# STUDY ON FINITE ELEMENT ANALYSIS OF COLD FORMED STEEL TUBULAR T-SECTION WITH DIFFERENT SUPPORT CONSTRAINTS

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## ABSTRACT:

Cold-Formed Steel (CFS) tubular sections are growing in use in building construction because it is very strong in strength to weight ratio and buckling strength. It is very important to be aware of how they perform at different loads and in different support conditions, to ensure that they can be safely and effectively designed. This is a finite element (FE) investigation into the structural behaviour of CFS tubular T-sections. The paper is a study of the structural behaviour of T-joints with and without reinforcement (a collar plate and ring stiffener). The aim is to identify their failure modes, strength, stiffness, and deformation at various loads of a different boundary condition and β (0.5, 0.75, and 1.0). The quantitative study will entail development of 3D models, suitable process of meshing and non-linear analysis.

*Keywords: Cold-Formed Steel (CFS), Finite Element Method (FEM), Collar Plates, Stiffness, Failure Modes, Buckling.*

## INTRODUCTION:

In the current structural engineering, the need to have lightweight, high-strength and low-cost materials is central. Cold-Formed Steel (CFS) has turned out to be an important material to take these needs, and its production by means of heating to room temperature of steel sheets or coils improves its yield strength, as well as, gives the material the accuracy of dimensions. Their resulting low mass-to-strength ratio and lightweight make them easier to transport and erect and therefore make overall project costs and schedules less expensive and time-consuming. Tubular sections, especially, are extremely efficient in withstanding compression and torsional forces. This has rendered them suitable in a large range of uses, including trusses, columns, and space frames, industrial buildings, warehouses, multi-level bridge systems and other intricate connections found in these structural frames. The behaviour of these connections, particularly when subjected to alternate supporting constraints and when supported using different reinforcement techniques, is very important in the safety and stability of the whole structure although physical experimentation of structural components can be very costly and time-consuming. The applied value of FEM to CFS tubular sections is especially significant because of the possibility to take into consideration the intricate nature of the joints, the effects of local buckling and non-linear material behaviour. In this study, FEM is used to make a parametric study that would otherwise be too difficult to achieve without using real-world tests, but the structural response of a CFS tubular T-joint is a complicated phenomenon. Its geometry has a great impact on it, as well as the reinforcement technique and the boundary conditions at supports. Whereas some design guidance is offered by standards, the exact interaction between the different types of reinforcement (e.g., collar plates and ring stiffeners) and the different types of support constraints (e.g., fixed and hinged) is not entirely recorded. Such level of insufficient detail may result in overly conservative or even unsafe design, thus, a special study is needed to explore the impact of these factors on the load capacity, stiffness, and failure modes of T-section numerically and quantitatively.

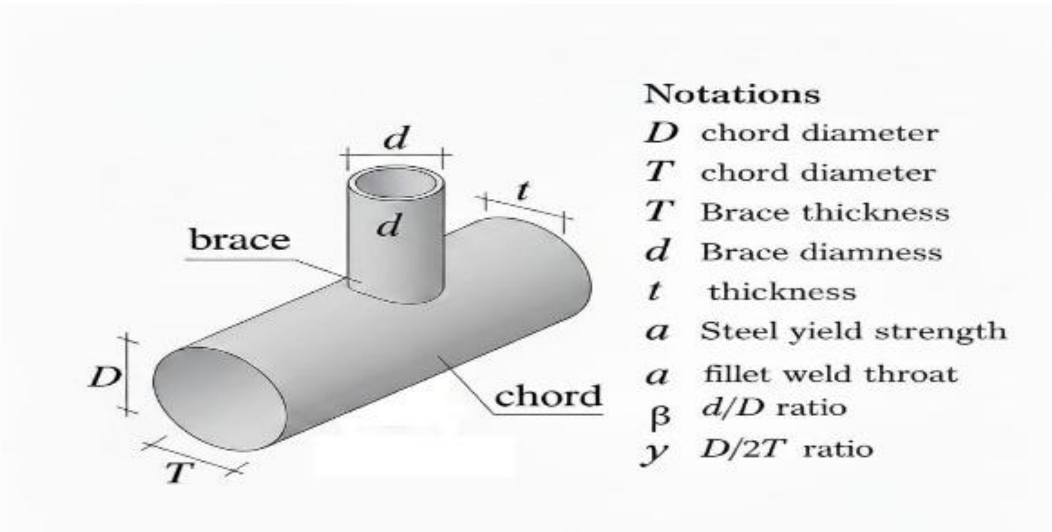



**Figure 1. Notations of CFS Tubular T – Section**

## SPECIMEN DESCRIPTION:

The main specimen to be used in this study is that of T-joints which have a major member known as Chord and a second constituent known as Brace. The paper has compared the performance of such joints when these joints are in unreinforced condition and external reinforcement of two forms.

### Unreinforced T-joints:

The base models where the brace is welded to the chord directly. These models are named according to their ratio of beta . The three models that have not been reinforced are β-0.58, β-0.758, β-1.

### Reinforced T-joints:

To investigate methods of enhancing the joint's strength and stiffness, two types of external reinforcements were studied.

### Collar Plate (CP):

This is a welding technique because it is applied to the junction between the brace and the chord. The plate strengthens the bonding thereby reducing stress concentration at the welding, as well as increasing its stiffness. These models are designated as β-0.58, β-0.758, β-1.

### Ring Stirrups (RS):

This method involves welding two external ring stiffeners to the chord member, positioning one on each side of the brace connection. These stiffeners assist in effectively transferring the load from the brace to the chord member and help prevent local buckling or ovalization of the chord wall. These models are designated as β-0.58, β-0.758, β-1.

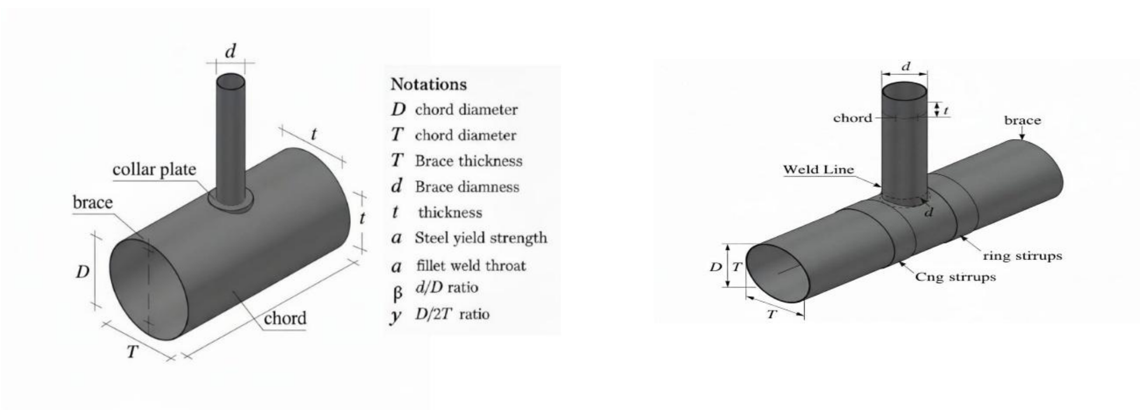



**Figure 2: Schematic of Reinforced T-joints**

## SPECIMEN PARAMETERS AND DIMENSIONS:

The geometric properties of all the specimens considered in the numerical study are presented and All measurements are expressed in millimetres (mm). The parameters $d_b$, $t_b$, $d_c$, $t_c$, $L_c$, and $l_b$represent the brace diameter, brace thickness, chord diameter, chord thickness, chord length, and brace length, respectively. A schematic diagram depicting these dimensions for an unreinforced T-joint is shown for better visualization and understanding of the joint configuration.

**Table 1: Dimensions of Unreinforced and Reinforced T-joints**

| Joint ID | β | $d_b$ (mm) | $t_b$ (mm) | $d_c$ (mm) | $t_c$ (mm) | $l_c$ (mm) | $l_b$ (mm) | $D_o$(mm) | $D_1$(mm) | $t_o$(mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| T- 0.5 β | 0.5 | 76 | 3 | 139 | 3 | 600 | 460 | - | - | - |
| T- 0.75 β | 0.75 | 76 | 3 | 101 | 3 | 600 | 500 | - | - | - |
| T - 1 β | 1 | 76 | 3 | 76 | 3 | 600 | 524 | - | - | - |
| T- 0.5 β - CP | 0.5 | 76 | 3 | 139 | 3 | 600 | 464 | 120 | 78 | 3 |
| T- 0.75 β - CP | 0.75 | 76 | 3 | 101 | 3 | 600 | 510 | 120 | 78 | 3 |
| T - 1 β - CP | 1 | 76 | 3 | 76 | 3 | 600 | 526 | 120 | 78 | 3 |
| T- 0.5 β - RS | 0.5 | 76 | 3 | 139 | 3 | 600 | 464 | - | - | - |
| T- 0.75 β - RS | 0.75 | 76 | 3 | 101 | 3 | 600 | 510 | - | - | - |
| T - 1 β - RS | 1 | 76 | 3 | 76 | 3 | 600 | 526 | - | - | - |

## THE STRUCTURAL BEHAVIOR OF A COLD-FORMED STEEL (CFS) TUBULAR T -STYLE SECTION:

The structural behaviour of a Cold-Formed Steel (CFS) tubular T -style section when applied on the brace is controlled by the forces of the brace being transferred to the chord and the subsequent deformation of the chord wall.

### 1.Load Transfer Path Load Application:

This is compressive load N put on top of the brace. Brace to Chord: This force flows along the brace and is transmitted to the chord member across the weld at the brace -chord junction. This force is exerted at the junction of the wall of the chord to the top and circles around the chord and is transferred to supports.

**2. Primary Failure Modes:**

The local deformation affecting the chord, which is relatively a thin walled section, will certainly occur much earlier than the fracture of the steel itself. These deformation-based failure modes are being analysed by FEA results.

**The major failure modes of this kind of joint are:**

a) **Chord Wall Ovalisation:** This is the most significant and most prevalent failure mode, and in your unreinforced models. The high compression of the brace makes the circular chord pinched or flattened. The front and back walls are forced inwards, and the top and bottom walls are forced outwards, and this makes the shape circular take an oval shape.

b) **Brace Local Buckling:** The buckling at the junction as the sides locally buckle in a brace can occur when the brace is super thin (large diameter to thickness ratio) and the chord may break.

c) **Chord Shearing:** Sometimes the wall loses its structural integrity in shear and projects the impression of the brace punching through.

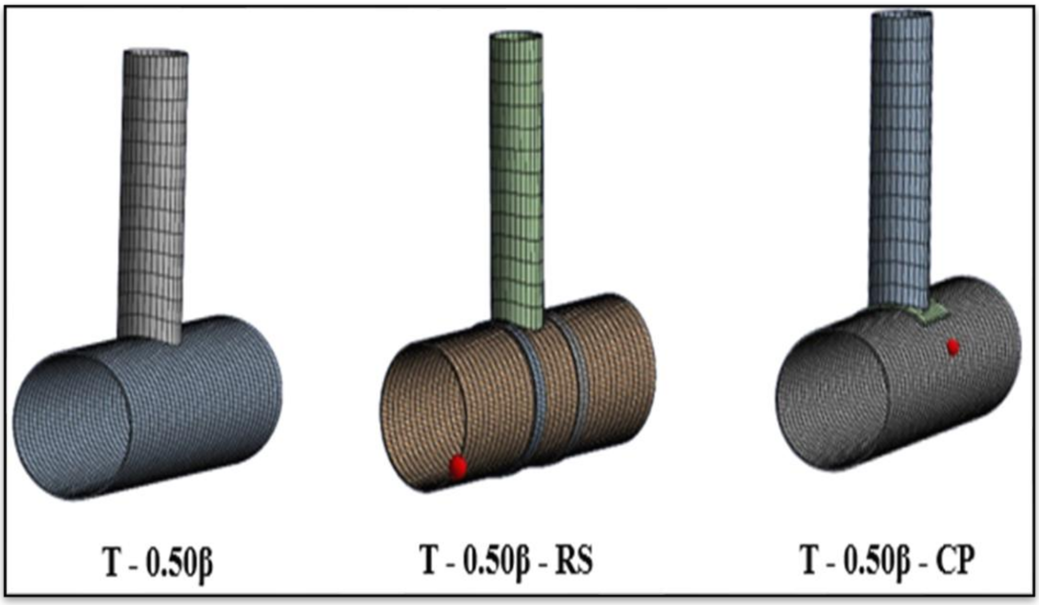



**Figure 3 a) Applied Load b) Axial Compression**

## NUMERICAL INVESTIGATION (FINITE ELEMENT MODELING):

A numerical investigation was performed to study the effect of reinforcement and support constraints on the axial capacity of the T-joints. The study was conducted using the large deformation elastoplastic finite element method. This chapter details the development of the finite element models.

### Finite Element Software:

The software ANSYS-2026 R2.1 was used to carry out the numerical simulation. ANSYS is a robust and widely validated commercial FEA package capable of handling the non-linear material behaviour and large deformations inherent in this type of structural analysis. The geometry of the T-joints was developed within the ANSYS environment.

### 3d Model Development and Meshing:

The thin-walled nature of the CFS sections makes them ideal for modeling with shell elements, which are computationally more efficient than solid elements for this geometry. A 4-node shell element (such as SHELL181 in ANSYS) was likely used, as it accurately captures membrane, bending, and transverse shear strains.

The geometry of the T-joint was developed and meshed as shown in below Figure A fine mesh was applied, particularly at the brace-chord intersection. This is the area of highest stress concentration, and a finer mesh is required to accurately capture the steep stress gradients and the initiation of local buckling or yielding. A mesh convergence study is typically performed to ensure the results are independent of the mesh density.

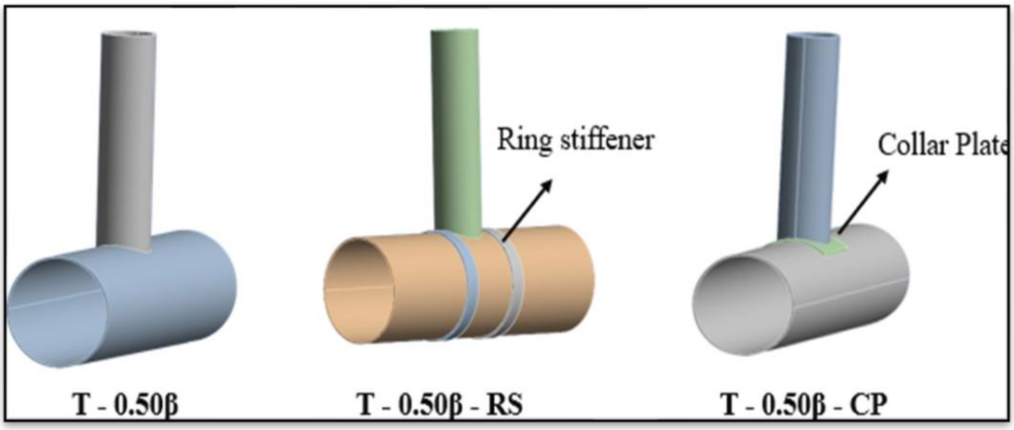



**Figure 4 Typical 3D Model and Meshed Model of T-Joints**

## ANALYSIS PROCEDURE:

A non-linear static analysis was performed. To accurately capture the buckling and post-buckling behaviour, the non-linear Newton-Raphson equation solver was employed, as stated in your presentation. This is an iterative method that solves the non-linear equations at discrete load steps. The load was applied gradually in a step-by-step method to trace the full load-deformation path and accurately identify the ultimate load (the peak of the curve). Large-deformation analysis was turned on to account for the significant changes in geometry during buckling.

## LOADING AND BOUNDARY CONDITIONS:

### Loading Application:

A static, axial compressive load was applied to the T-joint. The load was induced as a uniform pressure or nodal force on the top surface of the brace, simulating a compressive force being transferred from the brace to the chord.

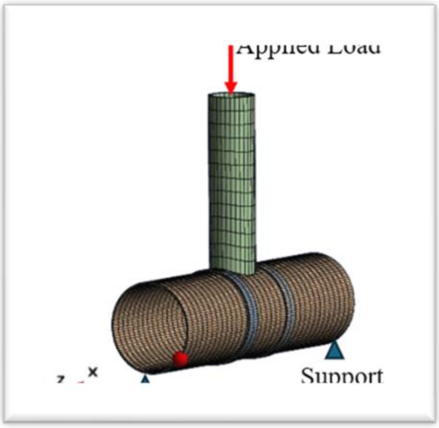


**Figure 5 Loading and Boundary Condition Schematic**

### Parametric Study of Support Constraints:

This is the core variable of the project. The chord was supported at its two ends, and the constraints at these supports were systematically varied to simulate different real-world installation conditions. The coordinate system is assumed to be X-axis along the chord, Y-axis along the brace, and Z-axis transverse to the X-Y plane.

### Case 1: Both Ends Fixed (FIX-FIX)

Simulates a fully rigid connection. Both chord ends are restrained in all 6 degrees of freedom: all translations (UX, UY, UZ) and all rotations (ROTX, ROTY, ROTZ) are set to zero.

**Case 2: One End Fixed (FIX-FREE)**

Simulates a cantilevered condition. One chord end is fixed (all 6 DOFs restrained). The other end is completely free.

**Case 3: Both Ends Hinged (HINGE-HINGE)**

Simulates a connection that allows rotation but not translation (like a simple support). Both chord ends are restrained in all translations (UX, UY, UZ = 0) but are free to rotate about all three axes (ROTX, ROTY, ROTZ are free).

**Case 4: Hybrid Condition 1 (FIX-HINGE)**

One end is rigid; the other is simply supported. One end is fixed (all 6 DOFs = 0). The other end is hinged (UX, UY, UZ = 0; rotations free).

**Case 5: Hybrid Condition 2 (HINGE-FREE)**

One end is simply supported; the other is free. One end is hinged (UX, UY, UZ = 0; rotations free). The other end is completely free.

**Case 6: Rotational Release (Rotation Z Only Free)**

Fixed ends, but free to twist (torsion). Both ends fixed for translations (UX, UY, UZ = 0) and bending (ROTX, ROTY = 0), but free to rotate about the Z-axis.

**Case 7: Rotational Release (Rotation Z, X Only Free)**

Fixed against translation, but free to twist and bend in one plane. Both ends fixed for translations (UX, UY, UZ = 0) and bending about Y-axis, but free to rotate about X and Z axes.

**Case 8: Rotational Release (Rotation Z, X, Y Free)**

This is identical to Case 3 (Both Ends Hinged), where all translations are fixed and all rotations are free.

This comprehensive matrix of support constraints allows for a deep understanding of how end-fixity, which controls the member's stiffness and ability to redistribute load, interacts with the local strength of the T-joint.

## RESULTS AND DISCUSSION:

## PART 1: FIXED AND HINGED SUPPORTS:

This chapter presents the primary results from the finite element analysis. The findings are organized by the type of support condition, starting with the most common "fixed" and "hinged" cases. The discussion focuses on the ultimate load-carrying capacity, the load-deformation behaviour, and the observed failure modes. The results from your presentation for T-0.5β, T-0.75β, and T-1β are presented and compared.

## CASE 1: 'BOTH ENDS FIXED' SUPPORT CONDITION:

In this configuration, both ends of the chord were fully restrained against all translation and rotation. This represents the most rigid support condition, maximizing the member's stiffness.

### Load-Deformation Behaviour:

The load-deformation behaviour was plotted for all specimens. The axial deformation of the brace and the ovalization of the chord were the primary metrics.

**Table 2 Load vs. Axial Deformation for T-0.5β Specimens**

**(Both Ends Fixed)**

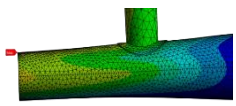
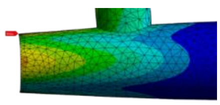
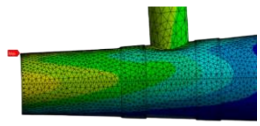
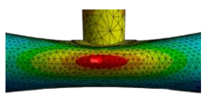
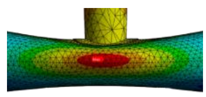
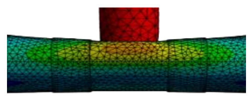
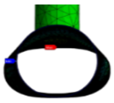
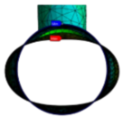
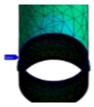
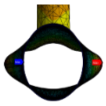
| Specimens | **T-0.5 β (with reinforcement)** | **T-0.5 β (without reinforcement)** | **T-0.5 β ( ring stirrups)** |
|---|---|---|---|
| One end fixed |  |  |  |
| Both end fixed |  |  |  |

**Table 3 Load vs. Ovalization for T-0.5β Specimens (Both Ends Fixed)**

| Specimens | **T-0.5 β (with reinforcement)** | **T-0.5 β (without reinforcement)** | **T-0.5 β ( ring stirrups)** |
|---|---|---|---|
| One end fixed |  |  |  |
| Both end fixed |  |  |  |

The graphs show that for all β-ratios, the reinforced specimens (CP and RS) exhibited significantly higher stiffness and ultimate load capacity compared to the unreinforced (UR) model. The unreinforced model typically fails at a much lower load due to premature local buckling of the chord wall.

From the results tables, for the T-0.5β specimen, the unreinforced model failed at 97 kN. The collar plate (CP) reinforcement (labeled "Reinforced" in your tables) increased this to 112 kN, while the ring stirrups (RS) provided a massive increase to 374 kN. This trend holds for T-0.75β and T-1β as well.

**Unreinforced:** The unreinforced specimen shows significant ovalization and local yielding of the chord face directly under the brace.

**Collar Plate (CP):** The collar plate helps to distribute the load from the brace over a larger area of the chord, reducing the peak stress. Failure is still localized but occurs at a higher load.

**Ring Stiffener (RS):** The ring stiffeners provide exceptional radial support, effectively preventing the chord wall from deforming (ovalizing). This forces the failure to a different mode, such as yielding of the brace or the stiffeners themselves, resulting in a much higher ultimate load.

The maximum stress for the T-0.5β-RS specimen was 29.6 kN/m², compared to 2.04 kN/m² for the unreinforced model.

## CASE 2: 'ONE END FIXED' SUPPORT CONDITION

This case simulates a cantilevered chord, which is much more flexible than the 'Both Ends Fixed' condition.

### Load-Deformation Behaviour

With one end free, the entire chord is free to deflect vertically, leading to global bending in addition to local joint deformation. This increased flexibility results in much larger deformations.

**Table 4 Load vs. Axial Deformation for T-0.5β Specimens (One End Fixed)**

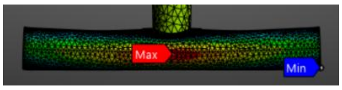
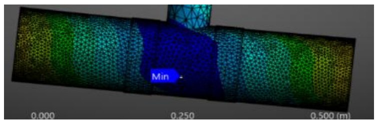
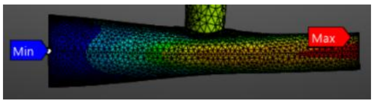
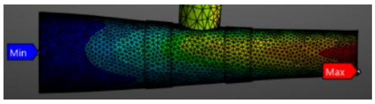
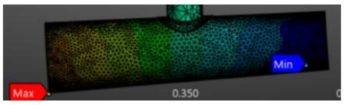
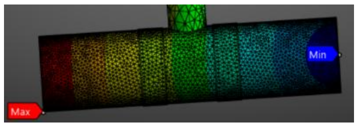
| Specimens | **T-0.5 β (with reinforcement)** | **T-0.5 β ( ring stirrups)** |
|---|---|---|
| Both End hinged |   |   |
| One End Fixed One End Hinged |   |   |
| One End Hinged One End Free |   |   |

**Table 5 Load vs. Axial Deformation for T-0.75β Specimens (One End Fixed)**

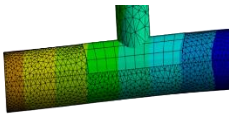
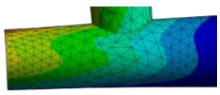
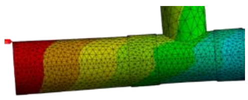
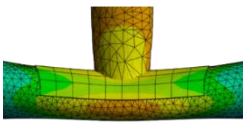
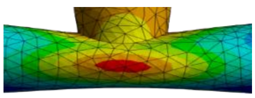
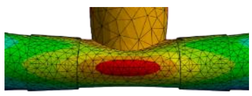
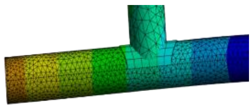
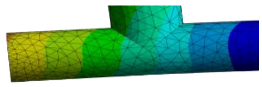
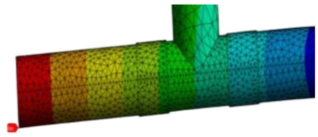
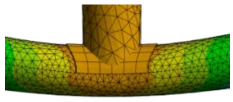
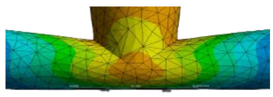
| Specimens | T-0.75 β (with reinforcement) | T-0.75 β (without reinforcement) | T-0.75 β ( ring stirrups) |
|---|---|---|---|
| One end fixed |  |  |  |
| Both end fixed |  |  |  |

**Table 6 Load vs. Axial Deformation for T-1.0β Specimens (One End Fixed)**

| Specimens | **T-1β (with reinforcement)** | **T-1β (without reinforcement)** | **T-1β ( ring stirrups)** |
|---|---|---|---|
| One end fixed |  |  |  |
| Both end fixed |  |  |  |

the T-0.5β specimen, the unreinforced model failed at 161 kN. The Ring Stiffener (RS) model failed at a *lower* load of 100.26 kN, while the Collar Plate (CP) model performed best, failing at 227 kN. This same trend (CP > UR > RS) is seen for the T-1β specimen. For T-0.75β, both reinforcements improved the strength.

The Ring Stiffeners (RS) create a very rigid "point" on the chord, but they do not prevent the global bending of the member. This high local rigidity combined with high global flexibility seems to create a stress concentration that leads to an earlier failure.

The Collar Plate (CP), however, is designed to stiffen the *joint intersection* itself. This proves more effective when the chord is undergoing global bending, as it maintains the integrity of the brace-chord connection while the entire member deflects.

**Table 7 Max Load and Stress Comparison for T-0.5β**

**(Fixed Conditions)**

| Joint ID | Support | Max Load (kN) | Max stress ($kN/m^2$) |
|---|---|---|---|
| Unreinforced | Both End Fixed | 97 | 2.04 |
| Reinforced (CP) | Both End Fixed | 112 | 15.3 |
| Reinforced (RS) | Both End Fixed | 374 | 29.6 |
| Unreinforced | One End Fixed | 161 | 4.9 |
| Reinforced (CP) | One End Fixed | 227 | 8.8 |
| Reinforced (RS) | One End Fixed | 100.26 | 4.7 |

**Table 8 Max Load and Stress Comparison for T-0.75β (Fixed Conditions)**

| Joint ID | Support | Max Load (kN) | Max stress ($kN/m^2$) |
|---|---|---|---|
| Unreinforced | Both End Fixed | 119 | 3.74 |
| Reinforced (CP) | Both End Fixed | 141 | 17.95 |
| Reinforced (RS) | Both End Fixed | 381 | 18.7 |
| Unreinforced | One End Fixed | 264 | 6.5 |
| Reinforced (CP) | One End Fixed | 347 | 7.4 |
| Reinforced (RS) | One End Fixed | 381 | 18.7 |

**Table 9 Max Load and Stress Comparison for T-1.0β (Fixed Conditions)**

| Joint ID | Support | Max Load (kN) | Max stress ($kN/m^2$) |
|---|---|---|---|
| Unreinforced | Both End Fixed | 147 | 4.18 |
| Reinforced (CP) | Both End Fixed | 191 | 25.29 |
| Reinforced (RS) | Both End Fixed | 565 | 17.7 |
| Unreinforced | One End Fixed | 556 | 10.1 |
| Reinforced (CP) | One End Fixed | 567 | 10.1 |
| Reinforced (RS) | One End Fixed | 135 | 8.1 |

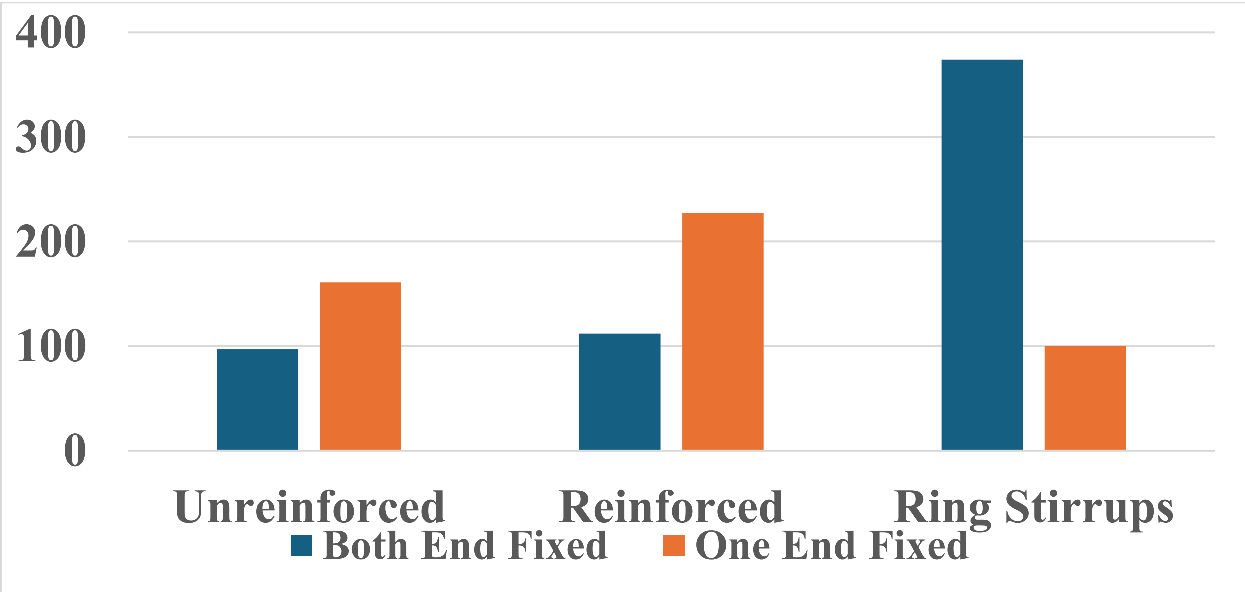



**Figure 6 Bar Chart Comparison of Max Load for T-0.5β Specimens**

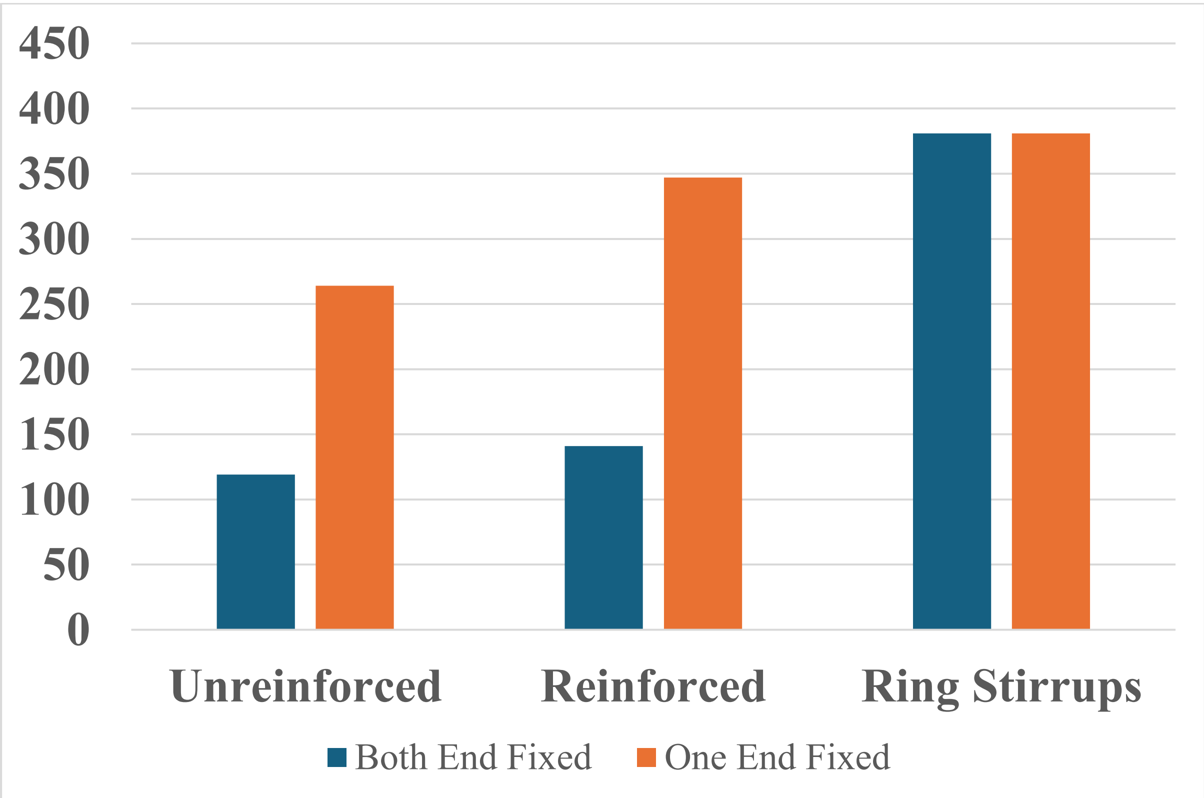



**Figure 7 Bar Chart Comparison of Max Load for T-0.75β Specimens**

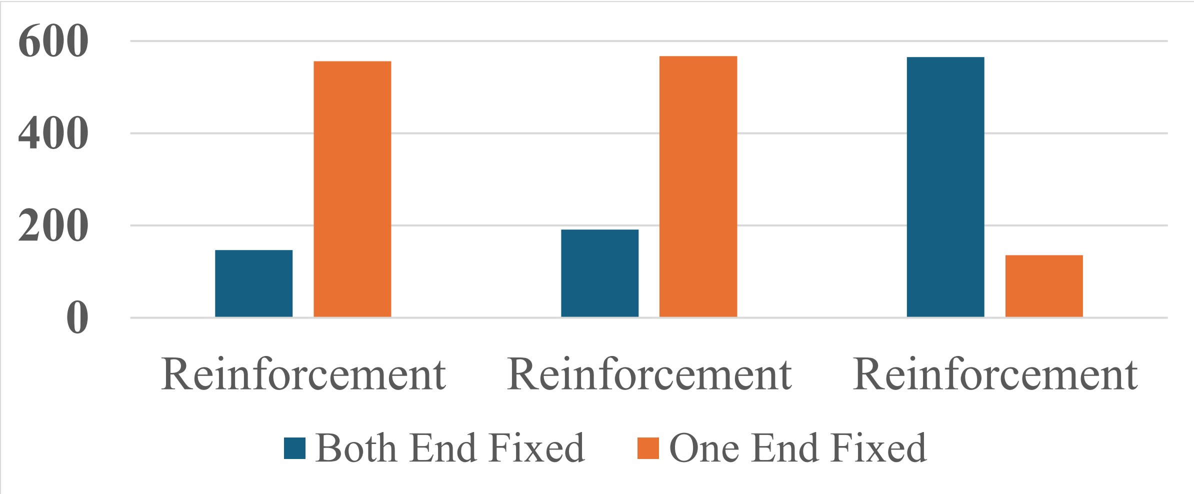



**Figure 8 Bar Chart Comparison of Max Load for T-1.0β Specimens**

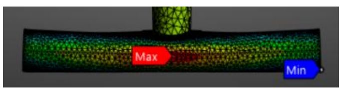
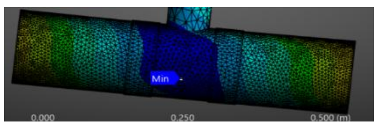
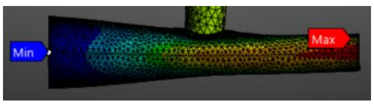
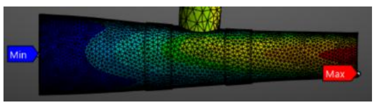
For rigidly supported systems ('Both Ends Fixed'), failure is local. Ring Stiffeners (RS) are extremely effective because they directly address the local failure mode (chord ovalization).

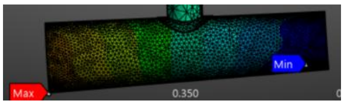
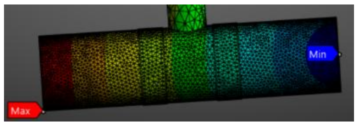
For flexible, ('One End Fixed'), failure is a mix of local and global bending. Collar Plates (CP) are more effective because they strengthen the joint connection itself, allowing the member to act as a composite whole, while Ring Stiffeners seem to cause a detrimental stress concentration.

## CASE 3: 'BOTH ENDS HINGED' SUPPORT CONDITION

This case (analysed in your PPT as "Rotation Z,X,Y Free") represents a simply supported condition where the chord ends cannot translate but are free to rotate. This allows the chord to bend freely under the brace load.

**Table 10 Deformation Plot (Both Ends Hinged, T-0.5β, Reinforced)**

| Specimens | **T-0.5 β (with reinforcement)** | **T-0.5 β ( ring stirrups)** |
|---|---|---|
| Both End hinged |   |   |
| One End Fixed One End Hinged |   |   |

| | | |
|---|---|---|
| One End Hinged One End Free |  |  |

The ultimate load capacities for this condition are expected to be lower than the 'Both Ends Fixed' case but higher than the 'One End Fixed, One End Free' case

## PART 2 HYBRID AND ROTATIONAL CONSTRAINTS

This chapter explores the more complex and nuanced boundary conditions presented in your study. These "hybrid" conditions (e.g., Fixed-Hinged) and "rotational release" conditions (e.g., Rotation Z-Free) are crucial for understanding the sensitivity of the T-joint to specific degrees of freedom. These scenarios simulate real-world connections that are neither perfectly rigid nor perfectly free, such as connections to other members with some flexural or torsional flexibility.

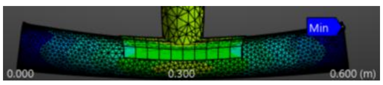
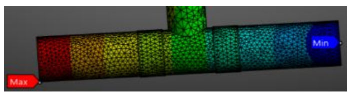
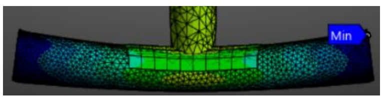
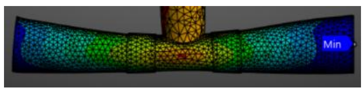
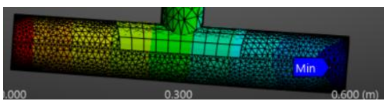
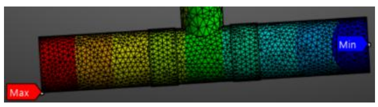
### Analysis Of Hybrid Support Conditions

These cases investigate asymmetrical supports, which can induce complex bending and torsional modes.

### Case: One End Fixed, One End Hinged (FIX-HINGE)

This condition is a propped cantilever. It is more rigid than a simple hinge-hinge support but more flexible than a fixed-fixed support.

**Table 11 Deformation Plot (One End Fixed, One End Hinged, T-0.75ß)**

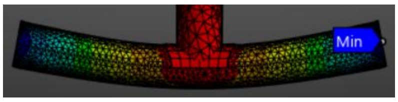
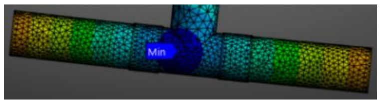
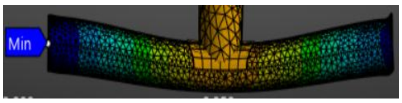
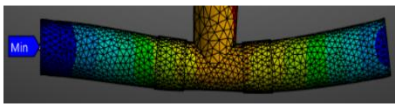
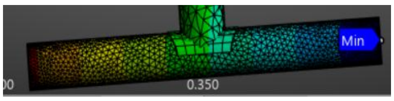
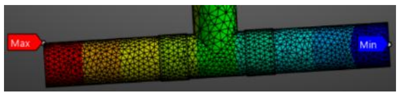
| Specimens | **T-0.75 β (with reinforcement)** | **T-0.75 β ( ring stirrups)** |
|---|---|---|
| Both End hinged |  |  |
| One End Fixed One End Hinged |  |  |
| One End Hinged One End Free |  |  |

The failure mode is expected to be a combination of global bending (with the point of maximum bending shifted toward the hinged end) and local joint deformation. The analysis of this case shows how the load is redistributed along the chord. The fixed end absorbs a significant moment, reducing the peak deflection at the center compared to a fully hinged case. The performance of CP vs. RS stiffeners here is critical, as the joint must resist both local deformation and the bending moment.

**Case: One End Hinged, One End Free (HINGE-FREE)**

This case represents an unstable "pendulum" like condition *unless* the joint itself provides stability. The member is free to rotate about the hinged end.

**Table 12 Deformation Plot (One End Hinged, One End Free, T-1.0β)**

| Specimens | **T- 1β (with reinforcement)** | **T- 1β ( ring stirrups)** |
|---|---|---|
| Both End Hinged |  |  |
| One End Fixed One End Hinged |  |  |
| One End Hinged One End Free |  |  |

The deformation plots for this case likely show very large, sweeping deformations as the entire member rotates around the hinge. The ultimate load capacity is expected to be extremely low, as failure is governed by global instability rather than local joint strength. This case effectively demonstrates that without some rotational restraint, the local strength of the T-joint is irrelevant.

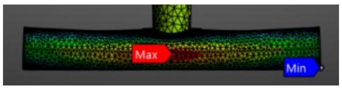
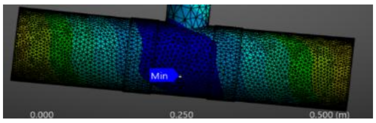
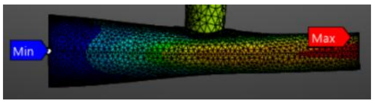
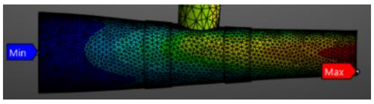
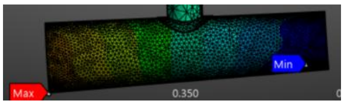
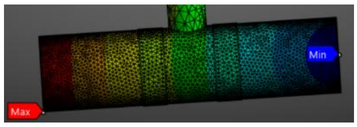
**Analysis of Released Rotational Constraints:**

These cases are designed to isolate the effect of each rotational degree of freedom on the joint's capacity.

**Effect of Rotation Z Release**

This case (labelled "Rotation Z Only Free" in your PPT) simulates a chord that is fixed against bending in both planes (ROTX=0, ROTY=0) and all translations but is free to twist about its own longitudinal axis (ROTZ is free).

**Table 13 Deformation Plot (Rotation Z Only Free, T-0.5β, RS)**

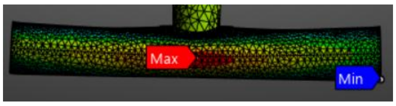
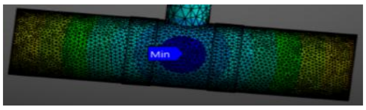
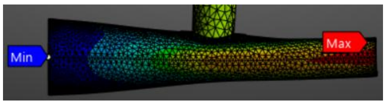
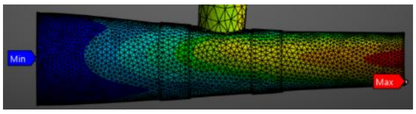
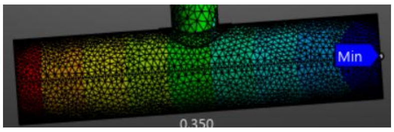
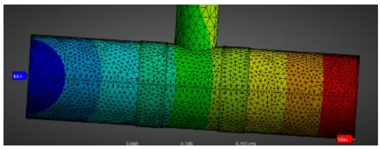
| Specimens | **T-0.5 β (with reinforcement)** | **T-0.5 β ( ring stirrups)** |
|---|---|---|
| Both End hinged |   |   |
| One End Fixed One End Hinged |   |   |
| One End Hinged One End Free |   |   |

However, any slight, unavoidable eccentricity (either in the model or induced by initial buckling) would cause the chord to twist, leading to a torsional failure. The plots from your presentation, however, show simple bending, suggesting the label "Rotation Z Only Free" might be a misinterpretation of the "Both Ends Hinged" case.

**Effect of Rotation X & Z Release:**

This case ("Rotation Z,X Only Free") simulates a chord that is fixed against translation and bending in one plane (ROTY) but free to bend in the other (ROTX) and twist (ROTZ). This is a more realistic "simple" support.

**Table 14 Deformation Plot (Rotation Z, X Only Free, T-0.75β, CP)**

| **Specimens** | **T-0.5 β (with reinforcement)** | **T-0.5 β ( ring stirrups)** |
|---|---|---|
| Both End hinged |   |   |
| One End Fixed One End Hinged |   |   |
| One End Hinged One End Free |   |  |

The results here show a combination of bending and twisting. The ability of the member to twist and bend simultaneously reduces its stiffness and ultimate capacity compared to the fully fixed case.

## OVERALL DISCUSSION ON THE INFLUENCE OF SUPPORT CONSTRAINTS:

The complete set of results, spanning from fully fixed to fully free, provides a clear picture: **the support constraints are as important as the joint's local design.**

A summary of the findings would be:

1. **High-Stiffness Systems:** In these systems, the chord cannot easily deform globally. All load is forced into the local joint. Failure is by local chord buckling. **Ring Stiffeners (RS)**, which directly prevent this local deformation, are the most effective solution.

2. **Low-Stiffness Systems:** In these systems, the chord undergoes large global bending or rotation. Failure is governed by global instability or a combination of global bending and local joint failure. **Collar Plates (CP)**, which strengthen the brace-chord connection itself, are more effective as they maintain the joint's integrity while the member deflects.

3. **Intermediate-Stiffness Systems:** These systems exhibit a mixed-mode failure. The choice of reinforcement is non-obvious and depends on the

specific parameters. As seen in the T-0.75β case, both CP and RS reinforcements can provide significant, and sometimes similar, benefits.

This study conclusively demonstrates that a reinforcement solution cannot be "one size fits all." It must be chosen in direct consideration of the T-section's role and boundary conditions within the larger structure.

**Table 15 Results for T-0.5β (Hybrid and Rotational Constraints)**

| **Joint ID**<br>**Both End Fixed** | **Maximum Load** | **Maximum Stress** |
|---|---|---|
| T – 0.5β Reinforced | 112 kN | 15.25 kN /m$^2$ |
| T – 0.5β Ring Stirrups | 374 kN | 29.6 kN /m$^2$ |
| **Joint ID**<br>**One End Fixed** | **Maximum Load** | **Maximum Stress** |
| T – 0.5β Reinforced | 227 kN | 8.8kN /m$^2$ |
| T – 0.5β Ring Stirrups | 100.26kN | 4.7 kN /m$^2$ |

**Table 16 Results for T-0.75β (Hybrid and Rotational Constraints)**

| **Joint ID**<br>**Both End Fixed** | **Maximum Load** | **Maximum Stress** |
|---|---|---|
| T – 0.75β Reinforced | 141 kN | 17.95 kN /m$^2$ |
| T – 0.75β Ring Stirrups | 381 kN | 18.7 kN /m$^2$ |

| **Joint ID**<br>**One End Fixed** | **Maximum Load** | **Maximum Stress** |
|---|---|---|
| T – 0.75β Reinforced | 347kN | 7.4 kN /m$^2$ |
| T – 0.75β Ring Stirrups | 381 kN | 18.7 kN /m$^2$ |

**Table 17 Results for T-1.0β (Hybrid and Rotational Constraints)**

| **Joint ID**<br>**Both End Fixed** | **Maximum Load** | **Maximum Stress** |
|---|---|---|
| T – 1β Reinforced | 191kN | 25.29 kN /m$^2$ |
| T – 1β Ring Stirrups | 565 kN | 17.7 kN /m$^2$ |
| **Joint ID**<br>**One End Fixed** | **Maximum Load** | **Maximum Stress** |
| T – 1β Reinforced | 567kN | 10.1kN /m2 |
| T – 1β Ring Stirrups | 135.9kN | 8.1 kN /m2 |

## SUMMARY, CONCLUSION, AND FUTURE SCOPE:

### Summary of Work:

This project presented a comprehensive numerical study on the structural behaviour of Cold-Formed Steel (CFS) tubular T-sections. Using the Finite Element Analysis software ANSYS, a parametric investigation was conducted to understand the influence of different support constraints on the ultimate load-carrying capacity and failure modes.

The study modelled T-joints with three distinct β-ratios (0.5, 0.75, and 1.0) and three reinforcement configurations (Unreinforced, Collar Plate reinforced, and Ring Stiffener reinforced). The primary contribution of this research was the systematic analysis of a wide matrix of boundary conditions, ranging from fully fixed and cantilevered to fully hinged and various hybrid/rotational release scenarios. A non-linear, large-deformation static analysis was performed for each configuration, and the resulting load-deformation curves, ultimate loads, and failure modes were extracted and compared.

**Conclusions:**

1. Support Constraints are a Critical Variable: The structural response and ultimate load of a T-joint are not intrinsic properties but are a direct function of the member's boundary conditions. Changing the support from 'Both Ends Fixed' to 'One End Fixed' (cantilever) completely changed the failure mode and the relative effectiveness of the reinforcement strategies.
2. Reinforcement Effectiveness is Coupled to Support Type: There is no universally "best" reinforcement.
   - For rigidly supported systems ('Both Ends Fixed'), where failure is local (chord ovalization), Ring Stiffeners (RS) were found to be exceptionally effective, increasing load capacity by up to 385% (for T-0.5β) and 284% (for T-1β).
   - For flexible systems ('One End Fixed'), where failure involves global bending, Collar Plates (CP) were found to be the superior solution, increasing load capacity by 41% (for T-0.5β) while Ring Stiffeners were detrimental.
3. β-Ratio Influence: Increasing the β-ratio (i.e., making the brace and chord diameters closer) generally increases the joint's stiffness and ultimate load in the unreinforced condition for fixed supports.
4. Failure Mode Shift: The support constraints dictate the failure mode. Fixed supports force a local failure at the joint. Flexible or hinged supports allow for global bending or instability, which often becomes the governing failure mode at a different load threshold.
5. Design Implication: This study proves that structural designers cannot simply select a reinforcement detail from a manual. They must analyse the T-joint as part of the entire structural system and select a reinforcement strategy (CP or RS) that is appropriate for the *specific* boundary conditions and failure modes (local or global) anticipated for that member.

**Limitations of The Study:**

This research was purely numerical and carries the inherent limitations of computational modelling:

1. No Experimental Validation: The study was not accompanied by a physical experimental program for direct validation, relying instead on methods validated from the literature.
2. Geometric Imperfections: Initial geometric imperfections, which are known to affect the buckling load of CFS, were not explicitly modelled. *(If you did model them, change this line.)*
3. Residual Stresses: The effects of residual stresses from the cold-forming process and from welding the brace to the chord were not included in the model.
4. Material Model: The material was modelled as a simple elastic-plastic, which may not capture the full complexity of strain-hardening at the corners.

**Scope for Future Work:**

1. Experimental Validation: Conduct physical laboratory tests on T-sections with CP and RS reinforcements under 'Both Ends Fixed' and 'One End Fixed' support conditions to experimentally validate the "performance reversal" observed in this numerical study.
2. Broader Parametric Study: Expand the study to include other parameters, such as the chord-thickness-to-diameter ratio ($\gamma$), brace-to-chord-thickness ratio ($\tau$), and different steel grades.
3. Different Loading Conditions: Investigate the effect of support constraints on T-joints under different loading, such as brace bending, chord bending, or combined axial and bending loads.
4. Cyclic Loading: Analyse the performance of these reinforced joints under cyclic (seismic) loading to evaluate their ductility and energy dissipation capacity.
5. Other Geometries: Apply the same methodology (varying support constraints) to other joint types, such as X-joints, K-joints, or joints made from Rectangular Hollow Sections (RHS).

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