ADMI IJST International Journal Science and Technology
OPEN ACCESS

IJST Vol 4 No. 3 | November 2025| ISSN: 2828-7223 (print), ISSN: 2828-7045 (online), Page 89-103

Study of WF Profile Analysis as a Compression Element Reviewed Based on the Weight to Strength Ratio Using the LRFD Method

Kharisma Nur Cahyani[1*], Yehezkiel Septian Yoganata[2], Rif'atul Khusniah[3], Kartika Purwitasari[4]
[1,2,3]Civil Engineering Department, State Polytechnic of Malang, Indonesia

Article History
Received : December 11, 2025
Accepted : December 23, 2025
Published : December 24, 2025
Available Online
December 24, 2025

Corresponding author*:
kharismanurcahyono@polinema.ac.id

Cite This Article:
Kharisma Nur Cahyani, Yoganata, Y. S., Khusniah, R., & Purwitasari, K. (2025). Study of WF Profile Analysis as a Compression Element Reviewed Based on the Weight to Strength Ratio Using the LRFD Method. International Journal Science and Technology, 4(3), 89–103.

DOI:
https://doi.org/10.56127/ijst.v4i3.2407

Abstract: This study investigates the efficiency of WF steel profiles as compression members by evaluating the strength-to-weight ratio using the Load and Resistance Factor Design (LRFD) method. The analysis was conducted on seven variations of WF profiles made of ASTM A36M steel (Fy = 250 MPa, Fu = 450 MPa). The primary parameters considered were axial compressive capacity and profile weight, which were used to determine the strength-to-weight ratio as an indicator of material efficiency. This study contributes to existing research by integrating a systematic strength-to-weight–based evaluation to support optimal WF profile selection beyond conventional strength verification. The results indicate that the strength-to-weight ratio ranges from 592.15 to 611.31, with the highest value obtained for profile 300.300.9.14. In contrast, the maximum compressive capacity of 260,599 kg was achieved by profile 300.300.11.17. Overall, WF profiles with 300×300 dimensions demonstrate superior performance compared to 250×250 profiles in terms of both strength and efficiency. The findings suggest that profile selection may be adapted to design priorities, emphasizing either material efficiency or maximum load-carrying capacity.

Keywords: Compression Member, LRFD, Efficiency, Strength To Weight Ratio. WF Profile

INTRODUCTION

Steel structures are one of the construction systems widely used in the construction of high-rise buildings, bridges, and other infrastructure. One of the main elements in steel structures is the Wide Flange (WF) profile, which is often used as a compression element, especially columns. WF profiles are chosen because they have good capacity to withstand axial loads, even stress distribution, and efficiency in construction implementation (AZoM, 2012). However, the selection of a non-optimal WF profile can result in material waste and increased structural weight, or conversely, reduced performance due to the potential for local or global buckling in cross-sections with a high slenderness ratio (Alam & Kanagarajan, n.d.).

Wide Flange (WF) steel profiles, often called H-Beams, are one of the most used structural elements in modern steel buildings. Their cross-sectional shape resembles the letter "H" with wide flanges and relatively thick perpendicular webs. This configuration makes WF profiles very efficient in resisting bending moments while having a high axial capacity, so they are widely applied as beams and columns in steel portal systems. The main advantage of WF compared to other profiles lies in their large inertia-to-weight ratio, so that structures can be designed more economically without reducing stiffness (Meng & Gardner, 2023).

As design requirements evolve, several international studies have re-evaluated the performance of WFs under combined loading conditions. Previous studies have investigated the behavior of welded I-sections (equivalent to WFs) under combined axial and unidirectional bending loads. The results indicate that traditional design methods such as Eurocode-3 (EN-1993) and AISC tend to be conservative, while the Continuous Strength Method (CSM) provides more realistic predictions of ultimate load capacity (Meng & Gardner, 2023). This finding is important because it demonstrates that WF design can be optimized using a deformation-based approach, rather than simply based on nominal yield strength values.

In addition to the pure capacity aspect, other studies also highlight the seismic performance of structural systems using WF as beam elements. This serves as the basis for evaluating prefabricated frame systems with concrete-filled steel tubular (CFST) columns and WF beams. Test results show that the use of WF in this modular system results in good hysteretic energy distribution and reduces damage concentration at the joints. This indicates that WF is not only superior in flexural capacity, but also contributes to improving the seismic performance of modern steel structures(Zhang et al., 2024).

Steel structural specifications also provide better ductility and simplify fabrication and welding processes. With a combination of efficient cross-sectional shapes, proven structural performance under various load conditions, and supportive material standards, WF profiles remain the primary choice in steel structural design for both conventional and modern prefabricated buildings.

For the design analysis process of compressive element structure planning in this study, the Load and Resistance Factor Design (LRFD) method is used, which has become a widely used design approach because it considers load factors and strength reduction factors simultaneously. Based on the LRFD method, design reliability can be more uniform compared to conventional methods such as Allowable Stress Design (ASD). LRFD also allows for more realistic calculation of profile compressive capacity by considering the buckling and strength reduction aspects of the cross-section (Badan Standardisasi Nasional, 2020b).

Although much research has been conducted, there are research gaps that need to be further studied. First, most previous studies have not explicitly discussed the optimization of the weight-to-strength ratio of WF profiles as compression elements, even though weight efficiency is a major determinant of construction costs and structural performance (Pribadi & Rumbyarso, 2023). Second, previous studies tend to focus on the overall structural system, such as portals or roof trusses, and have not specifically optimized WF profiles as single compression columns (Arianto & Tedianto, 2019). Third, the LRFD method is more often used as a verification tool, rather than as an optimization framework for evaluating alternative steel profiles (Segui, 2017). Furthermore, research based on national standards (Badan Standardisasi Nasional, 2020b) is still limited, even though its application is very important for the context of structural design in Indonesia.

Based of the previous studies on WF steel profiles as compression members generally focus on strength verification and stability requirements based on design codes, without explicitly evaluating material efficiency through a systematic strength-to-weight ratio analysis. In addition, comparative assessments between different WF cross-sectional dimensions to identify the most efficient profile remain limited, particularly when using the LRFD method. Therefore, this research is directed to address these gaps by optimizing WF profiles as compression elements through an efficiency-based approach. The analysis emphasize the evaluation of strength-to-weight ratios to determine the most optimal WF profile that is lightweight while still satisfying strength and stability requirements in accordance with applicable standards (American Institute of Steel Construction, 2017; Badan Standardisasi Nasional, 2020b).

This study aims to evacuate and compare the efficiency of various WF profiles used as compression members based on their strength-to weight ratios using LRFD method. The objectives are to identify the most material-efficient WF profiles, to examine the relationship between efficiency and compressive capacity among different profile dimensions and to provide a rational basis for WF profile selection that balances structural performance and material efficiency in steel structure design practice.

RESEARCH METHOD

Research Framework

This study employed a structured analytical framework to evaluate the efficiency of WF profiles used as compression members. The research procedure consisted of:

1. Comprehensive literature review related to compression members and steel design standards.
2. Selection and collection of WF profile data.
3. Evaluation of compressive strength and efficiency of the selected profiles based on the provisions of SNI 1729:2020 using the LRFD method.
4. Comparative analysis and discussion of the results.
5. Formulation of conclusions and design recommendations.

The following are the research stages from start to finish in accordance with **Figure 1**.

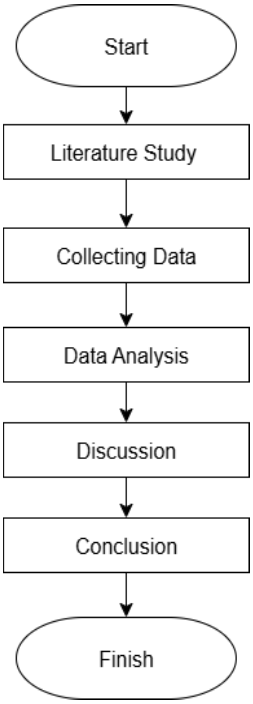

Figure 1. Research Flowchart

Design Assumptions

The analysis was conducted under several simplifying assumptions to ensure consistency with design standards. WF steel profiles were assumed to function as concentrically loaded compression members without load eccentricity. The steel material was considered homogeneous, isotropic, and to follow elastic–plastic behavior in accordance with the specified steel grade. Ideal boundary conditions were assumed, while the effects of dynamic loading, corrosion, residual stresses, and initial geometric imperfections were not explicitly considered. All calculations were performed in accordance with SNI 1729:2020 using the LRFD approach.

Calculation procedure

The calculation process was carried out sequentially to ensure reproducibility. First, the cross-sectional properties of each WF profile, including area, moment of inertia, and radius of gyration, were determined. Second, the nominal compressive strength was calculated based on the governing buckling mode and slenderness criteria specified in SNI 1729:2020. Third, the design compressive strength was obtained by applying the appropriate LRFD resistance factors. The self-weight of each profile was then calculated based on its cross-sectional area and steel density. Finally, the strength-to-weight ratio was computed as a measure of material efficiency. The results were compared across all profiles to identify both the most efficient profile and the profile with the highest compressive capacity.

Analysis Parameters

To improve transparency and clarity, the main parameters used in the analysis are summarized in Table 1.

Table 1. Key parameters Used in the Analysis

Parameter	Description
WF profile dimensions	Section depth, flange width, web thickness, flange thickness
Steel grade	In accordance with SNI 1729:2020
Design method	Load and Resistance Factor Design (LRFD)
Member type	Axial compression member
Loading condition	Concentric axial compression
Performance indicators	Compressive strength and strength-to-weight ratio

Planning Data

The object of this research is a column structural element made of WF (Wide Flange) type steel profile which works under axial compression conditions. Steel structural elements are available in various profile types, such as WF, H-beam, and castellated sections, which are obtained by modifying WF or H-beam profiles to increase the web depth and improve structural capacity (Pang et al., 2025). However, this study focuses on conventional WF profiles due to their common application as compression members in building structures.

Under axial compressive loading, the behavior of WF profiles is influenced by buckling mechanisms that directly affect their strength and stability. Classical thin-walled structural theory assumes that the cross-sectional contour remains undeformed and considers global buckling modes, including flexural buckling, torsional buckling, and flexural–torsional buckling (Yurchenko & Peleshko, 2022). In practical applications, however, WF profiles may exhibit additional buckling behavior due to the relatively slender flange and web elements compared to the member length.

Specifically, WF profiles may experience local buckling, which occurs when the flange or web plates buckle prior to global instability while the junction line between the flange and web remains relatively straight. In addition, distortional buckling may also occur, characterized by relative displacement or rotation between the flange and web when the stiffness of the section elements is insufficient. These buckling behaviors are directly relevant to the evaluation of compressive strength and efficiency of WF profiles analyzed in this study.

The following are the geometric and sectional properties of the WF profiles used in this study, as presented in Table 2, which serve as the basis for the comppressive strength and strength-to weight ratio analysis in accordance with SNI 1729:2020.

Table 2. WF Profile Data Used

No	Profil WF
1	250.250.9.14
2	250.250.14.14
3	300.300.9.14
4	300.300.10.15
5	300.300.11.17
6	300.300.12.12
7	300.300.15.15

Loads and Load Combinations

In civil engineering, structural loading is the process of determining all forces acting on a building. This step is essential for ensuring that each structural element can safely support the load. This process includes permanent loads, surcharged loads, and variable loads influenced by human activity and environmental conditions.

Dead load

Permanent load or dead load is a fixed load that works throughout the life of the structure, including the weight of the steel structure itself and non-structural elements. Previous studies have examined the behavior of composite steel frame bridges against live vehicle loads and combined loads. The results of numerical analysis show that the maximum stress due to live loads and combined loads is still below the limits permitted by the AASHTO LRFD standard, indicating that the current steel structure design is relatively safe and efficient in carrying permanent and variable loads (Khudair et al., 2025).

Superimposed dead load (SDL)

Additional dead loads are determined based on SNI 1727:2020 (Badan Standardisasi Nasional, 2020a). These loads include floor coverings, partition walls, mechanical-electrical-plumbing (MEP) installations, and ceilings. An example of additional dead load calculations can be seen in Table 2 below:

Table 3. Additional dead load on building structures

Building Components	Weight (kN/m³)	Magnitude (m)	Load (kN/m²)
Load on the plate (Uniformly distributed load)			
Sand (10 mm)	16	0,01	0,16
Spent (30 mm)	21	0,03	0,63
Ceramic (20 mm)	24	0,02	0,48
Acoustic ceiling + suspension	0,2		0,2
Partition Wall	0,57		0,57
MEP Installation	0,25		0,25
Amount			2,29
Load on Beam (Line Load)			
Fit. Lightweight brick wall	3,06	6	2,754
	3,06	8	3,672

Burden of life

On the other hand, live loads are fluctuating and not always present uniformly, such as vehicles on bridges or human activities in buildings. Previous research also showed a mismatch between the live load model of the design code and the actual conditions in truss bridges based on weigh-in-motion data. This emphasizes the importance of recalibrating the load model if we want to improve the accuracy of real live load predictions in steel structures (Hernández-Martinez et al., 2023).

Modern design approaches such as Load and Resistance Factor Design (LRFD) are applied to accommodate load uncertainty, by providing combination loads such as the commonly used 1.2D + 1.6L. Although much information on industrial practices is available, recent international journals specifically on LRFD in the context of steel structures are still limited in the period 2020–2025. However, real-world observations from (Khudair et al., 2025),still imply that code approaches such as LRFD successfully maintain structural safety in combined live and dead load scenarios (Badan Standardisasi Nasional, 2020a).

Live loads are determined based on the building function according to the table in SNI 1727:2020 [13]. For office buildings, the live load used is 2.40 kN/m² which works evenly on floors 1 to 29. Meanwhile, for the roof, a live load of 0.96 kN/m² is used. This value considers variations in human activity, furniture, and other temporary loads that can change at any time in the building.

The profile geometry (WF) data shown in Table 1 is used as the basis for analyzing the column's ability to withstand axial loads. The table presents several alternative WF profiles with different dimensions and cross-sectional properties, allowing for an evaluation of the structural performance of each profile against the applied loads.

The case study analyzed is a single column with a height of 4000 mm, where the placement conditions are set in the form of a clamp at the base and a hinge at the top. This column receives a centric axial compressive load due to a combination of a dead load (DL) of 95 tons and a live load (LL) of 30 tons. The total axial load is then combined according to the load factor provisions to obtain the design compressive force. The material used is ASTM A36M steel with a yield strength of Fy = 250 and a maximum tensile strength of Fu = 450 MPa. These parameters serve as a reference in determining the nominal capacity of the column. In addition, the effective length of the column is calculated by considering the end conditions (fixed pinned) which results in an effective length factor K = 0.8. This value is then used in determining the slenderness ratio $\lambda = KL / r$, where r is the radius of gyration of the cross-section obtained from the WF profile data.

Theoretical Analysis of Steel Compression Element Capacity

A compression member is a steel structural element that receives an axial compressive force along its principal axis. The design of a compression member must consider the phenomenon of buckling (*buckling*), both local and global, because it can cause sudden structural failure. There are several stages used in analyzing the design of compression elements, including, checking the classification of cross-sectional elements both in the flange and web sections, determining the formula used based on table E1.1 SNI 1729:2020 (Badan Standardisasi Nasional, 2020b) calculating the nominal compressive strength according to the WF profile bending variety.

In the initial stage, namely checking the classification of cross-sectional elements, it can be calculated using the following formula:

Part *flange*

$$\lambda \leq \lambda r \quad (1)$$

$$\frac{b}{t} \leq 0{,}56\sqrt{\frac{AND}{My}} \quad (2)$$

Part *web*

$$\lambda \leq \lambda r \quad (3)$$

$$\frac{h}{tw} \leq 1{,}49\sqrt{\frac{AND}{My}} \quad (4)$$

Nominal Press Capacity

In steel structure planning, the nominal compressive capacity of an element is determined by considering **critical stress (Fcr),** which is influenced by the effective bending length (Lc), radius of gyration (r), steel yield stress (Fy), and modulus of elasticity (E). The nominal compressive capacity can be written as:

$$P_n = F_{cr} . A_g \quad (5)$$

with:

Ag = gross cross-sectional area of the element (mm^2),

Fcr = critical stress (MPa).

The critical stress Fcr is determined based on the boundary conditions between material yielding and the elastic stability of the element, thus covering two main possibilities, namely flexural buckling and torsional/torsional-flexural buckling.

Bending Flexure

For compression bars with dominant bending behavior, the critical stress is calculated from the effective slenderness ratio Lc/r. Two conditions apply:

- Low slenderness ratio

$$F_{cr} = \left[0{,}658^{\frac{My}{Fe}}\right].My \quad (6)$$

- High slenderness ratio

$$F_{cr} = 0{,}877.F_{and}$$

(7)

With the following Fe values:

$$F_{and} = \frac{\pi^2 AND}{\left(\frac{Lc}{r}\right)^2} \quad (8)$$

This condition indicates that elements with low slenderness tend to fail due to material yielding, while elements with high slenderness fail due to elastic Euler buckling.

Torsional Bending and Torsional-Bending

In addition to flexural buckling, steel compression members can also experience torsional buckling or torsional-flexural buckling, especially in asymmetrical or open profiles that are not laterally restrained. This provision applies to:

1. Single symmetric and asymmetric structural components.
2. A doubly symmetrical structural member with a torsional unbraced length exceeding the lateral buckling length.
3. Single elbow profile with:

$$\frac{b}{t} > 0{,}71\sqrt{\frac{AND}{F_{and}}} \quad (9)$$

In this condition, the critical stress is determined based on the elastic bending stress due to torsion (Fe) which is calculated by considering the type of cross-section in the double symmetrical component, this is done because the WF profile used is a double symmetrical component.

$$F_{and} = \left(\frac{\pi^2 ANDC_{In}}{L_{cz}{}^2} + GJ\right)\frac{1}{I_x + I_{and}} \quad (10)$$

RESULT AND DISCUSSION

Analysis of nominal pressure capacity value

Analysis was performed on seven variations of WF profiles, as shown in Table 1, considering the nominal compressive capacity calculated using LRFD. The compressive capacity is determined through the critical stress (Fcr) which depends on the slenderness ratio. This value is then multiplied by the gross cross-sectional area to obtain the nominal capacity (Pn).

To assess the efficiency of each profile, an evaluation was performed on the ratio between the profile's weight per unit length and its nominal compressive capacity. This ratio provides an indication of the material's effectiveness; the smaller the ratio, the more efficient the profile, as it can withstand greater compressive loads at a relatively lighter weight.

In terms of assessing the efficiency of each WF profile, it was analyzed using a case study on a steel column with a total length of 4000 mm, with the joint placed at the top end and the clamp at the bottom end according to Figure 2.

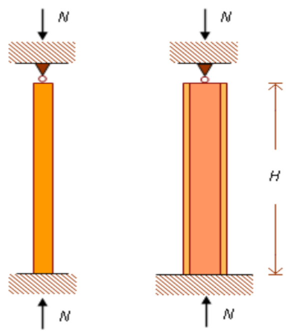

Figure 2. Placement of Joint Clamps on Columns (Nasution, 2011)

Furthermore, based on this condition, the effective length K = 0.8 is obtained, with the working load consisting of a dead load of 95,000 kg and a live load of 30,000 kg. With a combination of LRFD loads (1.2DL + 1.6LL). The total factored load that the column must be able to carry is 162,000 kg. The material used is ASTM A36M steel with a yield stress of Fy = 250 MPa, with a maximum tensile stress of Fu = 450 MPa.

The determination of the nominal compressive capacity is carried out using the LRFD method, in accordance with AISC provisions, with the critical stress determined based on the slenderness ratio limit. Next, the column design capacity is calculated by multiplying the nominal capacity by the factor Ø = 0.9.

The calculation results show that all analyzed WF profiles, starting from WF 250,250,9.14 to WF 300,300,15.15 have a design capacity ØPn that is greater than the factored load Pu. The design capacity obtained is between 171,486.959 kg to 259,778.662 kg, so that all profiles meet the strength requirements. The smallest profile, namely 250,250,9.14, is still able to withstand the factored load with a margin of around 23%, while larger profiles, such as WF 300,300,11.17 provide a higher capacity margin, reaching 80% above the load requirement. The results of the nominal compressive strength analysis of each profile can be seen in Table 4.

Table 4. Results of analysis of nominal compressive capacity and weight of WF profiles.

No	WF Profile	Strength (kgf)	Weight (kg)
1	250.250.9.14	171,486.959	289.6
2	250.250.14.14	198,004.663	328.8
3	300.300.9.14	212,734.761	348.0
4	300.300.10.15	228,538.808	376.0
5	300.300.11.17	260,599.228	432.0
6	300.300.12.12	202,449.870	338.0
7	300.300.15.15	259,778.622	432.0

In terms of efficiency, the weight-to-strength ratio shows that profiles with larger dimensions tend to provide greater compressive capacity, but this is not always commensurate with the increased weight. Therefore, selecting the optimal profile not only considers the compressive capacity but also the weight efficiency of the structure. The following is a calculation of the strength-to-weight ratio of the profiles as shown in Table 5.

Table 5. Comparison Ratio Between Nominal Compressive Strength and Weight

No	WF Profile	Strength (kgf)	Weight (kg)	Ratio (kgf/kg)
1	250.250.9.14	171,486.959	289.6	592.151
2	250.250.14.14	198,004.663	328.8	602.204
3	300.300.9.14	212,734.761	348.0	611.307
4	300.300.10.15	228,538.808	376.0	607.816
5	300.300.11.17	260,599.228	432.0	603.239
6	300.300.12.12	202,449.870	338.0	598.964
7	300.300.15.15	259,778.622	432.0	601.339

The results of the comparative analysis of the strength to weight ratio of the WF profiles show values between 592.151 to 611.307. This indicates that all profiles have relative efficiency, but there are some profiles that have higher ratio values. Based on the analysis results, the 300,300,9.14 profile has the highest ratio of 611.307, so it can be said to be the most efficient in supporting loads according to the case study. On the other hand, the 250,250,9.14 profile shows the lowest ratio of 592.151, so it is less than optimal in terms of material efficiency. Thus, it can be concluded that the 300x300 profile tends to be superior to the 250x250 profile in terms of both strength and efficiency.

Overall, this case study demonstrates that all tested WF profiles are suitable for use under centric compression conditions with the analyzed load combinations. The selection of a specific profile can be tailored to specific needs, whether for material efficiency or a higher safety margin against potential future additional loads.

CONCLUSION AND SUGGESTION

Conclusion

The following are the conclusions obtained from the discussion:

1. This study demonstrates that the strength-to-weight ratio of the analyzed WF steel profiles ranges from 592.151 to 611.307, indicating measurable differences in material efficiency among profiles with varying dimensions and thicknesses.
2. WF profile 300.300.9.14 exhibits the highest strength-to-weight ratio of 601.307, identifying it as the most material-efficient profile among those studied and highlighting the effectiveness of efficiency-based evaluation beyond conventional strength checks.
3. WF profile 300.300.11.17 provides the highest compressive capacity, reaching 260,599.22 kg, although its strength-to-weight ratio is lower than that of the thinner profile, indicating a trade-off between maximum load capacity and material efficiency.
4. In general, WF profiles with 300×300 cross-sectional dimensions show superior performance compared to 250×250 profiles in terms of both compressive strength and efficiency, contributing to a clearer understanding of the influence of section size on compression behavior.
5. From a practical design perspective, WF profile selection can be adjusted according to structural requirements: WF 300.300.9.14 is more suitable for designs prioritizing material efficiency and weight reduction, while WF 300.300.11.17 is recommended for applications requiring higher axial load capacity, providing direct guidance for structural planners and practitioners.

Suggestion

To support ongoing research, the following are suggestions for further research, including:

1. The analysis can be extended by considering a combination of earthquake and wind loads to determine the behavior of the WF profile under extreme loading conditions.
2. The use of the Finite Element Method (FEM) with non-linear modeling of materials and geometry will provide more accurate results, compared to a simple analysis approach.
3. Further research can add variations in steel grades with higher yield strength, to evaluate efficiency compared to conventional ASTM A36 steel.
4. An analysis combining structural efficiency with material and fabrication costs is necessary to determine the most optimal profile, both technically and economically.

REFERENCES

Alam, P. J. M. I., & Kanagarajan, B. (n.d.). *Optimal design of thin-walled open cross-section column for maximum buckling load*.

American Institute of Steel Construction. (2017). Specification for Structural Steel Buildings (ANSI/AISC 360-16). *Text and Performance Quarterly*, *37*(2), 169–170. https://doi.org/10.1080/10462937.2017.1349256

Arianto, J., & Tedianto, L. (2019). Analysis of the Effect of Web Stiffener Area on the Compressive Strength of Light Steel Channel Profile Using the Finite Element Method. *JMTS: Jurnal Mitra Teknik Sipil*, *2*(1), 179. https://doi.org/10.24912/jmts.v2i1.3423

AZoM. (2012). ASTM A36 Mild / Low Carbon Steel. *AZoM*.

Badan Standardisasi Nasional. (2020a). *SNI 1727:2020 Minimum Loads for Designing Buildings and Other Structures*.

Badan Standardisasi Nasional. (2020b). *SNI 1729:2020 Specifications for Structural Steel Buildings*.

Hernández-Martinez, A. et al. (2023). Inconsistencies between the Forces from Code Live Load Models and Real Traffic on Truss Bridges. *ArXiv Preprint*.

Khudair, A. W. et al. (2025). Damages Inspection and Finite Element Model Analysis of Static and Dynamic Factors of Steel Girder-Concrete Composite Span Due to Vehicles Live Load and Loads Combination. *International Journal of Structural Theory, Dynamics and Innovation*.

Meng, X., & Gardner, L. (2023). Cross-sectional behaviour and design of normal and high strength steel welded I-sections under combined axial compression and uniaxial bending. *Thin-Walled Structures*, *188*, 110829. https://doi.org/10.1016/j.tws.2023.110829

Nasution, T. (2011). *Mode 2 Mode 2*.

Pang, E. B. B. et al. (2025). Optimization of Column Beam Cross Sections in Gable Portals. *Teknologi*, *23*(91), 35–44.

Pribadi, G., & Rumbyarso, Y. P. A. (2023). Analysis of WF Steel Roof Profiles with the LRFD Method Using SAP2000 and IDEA StatiCa. *Integrated Industrial Technology*, *6*(4), 1543–1559. https://doi.org/10.31004/jutin.v6i4.21662

Segui, W. T. (2017). *Steel Design*. Cengage Learning.

Yurchenko, V., & Peleshko, I. (2022). Optimization of Cross-Section Dimensions of Structural Members Made of Cold-Formed Profiles Using Compromise Search. *Eastern-European Journal of Enterprise Technologies*, *5*(7–119), 84–95. https://doi.org/10.15587/1729-4061.2022.261037

Zhang, Y. et al. (2024). Seismic behavior of prefabricated frame with special-shaped concrete-filled steel tubular columns and H-shaped steel beams. *Structural Concrete*, *25*(6), 5185–5201. https://doi.org/10.1002/suco.202300583