Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 8, S. 510-516, 2, 2024

Araştırma Makalesi

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 8, pp. 510-516, 2, 2024

Research Article

IJANSER

https://as-proceeding.com/index.php/ijanser
ISSN: 2980-0811

The Influence of Semi-Rigid Joints on the Seismic and cyclic Response on the structural steel

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(Received: 12 March 2024, Accepted: 13 March 2024)

(4th International Conference on Innovative Academic Studies ICIAS 2024, March 12-13, 2024)

ATIF/REFERENCE: Chafaı, H., Ihaddoudene, A. N. T. & Wafa, M. (2024). The Influence of Semi-Rigid Joints on the Seismic and cyclic Response on the structural steel. *International Journal of Advanced Natural Sciences and Engineering Researches, 8(2), 510-516.*

Abstract **–** Structural connections in steel structure are traditionally designed on the assumption that the beam to column joint is either fully rigid or pinned. Numerous experimental, analytical, and numerical studies have shown that their behavior is between these two extreme cases: it's semi-rigid. The consideration of their real behavior "semi-rigid joints" had an important impact on the overall behavior of steel structures. In this study, a nonlinear numerical analysis was carried out on the steel structure under cyclic and seismic loading. The joints were taken with rigid and semi-rigid behavior. The investigation focuses on a four stories plane steel structure using the seismostruct software. The Richard-Abbott model is employed to predict the nonlinear behavior of the semi-rigid joints. The consideration of semi-rigid joint connections in seismic area has a very great impact on the behavior of structures and a good efficiency in terms of energy dissipation for structures located in seismic zones.

Keywords – Semi-Rigid Joints, Structural Steel, Cyclic Loading, Seismic Behavior, Numerical Analysis.

I. INTRODUCTION

Numerous seismic design studies have been conducted with the aim of understanding the behavior of structures in seismic area. Structural steel is generally considered a viable solution to mitigate the impact of these natural disasters, given their excellent material ductility. However, they are costly and susceptible to the phenomenon of section yielding and plasticity. Consequently, engineers are moving towards more rigorous designs and the stiffening of nodes, calculating them as rigid joints using their total resistances. Current research has shown that using the partially resistance of joints provides large flexibility and ductility to the structure.

Steel structures were traditionally designed assuming that beam-column connections were either perfectly pinned or rigid: rigid joints do not allow any rotation whereas the pinned joints do not transfer any bending moment. The behavior of the joint's connections can be incorporated into the structural analysis using the moment-rotation (M-φ) curve. Several models can be employed to determine the mechanical behavior of connections, achieved by the development of the mechanical properties of the connection. The most widely adopted model is the mechanical model, based on the component method, as endorsed by Eurocode 3 [1].

Currently, there are numerous studies on steel structures with semi-rigid connections: Braham and Jaspart [2], Ashraf et al. [3], [4], Ihaddoudène et al. [5], Darío et al [6], Faella et al. [7]. Static and dynamic nonlinear analysis of a structure has been the focus of multiple works by YANG et al. [8], Razavi and Abolmaali [9], Da Silva et al [10], Mathe A et al. [11], Al-Bermani et al. [12], Masoodi, A. R., and Moghaddam, S. H. [13].

Recently S.F. Fathizadeh et Al were Studie the seismic performance of a structure with semi-rigid joints using a curved plate dumper [16], , Abed Rigi et Al were study the seismic behavior of several variants of multi-story structure using a various value of linear rigidity of connection [17], Shengcan Lu were study the Seismic Performance Analysis of Semi-rigid Spatial Steel Frames[18].

Among various mathematical models such as the polynomial model, bounding-line model, and Ramberg-Osgood model. the Richard-Abbott model [14], implemented by Nogueiro [15], is used to predict the nonlinear behavior of four-story steel structure under seismic and cyclic loading using a particularity and specificity of semi-rigid joints.

In this Studie a four stories steel frame with a fixed support is used to predict the effect of semi rigid joints in the behavior of structure in seismic area. The joints are assumed to be rigid and semi rigid with a nonlinear behavior to describe and understand the real behavior of the structure. The beam and the column were connected between us by joint, which is represented by a nonlinear rotational spring with zero length. The steel behavior is assumed with a nonlinear hardening material. The buckling of the column is note considered.

II. STATE OF STUDIES

A fixed base steel structure with two spans of six (06) meter by spam and four (04) stories with 3.5m by story was modeled using a seismostruct software. All the beams and the columns were in IPE 360 and HEA400 respectively (figure1). The material used is an S235 steel grad assumed to exhibit non-linear hardening behavior (figure 2). The structure is subjected to the permanent distributed load on the beam with an intensity of 50kN/ml.

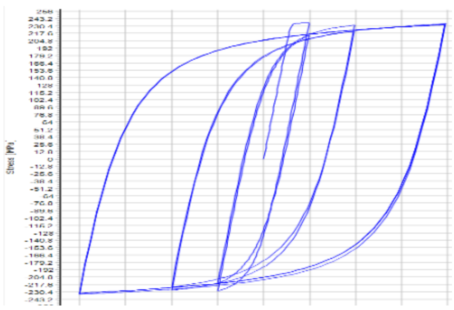


Fig 1: Stress-strain behavior curve of steel structure

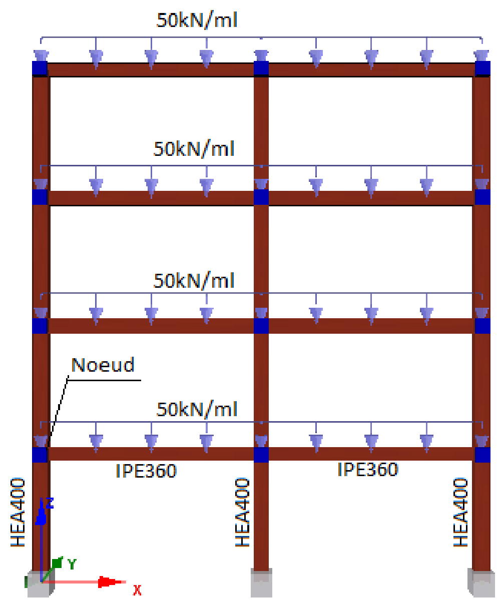


Fig 2: Stress-strain behavior of steel structure

The connection of beam-column joint is modeled by a non-linear rotational spring. Assumed to be either rigid or semi-rigid.

The Richard-Abbott model is employed to simulate the behavior of the connections, hence the mechanical properties implemented by Nogueiro [15] are used to predict the behavior of this connections. The figure 3, 4 and 5 shown the behavior of joints under cyclic loading.

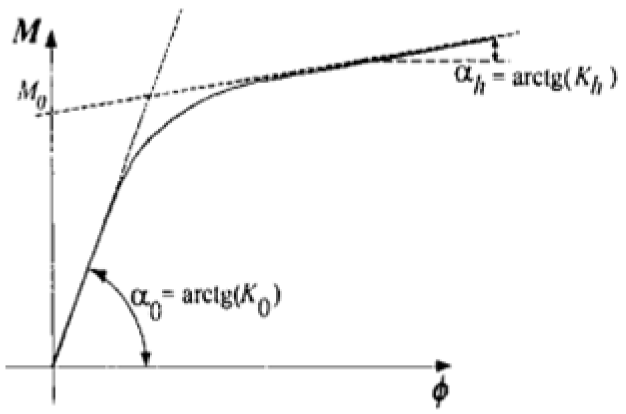


Fig 3: moment rotation behavior of semi rigid joint (M-φ).

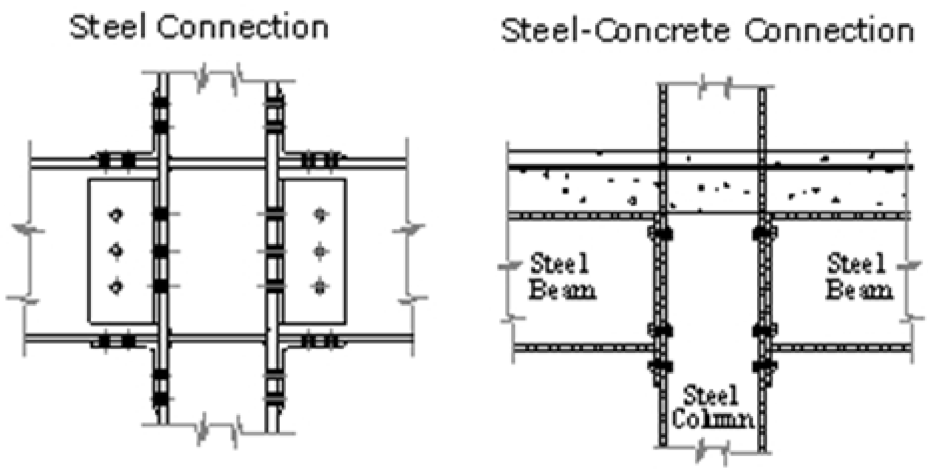
Richard-Abbott model

This curve is given by the equation (1)

$$M = \frac{(k - k_p)|\varphi_c|}{\left[1 + \left|\frac{(k - k_p)|\varphi_c|}{M_0}\right|^n\right]^{1/n}} + k_p|\varphi_c| \tag{1}$$

in which k is the initial stiffness, k_p is the strain-hardening stiffness, M_0 is a reference moment and **n** is a parameter defining the sharpness of the curve.

Two types of semi rigid joints are used "SR02" and "SR01" which describe the behavior of connection with and without the concrete slab contribution respectively.



(a) SR01 (b) SR02

Fig 4: conception of the semi-rigid joints (a) and (b)

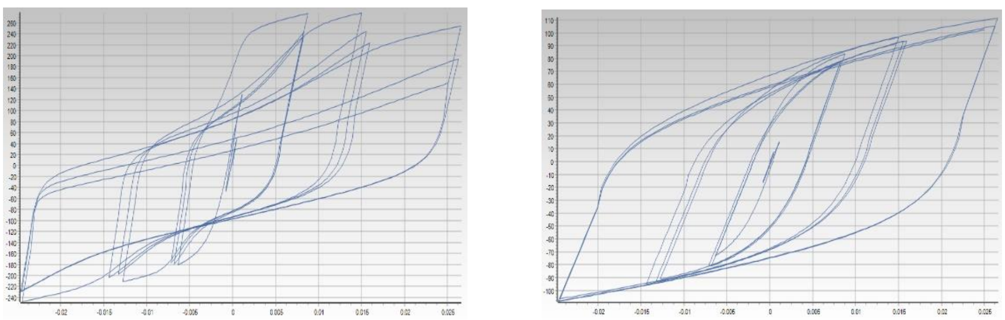


Fig5: Hysteresis behavior (M-φ) of Richard-Abbott model for SR01 and SR02.

The connection of SR01 is made by the top and seat angel connection without concrete contribution and the connection of SR02 is made by the flush and plate connections with the concrete contribution. Whose the mechanical characteristics are given in the Table 1, aiming to predict the real behavior of joints.

Table 1: Mechanical characteristics of semi-rigid nodes according to Nogueiro

SR1	K_a	M_a	K_{pa}	n_a	K_{ap}	M_{ap}	K_{pap}	n_{ap}	t_{1a}	t_{2a}	C_a	i_{Ka}	i_{Ma}	H_a	$E_{max\,a}$
	42697	230	1280	2	42697	115	1280	1	15	0.15	1	20	0.01	0.02	0.1
	K_d	M_d	K_{pd}	n_d	K_{dp}	M_{dp}	K_{pdp}	n_{dp}	t_{1d}	t_{2d}	C_d	i_{Kd}	i_{Md}	H_d	E_{maxd}
	45118	200	1250	2	45118	100	1250	1	20	0.15	1	10	0.01	0	0.1
SR2	K_a	M_a	K_{pa}	n_a	K_{ap}	M_{ap}	K_{pap}	n_{ap}	t_{1a}	t_{2a}	C_a	i_{Ka}	i_{Ma}	H_a	$E_{max\,a}$
	16500	85	825	2	16500	40	825	1	6	0.15	1	3	0.01	0.04	0.1
	K_d	M_d	K_{pd}	n_d	K_{dp}	M_{dp}	K_{pdp}	n_{dp}	t_{1d}	t_{2d}	C_d	i_{Kd}	i_{Md}	H_d	E_{maxd}
	18830	80	940	2	18830	60	940	1	5	0.15	1	1	0.01	0.02	0.1

These parameters are defined by Nogueiro [15]. in total, 30 parameters have to be defined for this model, fifteen for the ascending branches (subscript a) and fifteen for the descending branches (subscript d): K_a (and K_d) is the initial stiffness. M_a (and M_d) is the strength, K_{pa} (and K_{pd}) is the post limit stiffness, n_a (and n_d) is the shape parameter, all these for the upper bound curve (see figure 3), Kap (and K_{dp}) is the initial stiffness. M_{ap} (and M_{dp}) is the strength, K_{pap} (and K_{pdp}) is the post limit stiffness, n_{ap} (and n_{dp}) is the shape parameter, all these for the lower bound curve, t_{1a} and t_{2a} (and t_{1d} and t_{2d}) are the two parameters related to the pinching, C_a (and C_d) is the calibration parameter related to the pinching, normally equal to 1, i_{Ka} (and i_{Kd}) is the calibration coefficient related to the stiffness damage rate, I_{Ma} (and i_{Md}) is the calibration coefficient related to the strength damage rate, H_a (and H_d) is the calibration coefficient that defines the level of isotropic hardening and E_{maxa} (and E_{maxd}) is the maximum value of deformation.

The first cases of Studie are to subject the structure for the the seismic acceleration of the Boumerdès earthquake in May 2003 in Algeria ((Peak Ground Acceleration PGA=0,394m/s²) were given by figure 6.

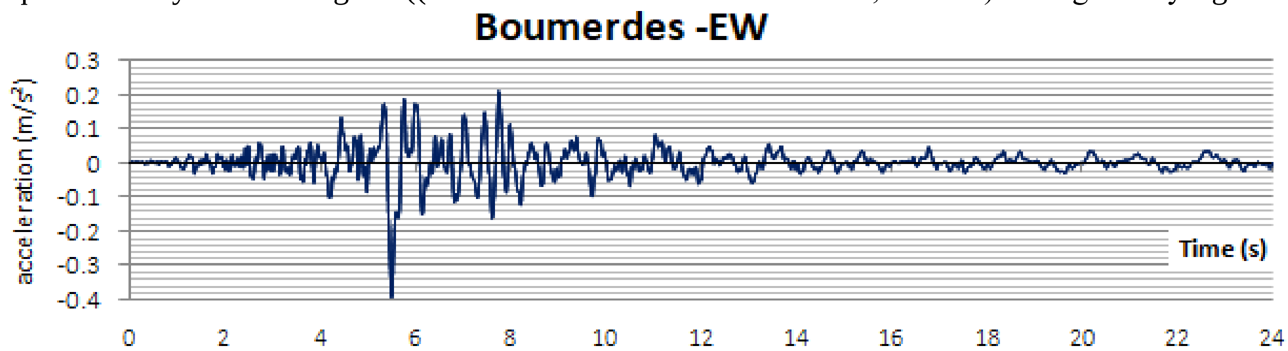


Fig 6: Recording of the Boumerdès earthquake in the EW direction with a PGA= 0.394 m/s².

The second case is to subject the structure at a cyclical loading at the top of the 4th story to describe his cyclical behavior and evaluate the energy dissipation. The load curve is given by the figure 7

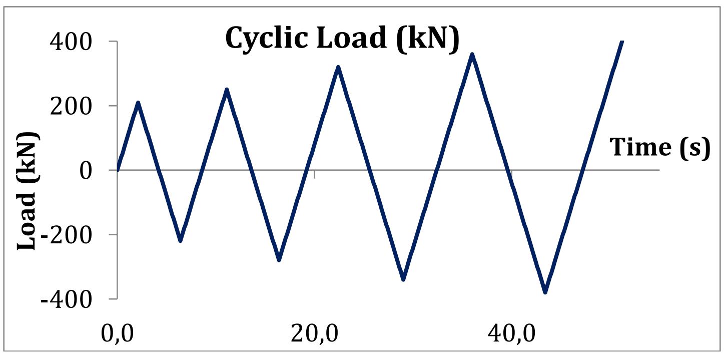


Fig 7: Cyclic loading

III. DISCUSSION OF RESULTS:

In the first cases for the seismic load: Compare the displacements values given in table 2 and (Fig 8.) we see clearly that the consideration of the aspect of semi-rigid nodes in the overall analysis of structures provides significant flexibility and ductility. This allows for a plastic adaptation of structures, as well as when we compare base shear forces of seismic response, we see there are a good dissipation of seismic energy (Fig 9.).

Table 2: Maximum displacement for each story (cm)

Levels	Displacement (cm)		
	Rigid	SR-01	SR-02
Base	0	0	0
Story1	2,3	2,7	2,1
Story2	5,6	7	6,1
Story3	9,5	11,9	11,7
Story4	12,3	16,4	17,8

According to the figure (9); the energy dissipation involved when we use the semi rigid concept SR01 and SR02 is estimated about 20% and 28% respectively

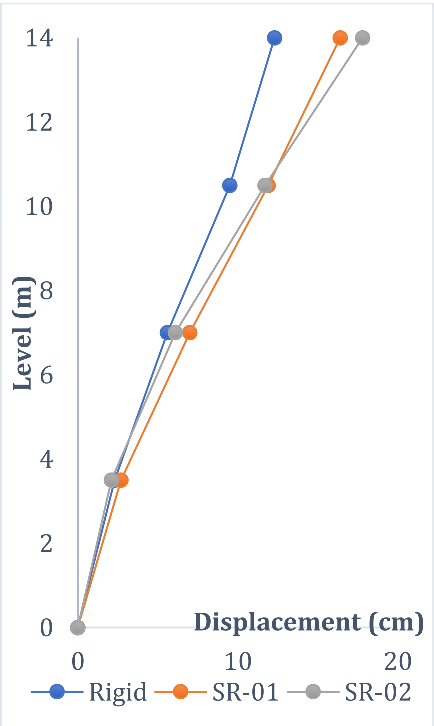


Fig 8. Maximum displacement of etch story

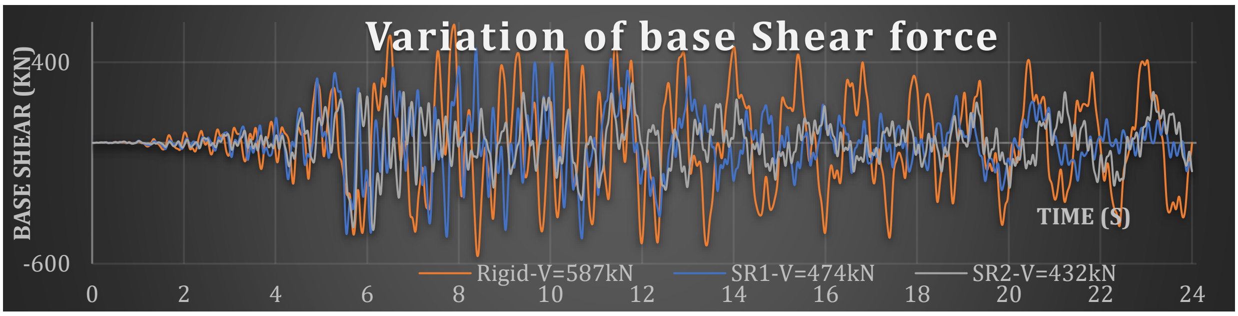


Fig 9: Seismic base Shear force variation

In the second cases the cyclic response of the structure the same observation compared to the first cases when we regarding the fig 10. We see that the top and seat angle connections without concrete slab are more rigid of the flush and plate connection with slab.

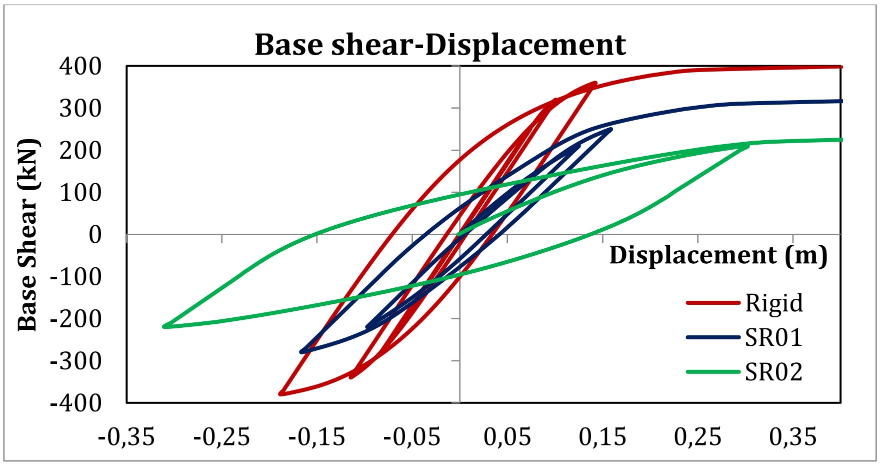


Fig10: The hysteresis loops obtained through cyclic analysis of the structure.

The hysteresis loops illustrated in Figure10, obtained through cyclic analysis of the structure, taking into account the semi-rigid concept of the joints and their cyclic behavior as given by the Richard-Abbott model according to Nogueiro et al. [15], demonstrated perfectly the degradation of shear force at the base as a function of the structure's ductility.

IV. CONCLUSION

Taking into account the semi-rigid joints concept in the overall analysis of structures in seismic zones or under cyclic loading provides ductility, allowing for a plastic adaptation of structures and significant energy dissipation compared to rigid nodes. Analyzing structures while considering semi-rigid joints thus represents a necessary compromise for an economical design solution for structural elements.

The energy dissipation involved when we use the semi rigid concept SR01 and SR02 is estimated about 20% and 28% respectively it’s a significate value of economical aspect.

Considering semi-rigid joints in the modeling of structural steel in seismic area is essential to understand their nonlinear behavior and improve their ability to withstand seismic response.

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