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Comparative Study of Computational Modeling Techniques for the Truss Type Shear Connector

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Abstract. Studies on composite structural systems demonstrate that such solutions offer feasibility both from structural and economic perspectives when compared to conventional structures. Shear connectors are mechanical devices responsible for transferring shear forces at the steel-concrete interface, ensuring the effective behavior of composite steel-concrete structures. Truss type connectors (TC) are an alternative to traditional models such as the Stud Bolt, providing structural efficiency, reduced cost, and faster execution. The mechanical behavior of these devices is assessed through push-out tests, as standardized by Eurocode 4, serving as a basis for validating numerical models developed over the years. In this context, computational modeling contributes to the advancement of Structural Engineering by enabling a more practical and efficient analysis of various loads, materials, and construction techniques. However, the computational cost of simulations may be high, especially when considering all contact interactions between modeled parts and the nonlinear behavior of materials. This research aims to compare two modeling techniques applied to the isosceles truss shear connector, with numerical models developed using three-dimensional and wire elements. Based on the analysis of load-slip curves and stress distributions in steel and concrete, it was concluded that the wire element model, like the three-dimensional element model, satisfactorily simulates the behavior of the TC, with the benefit of a computational cost approximately 40 times lower than the three-dimensional model.

Keywords: composite steel-concrete structures, numerical modeling, nonlinear analysis, truss shear connector.

1 Introduction

The dynamic nature of the modern world requires Civil Engineering to develop and enhance increasingly efficient construction solutions. In this context, research on composite structural elements highlights their economic and structural benefits when compared to conventional structures, i.e., those composed of a single type of material. Composite structures are structural systems that combine the advantages of different materials—typically steel and concrete—allowing these materials to be used more efficiently compared to steel-only or reinforced concrete structures. As a result of this combination, a more stable, stiffer system is achieved, with faster construction due to the reduced need for formwork and shoring compared to cast-in-place reinforced concrete structures.

To ensure the proper performance of the composite structure, steel and concrete must deform together, ensuring the transfer of forces between the materials. The transfer of shear forces at the steel-concrete interface is achieved through mechanical devices known as shear connectors. Currently, Stud Bolt connectors are the most commonly used shear connectors in composite structure designs, especially in projects located far from urban centers. However, this model presents limitations in terms of manufacturing, installation, and structural

behavior, which may complicate or even hinder the execution of composite structures.

To propose an economically and structurally viable alternative, Barbosa [1] developed the isosceles truss-type and straight truss-type shear connectors, manufactured with CA-50 steel bars. These models demonstrated greater load capacity than the Stud Bolt and ductile behavior, motivating further numerical and experimental research. Furthermore, according to Rocha [2], it was found that the truss type connector has a unit cost 46% lower than that of the Stud Bolt, reinforcing its economic advantage. This cost difference had a direct impact on the total cost of the structure's connectors, resulting in a 51% reduction in the final cost.

Among the researchers, Lima [3] numerically investigated the influence of geometric and physical parameters on the load-bearing capacity of the isosceles truss type connector applied to composite beams, leading to the development of an equation for calculating the connector's strength. Additionally, Lima et al. [4] conducted experimental studies on composite beams with the isosceles truss type connector, confirming its efficiency and applicability in structural design.

In the field of numerical analysis, advances in computational tools have enabled the study of complex structural elements with greater practicality and efficiency, accelerating the development of Structural Engineering. Various modeling techniques can be used to represent the engineering problem computationally. Each technique offers different levels of accuracy and computational demand, making it essential to evaluate the cost-benefit ratio of each approach.

Thus, this study aims to compare two computational modeling techniques—using three-dimensional elements and beam-type (one-dimensional) elements—applied to the isosceles truss-type shear connector to identify which offers better computational performance without compromising the reliability of the results. For this purpose, numerical simulations of the push-out test were performed using the ABAQUS software (2014), based on the Finite Element Method.

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2 Development of the numerical tridimensional model

To numerically simulate the push-out tests of the isosceles truss-type (IT) shear connectors conducted by Barbosa [1], the ABAQUS software was used, modeling the components separately: steel profile, IT connectors, slab reinforcements, and concrete slab. This separation allowed each part to receive an independent mesh, improving accuracy, computational efficiency, and physical representation of the system, as noted by Lima [3].

For the 3D model, the mesh elements used were C3D8R (8-node hexahedral three-dimensional element with reduced integration), C3D4 (4-node tetrahedral three-dimensional element), and TRD2 (2-node truss three-dimensional element). The C3D8R element, ideal for regular regions, was used in the slab (areas away from the connector), the connectors (inclined and horizontal bars and top pin), and the steel profile. The C3D4 element, suitable for complex geometries, was applied in the slab (regions near the connector) and the curved areas of the connectors, increasing computational cost. The TRD2 truss element, with two nodes and three degrees of freedom per node, was used in the reinforcements.

Regarding constraints and contact interactions, the "tie" constraint was used to connect the horizontal bars of the connector to the flange of the steel profile and at the connector-concrete interface. For the interaction between the steel profile flange and the slab, the following properties were considered: frictionless tangential behavior and hard normal behavior to prevent penetration between surfaces.

Boundary conditions were applied according to the surfaces shown in Fig. 1. Surface 1 had all nodes restricted in the X direction, surface 2 in the Y direction, and surface 3 in the Z direction. The load, also shown in Fig. 1, was applied uniformly on the profile's cross-section (load-controlled). The analysis used the Explicit Dynamic Method, which can be employed in quasi-static analyses when inertial effects are controlled through slow load application. This method is efficient for complex models and appropriate for simulating push-out tests (Lima [3]). For material modeling, the Concrete Damage Plasticity model was used for concrete and the Plastic model for steel, both available in the ABAQUS libraries.

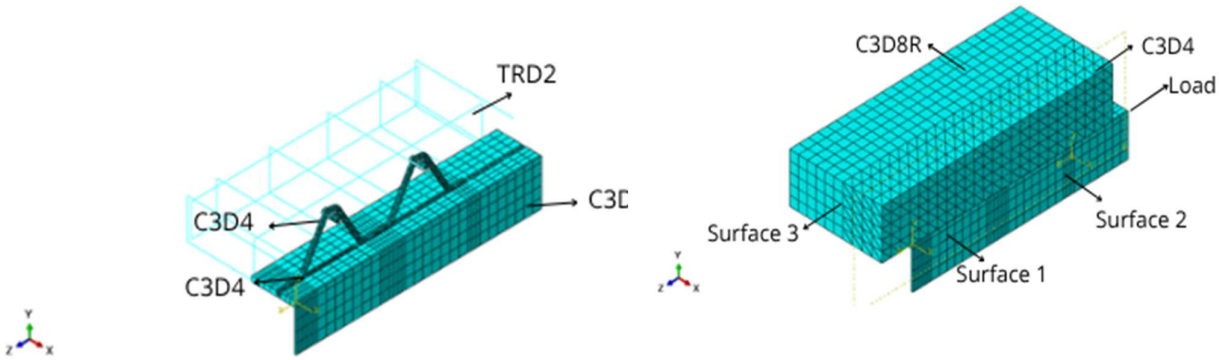


Figure 1: Malhas, superfícies de contato e carga do M3D

3 Development of the numerical wire model

The beam model (BM), developed by Moura [5] and implemented via ABAQUS, was based on the connector tested by Barbosa [1] and the 3D model proposed by Lima [3], as presented in Section 2. From the 3D model, the centerline of the connector geometry was extracted, preserving the opening angle and radius of the original model. The discretization of the connectors was carried out using B31 finite elements—3D beam elements with three degrees of freedom per node. This approach reduces the number of nodes and elements used in the analysis. The components of the model are the same as those presented for the 3D model and were also modeled separately to maintain mesh independence and ensure greater accuracy and computational efficiency. To further simplify the numerical modeling, the BM disregards the 16 mm pin at the curvature and the horizontal bars welded to the profile.

Regarding contact interactions, the embedded region property was used for both the connectors and reinforcements to embed these elements into the slab. This type of interaction simplifies the model, resulting in reduced computational cost. The weld was simulated using the tie property, connecting the connectors to the steel profile. For the interaction between the profile and the slab, frictionless tangential behavior and hard normal behavior were applied, as in the 3D model.

The boundary conditions, load application method, processing method, and constitutive models used in the beam modeling are the same as those adopted in the three-dimensional modeling and described previously, and are represented in Fig. 2.

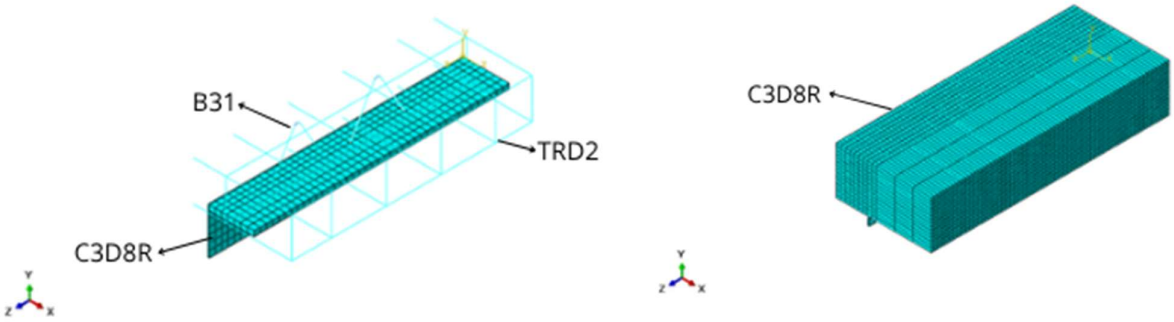


Figure 2: Malhas, superfícies de contato e carga do MB

4 Models validation

The validation of both models was conducted based on the experimental data from Barbosa [1] for the 12.5 mm connector. For this purpose, the analysis considered the load-slip curves and the deformed configuration of the connectors, which involves the tensioning of one of the connector's bars and the crushing of concrete in regions near the connector bases. Fig. 3 presents the load-slip curve comparing Barbosa's [1] experimental model with the numerical models—M3D for the 3D model and BM for the beam model. It is observed that both numerical models exhibit satisfactory validation compared to the experimental results. Among the numerical models, the BM more accurately reproduced the experimental curve. Figures 4 and 5 present the deformed configuration of the connectors for the M3D and wire models, respectively.

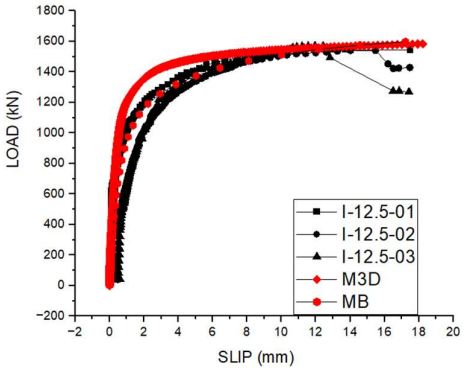


Figure 3: Validation of the three-dimensional numerical model (M3D) and the beam model (BM)

Table 1. Average load capacity

Model	Load Capacity (Kn)
Experimental	1458,4
M3D	1583,51
MB	1598,51

Both the M3D and BM models showed good agreement with the experimental data. The curves and the average load capacity indicate that the numerical models were able to satisfactorily reproduce the behavior observed in the push-out tests, including parameters such as initial stiffness, nonlinear behavior, and load capacity, without compromising result accuracy. The deformed configurations shown in Fig. 4 and Fig. 5 demonstrate good agreement between the M3D and BM, both consistent with the experimental results obtained by Barbosa [1].

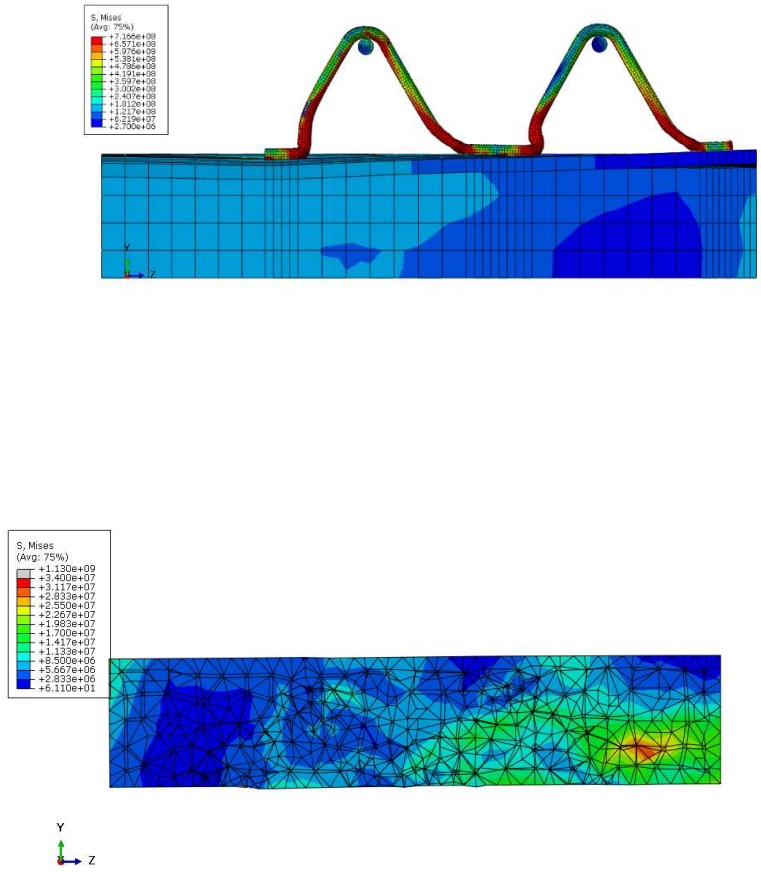
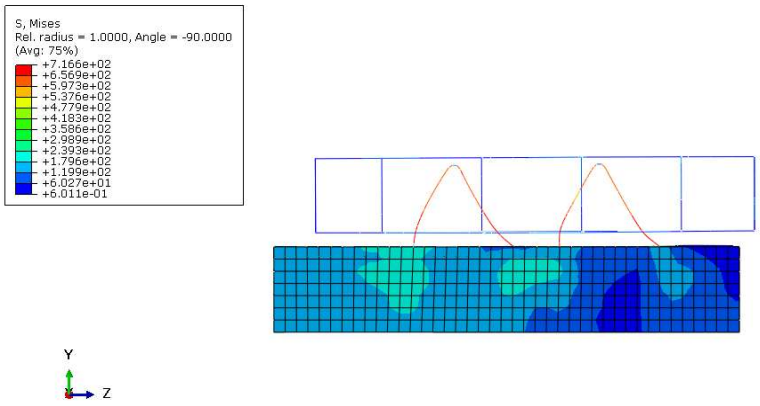


Figure 4: Deformed configuration in the M3D model for connectors, profile and slab, respectively.



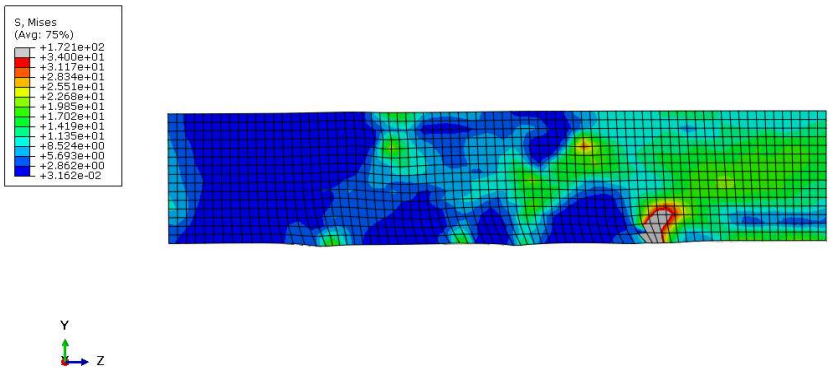


Figura 5:Deformed configuration in the MB model for connectors, profile and slab, respectively.

5 Comparison of Computational Cost Between the Three-Dimensional and Beam Models

The development of the BM aims to simplify the modeling of the isosceles truss-type shear connector and, consequently, to reduce the computational cost of the numerical simulations reproducing the push-out test for this connector. The processing time of the models is a critical parameter for the feasibility of numerical studies involving multiple contact interactions, nonlinear material behavior, and complex geometries. The computational cost can be evaluated based on the time required to complete the simulation process. Table 2 presents the specifications of the machine used to run both models, and Table 3 shows the average processing time per simulation. The processing time of the BM was approximately 98.92% faster than that of the M3D, confirming that the simplifications made in modeling the connectors directly influenced the processing time and, consequently, the embedded computational cost.

Table 2. Computacional configuration

Processor	AMD Ryzen 5 4600H with Radeon Graphics
Clock Speed	3 GHZ
RAM	8GB

Table 3: Computational Cost

M3D	01:21:50
MB	00:00: 53

6 Conclusions

This study aimed to compare the computational cost of two numerical modeling approaches—one using three-dimensional elements and the other using wire-type elements—in the context of numerically simulating the behavior of isosceles truss-type shear connectors in push-out tests.

The numerical results expressed in terms of load-slip curves and the deformed configuration of the connectors indicated satisfactory agreement between the experimental data and both simulated models, validating the approach adopted in this study.

In terms of computational cost, the BM model showed a significant reduction in processing time compared to the M3D. This computational economy did not compromise the quality of the results.Thus, modeling with wire-type elements is a viable and efficient alternative for simulations involving isosceles truss-type connectors, especially when multiple analyses or parametric studies are required.

As a suggestion for future work, the model developed in this study can be adapted and applied to the analysis of other types of shear connectors, contributing to the advancement of research in the field of composite structures. Moreover, its application in different structural contexts may enhance the understanding of the behavior of such elements and help optimize construction solutions.

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