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The Seismic Response of Multi-Storey Semirigid Steel Structures

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Abstract

The present contribution is focused on statical and kinematic components of seismic response of multi-storey steel structures with semi-rigid beam-column connections. The dynamic model of these structures is a system with finite degrees of freedom and concentrated masses at each level. The degrees of freedom are expressed by the lateral level displacements. The semi-rigid behaviour of the beam-column connection is considered cyclic and is asociated to an analytic model with four parameters M-θ_r. *The structure is subjected to seismic action Vrancea 1977. Analysis are the type of time-history. The presented results refers to lateral level displacement and seismic base shear force. The principal aim of this work is comparing the afferent parameters (statical and kinematic).*

Rezumat

Prezenta contribuţie este focalizată asupra componentelor statice şi cinematice ale răspunsului seismic a structurilor metalice multietajate cu conexuni semirigide riglă-stâlp. Modelul dinamic al acestor structuri este un sistem cu numărr finit de grade de libertate şi mase concentrate în dreptul nivelelor. Gradele de libertate sunt deplasările laterale de nivel. Comportarea semirigdă a conexiunilor grindă stâlp este considerată ciclică şi li s-a asociat modelul analitic cu patru parametrii M-θ_r. *Structura este supusă acţiunii seismice Vrancea 1977. Analizele sunt de tip time-history. Rezultatele prezentate se referă la deplasările laterale de nivel şi la forţa tăietoare seisimică de bază. Obiectivul principal al lucării este compararea parametrilor (statici şi cinematici) aferenţi răspunsului seismic al structurilor cu conexiuni semirigide.*

Keywords: Steel structures, seismic response, semirigid connections, analytical models, mechanical models, multi-storey structures.

1. Introduction

These days, taking into consideration the flexibility of beam-column connection is a concept developed by analytic point of view, based on a large set of experimental results and in the same time broadly accepted by the professional community. The state of semirigid connection is definitely determined by the design codes [1], [2] and unquestionable regarding its accuracy of modelling steel multi-storey structures. The base of semirigid behaviour of structure is the

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analytical model of bending moment-relative rotation $M\text{-}\theta_r$. In computational practice of semirigid structures several analytical models were imposed [3], [4], [5], as well mechanical models of beam-column connection [6], [7], [8]. The actual tendencies in analysis of these types of structures focus on three direction: refined modeling of semirigid connection zone [9], analytical modeling of periodic behaviour of semirigid connection [10], [11], [12], study of the absorption capacity of seismically inducing energy in the structure, conferred by pseudo-ductile behaviour of semirigid connections.

This contribution fits in the direction of modeling and periodic behaviour of multi-storey steel structures.
The aim of this work consist in comparative analysis of two components associated to seismic response of semirigid structures: lateral level displacements and respectively seismic base shear force. The lateral level displacement is a classical component of the seismic response and in the same time represents the most used tool of expressing the effects of rigidity.
The increased lateral rigidity implicitly means small lateral displacements.
The seismic base shear force is an expressive component of the rigidity state; a high lateral rigidity condition induces a great base shear force, so do the equivalent static level forces and lateral displacements.

This is how the rigidity state conduces to contrary effects (expressed by seismic response parameters). Emphasising these contrary effects aims this work. The analysed steel structures -plane frames- are dimensioned in accordance with provisions of actual codes [13], so as the ultimate bending capacity of connection ranges between 30% and 95% of bearing capacity of beam bending in plastic domain. The seismic actions are constituted from registered earthquakes and scaled to the peak value of ground acceleration $a_g = 0.2g$. The analytical model of semirigid beam-column connection used in analysis is based on the monotonous model with four parameters [5], (1):

$$M = \frac{k_{co}\theta_c}{\left[\mathbf{1}+\left(\dfrac{\theta_c}{\theta_{co}}\right)^n\right]^{1/n}} \tag{1}$$

The monotonous relation $M\text{-}\theta_r$ is developed and after, in a cyclic model installed in the used informatical product [14]. The global dynamic model of the analized structures is based on the formulation of finite elements method and corresponds to the systems with concentrated masses and finite degree of freedom.
The differential matrix equation associated with dynamic model is:

$$\boldsymbol{M}\cdot\boldsymbol{u}(t)+\boldsymbol{C}\cdot\boldsymbol{u}(t)+\boldsymbol{R}\cdot\boldsymbol{u}(t)=-\boldsymbol{m}\cdot\boldsymbol{u}_g(t) \tag{2}$$

where:

- $\boldsymbol{M}$ is the mass matrix (nxn),
- $\boldsymbol{R}$ is the rigidity matrix of the semirigid structure associated with those n degree of l dynamic freedom,
- $\boldsymbol{C}$ is the damping matrix (nxn),
- $\boldsymbol{m}$ is the vector (nx1) of inertion defined by the relation $\boldsymbol{m}=\boldsymbol{M.I}$ in which $\boldsymbol{I}$ is the unit vector (nx1),
- $\ddot{\boldsymbol{u}}(t), \dot{\boldsymbol{u}}(t), \boldsymbol{u}(t)$ are vectors (nx1) of lateral displacements, velocities and respectively lateral accelerations, in each level, of concentrated masses,
- $\ddot{\boldsymbol{u}}_g(t)$ is the registered accelerogram of applied seismic action.

The damping model is a ‘proportional damping’, in which:

$$\boldsymbol{C} = \alpha \boldsymbol{M} + \beta \boldsymbol{R} \tag{3}$$

It was considered an inherent state of damping coresponding to critical damping fraction of 5%.
The analysis are conduced by the software Seismostruct [14]. The behaviour of structure, inclusively the behaviour of semirigid connection, corresponds to elastic domain.
The obtained results includes specific parameters of dynamical behaviour of the structure (natural periods and frequencies of vibration), static and kinematical parameters which characterise the seismic response.
The dynamic model subjected to analysis is the one from the figure 1.

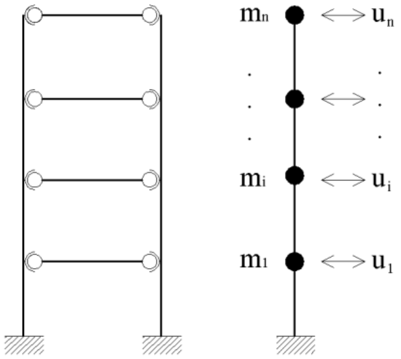


Fig.1. Dynamic model

The results associated with semirigid structures are presented in a comparative way versus the homologue results corresponding to the reference structure with rigid beam-column connection.

2. Structures, semirigid connections and seismic actions

The seismic analysis are conducted on a set of 3 plane frame multi-storey structures, each having 5 bays and 5, 9 and respectively 12 levels. The material used for the structures and semirigid connections is S355 steel. For the structure with 5 levels (Fig.2), the beams are profiles of IPE 400, respectively IPE500.

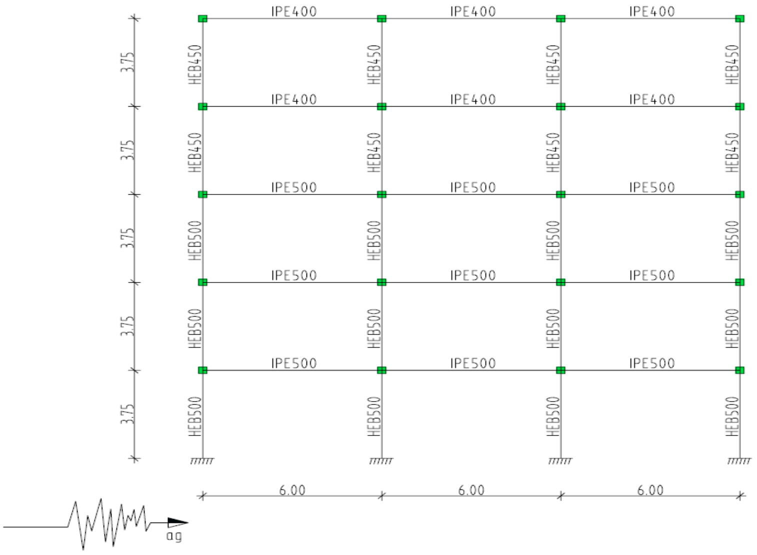


Fig.2. Structure with 5 levels

In this work the semirigid beam-column connection are considered ‘inferior angle+ superior angle+web angle’ type. (Fig.3).

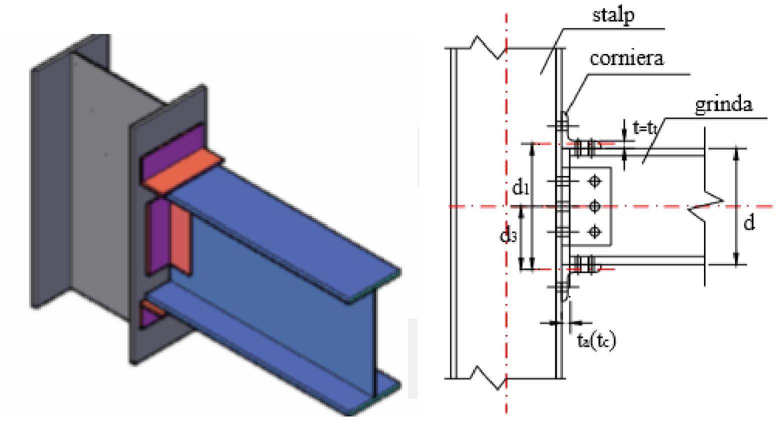


Fig.3. Connection with inferior angle, superior angle and web angle

The semirigid beam-column connections are considered in 6 different initial connection rigidity situations R_i. The analytical model Richard & Abbot associated with monotonous behavior of rigid connections implies the initial rigidity R_i. In the performed analysis, the initial rigidity is considered in 6 situations, referring to, continuously, node SR-1 up to node SR-6. The analytical model parameters Richard & Abbot, for beam, IPE400, associates with mechanical model (Fig.3), are presented in table 1.

Table 1

	Nod SR-1	Nod SR-2	Nod SR-3	Nod SR-4	Nod SR-5	Nod SR-6
R_i (kNm/rad)	40510	80690	121700	163800	208700	243500
M_u (kNm)	142	227	304	351	390	441
n	1,201	1,066	0,994	0,90	0,827	0,827

The treated seismic actions are the earthquakes Vrancea 77 (Fig.4), Northridge 94 and Kobe 95.

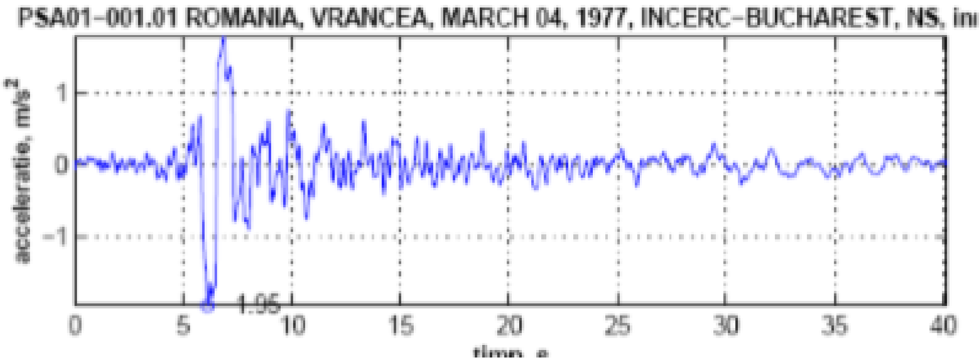


Fig.4. Accelerogram of Vrancea

In table 2 are presented the peak values of ground acceleration and the predominant periods of those 3 seismic actions.

Table 2

	acceleration, a_g (m/s^2)	T, predominant period (s)
Kobe	1,962	0,16
Northridge	1,961	0,26
Vrancea 77	1,95	1,16

3. Numerical results

Further are presented the numerical results obtained for the structure with 5 levels (Fig.2) actioned by the earthquake Vrancea 1977 (Fig.4). In the Figure 5 are given the structure's dynamic characteristics in those 6 situations of initial rigidity of semirigid connections, as in the case of reference structure (rigid connection).

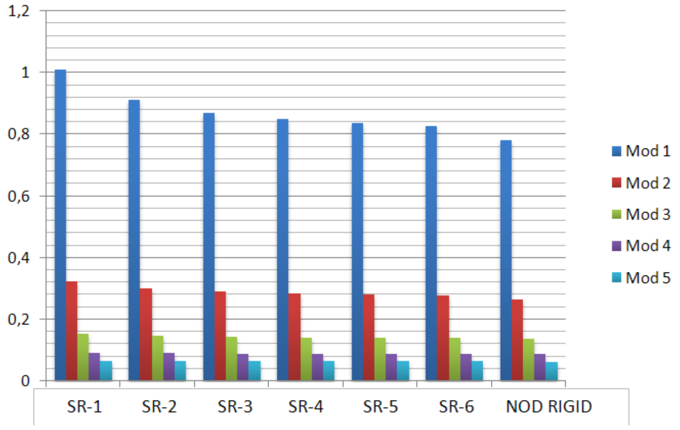
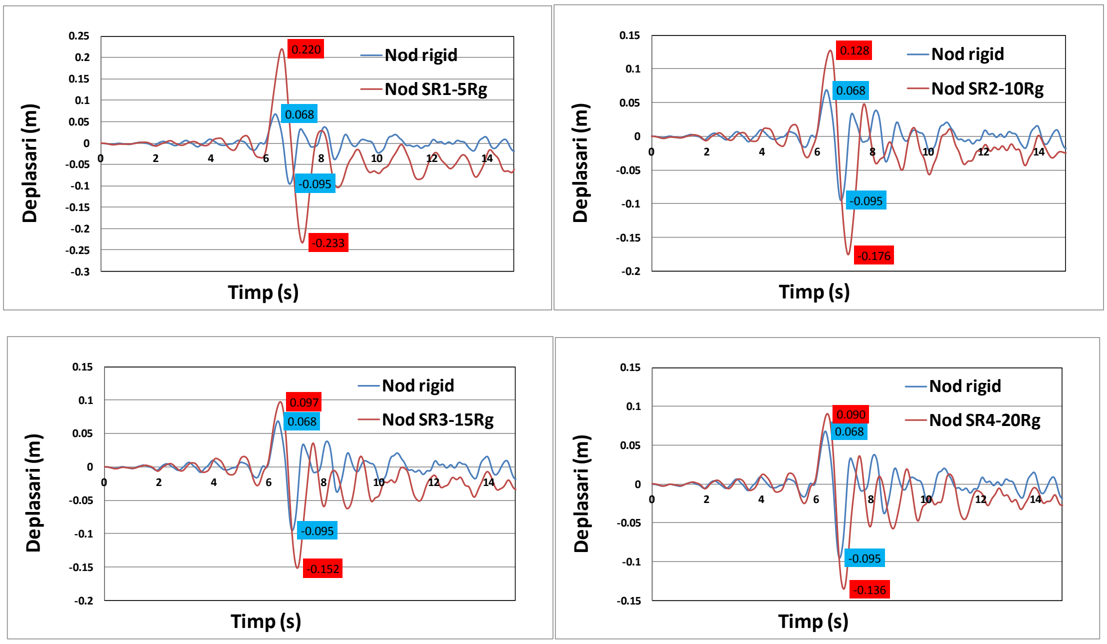


Fig.5. Structure's periods

The seismic response is represented by lateral displacements at the last level and by seismic base shear force. For clarity, the results are presented separately for each situation of semirigidity versus the homologue results obtained for reference structure (Fig.6).



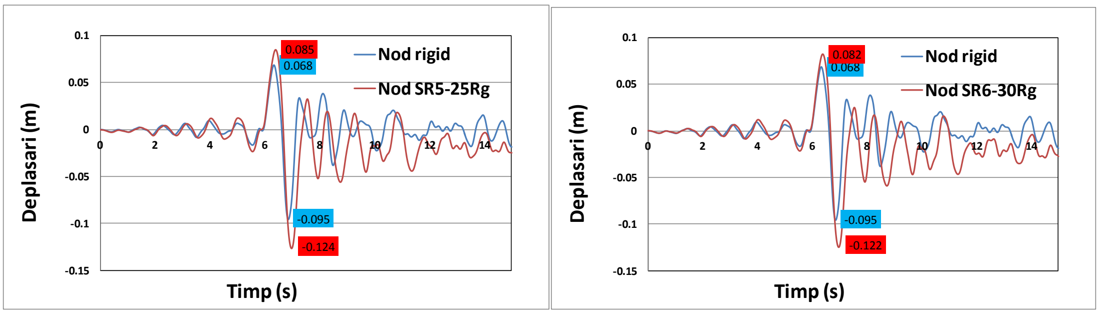


Fig.6. Comparison of displacements in case of accelerogram of Vrancea ’77

The seismic base shear forces are presented in pairs for each case of semirigidity versus the seismic base shear force associated to the reference structure (Fig.7).

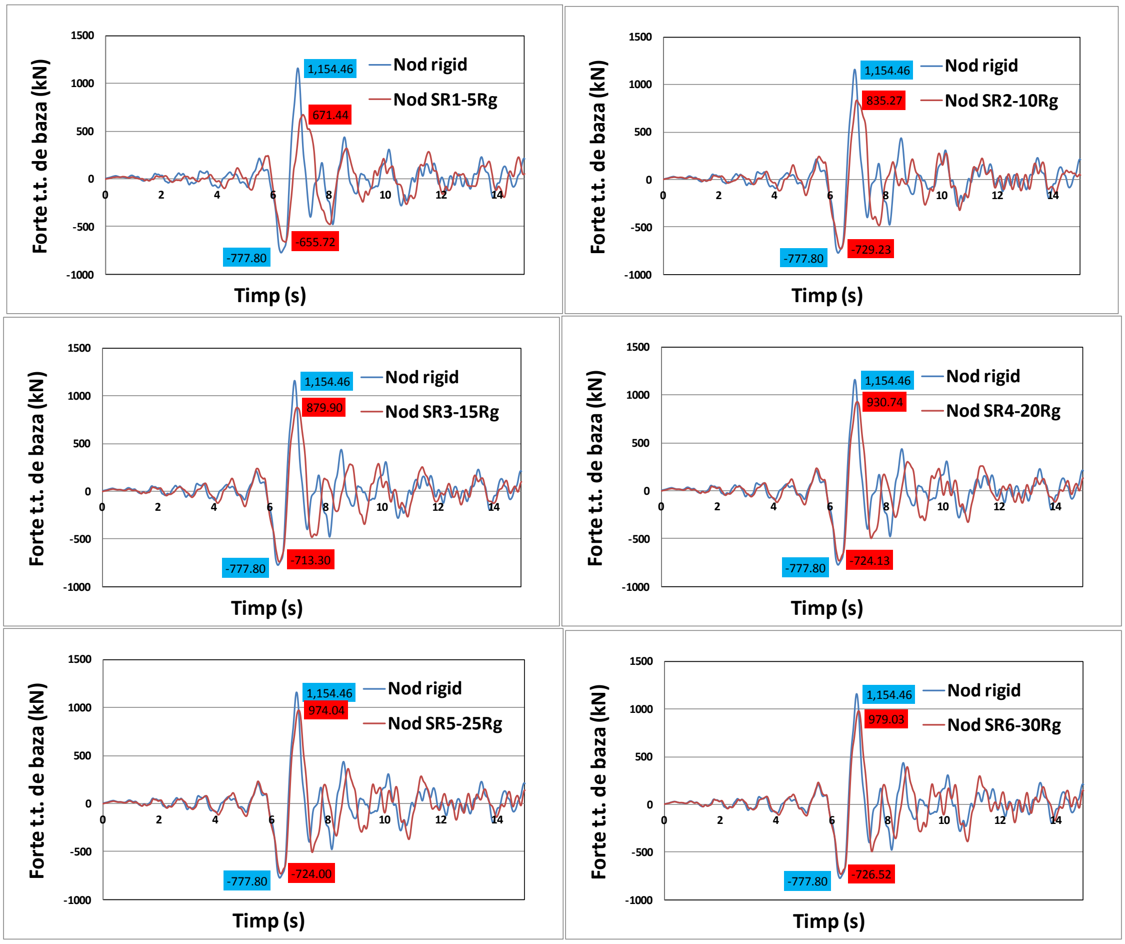


Fig.6. Comparison of total base shear force in case of Vrancea ’77 accelerogram

4. Conclusion

The presented results state both through calculated absolute values and through comparison with homologue results associated with structures of rigid connections - effect of the rigidity state on seismic response. Lateral rigidity state is conferred the “semirigidity” of beam-column connections. From the multitude of static and kinematical parameters through which seismic response is expressed, there were selected two, namely: lateral level displacements and respectively, seismic base shear forces. The contradictive results are induced by the rigidity state expressed in function of those two parameters, which are presented graphically in a comparative, simple and direct way, regarding to the influence of semi-rigidity state on seismic response.

5. References

[1] EN 1993-1-1, *Design of steel structures -General rules and rules for buildings*. CEN, European Committee for Standardization, 2004.

[2] FEMA-350, *Recommended seismic design criteria for new steel moment-frame buildings*. Report No. FEMA-350, SAC Joint Venture, Federal Emergency Management Agency, Washington, DC, 2000.

[3] Máthé, Aliz, *Analiza elastică geometric neliniară a structurilor metalice cu conexiuni flexibile*. Teză de doctorat, Universitatea Tehnică, Cluj-Napoca, 2009.

[4] Kishi, N. and Chen W.F., *Moment-rotation relations of semi-rigid connections with angles*. Journal of Structural Engineering, ASCE, 116(7), 1813-1834, 1990.

[5] Richard, R.M. and Abbott, B.J., *Versatile elastic-plastic stress-strain formula*. Journal of the Engineering Mechanics, ASCE, 101(4), 511-515, 1975.

[6] Popa, Anca, Mathe, Aliz, *Performance-Based Analysis of Steel Structures with Semi-Rigid Connections*. 34 th IABSE Symposium "Large Structures and Infrastructures for Environmentally Constrained and Urbanised Areas", Venice, 2010, pg. 356-364.

[7] Cătărig, A., Alexa, P., Kopenetz, L., Mathe, Aliz, Lădar, Ioana, *Problems of Geometrically Nonlinear Analysis of Semirigid Steel Structures.* International Seminar of IASS Polish Chapter, XV Jubilee LSCE 2009, Warsaw, 2009, pag.29-32.

[8] Alexa, P., Cătărig, A., Mathe, Aliz, Lădar, Ioana, Prodan, O., *Performance Based Alalysis of semigigid Steel Frames.* International Seminar of IASS Polish Chapter, XV Jubilee LSCE 2009, Warsaw, 2009, pag.14-19.

[9] Bâlc, Roxana, *Structuri metalice în cadre. Calculul şi alcătuirea nodurilor*. Teză de doctorat, Universitatea Tehnică, Cluj-Napoca, 2012.

[10] Stamatopoulos, G.N., *Seismic Response of Steel Frames Considering the Hysteretic Behaviour of the Semi-rigid Supports*. International Journal of Steel Structures September 2014, Vol 14, No 3, Athens, pg.609-618.

[11] Deierlein, G., Reinhorn, A. and Willford, M., *Nonlinear Structural Analysis for Seismic Design. A guide for practicing engineers*. NIST GCR 10-917-5, San Francisco, 2010.

[12] FEMA-P695, *Quantification of Building Seismic Performance Factors*. Federal Emergency Management Agency, Washington, DC, 2009.

[13] European Commission-EUR 18366, *Promotion of plastic design for steel and composite cross-sections: new required conditions in Eurocodes 3 si 4, practical tools for designers*. Technical steel research series, Luxembourg, 1998.

[14] www.seismosoft.com/**seismostruct**