ISSN 1840-4855
e-ISSN 2233-0046

Original scientific article
http://dx.doi.org/10.70102/afts.2024.1631.240

EXPERIMENTAL INVESTIGATION ON THE WELD STRENGTH OF THE STEEL BEAM WITH AND WITHOUT STIFFENER

S. Kalaiselvi[1*], R. Santhosh Kumar[2]

[1]Department of Civil Engineering, Sona College of Technology, India.*
e-mail: kalai_tptc@yahoo.co.in, orcid: https://orcid.org/0000-0002-8235-7219
[2]Department of Civil Engineering, Vinayaka Mission's Kirupananda Variyar Engineering College, Vinayaka Mission's Research Foundation (DU), India.
e-mail: santhoshbala146@yahoo.com, orcid: https://orcid.org/0000-0002-5723-1251

SUMMARY

In nature, the bucking behavior of the web of I section reduces the member's strength considerably. Hence, in common practice, people use the intermediate and end stiffeners to improve the strength of the beam. The stiffeners are connected to the web using the welded connections. In this paper, the experimental study on steel beams with and without stiffeners is reported. The weld length of the stiffeners has been varied and the study has been carried out. Three specimens were tested. One without stiffeners, one with full weld, and one with half weld. The strength will be enhanced due to the presence of stiffeners. The increase is about 53%. It is interesting to note that the strength of the half weld and full-weld specimens is not very different. All the other parameters such as ductility, stiffness, and energy dissipation are reported in the paper.

Key words: *i beam, weld, stiffeners.*

Received: August 11, 2024; Revised: October 18, 2024; Accepted: November 08, 2024; Published: December 24, 2024

INTRODUCTION

The buckling behavior of the web reduces the bending strength of the member considerably. Local buckling of the web can be minimized by many practices. In common practice, Stiffeners are used for effectively resisting and transferring loads from one structural system against buckling or crippling of the web. They efficiently control the construction cost and damage to the structural system. During the past few decades, a considerable improvement has been noticed in the types and placement of stiffeners. The behavior of such beams primarily depends on parameters such as stiffener size, thickness, connection, and distance between each stiffener [4].

In the case of beams without stiffeners, the beams are seeming to fail predominantly under web bucking or web crippling. By the application of stiffeners in the beams, they start to fail in the bending mode. This ultimately improves the flexural capacity of the steel beams [14]. The proper strength and rigidity of the steel members using the connections such as welds or bolts are still under research interests. Lots of coral provisions and theories are arrived at using many research outputs [11].

Developed a formula by considering the combined effect of the shear force on the primary supporting member and direct force from the longitudinal stiffener. By comparing the theoretical formula to the findings of the finite element analysis and earlier experiments high accuracy was proven. the proposed theoretical formula can be used to evaluate the strength of slot cut-out structures rationally [1].

It seems that there were several insights about steel plate shear walls (SPSWs), stiffeners, and their performance under seismic conditions. Here's a summary and clarification of the key points: [10] [2]

1. **Non-Welded Multi-Rib Stiffeners in SPSWs**:
   - These stiffeners help in evenly distributing the stiffness throughout the floors [8].
   - They enhance the dynamic performance of the structure, particularly during earthquakes, by reducing inter-story drift, acceleration, and out-of-plane deformation.
2. **Triangular Stiffeners**:
   - Increasing the height of triangular stiffeners improves the energy dissipation capacity of the section [6].
   - However, this also reduces the ductility of the structure.
3. **Double L-Shaped Junctions**:
   - The seismic performance improves when there is an adequate beam-column stiffness ratio and appropriate flexural rigidity of the L-shaped connector [3].
4. **Angular Distortion and Structural Constraints**:
   - Structural constraints have a minor effect on the flange's angular distortion but can significantly reduce web distortion.
   - Angular distortion and welding residual stress of the web decrease as the stiffener's width or its distance from the backing plate increases.
   - The placement of stiffeners may be more effective in controlling angular distortion than adjusting their dimensions.
5. **Welding and Martensite Formation**:
   - The amount of martensite (a hard microstructure formed during welding) increases gradually as the length of the repair weld increases [7].

The following description provided touches on some important aspects of Stiffener welding metallurgy, particularly regarding the influence of temperature cycles, filler materials, and microstructural changes on the mechanical properties of the weld.

Key Points:

1. Grain Development and Weld Length:
   - The direction of grain development at the bottom of the weld is less influenced by the weld length. This implies that other factors, such as thermal gradients and material properties, play a more significant role in determining grain structure.
2. Temperature Cycle and Filler Metal:
   - The temperature cycle during welding and the use of a nickel-based filler metal impact the grain size at the bottom of the weld. A typical result of this is the reduction in the number of large-angle grain boundaries, which are effective at hindering dislocation movement.
3. Mechanical Properties:
   - Microhardness and Tensile Strength: Both tend to decrease after welding repair. This could be due to the changes in grain structure or the dissolution of strengthening phases.

- Toughness: Despite the reduction in hardness and tensile strength, the toughness increases, likely due to the higher amount of austenitic structure. Austenite tends to be more ductile and tougher than other phases such as martensite or ferrite.

Weld repairs and their associated thermal cycles can lead to microstructural changes that reduce hardness and tensile strength but increase toughness due to austenitic phase formation. The grain structure, particularly at the bottom of the weld, is more influenced by factors like temperature cycles and filler materials than by weld length [5].

The amount of martensite steadily reduces as the repair weld length increases. The direction of grain development at the bottom of the weld is not greatly impacted by weld length. The temperature cycle of the weld and the nickel base filler metal influence the grain size at the bottom of the weld, and the quantity of large Angle grain boundaries with dislocation inhibiting effect diminishes.

RESEARCH SIGNIFICANCE

The information on the behavior of weld length over the beam stiffeners is very limited [13]. The size and length of welds are significant parameters to be studied. Hence, the research on behavior and strengthening of weld length is an important issue. Also, investigation for various measures of strengthening of the stiffeners is gaining importance. Hence, such research efforts are needed at this juncture. This study presents the experimental analysis of steel beams of varying weld lengths [12] [9].

EXPERIMENTAL STUDY

Geometry of the Specimen

The test series includes three steel beams of RS Joist 125 mm x 65 mm with a thickness of 5.3 mm. The length taken is 600 mm. Among the three specimens, one is without stiffeners, another is with stiffeners with full weld in the stiffener joint shows in Figure 1. One more specimen is with half weld in the stiffeners.

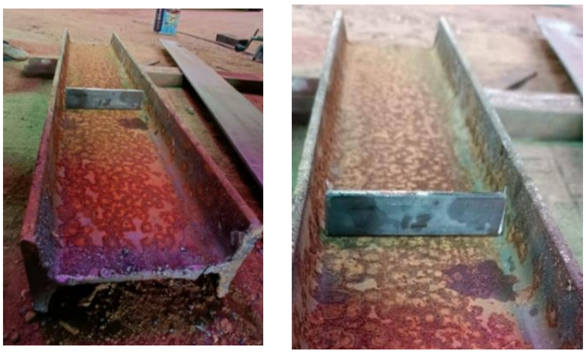


Figure 1. Specimen Preparation

Test Setup

In Figure 2 shows the test was carried out on the universal testing machine. The beam has been fixed with a centre -centre span of 400 mm. It has been tested as a specimen with a point load at the center. The beam flange has been damaged locally at the point of application of load. Then it has been decided to go for the uniformly distributed load. All the test specimens are tested with uniformly distributed load and deflection at the mid-span has been noted using a dial of 0.01 mm least count.

Figure 2. Test Setup

Loading Procedure

The specimen without stiffeners showed the failure by web buckling. As expected, the load and failure modes have been entirely changed with the addition of stiffeners. The beam with stiffeners showed the similar failure pattern as shown in the Figure 3.

Figure 3. Beams at Failure

EXPERIMENTAL RESULTS

Strength, Ductility and Stiffness

The Load vs. mid-deflection response in all three specimens is shown in Figure 4. It is obvious that the strength will be enhanced due to the presence of stiffeners. The increase is about 53%. It is interesting to note that the strength for half weld and full weld specimens has no much difference in them.

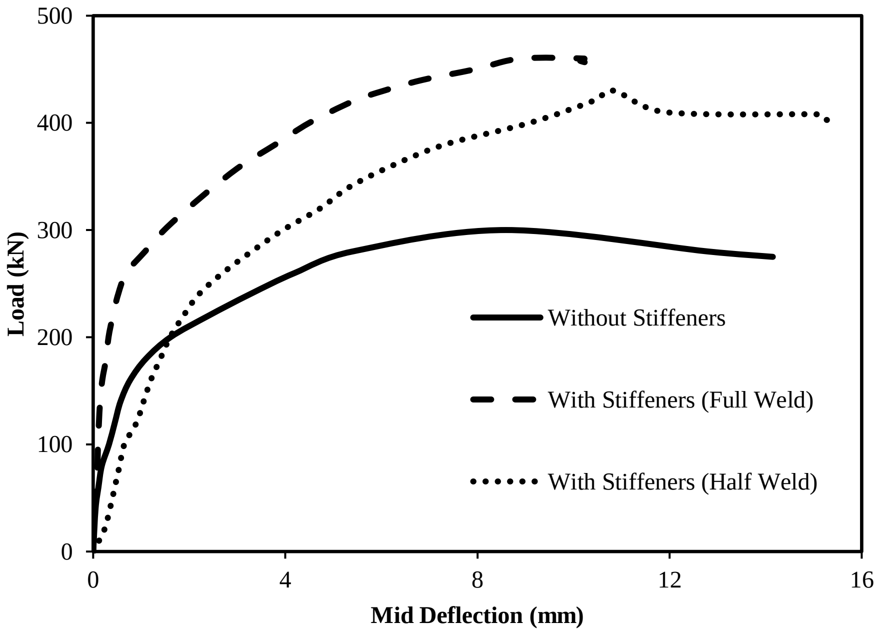


Figure 4. Load - Deflection Curve

Strength is the resistance of a substance to distortion or fracture. Peak value of load - deflection curve value is the peak deflection. Ultimate strength is the final value of the strength and corresponding deflection is the ultimate deflection.

$$\text{Ductility, } \frac{\Delta u}{\Delta p} = \frac{\text{ultimate deflection}}{\text{peak deflection}} \qquad 1$$

The degree to which an object resists deformation in response to an applied load is known as its stiffness. According to the load-deflection curve's greatest peak load, the secant rigidity has been computed. Table 1 listed the specimen's strength, displacement, ductility, and stiffness.

Table 1. Test Results

	Without Stiffeners	**With Stiffeners (Full Weld)**	**With Stiffeners (Half Weld)**
Peak Load (kN)	300	460	430
Peak Displacement (mm)	8.6	8.9	10.85
Ultimate Load (kN)	275	455	402
Ultimate Displacement (mm)	14.15	10.38	15.34
Ductility	1.65	1.17	1.41
Secant rigidity (kN/mm)	35	51.7	39.63

It can be noted that the strength and stiffness of the specimen has been increased enormously by the stiffeners. Due to full weld, the ductility has been reduced considerably. Moreover, the presence of half weld maintenance the strength as that of full and also improved ductile nature of the specimen.

Stiffness Degradation

Figure 5 illustrates how the secant rigidity varies with each displacement according to the loading protocol. It is evident that when the subsequent loading increases, the stiffness decreases. The steel beam's deteriorating strength qualities are the cause of the drop in stiffness.

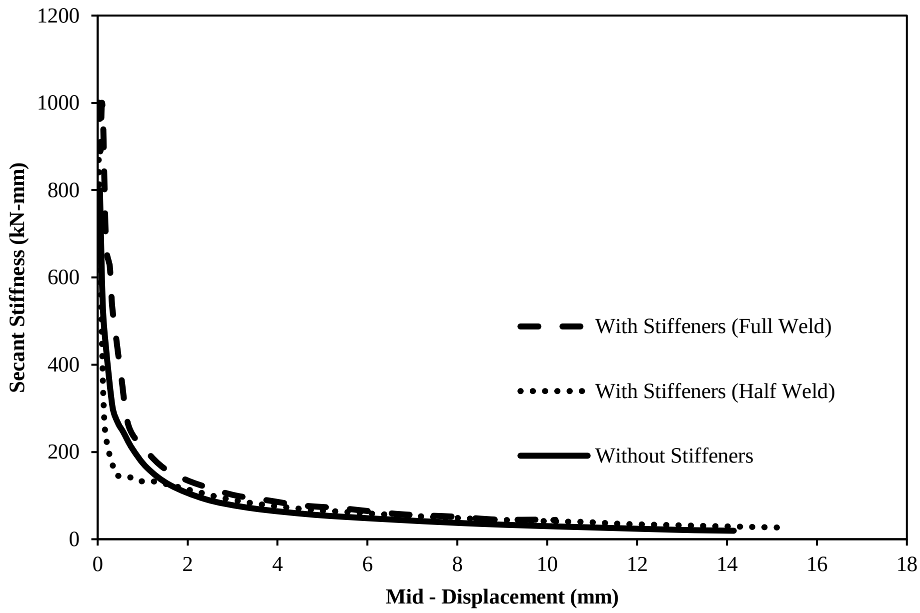


Figure 5. Stiffness Degradation

Energy Dissipation

The energy dissipation capability has been ascertained using the Equivalent Energy Elastic Plastic Curve (Equivalent Energy Elastic-Plastic Curve) principle. The elastic-plastic curve of Equivalent Energy Elastic-Plastic accurately depicts the specimen's actual response. Plotted until failure or until the energy dissipation capacity is equal, or until the area under the load-deflection curve equals the bilinear Equivalent Energy Elastic-Plastic curve. Figure 6 shows the several points of interest that were used to compute the Equivalent Energy Elastic-Plastic curve.

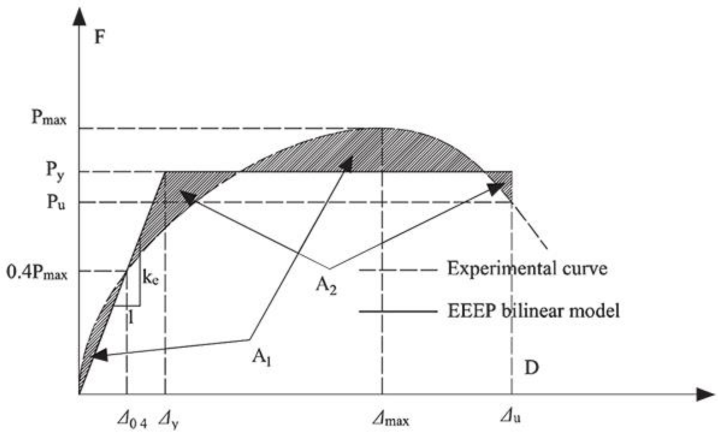


Figure 6. Equivalent Energy Elastic-Plastic Curve

The salient features of the EQUIVALENT ENERGY ELASTIC-PLASTIC bilinear curve are,

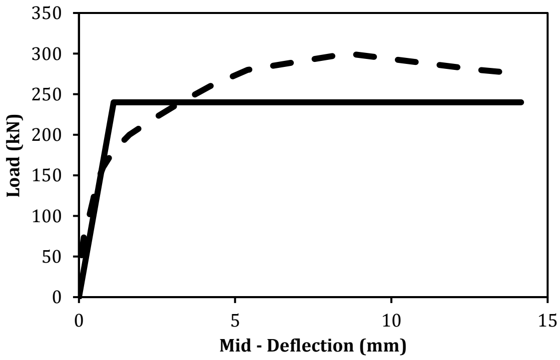
k_e – Secant Toughness at the point equivalent to 40% of the determined load

P_y – Profit strength as per Equivalent Energy Elastic-Plastic curve

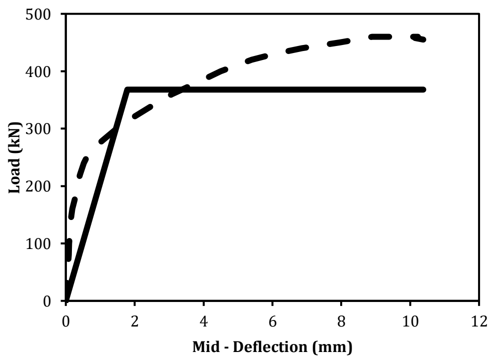
Δ_y – Profit Displacement corresponds to P_y

Δ_u – Definitive displacement which corresponds $0.8P_{max}$ at post peak

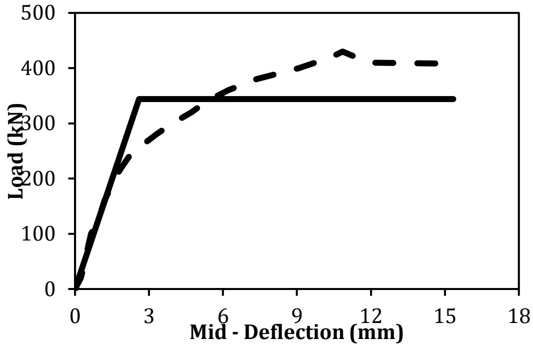
Then, up to the lateral displacement Δu, or the post-peak displacement that corresponds with the Equivalent Energy Elastic-Plastic curve, the area (energy) under the backbone curve was calculated. The slope of the inclined part of the Equivalent Energy Elastic-Plastic curve represents the Secant rigidity at 40% of the maximum load in the backbone curve. Next, a horizontal line depicting the plastic part of the Equivalent Energy Elastic-Plastic curve was inserted to make sure that the area enclosed by the curve and the back bone are equivalent. As a result, values for yield displacement and strength are calculated. The Equivalent Energy Elastic-Plastic curves for our specimen are shown in Figure 7.



a. Without Stiffeners



b. With Stiffeners with Full Weld



c. Without Stiffeners with Half Weld

Figure 7. Equivalent Energy Elastic-Plastic Curves for all Specimens

The energy dissipation capacity of the specimen has been calculated as the area under the Equivalent Energy Elastic-Plastic curve and listed in Table 2.

Table 2. Energy Dissipation Capacity

	Without Stiffeners	**With Stiffeners (Full Weld)**	**With Stiffeners (Half Weld)**
Energy Dissipation (kN-mm)	3263	3491	4830

CONCLUSION

The following conclusions have been drawn from this study.

a. Weld length is an important parameter that affects the behavior of the steel beam with stiffeners.
b. The presence of stiffeners improves the strength by 53%.
c. The specimen with half weld and full weld does not show much difference in terms of strength.
d. Due to full weld, the ductility has been reduced considerably. Moreover, the presence of half weld maintenance the strength as that of full and also improved ductile nature of the specimen.
e. Stiffness degradation maintains similar path in all specimens.
f. The energy dissipation capacity is high in case of half weld. This is achieved as the half weld specimen has high strength and high ductile nature.

Stiffeners are the best solution for the local web bucking or crippling in the steel beams. It is recommended that instead of full weld, we can go for half-weld which shows similar and even better behavior than the full weld specimen.

REFERENCES

[1] Okada T, Kawamura Y. Strength evaluation of intersection between stiffeners and primary supporting members considering the effect of shear force on the primary member web. Marine Structures. 2018 May 1;59:25-46. https://doi.org/10.1016/j.marstruc.2017.12.007

[2] Ramona P, Danica G. Analysis, Cost Estimation and Optimization of Reinforced Concrete Slab Strengthening by STEEL AND CFRP STRIPS. Archives for Technical Sciences/Arhiv za Tehnicke Nauke. 2023 Jul 1(29), 35-48.

[3] Yang Z, Cao W, Qiao Q, Zhang J. Experimental and numerical study on the prefabricated double L-shaped beam-column joint with triangular stiffener. Journal of Building Engineering. 2023 Jun 15;69:106315. https://doi.org/10.1016/j.jobe.2023.106315

[4] Levchenko A, Polikutin A, Barabash D. Crack Resistance of Reinforced Concreted and Reinforced Rubber Concrete Beams. Archives for Technical Sciences. 2020;1(22):21–26.

[5] Zhang M, Zhang Z, Lei L, Zhou W, Du M, Zhang B. Effect of repair weld length on microstructure evolution and mechanical properties of 30CrMnSiNi2A ultra-high strength steel. Journal of Materials Research and Technology. 2023 Mar 1;23:4828-4842. https://doi.org/10.1016/j.jmrt.2023.01.175

[6] Kadhim AA, Mohammed SJ, Al-Gayem Q. DVB-T2 Energy and Spectral Efficiency Trade-off Optimization based on Genetic Algorithm. Journal of Internet Services and Information Security. 2024;14(3):213-225.
[7] Li Y, Li Y, Zhang C, Lei M, Luo J, Guo X, Deng D. Effect of structural restraint caused by the stiffener on welding residual stress and deformation in thick-plate T-joints. Journal of Materials Research and Technology. 2022 Nov 1;21:3397-3411. https://doi.org/10.1016/j.jmrt.2022.10.127
[8] Subramanian R, Jagadeesan K. Experimental analysis and study on shear performances of castellated beam chassis under three cases of stiffener. Journal of Engineering Research. 2023;11(2B).
[9] Surendar A, Saravanakumar V, Sindhu S, Arvinth N. A Bibliometric Study of Publication-Citations in a Range of Journal Articles. Indian Journal of Information Sources and Services. 2024;14(2):97-103. https://doi.org/10.51983/ijiss-2024.14.2.14
[10] Yu JG, Feng XT, Li B, Chen YT. Effects of non-welded multi-rib stiffeners on the performance of steel plate shear walls. Journal of Constructional Steel Research. 2018 May 1;144:1-12. https://doi.org/10.1016/j.jcsr.2018.01.009
[11] Aydın MG, Depci T, Yalman E. Effect of Amorphous Silica Produced from Pumice and Quartzite on the Flow Characteristics of Drilling Mud. Natural and Engineering Sciences. 2022 Dec 1;7(3):319-324.
[12] Anupriya B, Jagadeesan K, Saranya B. Effect of stiffeners on castellated beams. Asian Journal of Research in Social Sciences and Humanities. 2016;6(12):30-37. https://doi.org/10.5958/2249-7315.2016.01274.0
[13] Anupriya B, Jagadeesan K. Experimental Investigation of Shear Strength of Castellated Beam with and without Stiffener. Structural Engineering Journal. 2015;42(4). Publisher Structural Engineering Research Centre, CSIR, Chennai.
[14] Standard BI. General construction in steel-code of practice. 3rd Revision, Bureau of Indian Standard, New Delhi, India, IS. 2007:800-2007.