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Buckling Analysis of Cold Formed Steel Compression Members at Elevated Temperatures

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Abstract: *Cold-formed steel members have been widely used in residential, industrial and commercial buildings as primary load bearing structural elements due to their advantages such as higher strength to weight ratio over the other structural materials such as hot-rolled steel, timber and concrete. However, they are susceptible to various buckling modes including local and distortional buckling. Fire safety design of building structures has received greater attention in recent times as fire events can cause loss of property and lives. Therefore it is essential to understand the fire performance of light gauge cold-formed steel structures under fire conditions. The buckling behavior of cold-formed steel compression members under fire conditions is not well investigated yet and hence there is a lack of knowledge on the fire performance of cold-formed steel compression members. Therefore, this paper deals with behavior of cold formed steel compression member under fire and to analyze the effect of fire on critical buckling load of compression member. Eigen value analysis for Lipped channel sections made of various thicknesses and both low and high strength steels was carried out through finite element method. The ultimate load carrying capacity results from experimental investigation and finite element analyses were then compared.*

Keywords: *Light gauge cold-formed steel, elevated temperatures, critical buckling load, reduced mechanical properties, finite element analysis.*

I. INTRODUCTION

In recent times light gauge cold-formed steel construction has replaced the conventional hot-rolled steel construction in many cases due to its many advantages. However, cold-formed steel structures are subjected to a more complex behavior than traditional hot-rolled steel structures. They are subjected to various buckling modes including local, distortional, and global and their interactions. Previous research was mostly concerned about local and global buckling modes and there is a wealth of knowledge on these modes at ambient temperature. [1]–[7].On the other hand, some research was mostly concerned about reduced mechanical properties of cold formed steel compression members at elevated temperatures [8],[9]. Structures can accidentally catch fire or are deliberately set on fire which can cause loss of life and property, not only because of fire but also due to the structural failure. Therefore, it is necessary to fully understand the structural behavior of light gauge cold-formed steel structures at elevated temperatures. Current knowledge on the structural behavior of light gauge cold-formed steel members under fire conditions is limited. The effects of fire conditions on the buckling behavior of light gauge cold-formed steel compression members are not known. Therefore, this research was conducted to investigate the buckling behavior of light gauge cold-formed steel compression members at ambient and elevated temperatures. This paper presents the details of an analytical study of light gauge cold-formed steel lipped channel compression members at ambient and elevated temperatures for low and high strength steels. The experiments were undertaken at varying temperatures up to 800°C by Thanuja Ranawaka [10]. The paper also describes a finite element model developed using ABAQUS for a range of lipped channel sections with various thicknesses. Finally the ultimate load carrying capacity results from experimental investigation and finite element analyses were then compared.

II. Experimental Investigation

Experimental investigations were carried out by Thanuja Ranawaka [10] for lipped channel sections made of low (G250 with the nominal yield strength of 250 MPa) and high (G550 with the nominal yield strength of 550 MPa) strength steels. The sections were designed to fail by pure distortional buckling at ambient and elevated temperatures.

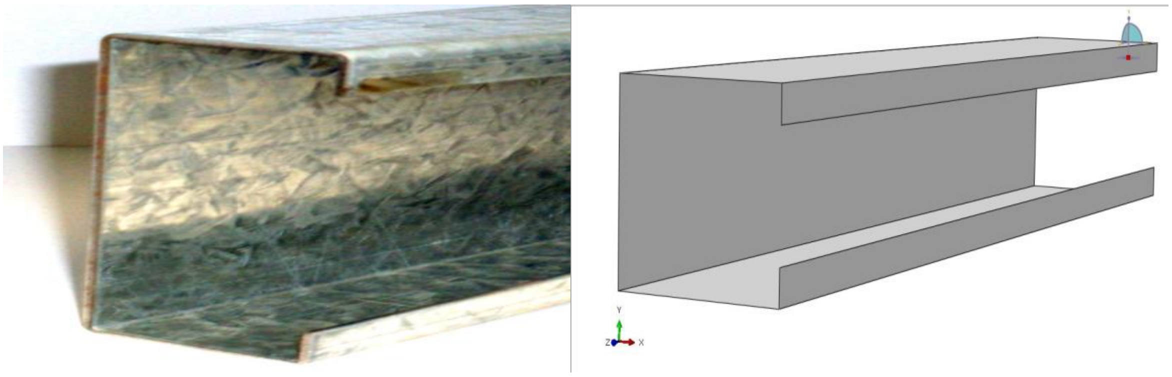

Fig. 1 Cross-section of a Lipped Channel Section

Table 1 Measured specimen dimensions

Steel grade (MPa)	Temperature °C	Web(mm) b	Flange(mm) f	Lip(mm) l	Thickness (mm)	Length (mm)
G250	20	30.84	31.6	5.7	0.79	190
	200	30.96	31.4	5.5	0.8	190.2
	350	30.92	31.4	5.45	0.79	190.1
	500	30.84	31.1	5.53	0.79	190
	650	30.82	31.1	5.41	0.79	190
	800	30.91	31.6	5.47	0.79	190.1
G550	20	31.07	31.5	5.47	0.8	190.2
	200	30.86	31.1	5.46	0.81	190
	350	30.92	30.95	5.53	0.8	189.9
	500	30.86	31.7	5.7	0.8	190.1
	650	30.8	31.7	5.48	0.8	190.2
	800	30.87	31.4	5.43	0.81	190.1

Where, b - web width, f - flange width, I-lip width

2.1 Mechanical properties

The mechanical properties have a significant effect on the behavior of light gauge cold-formed steel compression members. The mechanical properties are also essential for finite element and finite strip analyses under various temperatures. Therefore tensile coupon tests were carried out by Thanuja Ranawaka to determine the mechanical properties of light gauge cold-formed steels at ambient temperature (20°C), and obtained results are given in Table 2. The mean value of the measured Young's modulus was about 200,000 MPa for both steel grades. Table 2 values were then used in the finite element analysis.

Table 2 Mechanical properties at various temperatures

Temperature(°C)	Modulus Of Elasticity (ET)(MPa)	Yield Strength (fyT) (MPa)
20	200000	300
200	172000	283
350	130000	246
500	88000	179
650	43267	96.5
800	11647	30

Where, ET - Young's modulus at specified temperature
fyT - Yield strength at specified temperature

2.2 Finite Element Analysis

ABAQUS was used as finite element analysis tools to investigate the behavior of cold-formed steel compression members at ambient and elevated temperatures. S4R element type was selected to adequately simulate the buckling deformation and yielding of light gauge cold-formed steel compression members. A uniformly distributed compression load i.e. Shell edge load was applied to the upper and lower nodes of the member.

A 2 mm X 2 mm mesh was selected for all the sections (see Figure 1). The column is restrained in x and y direction at both ends (u=0, v=0) and at middle only z direction is restrained (w=0).Compressive load of magnitude 1000 KN is applied at both ends as shown in (see figure 2).

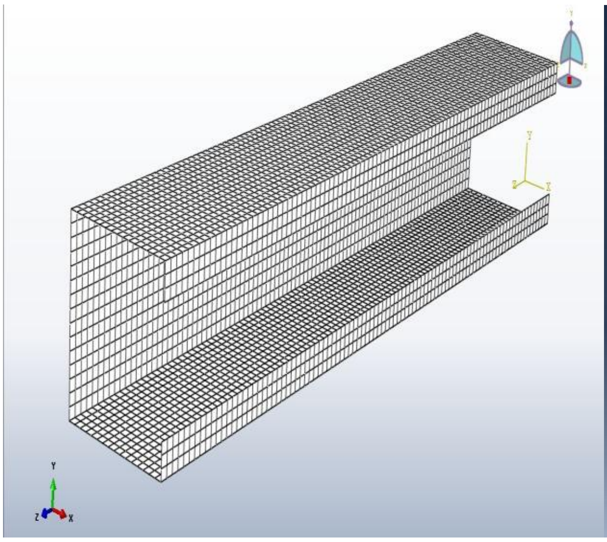

Fig.1 Finite element meshing using S4 Element

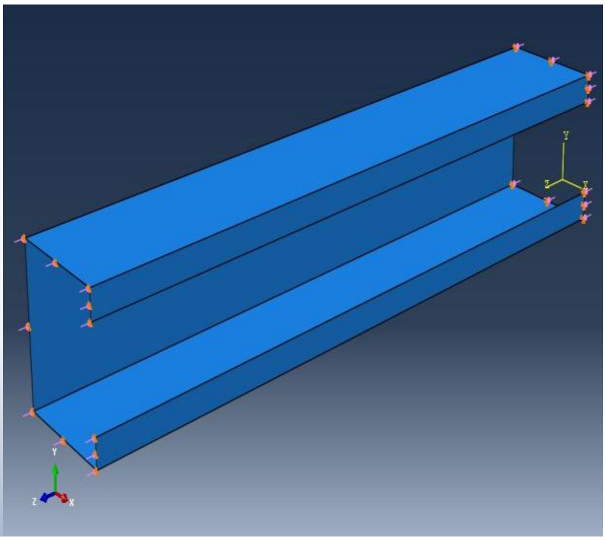

Fig.2 Loading and boundary condition

2.3 Linear Eigen Value Buckling Analysis

Buckling is that mode of failure when the structure experiences sudden failure when subjected to compressive stress. When a slender structure is loaded in compression, for small loads it deforms with hardly any noticeable change in the geometry and load carrying capacity. At the point of critical load value, the structure suddenly experiences a large deformation and may lose its ability to carry load. This stage is the buckling stage. In Abaqus, Linear Eigen Value Buckle step is used to calculate critical buckling load which is nothing but ultimate load. Two types of analysis were employed by using the developed finite element model: elastic buckling and nonlinear static analyses. Elastic buckling analysis gives the elastic buckling loads and corresponding buckling modes. The lowest Eigen vector obtained from elastic buckling analysis was used to calculate the critical buckling load.

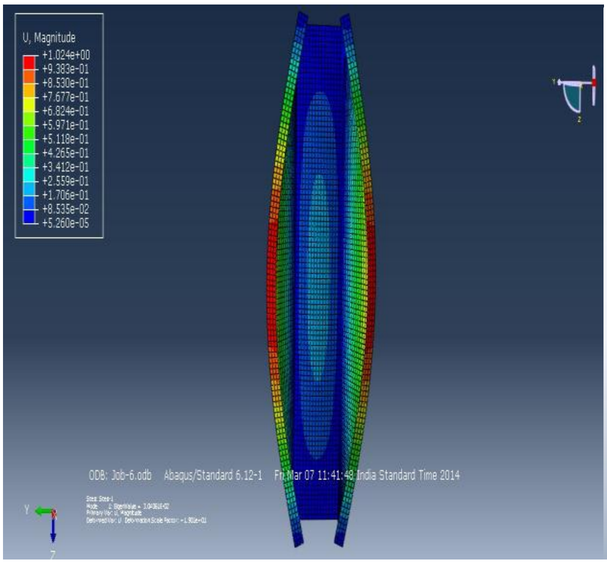

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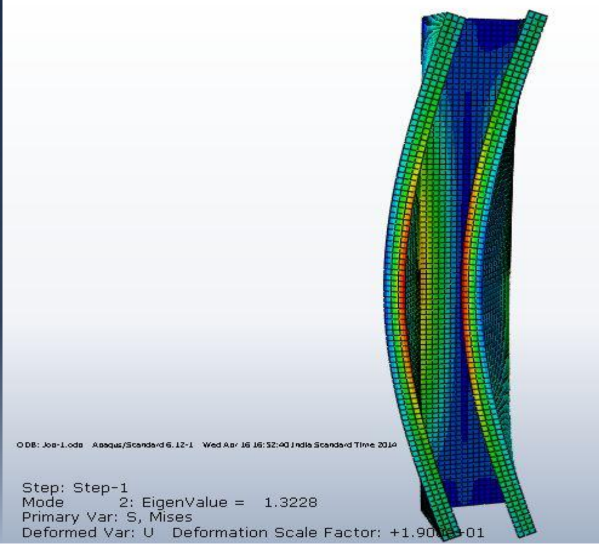
Fig.3a) First Buckling mode of column section in Abaqus at ambient temperature



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Deformed Var: U   Deformation Scale Factor: +1.90[illegible]+01
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Fig.3b) First Buckling mode of column section in Abaqus at elevated temperature

III. Results And Discussion

Table 1 Ultimate loads of 0.6 mm G250 steel columns

Temp. (°C)	Experimental Ultimate Load (KN)	FEA Ultimate Load (KN)
20	14.2	14.53
200	12.5	11.95
350	9.8	8.92
500	6.75	6.19
650	3.38	2.96
800	0.93	0.8

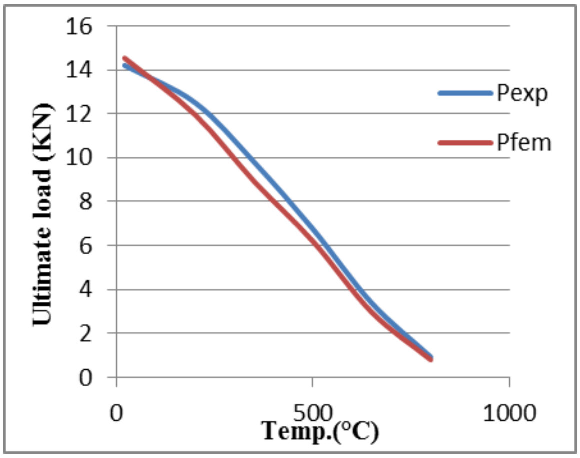

Fig.4 Ultimate load vs. temperature for 0.6 mm G250 steel column

Table 2 Ultimate loads of 0.6 mm G550 steel columns

Temp. (°C)	Experimental Ultimate Load (KN)	FEA Ultimate Load (KN)
20	16.55	15.32
200	14.6	13.20
350	11.65	10.76
500	8.35	7.38
650	4.35	4.01
800	1.14	1

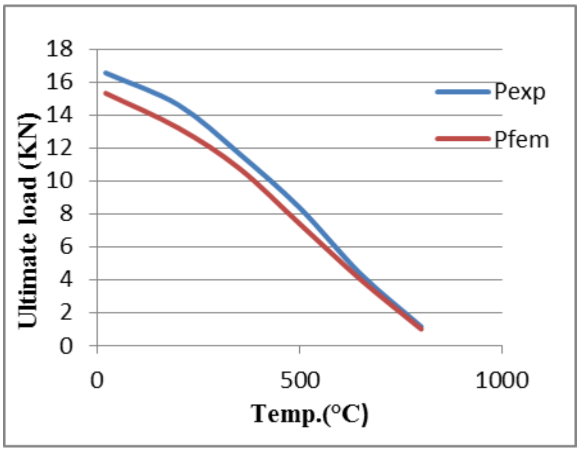

Fig.5 Ultimate load vs. temperature for 0.6 mm G550 steel column

Table 3 Ultimate loads of 0.8 mm G250 steel columns

Temp. (°C)	Experimental Ultimate Load (KN)	FEA Ultimate Load (KN)
20	20.8	20
200	17.7	17
350	15.6	13
500	11.46	9.5
650	4.1	3.7
800	1.4	1.3

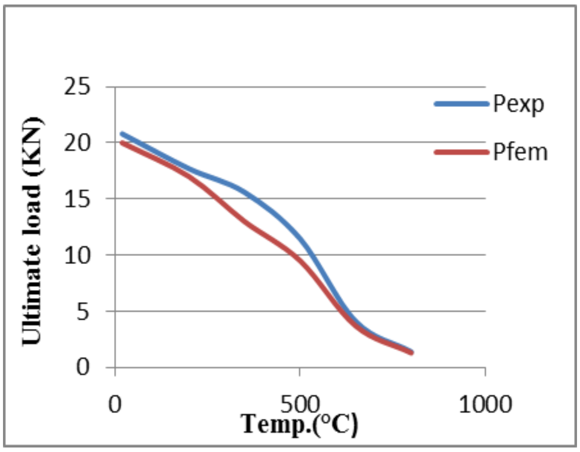

Fig.6 Ultimate load vs. temperature for 0.8 mm G250steel column

Table 4 Ultimate loads of 0.8 mm G550 steel columns

Temp. (°C)	Experimental Ultimate Load (KN)	FEA Ultimate Load (KN)
20	27.43	25.43
200	26.5	24.67
350	23.1	21.2
500	13.2	11
650	4.25	5
800	1.74	1.39

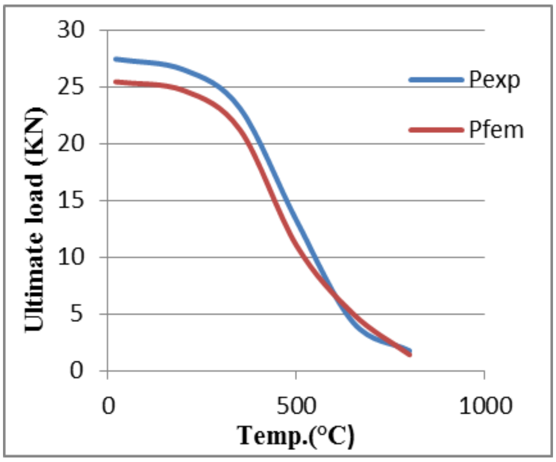

Fig.7 Ultimate load vs. temperature for 0.8 mm G550 steel column

Table 5 Ultimate loads of 0.95 mm G250 steel columns

Temp. (°C)	Experimental Ultimate Load (KN)	FEA Ultimate Load (KN)
20	26.89	25.67
200	24.64	23.89
350	20.29	19.34
500	14.24	13.47
650	7.26	7.08
800	2.02	2

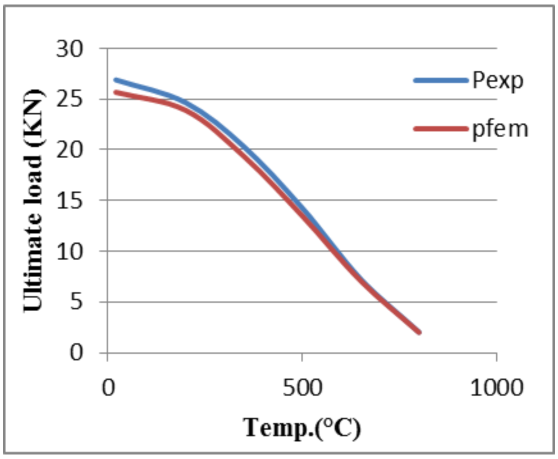

Fig.8 Ultimate load vs. temperature for 0.95 mm G250 steel column

Table 6 Ultimate loads of 0.95 mm G550 steel columns

Temp. (°C)	Experimental Ultimate Load (KN)	FEA Ultimate Load (KN)
20	36.35	34.97
200	31.79	30.23
350	24.8	22.56
500	17.16	15.33
650	9.07	8.87
800	2.4	1.87

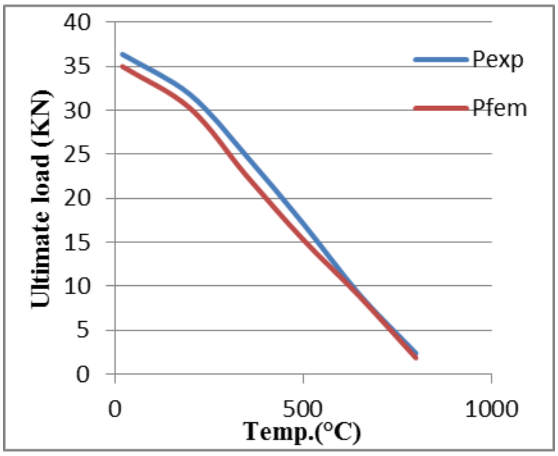

Fig.9 Ultimate load vs. temperature for 0.95 mm G550 steel column

IV. CONCLUSIONS

The most valuable outcomes obtained from this research are as follows:

1) Mechanical properties deteriorate at different rates at elevated temperatures and it appears that (ET/fyT) ratio has an effect on the buckling capacity.
2) Ductility of cold-formed steels was noted to increase with increasing temperature with significant increases beyond 500°C. However, the lowest ductility was observed at 200°C. A significant increase in the ductility was seen for the temperatures beyond 500°C.
3) The ultimate loads of the low and high strength steel specimens at varying temperatures are compared and it can be seen that the strength reduction with increasing temperature was not uniform. The compression strength reduced at a lower rate at low temperatures (up to 350°C), but reduced at a higher rate at high temperatures (350°C to 650°C).
4) It was found that ambient temperature results showed that columns failed by both flanges moving inwards or outwards (see figure 3a) while many columns failed due to one flange moving outward while the other flange moving inward at elevated temperatures (see figure 3b).

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