckling.

9. It has been found that the lipped channel cross section is the optimum of all the other elements, that lips apply an important role to reduce the buckling phenomena.

تأثير إضافة تقوية وألسنة الى المقاطع الفولاذية المشكلة على البارد نوع المجرى

الملخص: تتعلق هذه الدراسة باستخدام العناصر الفولاذية المشكلة على البارد التي لها شكل مقطع المجرى (الساقية) والتي تستخدم ككمرة ثانوية في أسقف المنشاءات المعدنية. أن هذا النوع من المقطع يعتبر احادي التماثل. تم تحميل العنصرالذي أخذ ككمرة بسيطة الاسناد بأحمال منتظمة. أن الكمرات الثانوية المصنعة على البارد تستخدم بشكل فعال في الأسقف لتدعيم الصفائح المعدنية المستخدمة لتغطية السقف. أن تلك الصفائح المعدنية قد تساهم الى حد ما في توفير التدعيم الجانبي ومنع حصول فتل للكمرات الثانوية لاتصالها بها. أن أتصال الكمرات الثانوية بالصفائح المعدنية قد يخفض من قيمة الأحمال الحرجة أو يزيد من قيمة مقاومة الكمرات الثانوية. أن هذه الدراسة أجريت للتحقق من تأثير التدعيمات الجانبية والدورانية، آخذين في الاعتبار الانبعاج الموضعي والتشوهي والالتواء الجانبي مع أستخدام اسلوب تغيير الشكل الهندسي للعنصر في حالة عدم اتصاله أواتصاله بشكل موثق بالصفائح. أن ظاهرة حدوث الانبعاج تعتبر خطيرة جداً والتي قد تحدث قبل حدوث الخضوع للعنصر الانشائي بالكامل. أن النتائج المتحصل عليها قورنت بالنتائج المتحصل عليها من التحليل بأستخدام الشرائح الدقيقة جداً والتي اجريت باستخدام البرنامج الفعال (انسيس) للعديد من الكمرات الثانوية المختلفة الابعاد. أن الاشتراطات الحدية المستخدمة عند التعامل مع الشرائح الدقيقة تتطلب اهتمام خاص اعتماداً على نوع الشريحة. تم تحليل الكمرات الثانوية بالوسائل المذكورة لتحديد قيم اجهادات الانحناء الخالصة والاجهادات المركبة من الانحناء والفتل الدوراني وأيضاً الهبوطات.

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