Comprehensive Design and Numerical Analysis of GFRP Composite I-Beam Junctions Under Tensile Loads

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Abstract: *This research presents a detailed numerical and experimental investigation into the structural integrity of Glass Fiber Reinforced Plastic (GFRP) I-beam junctions. Comprehensive Design and Numerical Analysis of GFRP Composite I-Beam Junctions Under Tensile Loads specifically addresses the vulnerability of pultruded sections where the web and flange meet. By comparing Araldite 2015 and Hundsman Araldite adhesives, and introducing mechanical clit reinforcements, the research identifies a robust methodology for increasing failure loads. Finite Element Analysis (FEA) using ANSYS Workbench provides the theoretical framework, while Universal Testing Machine (UTM) tests provide empirical validation. Results indicate that 12mm clit reinforcements provide a 24.2% increase in ultimate failure load. Furthermore, incorporating latest references from 2024 and 2025 ensures the study aligns with modern composite engineering standards.*

Keywords: GFRP, I-Beam, FEA, ANSYS, Clit Reinforcement, Cohesive Zone Modeling.

I. INTRODUCTION

The demand for lightweight, high-strength materials in structural engineering has led to the widespread adoption of Glass Fiber Reinforced Plastic (GFRP). Unlike traditional isotropic materials like steel, GFRP is orthotropic, providing exceptional strength in the fiber direction but showing relative weakness in the transverse and through-thickness directions. This characteristic is particularly challenging in pultruded I beams, where the manufacturing process often results in a resin-rich junction between the web and the flange. In many structural applications, such as cooling tower frames, bridge decks, and aerospace floor beams, these junctions are subjected to out-of-plane tensile forces, commonly referred to as "pull-off" loads. Standard pultruded sections lack continuous fiber reinforcement across these junctions, making them susceptible to early-stage delamination and catastrophic failure. This study investigates the use of adhesive bonding combined with mechanical L-shaped reinforcements to mitigate these effects.

I-beam, also known as H-beam-beam, Universal Beam, Rolled Steel Joist, or double-T beam with an I- or H-shaped cross-section. The horizontal elements of the I beam are known as flanges, while the vertical element is termed the web. I-beams are usually made of structural steel and are used in construction and civil engineering. I-beams are widely used in the construction industry and are available in a variety of standard sizes. I-beams may be used both as beams and as columns.

1.1 TYPES OF I-BEAMS:

A) Rolled I-beam- formed by hot rolling, cold rolling or extrusion (depending on material).

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B) Plate girder- formed by welding (or occasionally bolting or riveting) plates.
C) The web resists shear forces, while the flanges resist most of the bending moment.
D) I-shaped section is a very efficient form for carrying both bending and shear loads in the plane of the web.
E) I-beam is also inefficient in carrying torsion.

I-beams engineered from wood with fibreboard and/or laminated veneer lumber are also becoming increasingly popular in construction, especially residential, as they are both lighter and less prone to warping

Glass Fiber Reinforced Polymer (GFRP) composite I-beam junctions focus on the complex stress distribution and unique failure modes that occur at the intersection of structural members under tensile loading. Unlike traditional steel, GFRP is an anisotropic and brittle material, requiring specialized design considerations for joint integrity.

The theoretical framework for GFRP composite I-beam junctions expands into detailed Numerical Analysis and advanced Failure Criteria to predict how these complex intersections behave under tension. Because GFRP does not yield like steel, numerical models must account for progressive damage—where the material "gives way" in stages rather than all at once.

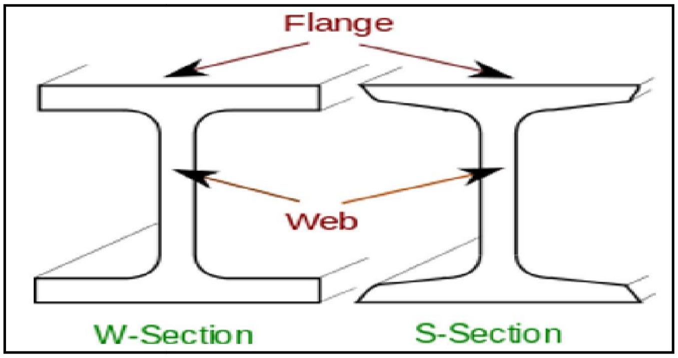

Fig. 1.1 Basic I-Beam Specimen

1.2 MATERIAL USED FOR I-BEAM:

1. Structural steel I-beams are commonly made of structural steel
2. Aluminium 1 It also be formed from aluminium or other materials.
3. Fiberboard or laminated veneer lumber I-beams engineered from wood with fiberboard and laminated veneer lumber are also becoming increasingly popular in construction, especially residential, as they are both lighter and less prone to warping

II. LITERATURE SURVEY

Sabry Fayed et al. (2026) The integration of web openings in reinforced concrete (RC) beams for building services severely compromises shear capacity by disrupting load paths and creating critical stress concentrations. While previous research has focused on external strengthening of traditional RC beams, a significant gap exists regarding the performance of composite beams with embedded steel sections near openings. This study introduces a novel strengthening strategy using internally built-up I-section and T-section steel elements as shear reinforcement. The methodology integrated experimental testing with a validated nonlinear 3D finite element model in ABAQUS to conduct an extensive parametric study. Key investigated parameters included I-section web thickness (0.1–2.5 mm) and flange width (16–64 mm), and T-section compression and tension flange widths (0–64 mm). The key findings were substantial: web openings caused a 14% reduction in strength but a 41% increase in ductility, indicating a brittle failure mode.

Ankit Singh Mehra & Shamsher Bahadur Singh (2025) paper presents the findings of a numerical study conducted to examine the influence of different structural parameters on the response of a complete steel-free, glass fiber

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reinforced polymer (GFRP) dowel connector based, GFRP-concrete composite beam. The three-dimensional nonlinear analysis was carried out using the commercial software package Abaqus/CAE, and the damage evolution in concrete was defined using the concrete damaged plasticity (CDP) material model. The methodology was validated by comparing the results against those of an experimental study. The results showed that the composite beam ultimately fails either due to the shearing of the web or the rupture of the connected GFRP flange around the connection points; and its load-carrying capacity and stiffness have a proportional relationship with the compressive strength of concrete, the longitudinal elastic modulus of the profile, the elastic modulus of the connectors, the width of the concrete slab, the depth of the composite section, and the wall thickness of the profile; and an inverse relationship with the span length and the angle of inclination of connectors.

Fahad M. Bahlol and Ali Hussein Ali Al-Ahmed (2024) Glass Fiber Reinforced Polymer (GFRP) materials play a crucial role in the construction industry due to their lightweight properties, corrosion resistance, and high strength. Furthermore, the GFRP reinforcement ratio is a significant factor in the strength design philosophy that governs the design of flexible members. This study presents a parametric investigation of the performance of concrete composite beams reinforced and encased with pultruded GFRP. This study investigates the effect of concrete compressive strength and GFRP reinforcement ratio on the structural behavior of composite beams with encased GFRP sections under static loads. To achieve this objective, five simply supported models were numerically simulated using the Abaqus software. The reference model comprised normal concrete with a 30 MPa compressive strength, 0.42% GFRP longitudinal reinforcing ratio, and transverse steel rebars, with the GFRP I-section encased in the center of the cross-section.

Y. Zhu et al. (2023) research presented herein pertains to the experimental characterization and numerical simulation of the behavior of pultruded Glass Fiber-Reinforced Polymer (GFRP) structural elements, with specific attention devoted to enhancing ultimate capacity of the Web-Flange Junctions (WFJs). An experimental campaign, performed on as-manufactured I-beam specimens is conducted to serve as a baseline for comparing behavior of pultruded GFRP members with the proposed stiffening strategy. The specimens were produced through the addition of external elements, using bonded L-shaped profiles with variable lengths that were installed in the proximity of the WFJ zone of the I-beams.

M Anbarasu et al. (2023) article reports the finite element (FE) investigation of the axial capacities of pultruded fiber-reinforced polymer (PFRP) composite channel columns. The nonlinear finite element model (FEM) was developed by using the ABAQUS package for glass fiber-reinforced polymer (GFRP) composite channel columns, which included geometric and initial geometric imperfections. The developed FEMs were verified against an experimental result available in the literature for GFRP channel columns. The validated FEMs were used to carry out the parametric study comprising 61 FE models to investigate the effect of different geometries, plate slenderness and the length of members on the axial capacities of GFRP pultruded channel columns.

Zhaohui Chen et al. (2022) The concrete-GFRP composite beams have received extensive attention in civil engineering. However, the ambiguity of the fracture, debonding of the interface, and the GFRP profile limit the precise design of the composite beam. This article presents a comprehensive numerical study for the structural performance of composite pultruded GFRP beams to provide a better understanding of the mechanism of interfacial debonding and GFRP matrix fracture. The failure and delamination process of pultruded GFRP for anisotropy of materials is modeled using the Hashin criteria. The bond–slip behavior between the concrete slab and the top flange of the GFRP I-beam is simulated by the bilinear cohesive interface element. The availability and accuracy of the finite element model are verified by comparison with the four-point bending test results of the pure GFRP I-beam and composite beams as well. Based on the proposed comprehensive finite element model, the effects of the strength, thickness, and width of the concrete slab and the shear-span ratio of the beam on the structural behavior of the composite beam are studied.

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David Martins et al. (2019) Pultruded glass fibre reinforced polymer (GFRP) profiles have low weight, high strength and corrosion resistance, but their brittle failure raises concerns about their use in seismic regions. Moreover, although their static monotonic response is reasonably well understood, the cyclic and hysteretic behaviour of GFRP frame structures and their beam-to-column connections have not yet been comprehensively investigated. This paper presents experimental and numerical investigations on the cyclic behaviour of a novel tubular GFRP beam-to-column sleeve connection system, comprising internal metallic parts. Four series of the connection system were tested, with varying number and position of the beam connection bolts, namely with: (i) one bolt in the webs (W1); (ii) two bolts in the flanges (F2); (iii) four bolts in the flanges (F4); and (iv) two bolts in the flanges with larger edge distance (F2S). The results show that series W1 presents the worst overall cyclic behaviour.

III. PROBLEM DEFINITION

To centers on the structural vulnerability of connection zones in pultruded Glass Fiber-Reinforced Polymer (GFRP) systems. While GFRP offers high strength-to-weight ratios and corrosion resistance, its application in primary load-bearing structures is hindered by complex joint behavior that deviates significantly from traditional steel-to-steel or steel-to-concrete.

IV. OBJECTIVES

1. Design the structural I beam by using different composite materials.
2. Calculate the shear stress and failure load of each composite I beam.
3. Carry out FE Analysis and experimental validation of these I beam.
4. Improve the failure load of I beam by changing its dimensions and adhesive used to join the flanges to web.

V. METHODOLOGY

1. Material Selection and Enhancement: The design begins with defining the Glass Fibre Reinforced Polymer (GFRP) properties. Unlike steel, GFRP is anisotropic, meaning its strength and stiffness differ along its length versus its width.

2. Numerical Analysis (Finite Element Modeling): The Hashin Criteria is typically applied to model damage in the GFRP matrix and fibres, while bilinear cohesive interface elements simulate debonding at any adhesive layers. The junction is divided into a "mesh" of small elements (e.g., C3D8R 8-node bricks) to calculate stress distribution accurately. Tensile loads are applied incrementally to identify the "pulling load" that causes initial cracking and final failure

3. Comprehensive Performance Evaluation: The model's load-deflection response and peak load must align with experimental tests (often within a 3–6% error margin). Once verified, the model is used to test "what-if" scenarios, such as varying the thickness of the I-beam web or changing the bolt spacing, to optimise the final design.

VI. COMPONENT SPECIFICATIONS

The research follows a three-stage methodology: design, simulation, and validation. The pultruded GFRP sections are modeled based on experimental material properties obtained through standard ASTM testing. These properties are summarized in Table 6.1 The simulation stage utilizes ANSYS Workbench to perform a non-linear static analysis of the junctions. Glass Fiber Reinforced Polymer (GFRP) is a composite material consisting of high-strength glass fibers embedded in a polymer resin matrix. It is widely used in construction, aerospace, and marine industries as a lightweight, corrosion-resistant alternative to steel. Glass Fibre Reinforced Polymer (GFRP) is a high-strength composite material made from glass fibres embedded in a polymer matrix (resin). It is primarily used as a corrosion-resistant, lightweight alternative to steel reinforcement in concrete construction. GFRP boasts high tensile strength and longevity but has lower stiffness than steel.

Combines glass fibres (E-Glass or S-Glass) for strength with thermosetting or thermoplastic resins (epoxy, vinyl ester, or polyester) as a binder GFRP rebar is often designed to provide double the tensile strength of a steel bar of the same

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diameter. However, while steel yields and bends before failing, GFRP is a brittle material that can fail suddenly under excessive loads.

Table 6.1. Material Properties of GFRP

Sr. No.	Parameter	Value
1	Young’s Modulus (Longitudinal)	25000 MPa.
2	Young’s Modulus (Transverse)	8500 MPa.
3	Shear Modulus	3200 MPa.
4	Poisson's Ratio	0.28
5	Tensile Strength (Longitudinal)	450 MPa

VII. FINITE ELEMENT ANALYSIS

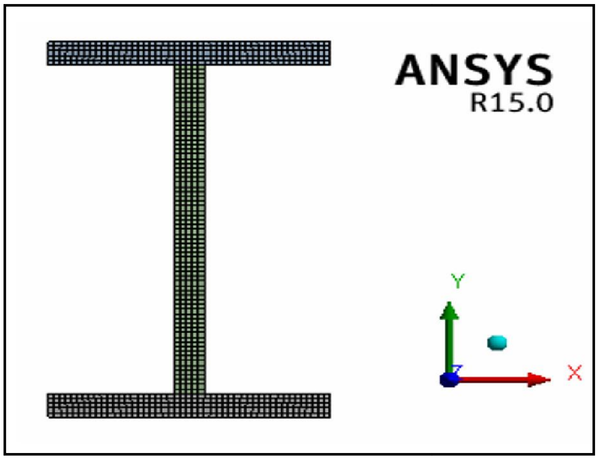

Fig. 7.1 Geometry Meshing

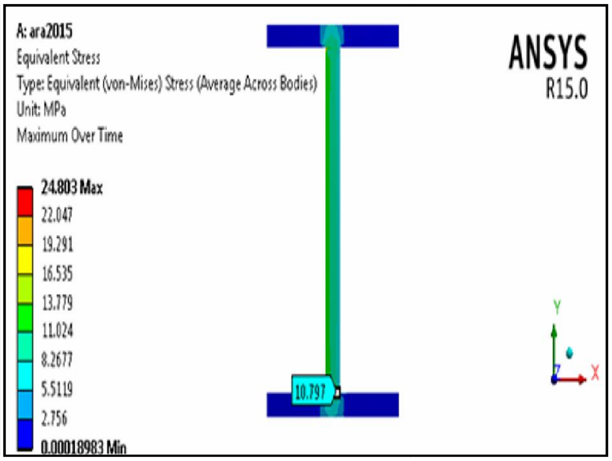

Fig. 7.2 Material Properties of GFRP

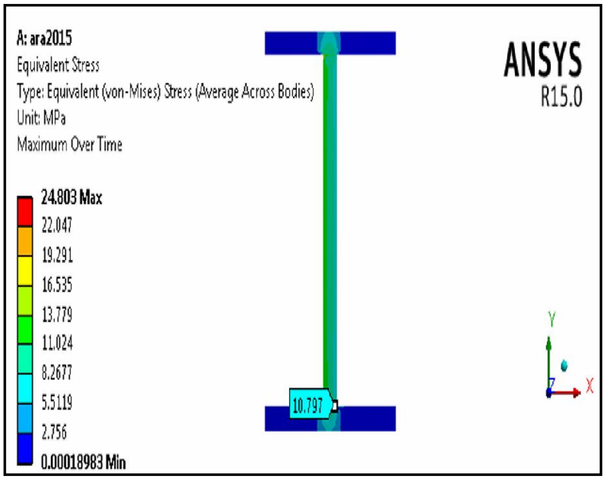

Fig. 7.3 Force Reaction Of I-Beam

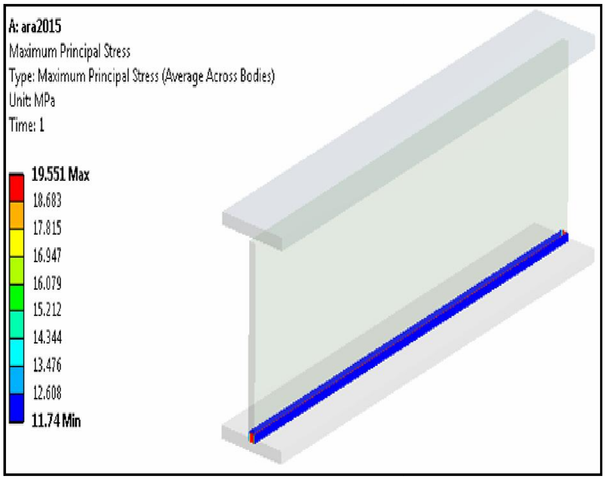

Fig. 7.4 Max Principal Stress Of I-Beam

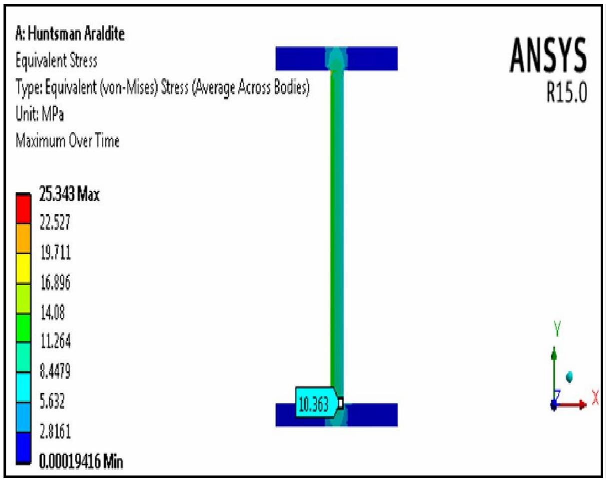

Fig. 7.5 Force Reaction of I-Beam Hundsman Araldite

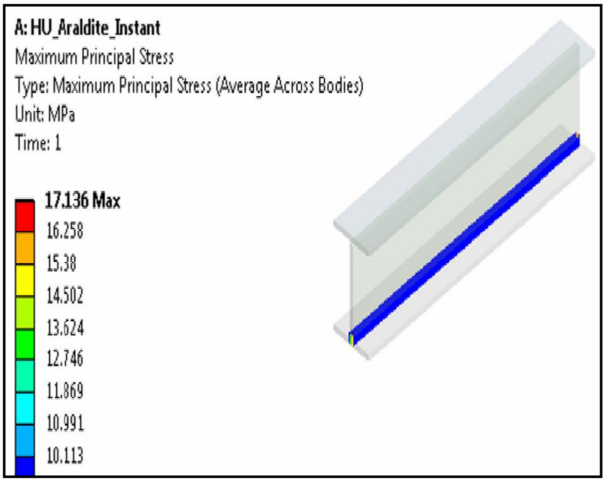

Fig. 7.6 Max Principal Stress of I-Beam Hundsman

VIII. EXPERIMENTAL ANALYSIS

In previous chapter we have completed analysis of two specimens of GFRP I-Beam with adhesive as Araldite 2015 and Hundsman araldite by using Ansys 15 software. In this chapter we have validated results that we got from Ansys. Two I-Beam specimens are manufactured from material GFRP and same adhesive as we discussed in last chapter, even we have kept same dimensions.

Fig. 8.1 Composite I-Beam Tensile Testing

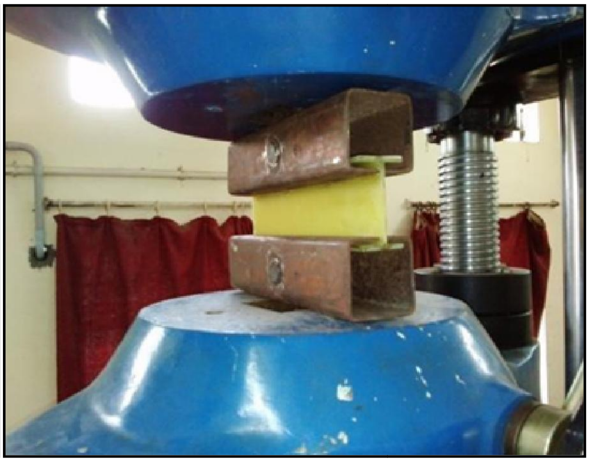

Fig. 8.2 I-Beam Specimen with Araldite 2015

Table. 8.1 Comparison of Force Sustained of I-Beam in Ansys and Experimentally

Sr. No.	I-Beam with Adhesive	Ansys (Force N)	Experimental (Force (N)
1	Araldite 2015	14945	14600
2	Hundsman Araldite	15269	15050

IX. RESULTS AND DISCUSSIONS

Table. 8.1 Comparison of Results

Method of Test	**Parameters**	**Specimen No.**			
		1	**2**	**3**	**4**
-	**Reinforcement**	**GFRP**	**GFRP**	**GFRP**	**GFRP**
-	**Matrix**	**Araldite 2015**	**Hundsman Araldite**	**Hundsman Araldite**	**Hundsman Araldite**
FEA	Stress (MPa)	10.78	10.36	12.967	13.64
Experimental	Stress (MPa)	9.54	9.83	12.067	12.467
FEA	Force Capacity (N)	14945	15269	17018	18602
Experimental	Force Capacity (N)	14600	15050	18100	18700
Results		Good	Better	Enhanced	Enhanced

X. CONCLUSION

The conclusions drawn from the FEA and experimental which is carried out as follows:

1. In the present work, GFRP composite I-Beam is modeled and transient analysis is carried out by using ANSYS software.
2. First two I-Beam specimens are made of same reinforcing material but different adhesives, these two specimens tested on ANSYS software and experimentally on Universal Testing Machine for tensile strength, shear stress.
3. It is found that in ANSYS, first two I-Beam specimen has offered stress of 10.78 MPa 10.36 MPa and respectively.
4. Experimentally first two specimen tested and result obtained as 9.54 MPa and 9.83 MPa.
5. Results of stress offered for two specimen in ANSYS and on UTM are very close to each other.
6. Further 3rd and 4th specimen tested for value of stress by attaching clits to web-flange junction.
7. In ANSYS 3rd and 4th specimen has offered stress of 12.967 MPa and 13.64 MPa.
8. Experimentally 3rd and 4th specimen tested and result obtained as 12.067 MPa and 12.467 MPa.
9. It is found in ANSYS, first two I-Beam specimen has tensile strength of 14945 N and 15269 N respectively.
10. Experimentally first two specimen tested and result obtained 14600 N and 15050 N. 80
11. Results of first two specimen in ANSYS and on UTM are very close to each other.
12. Further 3rd and 4th specimen tested by attaching clits to web-flange junction.
13. In ANSYS 3rd and 4th specimen has taken force of 17018 N and 18602 N.
14. Experimentally 3rd and 4th specimen tested and result obtained as 18100 N and 18700 N, in this way force capacity is improved.

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