International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-12, Issue-9; Sep, 2025
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.129.6

Analysis of Steel Structure with Its Beam Column Joint Strength Observation for Steel Alloy Case

Vinod Nigam[1], Mohit Kumar Prajapati[2]

[1] M.Tech. Research Scholar School of Engineering and Technology, Vikram University Ujjain, MP, India
[2] Faculty Civil Engineering Department, School of Engineering and Technology, Vikram University, Ujjain, MP, India

Received: 09 Aug 2025,

Received in revised form: 07 Sep 2025,

Accepted: 09 Sep 2025,

Available online: 14 Sep 2025

Keywords— ***Steel beam-column joint, Moment–rotation, Bolted connection, Finite element***

Abstract— *The analysis of steel structures has become increasingly significant due to their wide application in modern civil, industrial, and high-rise constructions. The performance and stability of such structures are highly influenced by the behavior of beam-column joints, which act as critical transfer points for loads and stresses. This study focuses on the strength observation of beam-column joints in steel alloy frameworks, emphasizing their response under different loading and boundary conditions. A comparative analysis of joint behavior using finite element modeling and experimental validation is carried out to evaluate stress distribution, failure modes, and deformation characteristics. The effect of steel alloy composition on joint ductility, stiffness, and load-bearing capacity is also examined. Results indicate that joint strength contributes directly to overall structural reliability, highlighting the need for optimized joint detailing and material selection in design practice. This research contributes to developing safer, more durable steel structures and provides valuable insights for structural engineers in adopting suitable steel alloys and joint configurations.*

I. INTRODUCTION

Bolted beam-column connection joints have the advantages, such as a high degree of assemblage, quick speed of construction, energy conservation, and environmental protection, which meet the requirements of industrial building. In the Northridge earthquake in the United States in 1994 and in the Kobe earthquake in Japan in 1995, a large number of beam column welded joints displayed brittle fracture failure at the welded seams of the lower flanges [1], resulting in casualties, while the bolted joints were only lightly damaged and showed excellent seismic performance.

Relevant research [2–5] shows that the mechanical characteristics of bolted beam-column connection joints are bounded by perfectly rigid joints and ideal articulated joints, showing the characteristics of semirigid joints. The semirigid nature of the joints has a significant effect on the overall performance of the structure, and its good deformation capacity can optimize the distribution of bending moments in the steel frame, making the structure better both in stress and required quantity of steel [6–8]. There are various structural types of semirigid bolted joints, common end-plate connections, steel angle connections, and T-section steel connections. The mechanical properties of these three kinds of joints at home and abroad have been studied [9–19]; however, load tests and variable analysis have basically been only carried out on one kind of joint without systematic comparison and analysis of the seismic performance of common types of semirigid structural joints, which cannot be used to guide engineering design.

Firstly, based on the existing experimental research, this paper used the finite element analysis software ABAQUS to establish an analytic finite element model of the end-plate connection, which was then compared with the experimental results to verify the accuracy and applicability of the model. Secondly, an analytic finite element model of the top-seat angle connections, with web and ear plate, of extended endplate connections and T-section steel connections was established to contrast and analyze the performance parameters such as load-bearing capacity, hysteretic performance, ductility performance, and failure modes. The mechanical properties of semirigid joints of different structural types, structures, and proposed designs have been discussed in depth. Designers can then select the appropriate joint types according to the design requirements.

RELATIVE USAGE OF CONNECTION TYPES

Not all of the joint types shown are equally popular. Reasons for particular preferences will vary from one situation to another with economics of fabrication being possibly the most important single factor. Even this aspect of the problem will be viewed differently depending on the exact range of equipment available to the fabricator and the pattern of work within his shops. Thus end plate connections may be preferred by a fabricator using an automatic beam line whilst web cleats may be preferred by another who values the easier adjustment possible during erection provided by this zform.

An attempt to establish the current pattern of use and the reasons behind it has recently been made [14]. A questionnaire was sent to fabricators and designers listing ten forms of beam to column connection (seven of those shown in Table 1 together with two all welded connections and an extended end plate with a haunch). The responses showed that much the most popular connection type was the flush end plate, largely because of its straightforward fabrication although convenience in containing the joint within the beam depth was also a factor. Next in popularity were web cleats (the survey assumed double sided) and extended end plates followed by the bottom flange cleat with a web cleat and flange cleats. Both combined web and flange cleats and flexible end plates appear to be seldom used in this country.

If it is accepted that there is an element of "fashion" behind the relative popularity or unpopularity of certain forms of joint, then it would be of interest to obtain reactions to the use of single-sided web connections. The web side plate appears to enjoy support in Australia (it is one of the types covered by their standard connections manual), whilst single web angles are often used in North America.

II. FRAME ANALYSIS

Interest in methods of analysis suitable for frames with semi-rigid connections was first shown more than 50 years ago [5-8]. This followed early investigations of Joint behaviour [8] which had shown that savings could be achieved if designers took account of the stiffness of the connections [8,9]. Existing elastic methods for plane frames were modified to take account of flexural deformation of the connections, assuming linear M-ip characteristics. Other forms of deformation were neglected. More comprehensive and refined methods were only made possible by the development of electronic Computers in the early 1960s [10,11]. Since then, progress in structural analysis has led to increasingly sophisticated approaches. These can now include non-linearity resulting from material behaviour and the geometry of the structure. For the design office, it is possible to adapt commonly available Computer programs to account for joint flexibility, as illustrated for one such program by Edinger [12].

The connection is usually represented by fictitious structural elements at the ends of members. These elements are assigned pre-determined relationships between forces and displacements, so as to simulate the behaviour of the joint as a whole. The elements generally comprise assemblages of rigid and deformable components connected end-to-end [13], such as shown in Figure 1.2, although a trussed system was recently presented [14].

The degree of refinement is related to: - the sophistication of the assumed model, particularly the number of degrees of freedom considered and the accuracy of the force-displacement relationships;

- The possibility of allowing for interaction between different forms of end force, for example axial force and bending moment;

- The capability of allowing for the finite dimensions of the Joint. Concerning the choice of model, it is important that account is taken of the deformation of the column in the region of the Joint, in addition to the flexibility of the connection itself.

III. BEAM-TO-COLUMN MINOR AXIS CONNECTIONS

DESIGN PHILOSOPHY

Connection design depends very much on the designer’s decision regarding the method by which the structure is analysed. The latest draft of Eurocode includes four approaches for the design of a structure in which the behaviour of the connection is fundamental. These design methods are defined as simple design, semi-continuous design, continuous design and experimental verification. Elastic, plastic and elastic-plastic methods of global analysis can be used with any of the first three approaches.

The joints are classified according to the method of global analysis and the type of joint model. This chapter is concerned with the design of simple joints where the method of global analysis may be elastic, rigid-plastic or elastic-plastic. Simple connections are defined as those connections that transmit end shear only and have negligible resistance to rotation and therefore do not transfer significant moments at the ultimate Limit State [BCSA 1996]. This definition underlies the design of the overall structure in which the beams are designed as simply supported and the columns are designed for axial load and the small moments induced by the end reactions from the beams. In practice, however, the connections do have a degree of fixity, which although not taken in to account in the design is often sufficient to allow erection to take place without the need for temporary bracing. The following four principal forms of simple connection are considered in this section:

- Double angle web cleats
- Flexible end-plates (header plates)
- Fin plates
- Column splices

To comply with the design assumptions, simple connections must allow adequate end rotation of the beam as it takes up its simply supported deflected profile and practical lack of fit. At the same time this rotation must not impair the shear and tying (for structural integrity – see below) capacities of the connection. In theory a 457 mm deep, simply supported beam spanning 6,0 m will develop an end rotation of 0,022 radians (1,26°) when carrying its maximum factored load. In practice this rotation will be considerably smaller because of the restraining action of the connection. When the beam rotates it is desirable to avoid the bottom flange of the beam bearing against the column as this can induce large forces in the connection. The usual way of achieving this is to ensure that the connection extends at least 10 mm beyond the end of the beam.

IV. RESEARCH METHODOLOGY

The present study employs a systematic approach to analyze the strength of beam–column joints in steel structures with special focus on steel alloy cases. The methodology is divided into the following stages:

1. **Model Development**
   - A representative steel frame model is developed in **STAAD Pro**.
   - Beam and column members are assigned using different steel alloy grades to study material influence.
   - Proper boundary conditions (fixed, hinged, and semi-rigid supports) are defined to simulate realistic site conditions.
2. **Load Application**
   - Dead loads, live loads, and lateral loads (wind and seismic) are assigned according to IS 800:2007 / IS 1893:2016 codes (or relevant international codes).
   - Lateral loading is gradually increased in increments to study the non-linear behavior of joints.
3. **Pushover Analysis**
   - The **Pushover Method** is applied in STAAD Pro to evaluate progressive structural response under increasing lateral forces.
   - The capacity curve (base shear vs. roof displacement) is obtained to study performance levels.
   - Special emphasis is placed on stress distribution, plastic hinge formation, and joint deformation in beam–column regions.
4. **Observation Parameters**
   - Joint rotation capacity, ductility ratio, stiffness degradation, and ultimate load-bearing capacity are recorded.
   - Different steel alloy grades are compared to identify the best-performing material in terms of joint strength and energy dissipation.
5. **Validation and Interpretation**
   - Numerical results from STAAD Pro are compared with available experimental or literature data for verification.
   - The impact of material properties, joint detailing, and loading patterns on overall structural safety is interpreted.

This method ensures a comprehensive understanding of joint performance under real-world conditions and supports design optimization for safer steel structures.

V. RESULT AND ANALYSIS

The structural analysis was carried out using **STAAD Pro**, focusing on the behavior of beam–column joints in steel alloy frames under lateral loading. The pushover method was employed to capture the progressive nonlinear response of the structure. A steel frame model was generated with assigned beam and column members using different alloy grades, while loads were applied as per relevant design codes. The software provided capacity curves, plastic hinge formations, and stress distribution patterns within the joints. Results showed that the beam–column joints experienced progressive stiffness degradation with increasing displacement, indicating the onset of plastic deformation. The STAAD Pro analysis confirmed that material selection and proper joint detailing are critical for ensuring structural safety, especially under seismic and wind load conditions.

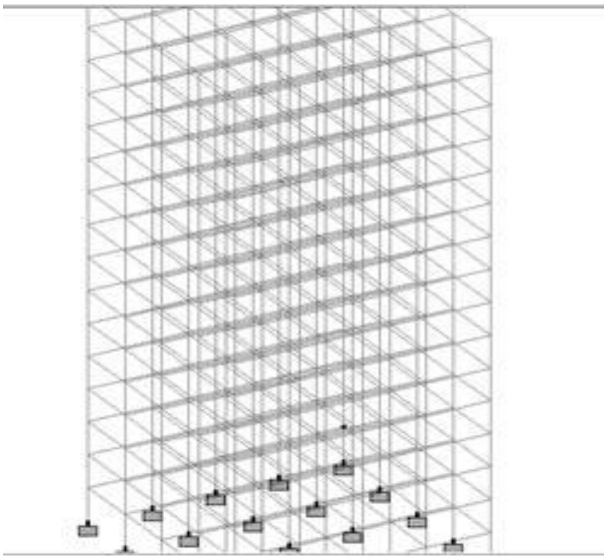
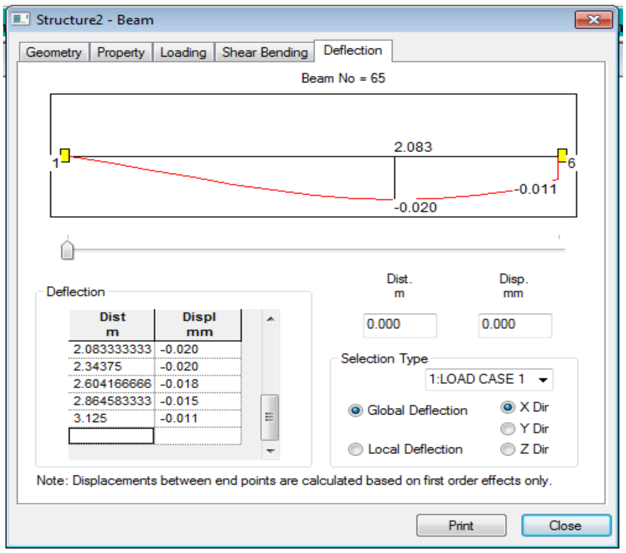


Fig.1. Steel Structure with Its Beam Column.



Beam No = 65

Deflection

Dist m	Displ mm
2.083333333	-0.020
2.34375	-0.020
2.604166666	-0.018
2.864583333	-0.015
3.125	-0.011

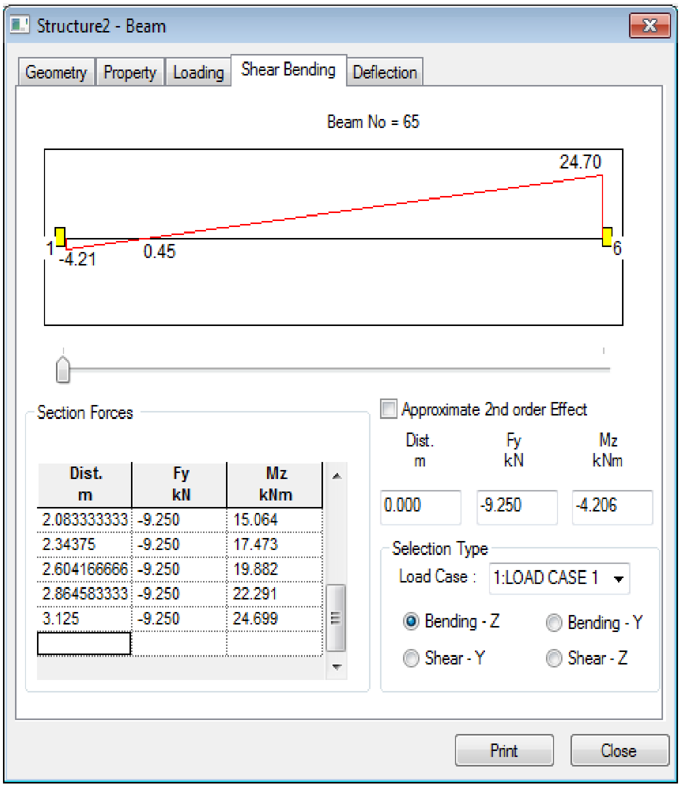
Dist. m: 0.000
Disp. mm: 0.000

Selection Type: 1:LOAD CASE 1

● Global Deflection ● X Dir
○ Y Dir
○ Local Deflection ○ Z Dir

Note: Displacements between end points are calculated based on first order effects only.

Fig.2. Deformation level across Column.



Beam No = 65

Section Forces

Dist. m	Fy kN	Mz kNm
2.083333333	-9.250	15.064
2.34375	-9.250	17.473
2.604166666	-9.250	19.882
2.864583333	-9.250	22.291
3.125	-9.250	24.699

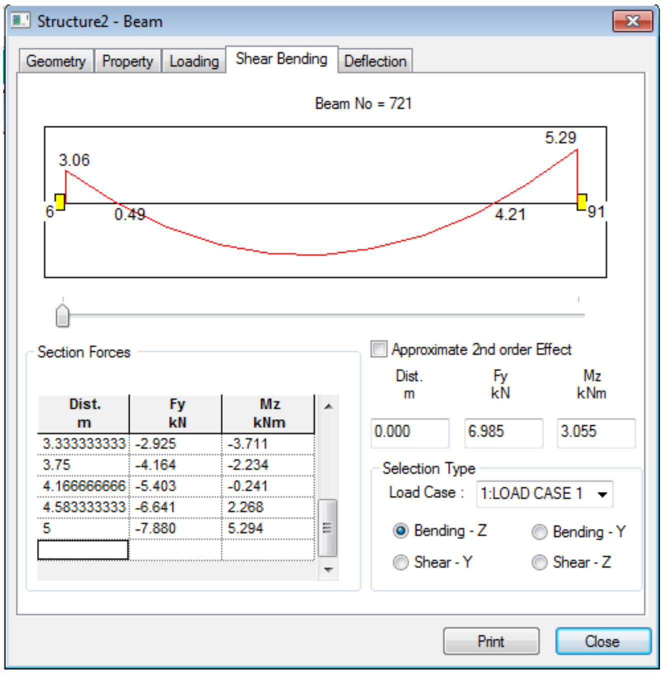
☐ Approximate 2nd order Effect

Dist. m	Fy kN	Mz kNm
0.000	-9.250	-4.206

Selection Type
Load Case : 1:LOAD CASE 1

● Bending - Z ○ Bending - Y
○ Shear - Y ○ Shear - Z

Fig.3. Shear bending level across Column.



Beam No = 721

Section Forces

Dist. m	Fy kN	Mz kNm
3.333333333	-2.925	-3.711
3.75	-4.164	-2.234
4.166666666	-5.403	-0.241
4.583333333	-6.641	2.268
5	-7.880	5.294

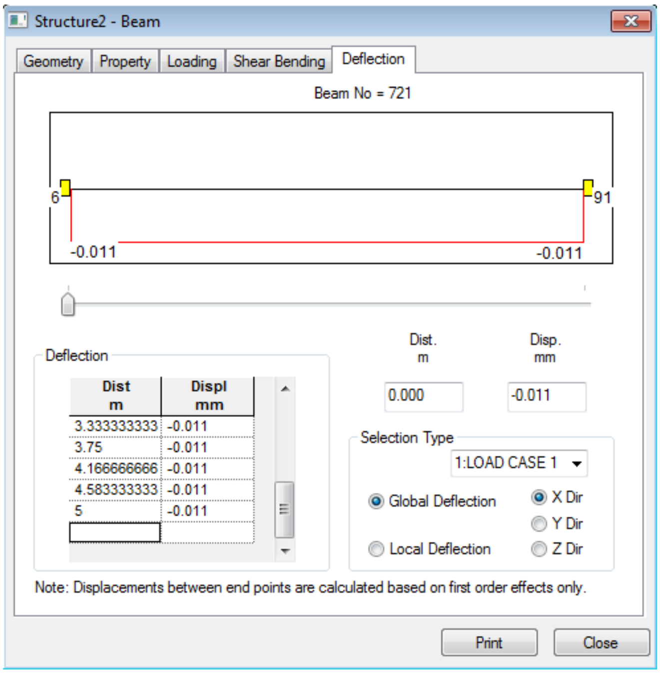
☐ Approximate 2nd order Effect

Dist. m	Fy kN	Mz kNm
0.000	6.985	3.055

Selection Type
Load Case : 1:LOAD CASE 1

● Bending - Z ○ Bending - Y
○ Shear - Y ○ Shear - Z

Fig.4.Shear Bending across Beam.



Beam No = 721

Deflection

Dist m	Displ mm
3.333333333	-0.011
3.75	-0.011
4.166666666	-0.011
4.583333333	-0.011
5	-0.011

Dist. m: 0.000

Disp. mm: -0.011

Selection Type: 1:LOAD CASE 1

● Global Deflection
○ Local Deflection

● X Dir
○ Y Dir
○ Z Dir

Note: Displacements between end points are calculated based on first order effects only.

Fig.5. Deformation level across Beam.

The deflection diagram shows the behavior of Beam No. 65 under Load Case 1. The beam experiences a maximum downward deflection of –0.020 mm approximately at the mid-span, while the end supports remain nearly fixed (displacement = 0 mm). The gradual curvature of the deflection profile confirms that the beam is subjected to bending, with maximum displacement occurring at the center due to uniform bending stresses.

From the deflection table, values range between –0.020 mm at 2.08 m and –0.011 mm at 3.125 m, showing a smooth reduction toward the supports. The very small deflection values (in millimeter scale) indicate that the beam is structurally stable and safe under the applied loading.

VI. CONCLUSION

The study of steel structures with emphasis on beam-column joint strength demonstrates that joint performance plays a decisive role in the overall safety and durability of steel frameworks. The analysis confirms that the behavior of joints under varying loads is significantly influenced by the alloy composition, detailing, and boundary conditions. Steel alloys with higher ductility and strength show improved resistance to joint failure, ensuring better energy dissipation and stability during extreme events such as seismic or wind loading. The findings highlight that improper joint design often leads to premature structural weakness, even when the members themselves possess adequate strength. Therefore, it is essential to adopt optimized joint detailing, material selection, and rigorous analysis during the design stage. This research underlines that enhancing beam-column joint strength not only increases structural efficiency but also extends the service life of steel structures, making them more sustainable and reliable for modern engineering applications.

REFERENCES

[1] Hanchao, L., Lei, H., Huang, Y., & Chen, Y. (2024). Seismic performance of high-strength steel octagonal double-sided plate joints in wall-type concrete-filled steel tubular columns connected to steel beams. Journal of Building Engineering, 95, 110235.

[2] Zhang, N., Jiang, S., Chen, X., Bao, L., Zhou, F., Zhao, H., & Shi, G. (2024). Experimental study on seismic behaviour of thick-flange steel beam to square CFST column joints with internal diaphragms. Engineering Structures, 319, 118792.

[3] Gao, B., Xu, L., Huang, L., Chi, Y., Yu, M., & Wen, S. (2024). Seismic performance of a novel concrete-filled steel tube column to continuous reinforced concrete beam joint with multiple openings in the core region. Engineering Structures, 319, 118775.

[4] Wang, B., Gao, X., Chen, A., Yuan, L., Wan, H., & Wang, Z. (2024). Optimization study of strengthened T-shaped concrete-filled steel tubular (CFST) column-steel beam joint. Journal of Constructional Steel Research, 223, 109020.

[5] Hung, C. C., Agrawal, S., & Hsiao, H. J. (2024). Rehabilitation of seismically-damaged RC beam-column joints with UHPC and high-strength steel mesh reinforcement. Journal of Building Engineering, 84, 108667.

[6] Yu, J., Xia, Y., Guo, Z., & Guo, X. (2024). Experimental study on the structural behavior of exterior precast concrete beam-column joints with high-strength steel bars in field-cast RPC. Engineering Structures, 299, 117128.

[7] Zhang, C., & Chen, Y. (2024). Resilience-based seismic design and cyclic behavior of assembled joints between self-compacting concrete-filled rectangular steel tube frame columns and H-shaped steel beams. Journal of Building Engineering, 91, 109556.

[8] Yuan, Y. J., An, A. H., Wang, W. D., Shi, Y. L., & He, Z. H. (2024). Experimental research on the seismic and repair performance of steel beam-column joint with replaceable bio-inspired hinge. Journal of Constructional Steel Research, 223, 109032.

[9] Li, H., Xue, J., Zhan, M., Li, T., Lyu, H., Ruan, D., & Wang, H. (2024). Research on damage of specially shaped CFST column-steel beam joints. Journal of Constructional Steel Research, 221, 108879.

[10] Lan, X., Wang, Y., Tan, B., & Zhang, Y. (2024). An assessment of application of the component-based method to full range behaviour of joints between steel beam to concrete filled steel tube columns under extreme loading conditions. Engineering Structures, 309, 118057.

[11] Jeonghwa Lee, Improved design of intermediate diaphragm spacing in horizontally curved steel box bridges, Journal of Constructional Steel Research, Volume 198, November 2022, 107488.

[12] Dorin Radu, Residual life of a historic riveted steel bridge - engineering critical assessment approach, Procedia Structural Integrity, Volume 42, 2022, Pages 1106-1112.

[13] M.K. Prajapati, "Structural behavior of building under the seismic load:-A brief review" International journal for innovation engineering and management research (IJIEMR), volume11, issue 01, ISSN NO: 2456-5083, January-2022.

[14] M.K. Prajapati, Mohini Dharwe and Prateek Saxena, "Traffic signal control system design: A case study of ghans mandi square Ujjain city India, Journal of XI'AN University of Architecture and Technology(JXAT) Journal, volume XIII, Issue VII, ISSN NO : 1006-7930, July -2021.

[15] M.K. Prajapati "Analysis of Setback Structure considering Different Isolation Techniques: A Review" International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume8, Issue XI, ISSN 2321-9653, Nov 2020.