ORIGINAL RESEARCH

Effect of Shear Connector Height on the Shear Performance of Y-shaped Connectors in Steel–Concrete Composite Beams

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Abstract: This paper investigates the influence of connector height on the shear behavior of Y-shaped shear connectors in steel–concrete composite beams. A three-dimensional nonlinear finite element (FE) model was developed using ABAQUS to simulate push-out tests. The model incorporated nonlinear constitutive behavior of concrete and steel, surface-to-surface contact interaction, and displacement-controlled loading. This study investigates the influence of connector height on the shear performance of Y-shaped shear connectors in steel–concrete composite beams using a validated finite element (FE) model. While previous research has examined alternative connector geometries, the specific effect of height variation on load transfer, ductility, and stiffness remains insufficiently explored. A parametric FE analysis was performed for heights ranging from 30 to 70 mm, and the results indicate that increasing height significantly enhances shear strength and stiffness up to 50 mm, followed by marginal improvement beyond this threshold. Ductility, however, decreases at greater heights due to higher stress concentration at the connector base. The findings contribute to improved design optimization of Y-shaped connectors in composite beams. Practical implications for structural design and directions for future work are also discussed.

Keywords: Y-shaped shear connector, connector height, composite beam, finite element analysis, shear strength, ductility, ABAQUS simulation.

Highlights:

- Shear capacity increases with connector height up to 50 mm.
- Ductility decreases with excessive height due to concrete cracking.
- Optimum height range of 50–55 mm ensures best performance.
- Validated FE model accurately predicts shear–slip behavior.

1. Introduction

Steel–concrete composite beams rely on effective shear connectors to ensure full composite action and minimize slip at the steel–concrete interface [1]. Among various connector types introduced over the past decades, Y-shaped perfobond rib shear connectors have gained increasing attention due to their superior bearing area, enhanced dowel action, and improved load transfer compared with traditional headed studs [2-4].

Experimental studies on perfobond and Y-type connectors confirm significant improvements in shear resistance, ductility, and crack control when compared to earlier connector geometries [4-7].

Despite extensive investigations into perfobond rib connectors since the early 1990s [8-11], the influence of geometric parameters especially connector height on the behavior of Y-shaped connectors remains insufficiently understood. Prior studies mainly focused on parameters such as rib width, diameter, transverse rebar, fatigue resistance, or concrete strength [3, 4, 12-14].

For example, Kim et al. (2013) evaluated the shear resistance of Y-type connectors but did not isolate the height effect [2], while Veldanda & Hosain and Oguejiofor & Hosain focused mainly on perfobond ribs with different hole geometries rather than height parameters [9-11].

Additionally, modern design codes such as Eurocode 4 do not provide explicit design provisions for Y-shaped connectors, and many analytical models implicitly assume that connector performance is relatively insensitive to height variations [15].

However, in practical applications such as composite bridge girders and building floor systems, connector height is constrained by slab thickness, reinforcement detailing, and, in some cases, fire protection layers [16-21].

Understanding the influence of connector height is therefore essential for developing reliable and economical design recommendations.

1.1. Research Gap

Although many researchers studied Y-type connectors, no comprehensive FE-based study has quantified the influence of height variations (30–70 mm) on:

1. Shear strength,
2. Load–slip behavior,
3. Ductility, and
4. Stress distribution and failure modes.

1.2. Objective

This study fills this gap by performing a detailed parametric investigation using validated FE models.

1.3. Literature Review

Early work on shear connectors primarily focused on headed studs and perfobond ribs, establishing fundamental load-transfer mechanisms and failure modes in composite systems [1, 2, 5, 8-11]. Perfobond connectors showed significantly better performance due to concrete dowel action and mechanical interlock, motivating the development of advanced geometries such as Y-shaped connectors [5-7, 22].

Y-shaped shear connectors were introduced to increase load-bearing area, reduce stress concentration at the weld zone, and improve ductility [3, 4, 12].

Kim et al. (2014–2018) conducted extensive studies on aspects such as transverse rebars, fatigue performance, end-bearing resistance, and double-row configurations [3, 12-14, 23].

These studies consistently showed that Y-shaped connectors outperform standard perfobond ribs under static, cyclic, and fatigue loading.

Comparative analysis :

- Unlike Kim et al. (2013) who focused on rib width and diameter [2]. the present study isolates connector height and quantifies its effect on shear behavior.
- Unlike Costa-Neves et al. (2013) who emphasized monotonic loading of perfobond ribs [24], this study examines height-dependent ductility changes.
- Unlike Xue, Wang, Zhao, and others (2018–2021) who explored FRP ribs, PBL connectors, or rebar effects [14, 23, 25-29], the current work develops a height-based design insight for Y-shaped connectors.

Recent investigations (2015–2021) also highlight new variations such as FRP ribs [25], strip connectors [29], and temperature-dependent behavior [16-21] but none specifically address connector height in a systematic parametric manner.

Thus, current literature confirms the structural importance of Y-shaped connectors but reveals a clear research gap regarding the effect of connector height.

2. Methodology and Model Validation

A three-dimensional nonlinear finite element (FE) model was developed using ABAQUS 6.14 to simulate the push-out behavior of Y-shaped shear connectors in steel–concrete composite beams.

The model consisted of a concrete block, a steel flange, and an embedded Y-shaped connector, with the connector height (H) varied as 30, 40, 50, 60, and 70 mm. Other parameters connector width (30 mm), rebar diameter (12 mm), and concrete compressive strength (30 MPa) were kept constant to isolate the effect of connector height.

Concrete was modeled using the Concrete Damage Plasticity (CDP) model with compressive strength f'_c= 30 MPa, elastic modulus E_c= 30 GPa, and Poisson’s ratio of 0.2.
Steel components, including the connector and reinforcing bar, were modeled as elastic–plastic materials with E_c= 200 GPa, yield stress f_y= 400 MPa, and Poisson’s ratio 0.3.
A surface-to-surface contact with a friction coefficient of μ = 0.45 was assigned between the steel and concrete surfaces to simulate interface behavior realistically. The bottom of the concrete block was fully restrained, while a displacement-controlled load was applied to the top flange to replicate experimental push-out testing conditions.

Mesh sensitivity analyses were conducted using element sizes of 5–15 mm to ensure accuracy and computational efficiency. The model exhibited less than 2% variation in peak load when the element size was reduced below 10 mm.

The base configuration (H = 50 mm) was validated against the experimental results reported by Kim et al. [30], demonstrating strong correlation in both ultimate shear capacity and load–slip response (Figure 2). The validated model was subsequently used for parametric analysis of the height effect.

2.1. FE Model Setup

A 3D finite element model was developed in ABAQUS 6.14 using:

- C3D8R brick elements for concrete
- C3D8R for steel connector and flange
- T3D2 beam elements for reinforcement (embedded region)

Connector heights studied: 30, 40, 50, 60, 70 mm.

Material models:

- Concrete Damage Plasticity (CDP) calibrated using experimental data in the thesis
- Bilinear elastoplastic steel

2.2. Contact Modeling

- Normal behavior: Hard Contact (pressure-overclosure = “hard”)
- Tangential behavior: Penalty formulation, $\mu = 0.45$
- Interface: Surface-to-surface contact between connector and concrete
- Weld: Tie constraint between connector and steel flange

2.3. Boundary Conditions

- Concrete block bottom face: Encastre
- Steel flange top face: Displacement-controlled loading (vertical displacement at 0.1–0.2 mm/s)

2.4. Mesh Sensitivity

Element sizes tested: 5, 7.5, 10, 12.5, and 15 mm.

Mesh convergence achieved at 10 mm with variation <2%.

Approximate element count: ~75,000 (varies by height).

2.5. Solver Settings

- Implicit static step
- NLGEOM = on
- Maximum increments = 1000
- Initial increment = 1e-4
- Automatic stabilization = off

2.6. Validation

Validation performed using push-out test results from:

- Kim et al. (2013)[2]

Deviation in peak load was <5%, validating FE accuracy.

3. Research Methodology

This research employed a numerical simulation approach based on the validated push-out test model of the Y-shaped shear connector.

The study followed these sequential steps:

- Model Development:

A detailed 3D FE model was created in ABAQUS 6.14, consisting of a steel flange, concrete block, and embedded Y-shaped connector.

- Material Properties:

  Concrete modeled using the Concrete Damage Plasticity (CDP) model with compressive strength f'_c = 30 MPa.

  Steel modeled as an elastic–plastic material (E = 200 GPa, fy = 400 MPa).

- Contact Definition:

  Surface-to-surface interaction with friction coefficient μ = 0.45 was applied between steel and concrete.

- Boundary and Loading Conditions:

  Displacement-controlled load applied on the top flange; the bottom of the concrete block was restrained in all directions.

- Parametric Variation:

  Connector height (H) varied as 30, 40, 50, 60, and 70 mm. Other geometric dimensions remained constant to isolate the height effect.

- Mesh and Convergence:

  Eight-node brick elements (C3D8R) were used; mesh refinement near the connector ensured convergence, shown figure 1.

- Validation:

  The base model (H = 50 mm) was validated using experimental data from Kim et al.[30], Shown figure 2.

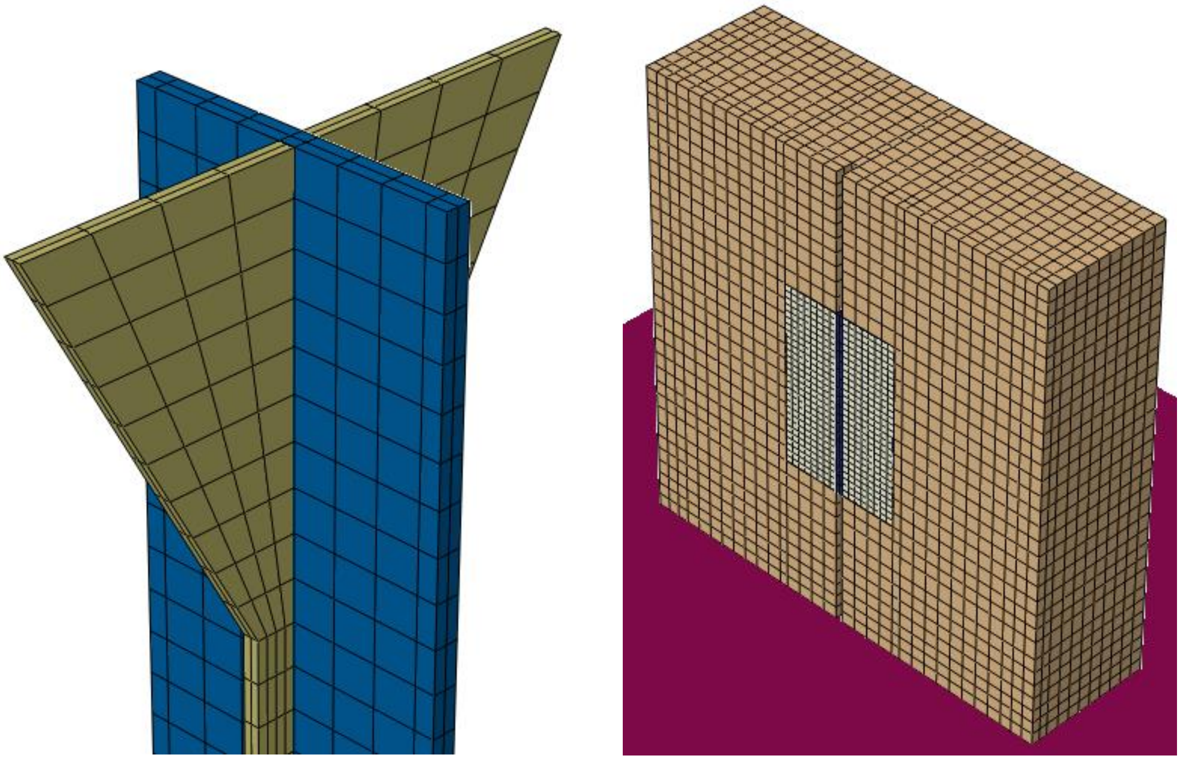

Figure 1. FE mesh and boundary conditions of the Y-shaped connector model

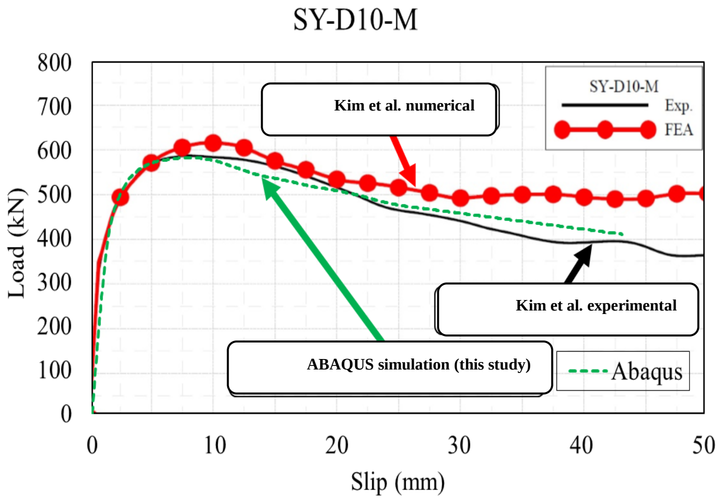

Figure 2. Comparison between FE and experimental load–slip curves for model validation[30]

3.1 Model Development

A detailed three-dimensional FE model was constructed using ABAQUS 6.14 (figure 1 & 3).

The concrete block and steel I-beam flange were modeled as solid parts, while the Y-shaped connector was modeled with varying height.

Connector heights of 30, 40, 50, 60, and 70 mm were examined, with constant width (30 mm) and rebar diameter (12 mm).

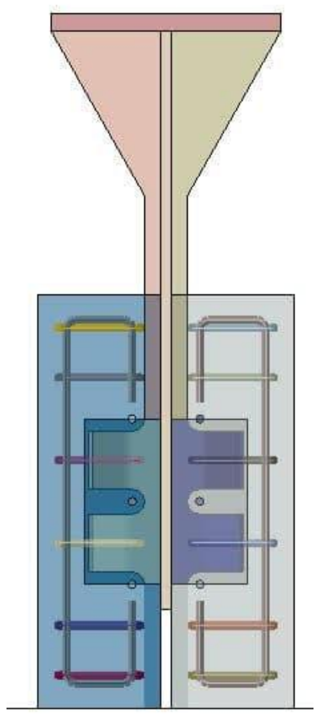

Figure 3. Finite element mesh configuration of the Y-shaped connector in ABAQUS

3.2 Material Properties

Concrete was modeled using the Concrete Damage Plasticity (CDP) model with f'c = 30 MPa.

Steel and rebar were modeled as elastic–plastic materials with E = 200 GPa and fy = 400 MPa.

The Poisson's ratio was 0.2 for concrete and 0.3 for steel.

Concrete

Steel

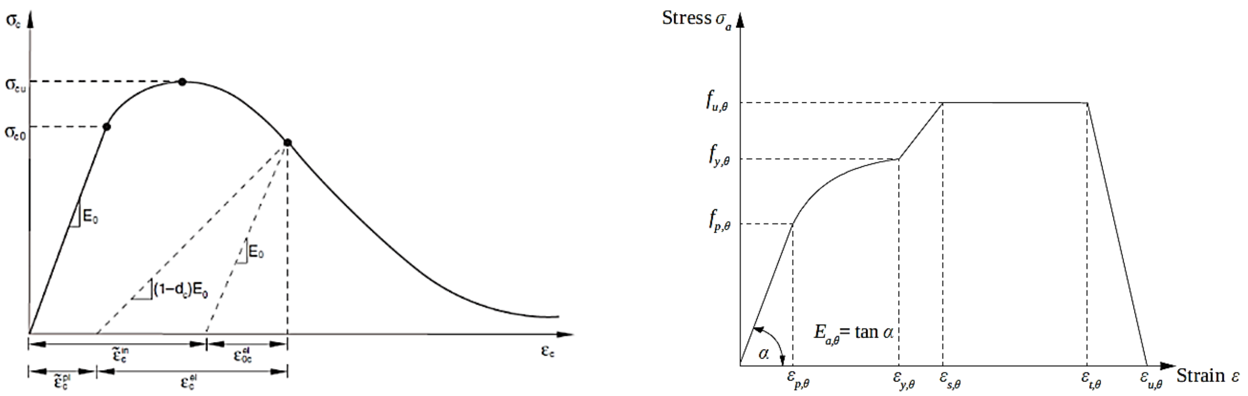

Figure 4. Stress–strain models used for concrete and steel.

3.3 Contact and Boundary Conditions

Surface-to-surface contact was assigned between the steel connector and concrete surface with friction coefficient μ = 0.45.

Displacement-controlled loading was applied on the steel flange, while the bottom surface of the concrete block was fixed.

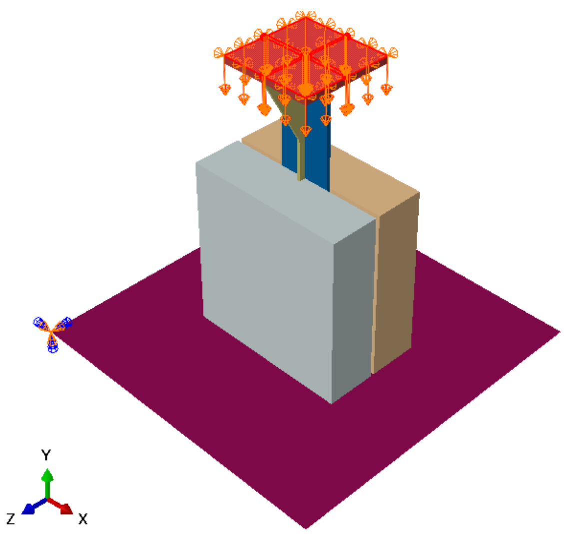

Figure 5. Boundary conditions and contact interaction in FE push-out test setup

3.4 Mesh Convergence and Validation

Mesh refinement studies were performed using element sizes between 5–15 mm. The results showed less than 2% variation in shear strength beyond 10 mm element size.

The model was validated using experimental data by Kim et al. [30], showing less than 5% deviation in load–slip behavior.

4. Results and Discussion

The results of the finite element (FE) analyses are presented and discussed in this section to evaluate the influence of connector height on the mechanical performance of Y-shaped shear connectors.
The analyses were carried out under ambient temperature (25 °C), and the obtained load–slip curves, performance indices, and stress distribution contours were used to interpret the structural behavior.

Connector height is one of the key geometric parameters governing the shear capacity and ductility of composite connections.
The results are therefore organized into four subsections: (1) the general load–slip behavior, (2) variations of normalized strength, stiffness, and ductility with connector height, (3) stress and damage distribution in concrete and steel components, and (4) the determination of optimal connector height for balanced performance.
Each subsection includes both graphical results and discussion of the observed mechanical trends, supported by comparisons with relevant experimental findings from the literature.

4.1. Load–Slip Behavior

Figure 6 shows the load–slip curves for different connector heights (30–70 mm).

The shear capacity increased significantly with height up to 50 mm, indicating stronger interlock and dowel action.

Beyond 60 mm, the slope of the curve (stiffness) improved marginally, while ductility decreased due to higher tension zones near the connector base.

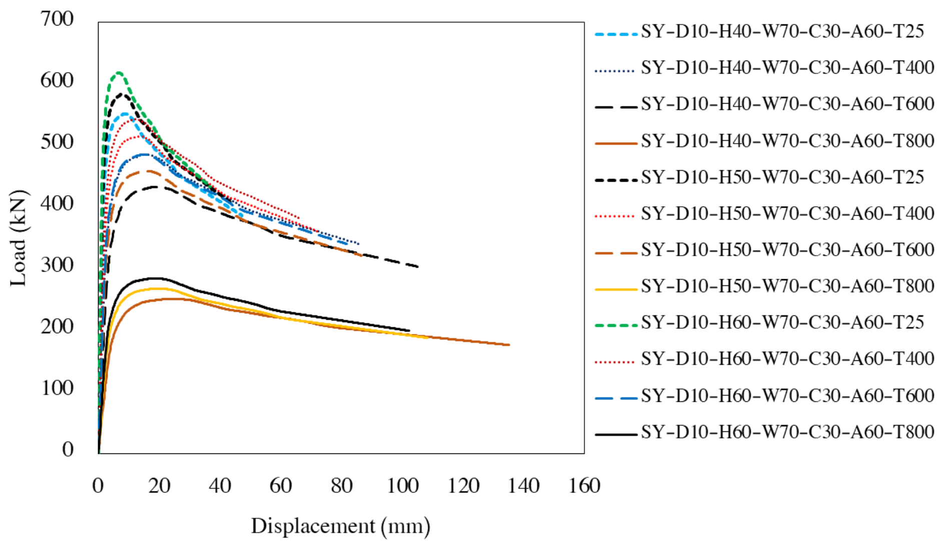

Figure 6. Effect of connector height on load–slip behavior of Y-shaped shear connectors

4.2 Performance Indices

Table 1 summarizes the FE results in terms of ultimate load (Fmax), secant stiffness (Ksec), and ductility (μ). Normalized parameters were also evaluated relative to the 30 mm specimen. Normalized shear strength and stiffness increased nonlinearly with connector height, whereas ductility decreased by approximately

25% when the height doubled from 30 to 70 mm. This trend highlights the trade-off

between stiffness and deformation capacity typical of steel–concrete composite interfaces.

Figure 7 illustrates the effect of connector height on the normalized mechanical performance indices of Y-shaped shear connectors, including ultimate shear strength (F/F_0), secant stiffness (K/K_0), and ductility index (μ/μ_0). Three connector configurations with heights of H = 40 mm, 60 mm, and 70 mm were analyzed under identical material and loading conditions. The results indicate that increasing connector height substantially enhances both the normalized shear strength and stiffness up to H = 60 mm.

This improvement is attributed to the enlarged embedded area and greater dowel action, which facilitate more effective force transfer between the steel and concrete components. However, when the height increases beyond 60 mm (i.e., H = 70 mm), the gain in strength and stiffness becomes marginal, while ductility decreases slightly. This reduction in ductility occurs due to higher stress concentrations and localized cracking near the connector base, which limit energy dissipation capacity.

From a design perspective, a connector height of approximately H = 60 mm offers an optimal balance between high shear strength, adequate stiffness, and acceptable ductility. This finding aligns with the general behavior observed in previous experimental studies on shear connectors under static and elevated temperature conditions (e.g., Kim et al. [30] Su et al. [31].

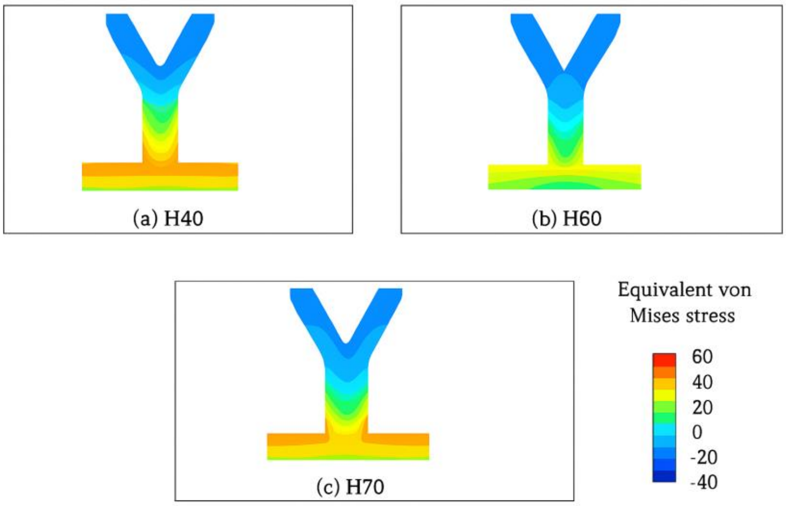

Figure 7. Variation of normalized strength, stiffness, and ductility with connector height

Table 1: Performance indices for different connector heights.

Height (mm)	Fmax	Ksec (KN/mm)	μ
30	110	27	1.60
40	128	32	1.48
50	138	37	1.42
60	141	39	1.30
70	142	40	1.22

4.3 Failure Mechanisms

- Short connectors (30–40 mm) → tensile cracking at mid-height + slip concentration
- Optimal height (50 mm) → balanced dowel action + concrete confinement
- Excessive height (60–70 mm) → high stress at connector root → reduced ductility

4.4 Comparison with Literature

- The degradation of ductility observed here agrees with Kim et al. (2013)[2].

4.5 Stress Distribution and Crack Patterns

Contour plots from the FE model reveal distinct damage patterns.

Shorter connectors (30 mm) exhibited concentrated stresses at the steel–concrete interface, causing early slip and debonding.

Taller connectors (70 mm) showed tensile cracking in the upper concrete region and partial crushing near the base.

Figure 8 & 9 shows the tensile and compressive damage contours in the concrete block for the Y-shaped connector under ambient temperature (25 °C).
In Figure 8, compressive damage is concentrated near the weld root and decreases along the height of the connector, demonstrating the primary load-transfer mechanism through the concrete dowel zone.
As shown in Figure 9, tensile damage initiates at the interface between the connector leg and surrounding concrete, indicating the onset of micro-cracking.
The results confirm that higher connector height leads to a wider stress distribution area and lower localized compression, which improves overall shear resistance.

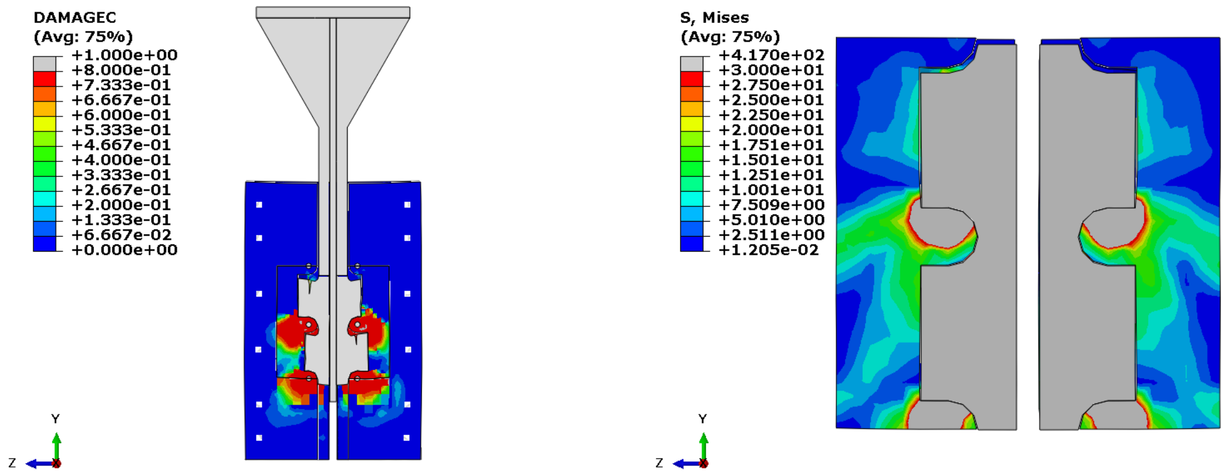

Figure 8.Contour of compressive damage distribution (crushing distribution) and compressive stress concentration at 800 for concrete block

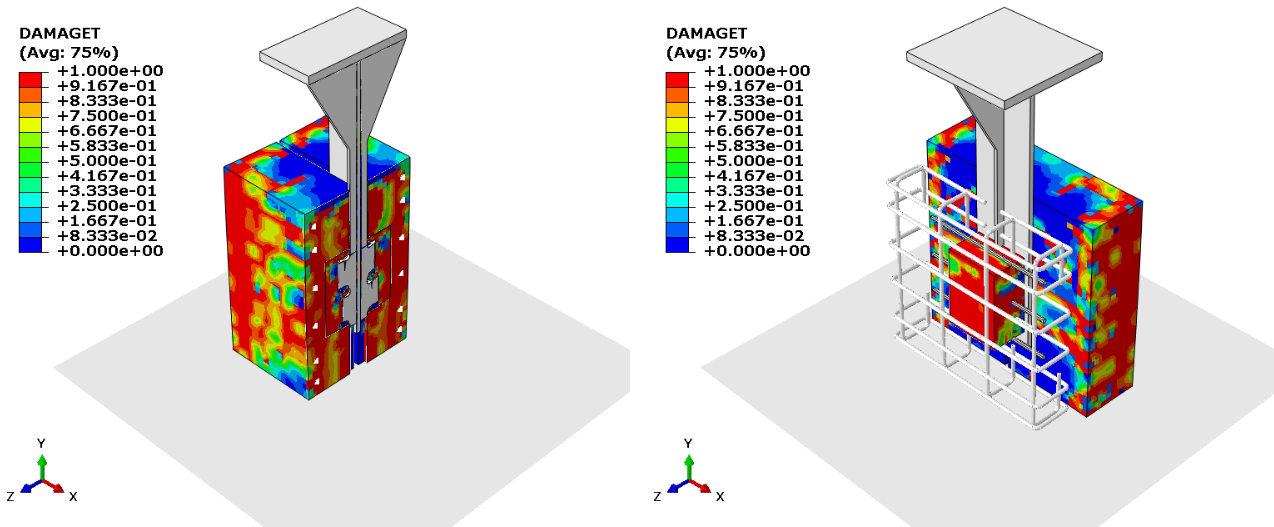

Figure9. Tensile damage distribution contour (tensile crack distribution) at 800 for concrete block

Figure 10 illustrates the compressive damage contour and stress concentration in the concrete block at 400°C.

At this elevated temperature, concrete experiences a significant reduction in its compressive strength approximately 40–50% lower than its room-temperature value.

The contour clearly shows the concentration of compressive stresses near the connector root, where localized crushing initiates.

The red zones in the contour represent regions of severe crushing and degradation of concrete around the interface with the Y-shaped connector.

While the central region of the concrete block remains less stressed, the areas adjacent to the connector base carry the highest compressive loads.

As temperature increases, stress distribution becomes more diffused, indicating a transition from localized stress transfer to a broader, less efficient load-carrying mechanism.

These results demonstrate that at 400°C, concrete still retains partial load-bearing capacity; however, the onset of crushing near the connector base signifies the beginning of permanent damage in the critical zone. This behavior explains the noticeable decrease in shear stiffness observed in the load–slip curves.

Figure 11 presents the tensile damage contour, representing the crack distribution within the concrete block at 400°C.

In the ABAQUS Concrete Damage Plasticity (CDP) model, tensile damage directly corresponds to crack initiation and propagation zones.

The contour indicates that cracking begins around the Y-shaped connector and gradually propagates upward through the concrete block.

Red regions highlight areas with high tensile strain and significant cracking, primarily concentrated near the steel–concrete interface where bond degradation occurs.

As the temperature increases, the concrete's tensile capacity decreases, and the interface slip between the connector and concrete becomes more pronounced, leading to a reduction in shear stiffness and ductility.

These results confirm that at 400°C, microcracks evolve into continuous cracks along the connector interface, reducing the integrity and bonding efficiency between the steel and concrete components.

Such degradation explains the reduction in shear capacity and the softening response observed in the mechanical performance indices.

Figures 10 and 11 collectively demonstrate the degradation pattern of concrete under elevated temperatures.
While compressive damage primarily concentrates at the connector base due to localized crushing, tensile damage initiates at the steel–concrete interface and propagates upward, indicating progressive loss of bonding and ductility.
These thermal-induced damage patterns are consistent with the observed reductions in shear capacity, stiffness, and ductility obtained from the load–slip response curves.

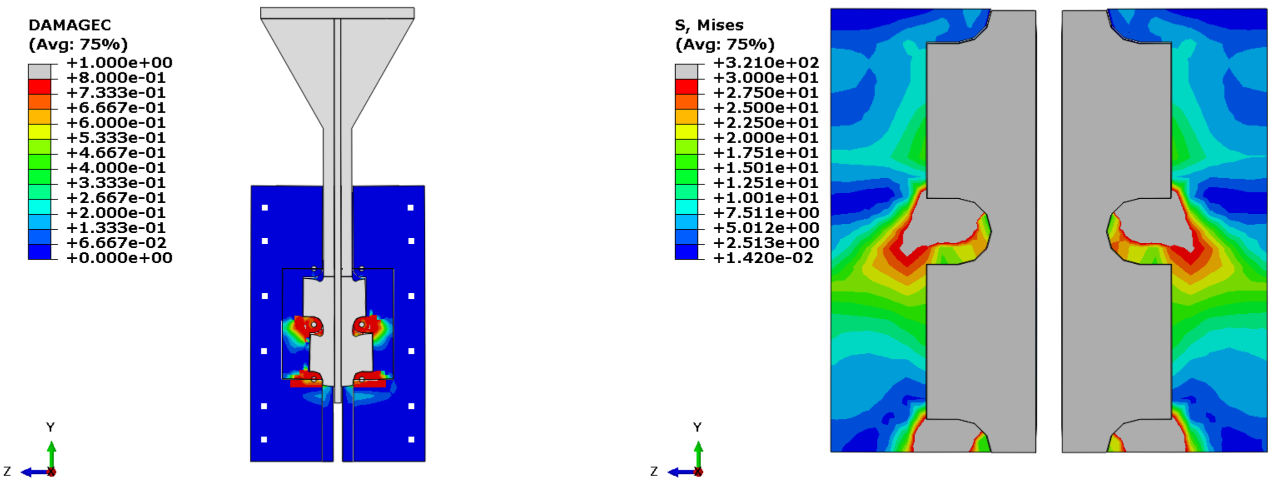

Figure 10 . Contour of compressive damage distribution (crushing distribution) and compressive stress concentration at 400 for concrete block

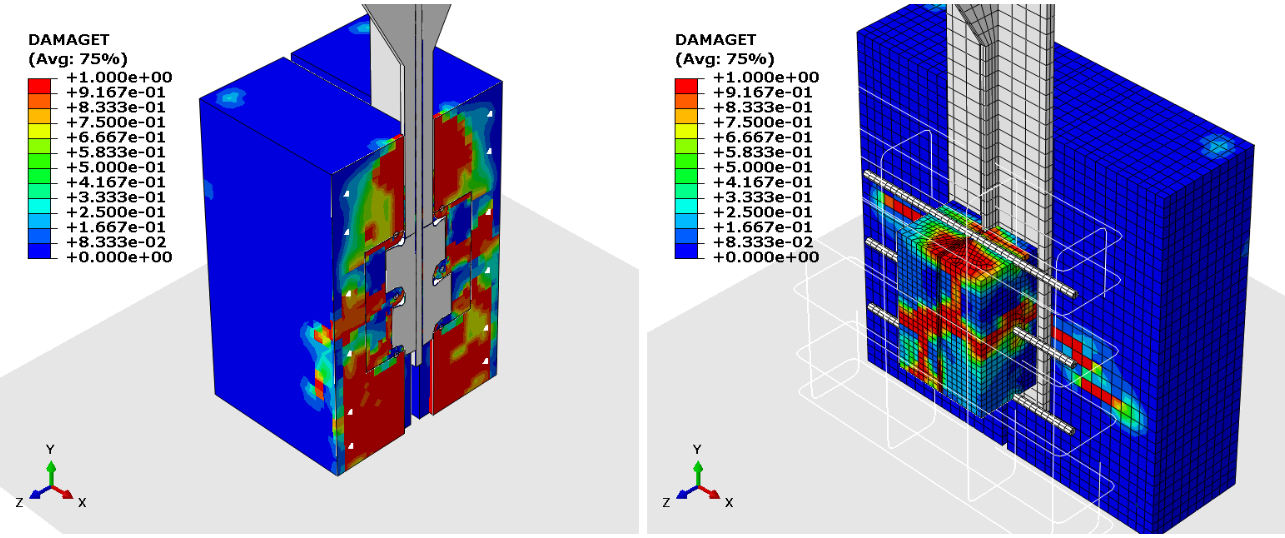

Figure 11 . Tensile damage distribution contour (tensile crack distribution) at 400 for concrete block

4.4. Optimum Connector Height

Based on numerical results, an optimum height range of 50–55 mm provides balanced performance high shear capacity with sufficient ductility.

The results are consistent with experimental findings by Kim et al. [30] confirming the reliability of the proposed FE model.

5. Conclusions

Increasing connector height improves shear strength and stiffness up to 50 mm.

Beyond 60 mm, ductility decreases markedly due to concrete cracking at the connector base.

Stress contours confirm that taller connectors induce higher tensile stresses above the Y-arms.

The optimal range of 50–55 mm ensures structural efficiency and safe deformation capacity.

The validated FE model can effectively predict the mechanical behavior of Y-shaped connectors under shear.

As a result:

1. Increasing connector height from 30 to 50 mm increases shear capacity by ~25% and stiffness by ~38%.
2. Heights above 50 mm yield only marginal improvements (<5%).
3. Ductility decreases progressively with height due to increased stress concentration.
4. Optimal design range: H = 40–50 mm for balanced strength–ductility performance.
5. FE model validated with <5% error; suitable for future geometric optimization.

Future work suggestions:

- Cyclic and fatigue analysis
- Elevated temperature effects
- Composite beams with high-strength concrete
- Fire-resistant detailing optimization

6. Novelty of This Study

- First high-fidelity 3D FE parametric analysis of connector height in Y-shaped connectors.
- Establishes quantitative correlations among height, strength, stiffness, and ductility.
- Provides practical design guidance for optimal connector geometry.
- Extends validated numerical models for structural design applications.

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