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RESEARCH ARTICLE

NUMERICAL INVESTIGATION OF THE DYNAMIC BEHAVIOR OF 2D STEEL STRUCTURES WITH CFST COLUMNS IN SEISMIC ZONES

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ABSTRACT

Concrete-filled Hollow Rectangular Section Columns (RHS-CFST) are widely used in steel structures in seismic zones due to their ductility, energy dissipation, and load-bearing capacity. This study investigates the seismic response of structures with I-beam to RHS-CFST column connections in compliance with the Algerian seismic code, RPA 99/2003. The dynamic response of a 9-story steel structure is analyzed, examining the impact of CFST columns, building height, and connection types. Results indicate that CFST columns exhibit symmetrical behavior under seismic loading, which effectively reduces base shear forces and minimizes inter-story drift. Despite their semi-rigid nature, these columns demonstrate high energy dissipation, significant ductility, and a broad hysteresis loop, ensuring structural resilience and safety. As the Algerian code currently lacks specific provisions for this structural type, this study provides critical insights to advance seismic performance parameters for steel structures that incorporate CFST columns.

I. INTRODUCTION

In seismic zones, enhancing the performance of steel structures is often achieved through the use of concrete-filled hollow rectangular section (RHS) columns (CFST), which provide high strength, ductility, and energy dissipation capabilities. Extensive research has investigated the behavior of these CFST systems, especially in connection with semi-rigid or rigid joints that influence seismic performance. Early studies by. [1],[2]. According to [3] focused on cyclic performance and hysteretic behavior in blind bolted end-plate connections to CFST columns, demonstrating notable seismic resilience in composite frames. Further experimental studies [4],[5] examined CFST column connections in moment-resisting frames, where performance metrics such as strength, ductility, and energy dissipation were highlighted, solidifying their applicability in earthquake-resistant designs.

Recent work has continued to expand on these findings, exploring new materials and joint designs to improve seismic response in composite steel structures. As an example, according to [6], investigated the axial compressive strength of CFST columns and observed a remarkable 50% improvement when the columns were reinforced with five layers of fiber-reinforced polymer (FRP). The influence of column height, connection type, and structural rigidity on seismic behavior has also been extensively examined in CFST frameworks [7], with findings emphasizing the critical role of joint semi-rigidity in dynamic response. Advances in modeling techniques, as demonstrated in numerical and pseudo-dynamic studies [8], further validate the CFST's effectiveness in reducing base shear and limiting inter-story drifts in multi-story steel buildings.

The present study seeks to contribute to this body of work by evaluating the inelastic dynamic responses of steel structures with both rigid and semi-rigid CFST column connections in high seismicity areas. Using SeismoStruct 2016 [9], simulations will assess the performance of CFST columns compared to open-section columns, with reference to the Algerian [10-12], seismic standards. Given the absence of CFST-specific provisions within the Algerian code, this research aims to establish foundational parameters for CFST-based design in Algeria and other high seismicity zones, enhancing safety and reliability in steel structural systems.

II. PRESENTATION OF THE INVESTIGATED STRUCTURES

This study examines a nine-story, two-dimensional (2D) steel frame designed as an office building, utilizing various column types for a comparative structural analysis (Figure 1). The building's dead load (G) is $18.84\, kN/m$, while the live load (Q) stands at $4.39\, kN/m$. Detailed specifications for all structural components—beams, columns, and connections—are provided in Table 1.

Each component within the portal frames is designed according to three structural codes: Eurocode 3 (EC3) [13], Eurocode 4 [14], and Algeria's seismic code [10],. For material properties, S235 grade steel is employed for the beams, while S355 grade steel is used for both steel and composite columns. In composite columns, C20/25 grade concrete is used. Structural modeling and analysis were conducted using SeismoStruct software [9], with the non-linear inelastic properties of each structural element—columns and beams—modeled using a force-based frame element approach ('infirmFB'). The model includes non-linear material properties and geometric effects, with fixed nodes assumed for rigid connections. A Response spectrum analysis was performed for the structural design, incorporating response spectrum data for high-seismic regions and load combinations specified in Algeria's [10],[11].

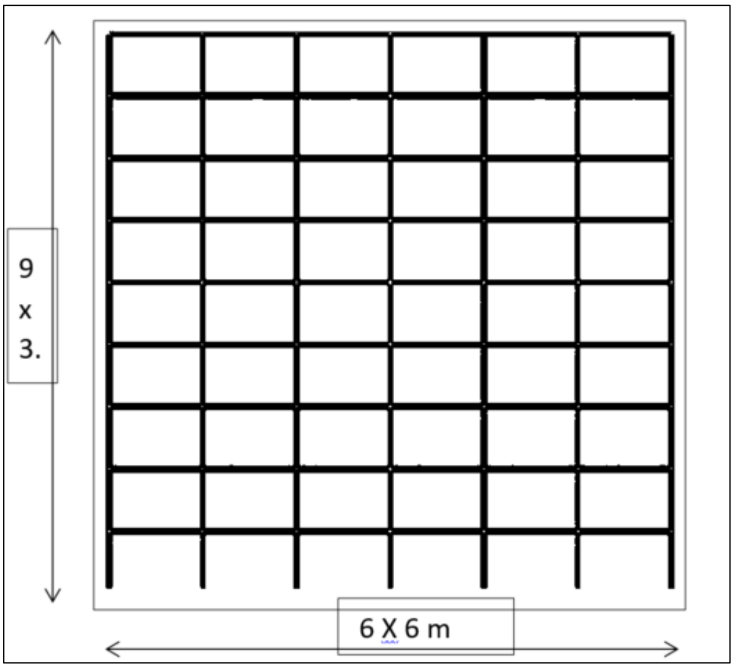

Figure 1: 2D frame configuration.
Source: Authors, (2025).

Table1: Cross-sections of structural elements.

Frame		Beam section	Column section
9FRJ and 9FSRJ*	Story 9	IPE 300	HEB 200
	Story 8		
	Story 7		
	Story 6	IPE 330	HEB 260
	Story 5		
	Story 4		
	Story 3	IPE 360	HEB 300
	Story 2		
	Story 1		
9FRJ-CFST* and 9FSRJ-CFST	Story 9	IPE 300	SHS 300X300X10
	Story 8		
	Story 7		
	Story 6	IPE 330	
	Story 5		
	Story 4		
	Story 3	IPE 360	
	Story 2		
	Story 1		

**FRJ: frame with rigid joints; FSRJ: frame with semi-rigid joints; CFST: frame with concrete filled steel tube.*
Source: Authors, (2025).

Two column configurations are presented (see Figures 2-a and 2-b), both utilizing an extended end plate connection type with plate dimensions of $450x180x30\ mm$ (Figure 2-c). The connection bolts have a diameter of $24\ mm$ and are classified as 8.8-grade. Connection properties, such as initial stiffness and resistance moments, were calculated according to Article 6, Table 6.1, of EC3 [13].

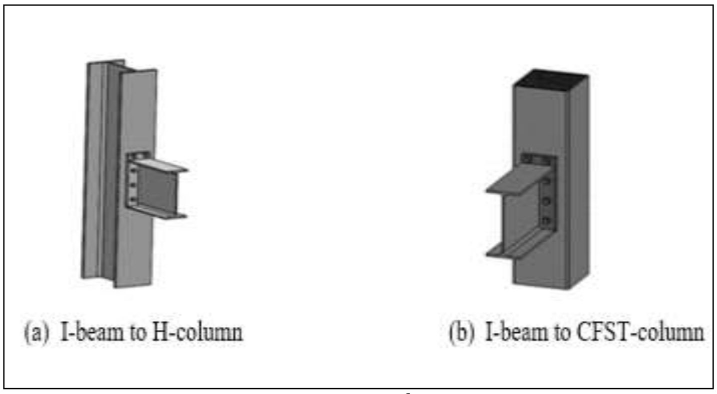

Figure 2: Joint configuration.
Source: Authors, (2025).

The structural integrity and stiffness of the tube face are determined using models by Silva et al. [15], In the global analysis, the semi-rigid connections are modeled with a cyclic bilinear behavior curve, incorporating strain hardening of $r = 0.1$ [16], capturing the realistic behavior of these connections under cyclic loading.

III. NONLINEAR DYNAMIC ANALYSIS

Given the significant influence of CFST (Concrete-Filled Steel Tube) columns on the inelastic dynamic behavior of steel frames, a nonlinear dynamic analysis was conducted using SeismoStruct software [9], For frames with relatively long natural periods, a notable response to seismic excitation, especially with a low a/v ratio (ratio between peak ground acceleration, PGA, and peak ground velocity, PGV), was anticipated.

To simulate seismic loading, an artificial ground motion time history was generated based on the target response spectrum from Algeria's [10], (see Figure 3). The dynamic behavior of the portal frames using CFST columns was evaluated by analyzing key dynamic response parameters, highlighting the influence of these columns on the overall structural performance under seismic conditions.

In addition to the nonlinear dynamic analysis, pushover analysis can be employed to investigate the nonlinear static behavior of these structures [17-19], This method provides valuable insights into the building's capacity, failure mechanisms, and potential plastic hinge formations, offering a complementary perspective on the seismic performance of steel frames with CFST columns.

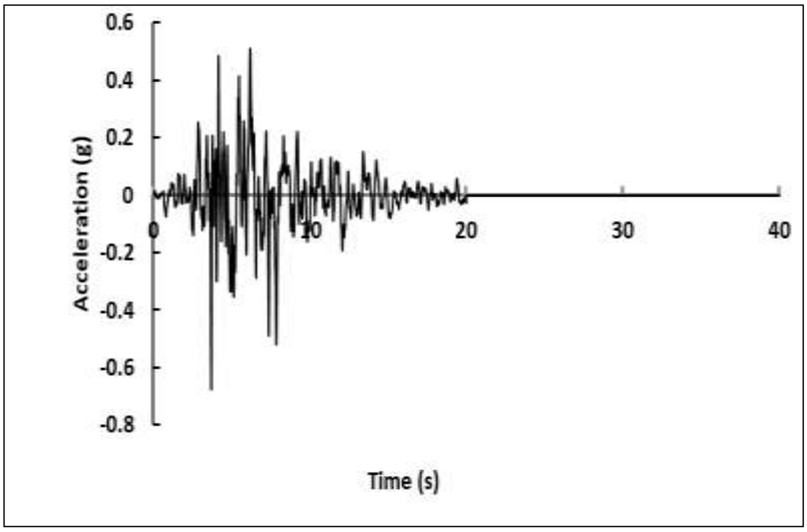

Figure 3**:** Artificial ground motion time history.
Source: Authors, (2025).

IV. RESULTS AND DISCUSSIONS

IV.1. MAXIMUM STORY DISPLACEMENT

Figure 4 depicts the maximum displacements at each story. The rate increases from for the portal frame with CFST columns. In dynamic analysis, this change is explained by the presence of the damping effect caused by both the connection and the structure.

It is worth noting that CFST columns exhibit symmetrical behavior in response to seismic excitation: displacements are nearly identical in both negative and positive directions, in contrast to frames with open sections columns, which exhibit asymmetrical behavior; this is another advantage of using CFST columns in seismic zones.

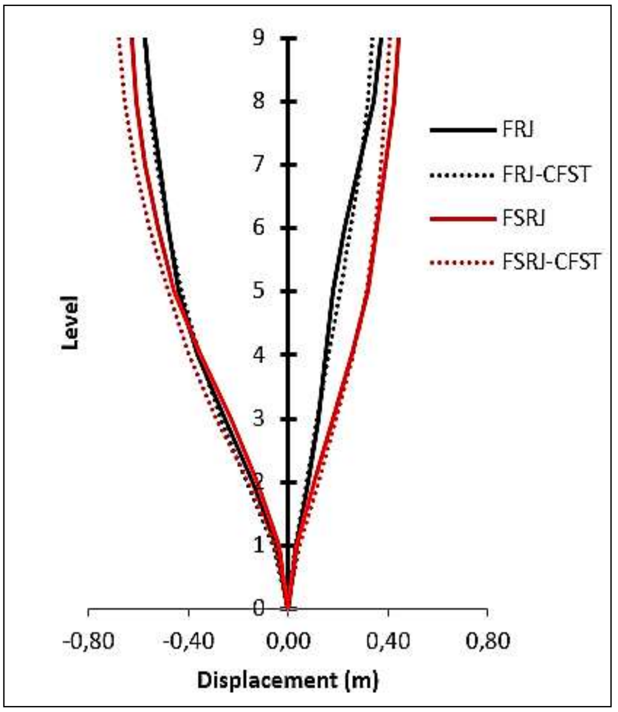

Figure 4: Maximum displacement.
Source: Authors, (2025).

IV.2. INTER-STORY DRIFTS

The inter-story drifts exceed the limits set by [10], in the majority of portal frame scenarios, as illustrated in Figure 5. Conversely, they remain below the thresholds established by FEMA 356 [12].

Furthermore, the increased inter-story drifts can be attributed to the fact that the [10], code does not account for the plasticity of structural elements in its design provisions. Instead, the code primarily relies on force-based design criteria. In contrast, the American FEMA 356 code [12], incorporates plasticity considerations in its approach.

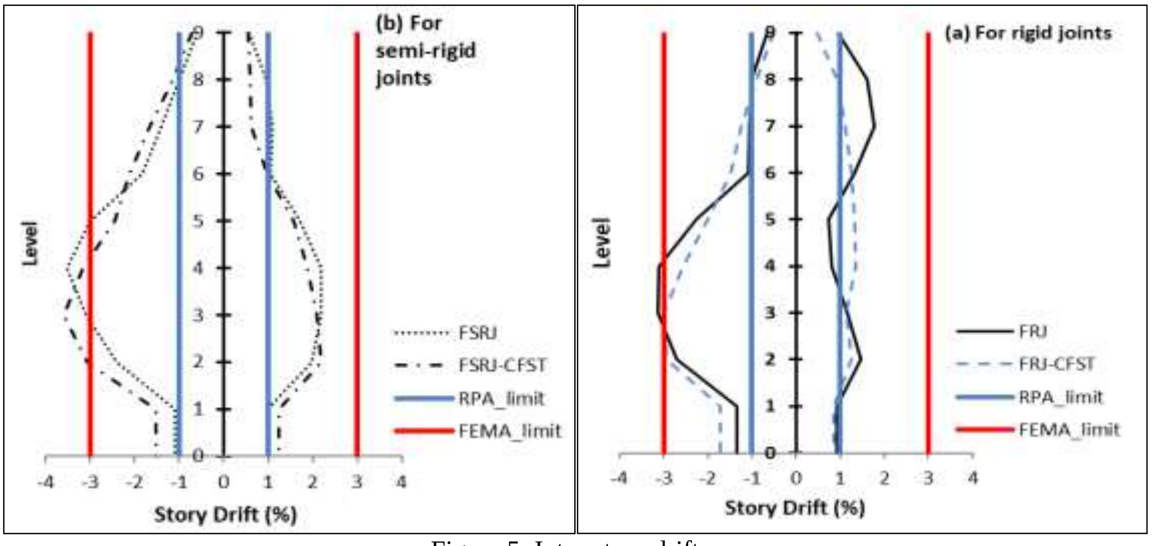

Figure 5: Inter-story drifts.
Source: Authors, (2025).

IV.3. BASE SHEAR FORCES

As demonstrated in Figure 6, the use of CFST columns reduces shear force at the base by 30% for rigid connections and 27% for semi-rigid connections as compared to the FRJ portal frame, reducing the influence of seismic loading in the structure's parts.

Furthermore, semi-rigid connections enhance shear forces at the base, which is connected to structural damping.

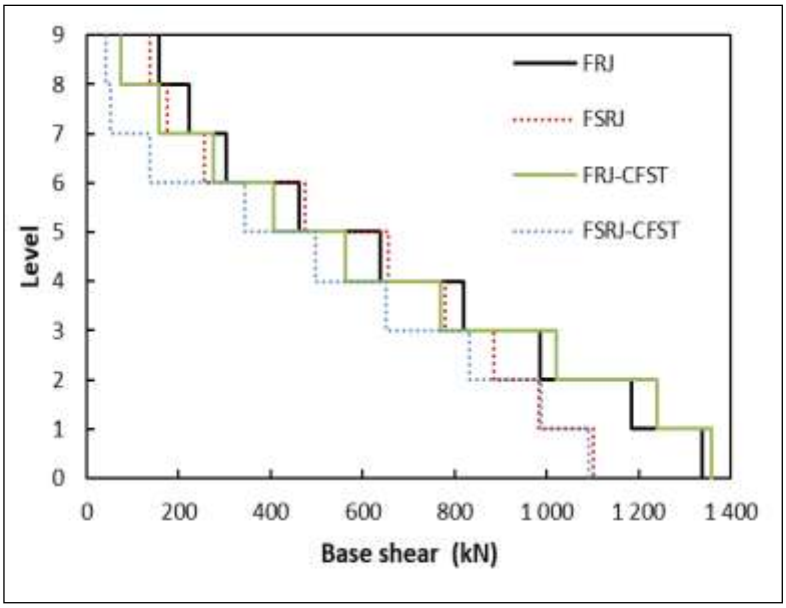

Figure 6: Base shear forces.
Source Authors, (2025).

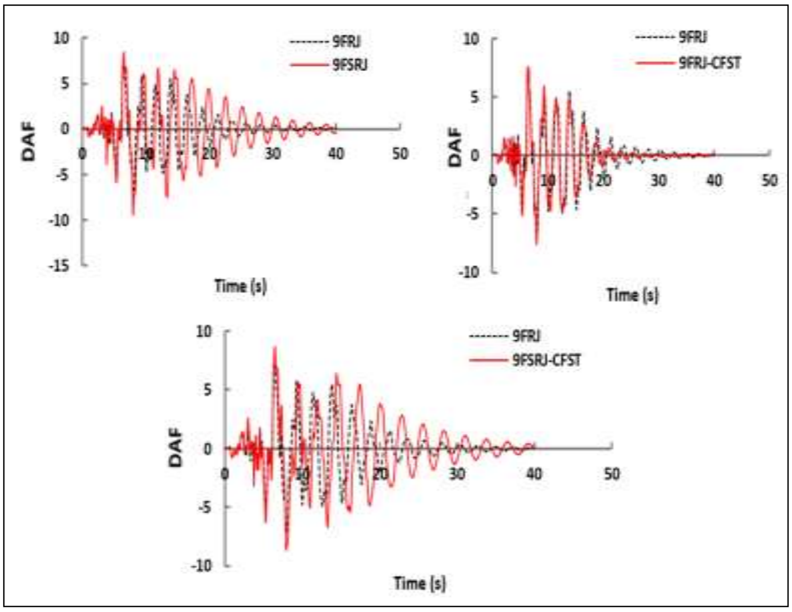

Figure 7: Dynamic amplification factor (DAF).
Source: Authors, (2025).

Figure 7 presents the dynamic amplification factor, which declines by 22% in the FRJ-CFST portal frame and 10% in the FSRJ-CFST portal frame. Compared to the FRJ frame, it increases by 4% in the FSRJ frame, as structures with semi-rigid joints exhibit higher damping than those with rigid joints.

V. CONCLUSIONS

The objective of this research is to emphasize the effect of using CFST columns with semi-rigid connections on the non-linear dynamic response of steel structures. The impact of the structure's height is taken into account by considering a 9-level structure. The primary conclusions of the comparison of these constructions with those with H-shaped columns may be stated as follows:

CFST columns reduce structural stiffness and have a greater maximum displacement than structures with rigid node;

Semi-rigid connections have a substantial impact on inter-story drifts;

The introduction of CFST columns increases the maximum displacement of the frames by 13% to 49%, depending on the type of connection, while also exhibiting symmetrical behavior under seismic excitation. However, they result in an inter-story drift rate of 2.75% in the studied examples. Additionally, portal frames with CFST columns reduce base shear forces by up to 30% and the dynamic amplification factor by up to 22%, owing to their significant damping properties.

The use of tubular columns filled with concrete CFST has convincingly demonstrated its impact on the seismic response of steel constructions. Other paths must be investigated to emphasize optimization studies in the evaluation of the performance of this sort of structure with the various examples of connections and structure design.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Dif Fodil.
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Investigation: Abderahman Younsi.
Discussion of results: Dif Fodil. Said Hicham Boukhalkhal.
Writing – Original Draft: Dif Fodil.
Writing – Review and Editing: Dif Fodil. Abdallah Yacine Rahmani.
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Supervision: Dif Fodil.
Approval of the final text: Dif Fodil. Said Hicham Boukhalkhal.

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