Thermal and Distortional Buckling Analysis of z Section on Cold-Formed Steel Member

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Abstract- ***Cold-formed steel (CFS) sections are extensively used in light-weight structural applications due to their high strength-to-weight ratio and ease of fabrication. However, when subjected to elevated temperatures such as in fire conditions, their mechanical performance deteriorates significantly. This study investigates the thermal and distortional buckling behavior of Z-section members with and without lips under a uniform temperature field using ANSYS Workbench 2023 R1. Transient thermal and eigenvalue buckling analyses were performed to evaluate the temperature distribution, deformation patterns, and critical buckling temperatures for different member lengths (1 m, 1.5 m, and 2 m). The results show that temperature rise causes rapid stiffness reduction and that longer members exhibit lower critical buckling temperatures, indicating higher susceptibility to thermal instability. The Z-section with lip demonstrates improved resistance to thermal buckling compared to the section without a lip, emphasizing the importance of stiffening elements in maintaining structural integrity under elevated temperature conditions.***

Index Terms- ***Cold-formed steel, distortional buckling, thermal analysis, critical buckling temperature, Z-section.***

1. INTRODUCTION

Cold-formed steel (CFS) members are widely used in light-gauge steel construction due to their high strength-to-weight ratio and fabrication ease. However, under elevated temperatures—such as during a fire—CFS members experience a significant reduction in stiffness and load-carrying capacity. To ensure safety and reliability, thermal analysis plays a critical role in determining the temperature distribution and thermal gradients within these members. The present study focuses on the thermal response of Z-section members with and without lip, subjected to a uniform temperature of 400 °C. The analysis is conducted using ANSYS Workbench to examine the temperature distribution, heat conduction behavior, and thermal deformation characteristics of cold-formed steel sections.

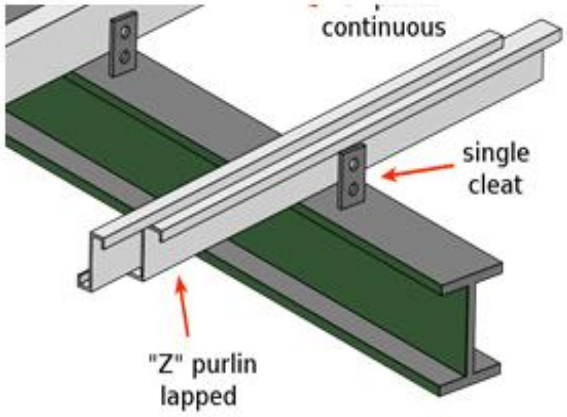

Fig 1: Illustration of z-section

2. METHODOLOGY

The thermal analysis was carried out using ANSYS Workbench 2023 R1. Two types of Z-sections were modelled:

- Z-section with lip: Flange = 200 mm, Web = 50 mm, Lip = 20 mm, Thickness = 2 mm
- Z-section without lip: Flange = 200 mm, Web = 50 mm, Thickness = 2 mm

Three different member lengths—1 m, 1.5 m, and 2 m-were considered to study the influence of length on the temperature response.

2.1 Geometry creation: 3D solid models of both sections were created in ANSYS Design Modeler.

2.2 Material properties: Steel with a temperature-dependent conductivity (50 W/m·K at 25 °C, 28

W/m·K at 500 °C) and specific heat (500J/kg·K) was assigned.

2.3 Meshing: Meshing plays a vital role in achieving accurate finite element results. The developed C- and Z-section models were discretized using the SHELL181 element in ANSYS Workbench. This element type is highly suitable for thin-walled structures and efficiently captures local, distortional, and global buckling modes.

2.4 Boundary conditions: One end of the section was fixed to restrict displacement. The outer surface was subjected to a uniform thermal load of 500 °C. Ambient air temperature of 25 °C was applied to the inner face to allow conduction.

2.5 Analysis of thermal behavior of cold formed steel member

Transient thermal analysis in ANSYS was used to examine the thermal response of cold-formed steel members exposed to fire. The thermal load, which tells how the temperature varies with time, was calculated using the ISO 834 standard fire curve. A temperature of 400 degrees Celsius was applied. The member's greatest temperature increase was noted on the time vs. temperature graph. At different time steps, the temperature distribution and thermal expansion behaviour were noted.

The fire exposure was assumed to act uniformly on the entire body of the section. Temperature rise with time applied as a thermal boundary condition.

A range of exposure durations, from 0 to 200 seconds, was used for the transient analysis. In this order to investigate the rate of transfer of heat and the thermal gradient throughout the section, the temperature distribution within the member was extracted at specific time intervals.

Temperature distribution across the cross-section obtained at different time intervals. The maximum nodal temperature values were recorded and tabulated, and the temperature response was obtained from ANSYS at critical points. The results indicate that the steel temperature rises rapidly in the initial stages, significantly reducing the stiffness of the section.

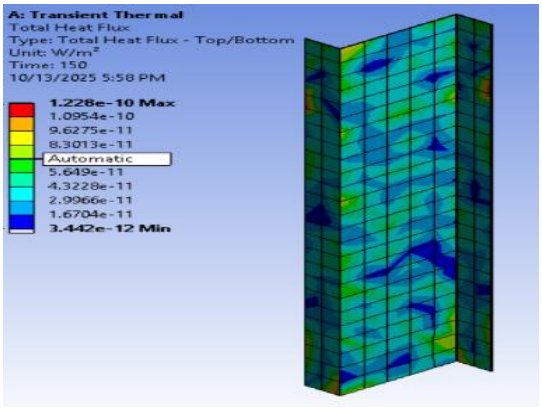

Fig 2: Distribution of total heat flux for Z section without lip 1m

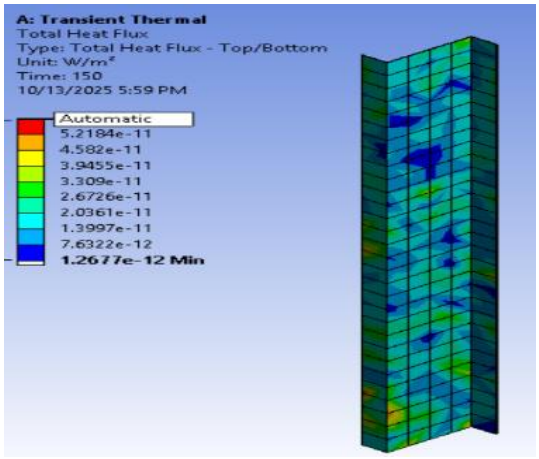

Fig 3: Distribution of total heat flux for Z section without lip 1.5m

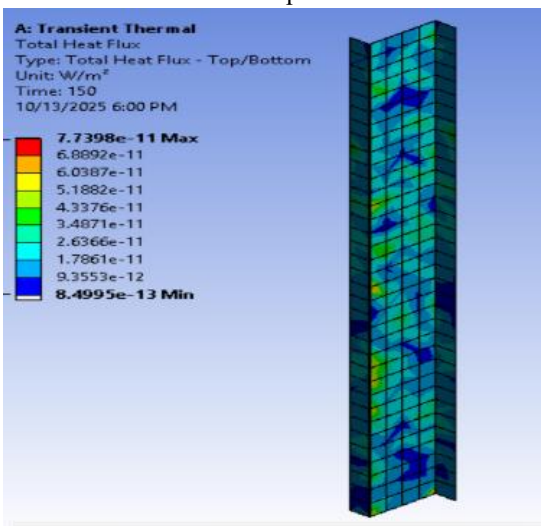

Fig 4: Distribution of total heat flux for Z section without lip 2m

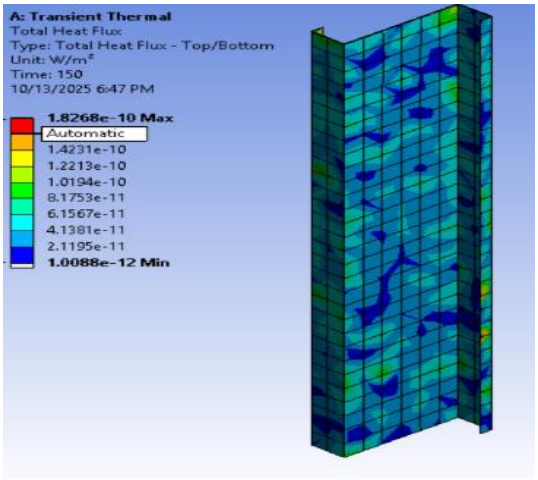

Fig 5: Distribution of total heat flux for Z section with lip 1m

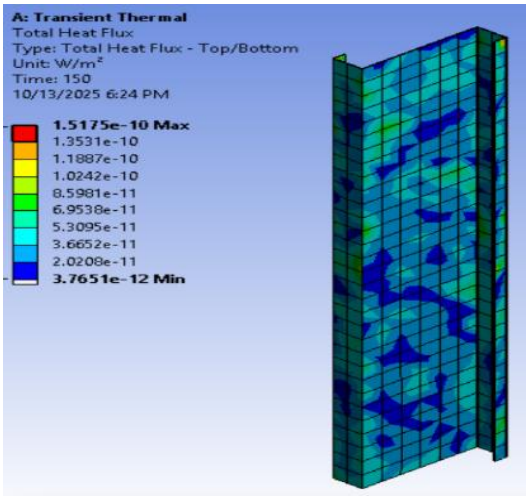

Fig 6: Distribution of total heat flux for Z section with lip 1.5m

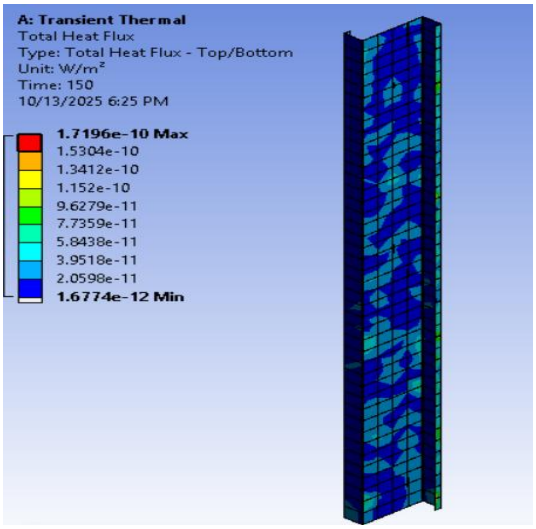

Fig 77: Distribution of total heat flux for Z section with lip 2m

2.6 Analysis of distortional buckling of cold formed steel member

Eigenvalue Buckling Analysis (EBA) was done in ANSYS after the heat analysis. The structural model was updated with the temperature distribution findings from investigation of thermal. To calculate the Load Multiplier, the analysis was done. To assess the stability of the cold-formed steel member under fire conditions, the critical buckling temperature was computed by multiplying the load multiplier by the applied thermal load. Eigenvalue buckling analysis was used to assess how high temperatures affected the buckling resistance of cold-formed steel members.

The eigenvalue buckling mode shape of cold-formed steel member, showing the deformation pattern corresponding to the first buckling mode. The maximum deformation occurs near the midspan region, highlighted in red, indicating the most critical zone of instability. This deformation shape reflects the distortional buckling behavior, where the flange and web experience localized bending due to compressive loading

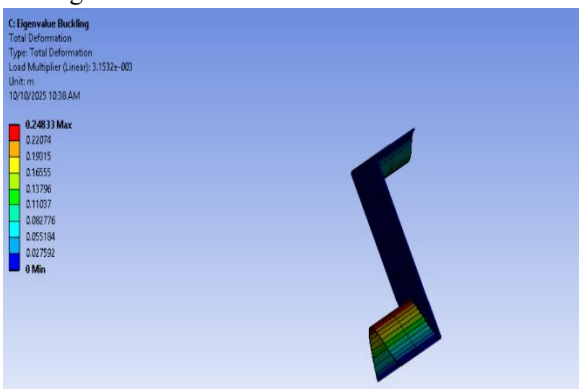

Fig 8: Distortional buckling mode of Z section without lip 1m

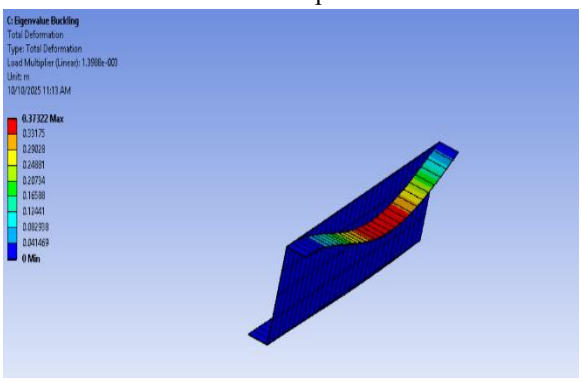

Fig 9: Distortional buckling mode of Z section without lip 1.5m

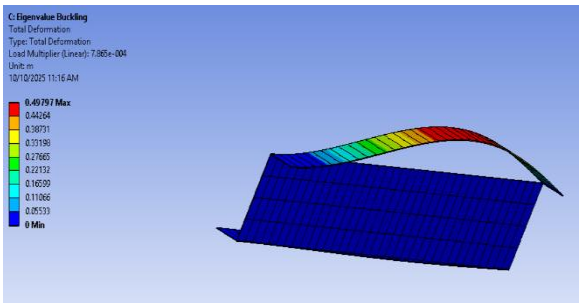

Fig 10: Distortional buckling mode of Z section without lip 2m

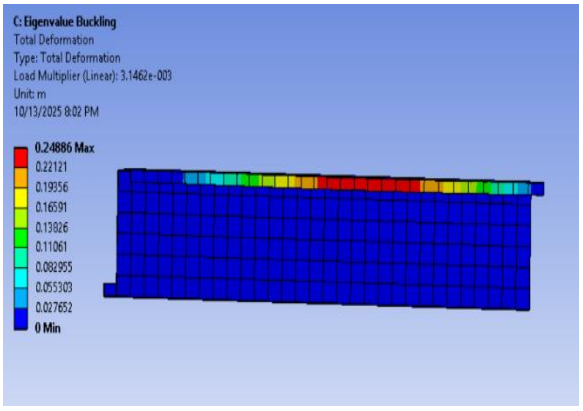

Fig 11: Distortional buckling mode of Z section with lip 1m

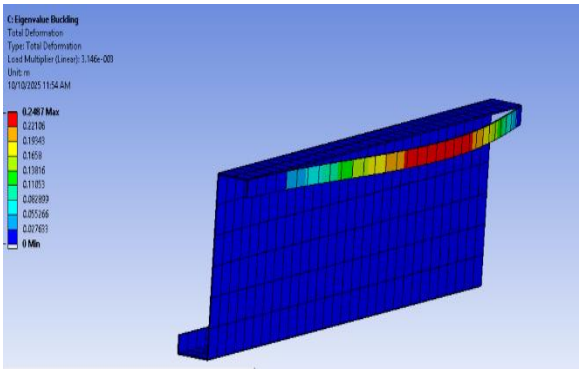

Fig 12: Distortional buckling mode of Z section with lip 1.5m

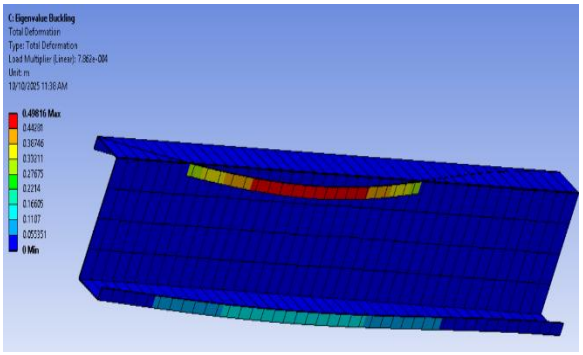

Fig 13: Distortional buckling mode of Z section with lip 2m

2.7 Critical buckling temperature vs Length

The observed rise in the measured value with length can be affiliated to the structural relationship between member length and its buckling behaviour. As the length of a plate increases, its susceptibility to both thermal and mechanical buckling also rises, thereby influencing the critical buckling conditions. Factors for example the length-to-thickness ratio, material properties, and BC's significantly affect this behavior. For longer members, the load or temperature required to initiate buckling generally decreases, resulting in a higher measured critical response as the length increases.

I. Variation of Length vs Critical Buckling Temperature

Table 1: C section without lip vs Z section without lip

Length (m)	Z-section without lip ΔTcr (°C)
1	360
1.5	160
2	90

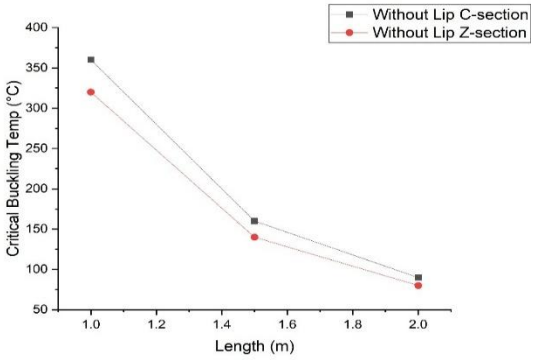

Fig 14: Length vs Critical Buckling Temperature

The Critical buckling temperature declines as the member length increases for both Z-section without lips. For a 1 m length, the Z-section exhibits a higher critical temperature of 360 °C. As the length increases to 1.5 m and 2 m, the ΔTcr values drop significantly, reaching 160 °C for the Z-section, and 90 °C, indicating that longer sections are more susceptible to thermal buckling as displayed in Table 1 and Fig. 14.

II. Variation of Length vs Critical buckling temperature

Table 2: C section with lip vs Z section with lip

Length (m)	Z-section with lip ΔTcr (°C)
1	400
1.5	195
2	110

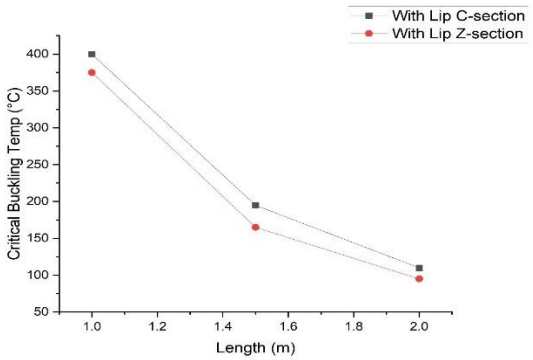

Fig 15: Length vs Critical buckling temperature

The Critical buckling temperature for both Z-section with lips declines the member length increases. At a length of 1 m, the Z-section with lip shows a higher ΔTcr of 400 °C, With increasing lengths of 1.5 m and 2 m, the ΔTcr drops to 195 °C and 110 °C for the Z-section, highlighting that longer members are more prone to thermal buckling as displayed in Table 2 and Fig. 15.

III. CONCLUSIONS

a. The Z-section with a lip demonstrated improved resistance to thermal and distortional buckling compared to the section without a lip.
b. The inclusion of a lip acts as a geometric stiffening element, significantly enhancing the section's rigidity and overall stability under elevated temperatures.
c. The critical buckling temperature (Delta Tcr) was found to decrease with increasing member length for both Z-sections. The 1-meter Z-section with a lip achieved the highest Delta Tcr of 400 Celsius.
d. In contrast, the longest 2-meter member with a lip recorded a significantly lower Tcr.
e. For the 1-meter length, the section without a lip had a lower Tcr of 360 Celsius compared to the lipped section.
f. The analysis confirmed that the temperature rise rapidly reduces the stiffness and load-carrying capacity of the cold-formed steel members.
g. Longer members (1.5 m and 2 m) exhibit lower critical buckling temperatures, indicating higher susceptibility to thermal instability.
h. The deformation pattern observed in the Eigenvalue Buckling Analysis (EBA) reflected distortional buckling behavior, where the flange and web underwent localized bending.
i. The results underscore that geometric stiffening is crucial for optimizing CFS member design and improving fire performance.

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