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Parametric Numerical Study on Flexural Behaviour of Cold-Formed Steel Channel Sections: Effects of Lip, Flange Width, and Thickness

Pavan Tikate, Ph.D[1*], Ishwar Sonar, Ph.D[2]

[1]Research Scholar, Department of Civil Engineering, COEP Technological University, Pune, 411005, India. Email: pavan.walchand@gmail.com
[2]Department of Civil Engineering, COEP Technological University, Pune, 411005, India. Email: ips.civil@coeptech.ac.in

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ABSTRACT

This paper presents a detailed numerical investigation on the flexural behaviour of cold-formed steel (CFS) channel sections with a focus on three critical geometric parameters: lip provision, flange width, and section thickness. The study aims to evaluate how these parameters influence the flexural capacity, stiffness, and overall performance of CFS members under loading. A series of channel configurations were modelled and analyzed using STAAD Pro under single-point load condition, replicating typical bending scenarios in real structures. Each configuration was examined for its load-deflection response, critical buckling behaviour, and capacity enhancement relative to standard design benchmarks outlined in IS 801:1975. The study concludes that lipped sections significantly outperform unlipped ones in terms of stiffness and stability. Additionally, increased thickness and wider flanges provide notable gains in load capacity and serviceability performance. The study provides a foundation for future development of composite systems involving CFS sections and additional reinforcements to mitigate identified structural weaknesses.

1. Introduction

Cold-formed steel (CFS) sections have gained significant traction in modern structural applications due to their high strength-to-weight ratio, ease of prefabrication, and geometric versatility. These cold-rolled alternatives to hot-rolled members are extensively used in lightweight framing systems, industrial sheds, modular structures, and secondary elements (Lim et al., 2015; IS 801:1975). However, due to their thin-walled nature, CFS sections are susceptible to local, distortional, and lateral-torsional buckling, especially under axial and flexural loading conditions (Huang & Yang, 2022; Schafer, 2008). The performance of CFS members is strongly influenced by geometric design parameters such as lip depth, flange width, and material thickness (Roy et al., 2020; Schafer & Ádány, 2006).

To mitigate these instabilities, several studies have explored geometric modifications to enhance stiffness, delay buckling, and increase flexural capacity. Akula et al. (2024) conducted a comprehensive study on HAT and Z sections and concluded that the addition of lips improved both local and global stability. El-Lafy et al. (2022) extended this approach by optimizing flange widths and lip sizes, reporting a significant increase in buckling resistance. Alex and

Iyappan (2023) emphasized the role of inside corner radius-to-thickness (R/t) ratios, noting that even minor changes could alter the bending response. Similarly, Roy et al. (2017) investigated the impact of screw spacing in built-up sections and found lip configurations crucial to axial load performance.

In parallel, Zhou et al. (2021) and Alabduljabbar et al. (2020) conducted flexural tests on lipped C-sections and observed substantial improvements in load-bearing capacity when flange and lip dimensions were optimized. Ahdab et al. (2022) proposed refined local buckling expressions for lipped channel members, supporting the effectiveness of empirical calibration. CUFSM-based studies by Schafer & Ádány (2006) also validated the importance of incorporating distortional buckling modes in design. Moreover, Ting et al. (2017) and Lim et al. (2015) analyzed built-up CFS members under axial compression and bending, finding enhanced performance with strategic flange-lip detailing.

Several computational studies using design software like STAAD.Pro have attempted to simulate these responses, yet gaps remain in standardized validation and integration with Indian codes (Bentley Systems, 2023). Despite the presence of the IS 801:1975 code, which outlines general design provisions for light gauge steel, it lacks detailed commentary on the combined influence of lip depth, flange width, and section thickness on C-channel sections (IS 801:1975). Additionally, Huang and Yang (2022) highlighted that distortional buckling remains underrepresented in simplified design models, calling for further code-aligned research.

Schafer (2008) emphasized the need for direct strength methods tailored to CFS design, yet implementation in Indian practice is limited. Therefore, while global literature has progressed in understanding localized buckling and strength enhancements, a unified and parametric investigation under IS 801:1975, supported by STAAD-based analysis—is yet to be fully explored.

While several studies have evaluated the role of lip, flange, or thickness individually, there is a lack of integrated, parametric assessment of these variables in standard C-channel configurations under flexural action, especially in the context of IS 801:1975. Furthermore, limited validation using widely adopted design tools like STAAD.Pro restricts their adoption in practical Indian structural engineering workflows. This study aims to fill that void through a systematic numerical investigation involving variation of lip depth, flange width, and thickness across representative configurations. The outcomes will aid in optimizing structural performance while ensuring code compliance and potential guidance for future revisions to design standards.

It is noted that STAAD Pro performs linear elastic analysis and does not explicitly capture local or distortional buckling modes. However, within the serviceability range, linear modelling remains a practical and widely adopted approach in routine design offices. The present study therefore focuses on comparative trends and relative performance rather than absolute failure prediction.

2. Methodology

The study was conducted through detailed numerical modeling and analysis of eighteen cold-formed steel (CFS) channel configurations using STAAD Pro. The primary parameters investigated were lip provision (presence or absence), flange width (40 mm, 50 mm, 60 mm, and 100 mm), and section thickness (2 mm, 3.15 mm, 4 mm, and 5 mm). All sections maintained a uniform web depth of 100 mm and a span length of 2000 mm to ensure consistent comparative analysis.

Material properties were standardized across all models, with a yield strength of 350 MPa, ultimate tensile strength of 450 MPa, Young's modulus of 2.01×10^5 MPa, and a Poisson's ratio of 0.3. Channel beams were modeled as simply supported at both ends, and single-point loading was applied at midspan to generate maximum bending effects.

Each configuration was analyzed for load-deflection behaviour, ultimate load capacity, and predicted failure modes. Midspan deflections were recorded and benchmarked against the serviceability and strength criteria defined in IS 801:1975 to validate model conformity and assess the accuracy of the numerical simulations.

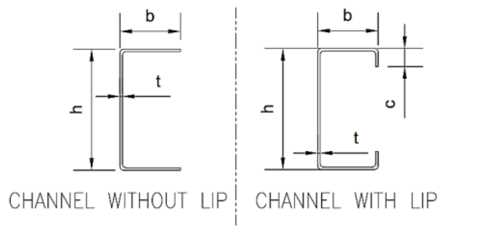

Figure 1 Geometrical configuration of a typical lipped and unlipped channel section

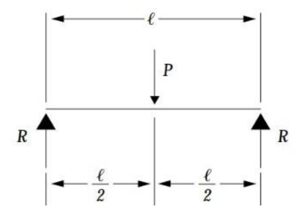

Figure 2 Loading setup for single-point loading

Sr. No.	Section Without Lip	Section With Lip	Depth, h (mm)	Flange, b (mm)	Thickness, t (mm)	Lip, c (mm) (only for Lipped)
1	100CU40X2	100CS40X2	100	40	2	15
2	100CU50X2	100CS50X2	100	50	2	15
3	100CU50X3.15	100CS50X3.15	100	50	3.15	15
4	100CU60X2	100CS60X2	100	60	2	15
5	100CU60X3.15	100CS60X3.15	100	60	3.15	20
6	100CU60X4	100CS60X4	100	60	4	20
7	100CU60X5	100CS60X5	100	60	5	25
8	100CU100X2	100CS100X2	100	100	2	25

Table 1 Summary of section properties (dimensions, thickness, lip presence)

Channel sections were modelled using beam elements with equivalent section properties as defined in STAAD Pro. Warping effects and nonlinear buckling modes were not explicitly modelled, consistent with linear elastic analysis commonly adopted for serviceability assessment. The objective of the study was to evaluate comparative flexural stiffness trends rather than ultimate failure behaviour.

3. Results and Discussion

This section presents the outcomes of the parametric analysis carried out on cold-formed steel channel sections subjected to flexural loading. Variations in lip presence, flange width, and section thickness were studied under single-point loading conditions using STAAD Pro. The structural performance of each configuration was evaluated based on maximum load-carrying capacity, mid-span deflection, and observed failure modes. Key trends and comparative insights are discussed in the following subsections.

3.1 Influence of Lip Provision

Channel sections with lips exhibited significantly enhanced flexural performance compared to their plain counterparts, as evidenced in Figure 3. The presence of lips provided additional edge stiffness, effectively restraining flange rotation and delaying the onset of local and lateral-torsional buckling. Load-deflection curves demonstrated that lipped sections achieved higher initial stiffness and carried greater ultimate loads.

Numerical analysis using STAAD Pro showed a consistent reduction of approximately 11% in mid-span deflection for lipped sections across the studied load range. This linear behaviour is attributed to the elastic modeling assumptions inherent in STAAD Pro. In actual experimental conditions, the influence of lips is expected to become more pronounced at higher loads due to nonlinear effects such as localized buckling and material yielding.

Overall, the incorporation of lips in channel sections enhances both serviceability and ultimate performance, confirming their critical role in optimizing cold-formed steel member design.

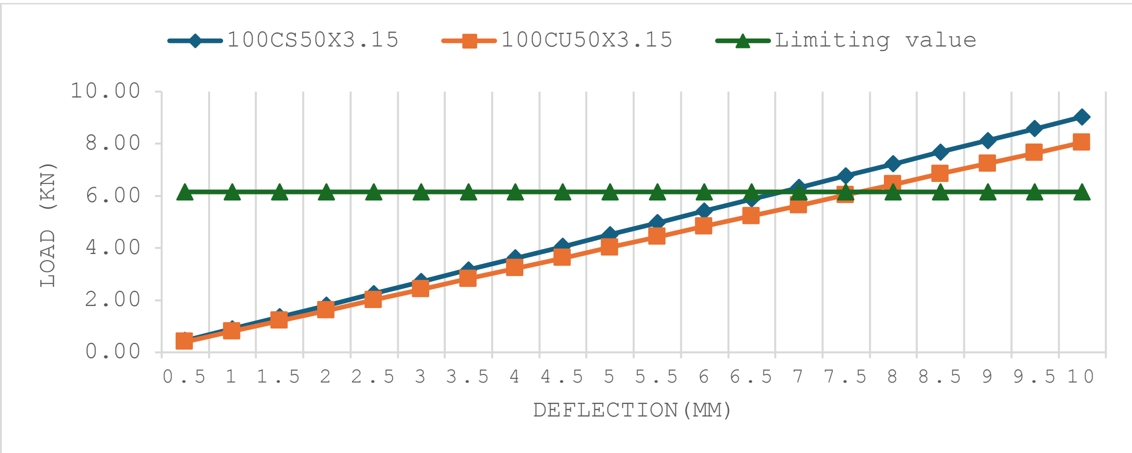

Figure 3 Load vs. Deflection – With vs Without Lip

3.2 Influence of Section Thickness

The influence of section thickness on the flexural behaviour of cold-formed steel sections was evaluated for both lipped and unlipped configurations under single-point loading, as shown in Figure 4 & 5. A direct and positive correlation between section thickness and flexural performance was observed.

Thicker sections demonstrated significantly lower mid-span deflections under identical loading conditions. For example, at 5 kN load, increasing thickness from 2 mm (100CU60X2) to 5 mm (100CU60X5) reduced deflection by approximately 54% for unlipped sections, and a similar trend was observed for lipped sections. This improvement is attributed to the increased moment of inertia and reduced slenderness ratios associated with thicker members.

Moreover, thicker sections enabled a more uniform stress distribution across the cross-section, enhancing load-bearing capacity and reducing localized deformations that are typically pronounced in thinner sections. In terms of serviceability, thicker sections delayed the onset of limiting deflections, with 4 mm and 5 mm thick sections maintaining compliance with the 6.16 mm deflection limit even up to the maximum tested load of 10 kN.

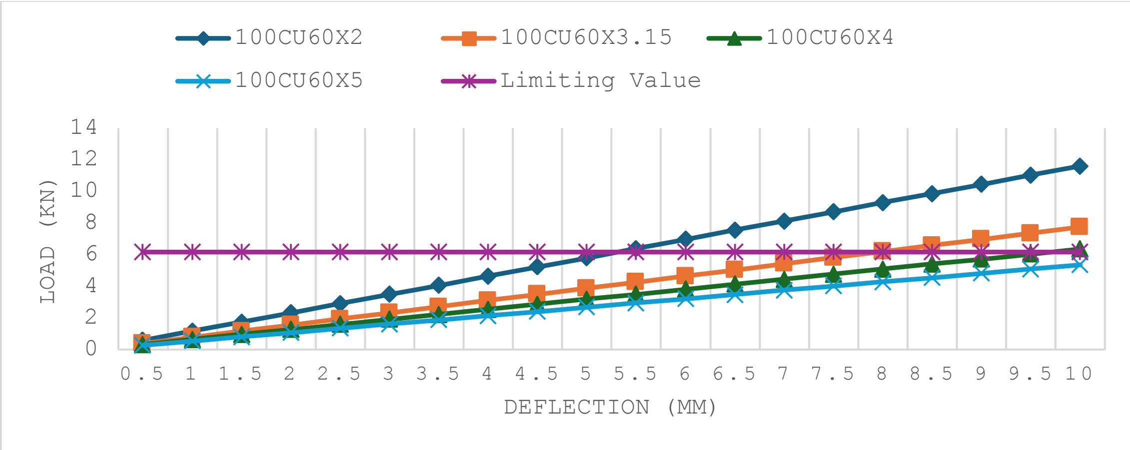

Figure 4 Load vs. Deflection – Varying Thickness (Without Lip)

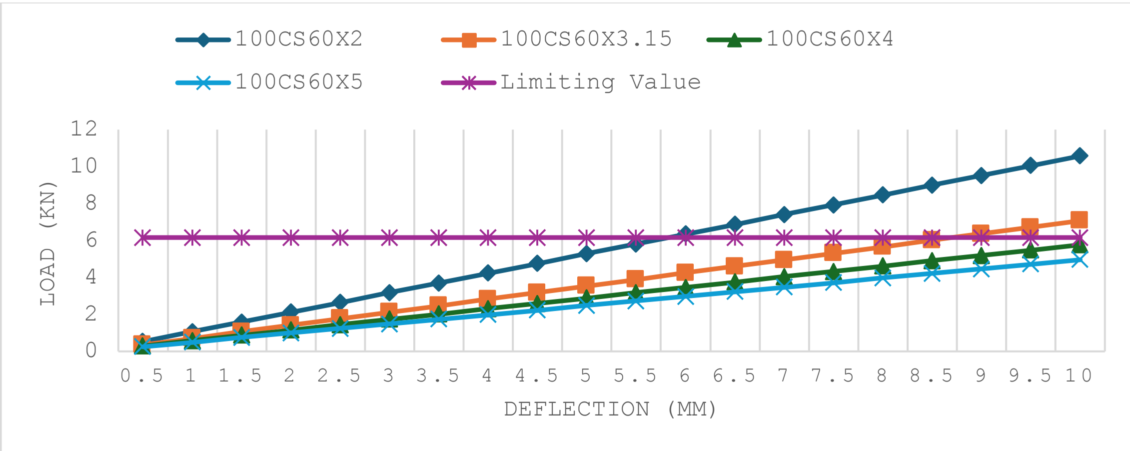

Figure 5 Load vs. Deflection – Varying Thickness (With Lip)

Overall, increased section thickness significantly enhances flexural stiffness, serviceability margins, and structural efficiency, confirming its critical role in optimizing the design of cold-formed steel elements.

3.3 Influence of Flange Width

The effect of flange width on the flexural performance of cold-formed steel sections was investigated for both lipped and unlipped configurations under single-point loading, as presented in Figure 6 & 7. An increase in flange width resulted in higher moment of inertia, improved lateral stability, and substantially reduced mid-span deflections.

For unlipped sections, the narrowest flange section (100CU40X2, 40 mm flange) exceeded the serviceability limit of 6.16 mm at loads around 5.0 kN, whereas the widest flange section (100CU100X2, 100 mm flange) remained within permissible limits up to approximately 8.0 kN. At 5 kN, the deflection reduction was approximately 53% between the narrowest and widest sections. A similar trend was observed for lipped sections, where wider flanges, combined with edge stiffening provided by lips, exhibited nearly 50% lower deflections compared to narrow-flanged counterparts.

Wider flanges also contributed to delaying the onset of flange-local buckling and facilitated improved stress distribution within the cross-section. The combined provision of increased flange width and lips further stabilized the member against torsional effects. Practically, this enables structural designers to tailor channel sections to specific load demands by adjusting flange dimensions, optimizing strength and serviceability without significant changes to manufacturing processes.

Thus, increasing flange width—especially when coupled with lips—emerges as an effective and practical strategy to enhance flexural stiffness, load-carrying capacity, and serviceability performance in cold-formed steel members.

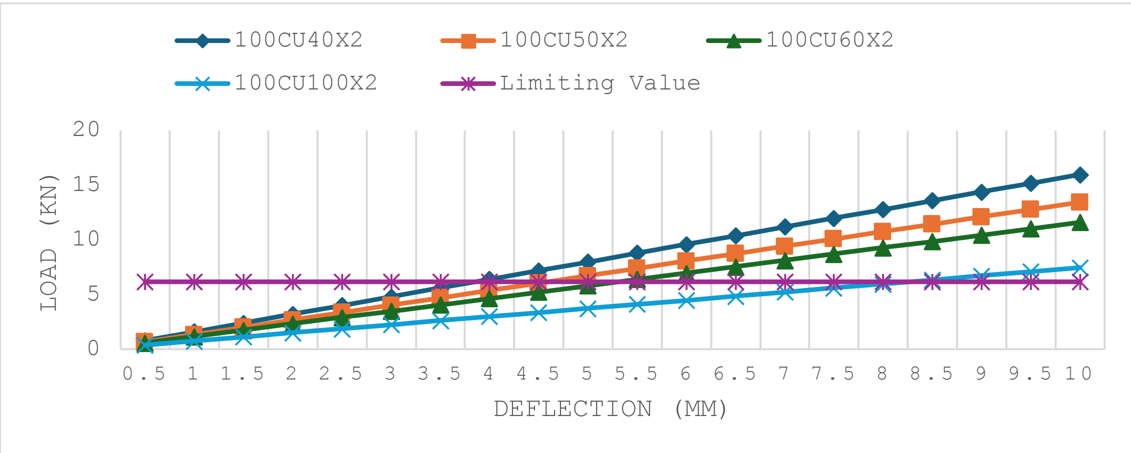

Figure 6 Load vs. Deflection – Varying Flange Width (Without Lip)

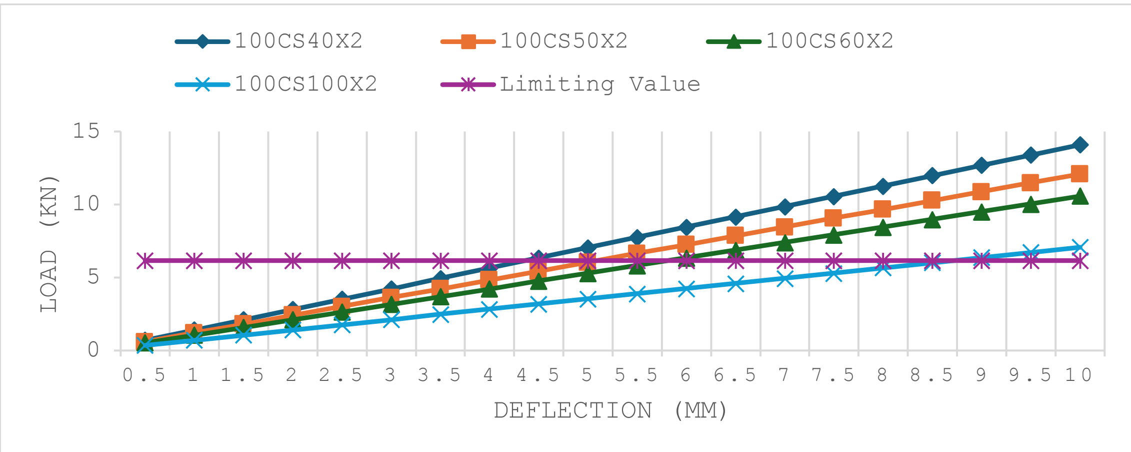

Figure 7 Load vs. Deflection – Varying Flange Width (With Lip)

3.4 Comparison with IS 801 Design Values

The numerically obtained deflections from STAAD Pro simulations were benchmarked against the permissible limits specified by IS 801:1975 for cold-formed steel structures. Across all section configurations, it was observed that the numerical deflections closely adhered to the serviceability limits prescribed by the code in the elastic range. For thinner and narrower sections, such as 100CU40X2 and 100CU60X2, deflections exceeded the limiting value of L/325 (approximately 6.16 mm) at lower loads, aligning with IS 801 expectations for slender members. Conversely, thicker and wider flange sections remained within acceptable limits up to higher load levels. Minor deviations between simulated and code-expected behaviour can be attributed to the idealized boundary conditions and material assumptions inherent in numerical modeling. Overall, the comparison validates that the STAAD Pro linear elastic analysis reasonably captures serviceability behaviour consistent with IS 801 provisions. IS 801:1975 does not explicitly address distortional buckling; therefore, comparison was limited to serviceability-based deflection criteria.

3.5 Summary of Results and Discussion

The parametric study clearly demonstrates that geometric parameters critically influence the flexural behaviour of cold-formed steel channel sections. The provision of lips substantially improves stiffness, delays local and lateral-torsional buckling, and increases load-carrying capacity compared to plain sections. Increasing section thickness enhances moment resistance and significantly reduces mid-span deflections, while wider flanges contribute to greater lateral stability and more efficient stress distribution across the cross-section.

Comparison with IS 801 serviceability criteria indicated that most configurations met deflection limits under typical loading, although thinner and narrow-flange sections approached or exceeded permissible thresholds at higher loads. This underscores the importance of careful selection and optimization of section geometry in practical design applications.

Overall, the study confirms that strategic adjustments to lip size, section thickness, and flange width can markedly enhance the serviceability and strength performance of cold-formed steel members. These insights highlight the need for developing cold-formed steel composite sections to enhance structural efficiency and address the limitations identified in the current study.

4. Conclusion

The parametric study on cold-formed steel (CFS) channel sections under flexural loading provided critical insights into the influence of geometric parameters on structural behaviour. The results confirmed that lips significantly enhance structural stability by restraining flange rotations and increasing torsional rigidity. Increased section thickness improves flexural stiffness, load-carrying capacity, and serviceability performance, while wider flanges promote more effective stress distribution and delay local and lateral buckling.

The cumulative optimization of lip provision, section thickness, and flange width leads to substantial gains in flexural resistance and overall structural stability. Benchmarking the numerical results against IS 801:1975 demonstrated the reliability of STAAD Pro in simulating the elastic behaviour of CFS sections within serviceability limits.

These findings emphasize the critical role of geometric design in optimizing CFS members and lay the groundwork for future development of hybrid systems, such as cold-formed steel–concrete composites, aimed at addressing identified serviceability challenges and enhancing structural efficiency in advanced applications.

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Author Profile:

Er. Pavan Tikate is a research scholar at Department of Civil engineering at COEP Technological University, Pune. Correspondence regarding this article can be sent to him on B6-201, Comfort Zone Plus, Oppsosite to Fatcook Restaurant, Baner - Balewadi Rd, Baner, Pune, Maharashtra 411045, 9422851684

Dr. Ishwar Sonar is Associate Professor at Department of Civil engineering at COEP Technological University, Pune. Correspondence regarding this article can be sent to him on Department of Civil Engineering, COEP Technological University- Pune, 411005. 9890272905