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Analysis the Effect of Bracing Systems on the Seismic Response of Steel Structures

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***Abstract*:** *The braced or seismic construction must be designed in such a way as to withstand action levels defined either by the snow and wind regulations or by the seismic regulation in force for each seismic area. However, for some heavy constructions containing reinforced concrete or mixed steel-concrete slabs, seismic actions are usually the most unfavorable.*

The design regulations are based on the use of simplified design methods (spectral, equivalent static) and aim to reduce elastic seismic forces to inelastic forces by exploiting the structure's ability to dissipate energy through inelastic deformations without breaking. The reduction of forces in the regulations is made by introducing a coefficient called "behavior coefficient". Actually, this coefficient of behavior depends mainly on the ductility related mainly to the configuration of the structure (geometry, stiffness, nature of the materials, mode of breakdown, etc. and the ability to dissipate energy.

The objective of this study, is to devalue the effect of bracing systems on the seismic response steel structures, using the methods analysis of the Algerian Seismic Regulation (RPA), which are the equivalent static method based on the first fundamental mode of vibration and the method of modal spectral analysis based on a response spectrum normalized. The different results obtained are compared and conclusions are drawn.

Keywords: *behavior coefficient, bracing systems, seismic response, steel structures, inelastic forces.*

1. Introduction

In the civil engineering, a bracing is a static system intended to ensure the overall stability of a structure with respect to the horizontal effects resulting from any actions on it. It is also used to locally stabilize certain parts of the structure (beams, columns) with respect to instability phenomena (buckling or overturning). To ensure the overall stability of a building, it must be braced in at least three vertical planes and one horizontal plane; a distinction is therefore made between vertical braces (intended to transmit horizontal forces in the foundations) and horizontal braces (intended to oppose the effects of torsion due to these forces). Bracing can be achieved by sails (vertical bracing) or plates (horizontal bracing) in reinforced concrete, masonry, wood or corrugated sheet; or by wooden or steel trellis [1].

Metal frames with concentric or eccentric bracing by triangular braces are frequently used as supporting structures for vertical and lateral loads in multi-storey metal buildings, because they have many practical advantages in terms of implementations. This choice is largely due to advances in construction methods and improved performance of buildings in service. In Algeria, this type of frame is much more or less widespread in practice although it is theoretically widely preferred over that of reinforced concrete because of its good

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resistance to seismic loads. This resistance is mainly due to the very good performance of the triangulated braces for bracing the metal frames to seismic loads [2].

2. The Notion of Behavior Coefficient

The coefficient of behavior or the reduction factor of the forces introduced in the paraseismic rule to reduce the elastic forces obtained from a linear elastic analysis, to take into account the dissipation of energy during the earthquake. This behavior factor globally takes into account the hysteretic dissipative capacity of the structure, making it possible to reduce its dimensioning to a level of elastic behavior with the introduction of equivalent seismic forces of reduced intensity. It is defined as the ratio between the maximum elastic lateral force V_e and the design inelastic lateral force V_d. It is given by the following expression:

$$R = V_e / V_d \tag{1}$$

This coefficient is most important parameter of the elastic analyzes therefore serves to reduce the elastic shear force at the base to a design shear force much lower than the first one. Indeed, since an effort is only the multiplication of a stress by a section, therefore reducing the effort means reducing the sections.

Results from an experimental research program at the University of Berkley in California were used to plot force-displacement curves for braced metal frames, but also to test the formulation of the behavior coefficient. Relationships of shear force at the base – displacement at the top of the buildings tested have been established: a metal building with centered triangular bracing and another metal building still, but with eccentric triangular bracing [5]. The capacity curves were established by plotting the displacement corresponding to the maximum shear force at the base for each simulation and for each model considered. Based on this database, the Berkley researchers proposed that the behavior coefficient be the multiplication of three factors: taking into account the resistance reserve, the ductility and the damping:

$$R = R_\mu . R_S . R_\xi \tag{2}$$

R_μ is the ductility factor

R_S is the overresistance factor

R_ξ is the damping factor

R_R: The redundancy factor.

The evaluation methods of behavior coefficient are classified into three main classes:

- **Methods based on Ductility**

The method of Newmark and Hallest the simplest of all methods, the ductility factor is a function of the period of vibration of the oscillator and its ductility [2].

Krawinkler and Nassar method This method is based on the response of a system with a single degree of freedom with elasoplastic behavior with work hardening [7].

Method of Giuffre and Giannini [7] this method, the ductility factor is calculated from approximate expressions expressed as a function of the period of the structure and of the ductility.

Method of Fajfar and Vidiç [8] this method has undergone simplifications based on statistical estimates made by (Vidiç & al). The end result is two equations that relate the ductility factor to the ductility and period of the structure.

Priestley's method The ductility factor proposed by Priestley takes into account the characteristic period specific to the site and is expressed by the following relation [2].

- **Method based on the Energy Approach**

Como and Lannic method This is a simplified method based on the energy approach was proposed by Como and Lanni. This method is based on a simplified model of the energy exchanges occurring in a structure during an earthquake [9].

- **Method based on the Accumulation of Damage**

The evaluation of the ductility factor according to these methods requires on the one hand, the availability of the curves of fatigue of the constituent elements of the structure, on the other hand, the application of these methods involves several calculations which are at the same time long and difficult [9]. According to the Algerian paraseismic regulations (RPA99 / 2003): Its unique value is given by the tables below according to the bracing system. If different bracing systems are used in the two directions considered, the lower value of the coefficient R should be adopted [3].

TABLE I: Values of the behavior coefficient for steel structures (RPA)

Structure type	R	Structure type	R
Ductile self stabilizing portal frame	6	Frame braced by X-shaped braces	4
Ordinary self stabilizing portal frame	4	Frame braced by triangulated V	3
Mixed portal frame /triangulated in X	5	Mixed portal frame/triaglted V	4

3. Description of Model of Structures Considered

The metal frame structures considered are made up of six floors (fig.1). The height of each floor is 3.06 m and the span of each span being 2.80 m and 4.20 m, for residential use located in the Bouira city Algeria. The bracing system adopted is defined by triangulated frames centered in X, V and inverted. The structures are designed and sized in accordance with the provisions of the metal construction rules of Eurocode EC3.

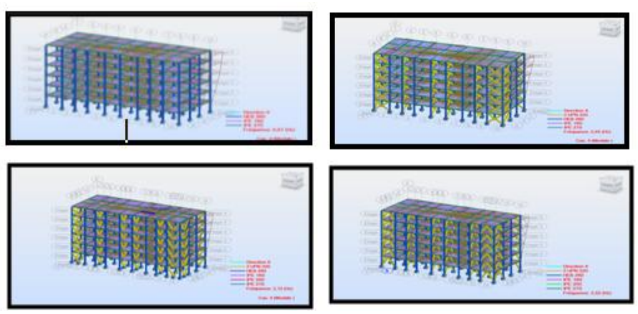

Fig. 1: 3D view of bracing system models considered for steel frame structures

The structure considered was thus subjected to the seismic loading. Analyzes are carried out using Robot Structural software. The seismic actions are based on the two analysis methods indicated in the RPA 2003 (equivalent static method and modal spectral method). The values of the coefficients are summarized in Table II for a soft site and a group of use 2.

TABLE II: Different Values of the coefficients for steel structures (RPA)

A	D	ξ	T1	T2	Q
0,15	2,5	5%	0,15sec	0,5sec	1,15

A, D, Q, R designate respectively the zone acceleration coefficient, the average dynamic amplification factor, the quality factor, the global behavior coefficient of the structure. And T_1,T_2 site periods

The calculation response spectra used for the different bracing systems are shown in the figures below.

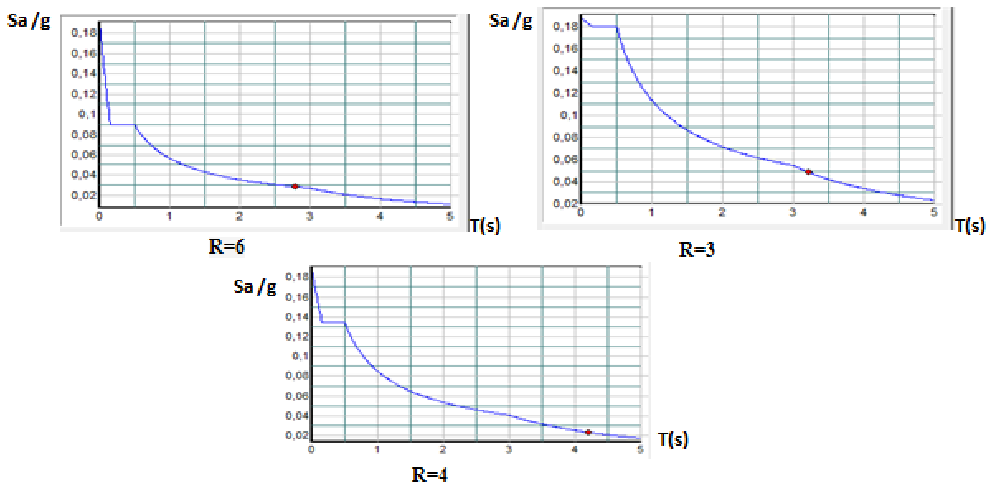

Fig. 2: Differents response spectra.

4. Results and Discussion

The results obtained in this study in terms of fundamental periods, displacements, shear and seismic forces for the different bracing systems considered are presented as below.

- Eigen periods

According to the figure 3, the fundamental period of the self stabilizing portal frame is larger than that of other portal frame. A reduction of between 47 and 62% in the fundamental period of the concentric systems (in X, V and inverted V) compared to that of the portal frame without triangulated.

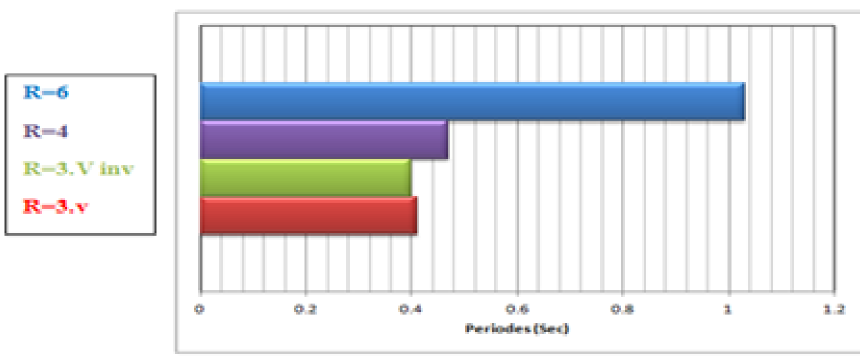

Fig. 3: The fundamental period relating to the different modes of vibration of the structures studied.

- Shear forces

The response of the structures in terms of shear force under the effect of the seismic load defined by the response spectrum, is represented in figures 4, 5, 6, there are different shear forces, due to the dissimilarity of the seismic loading applied to the structures considered. It can be seen that the structures with centered inverted-V bracing have a higher shear force at each storey, compared to the other structures. Although the structure with centered V bracing is subjected to the same seismic load as that of the structure with inverted V, the shear forces are different. This difference is very apparent in the case of the forces obtained by the method of spectral modal analysis. On the other hand, the self-stabilizing portal frame is characterized by a rather weak response compared to that observed in the X-bracing, although their seismic actions are identical, variation in the shear force from structure to another, mainly due to the behavior coefficient adopted by the paraseismic regulation. The most ductile structures in seismic zones are generally characterized by a high behavior coefficient, therefore, the more the overall ductility of the structure increases, the more its coefficient increases, which reduces the seismic action adopted by the regulation

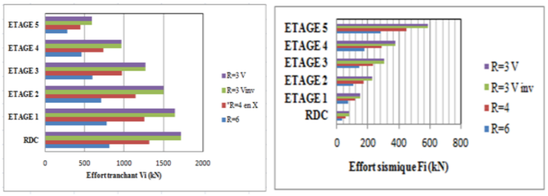

Fig. 4: Variation of shear, seismic force by static equivalent

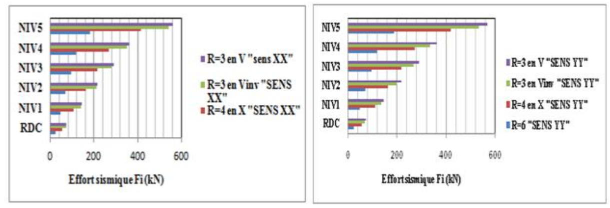

Fig. 5: variation of seismic force by spectral method.

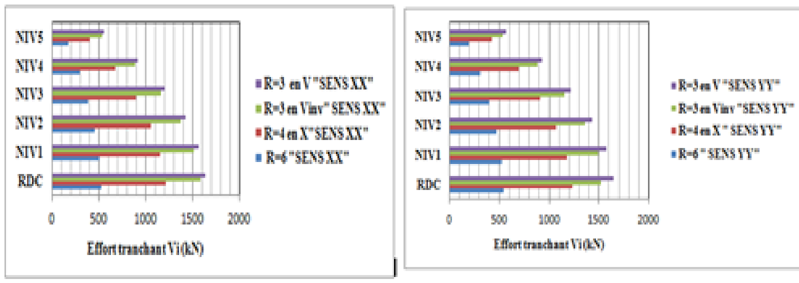

Fig. 6: variation of shear force by spectral method.

- Inter story lateral displacements

The lateral displacements of each floor of the different structures obtained are illustrated in figure 7 where it can be seen that the maximum lateral displacements of the freestanding gantry crane are generally greater than those of the other gantry cranes comprising triangulated bents. Moreover, note that this difference is significant on the upper floors. And on the other hand, all the braced structures are characterized by quite low lateral displacement, except the one with centered V-bracing, which has considerable deformation at the upper floors compared to the other structures. Unlike the self-stabilizing portal frame, braces centered in X show the lowest lateral displacements compared to those of other structures. The remarks indicated above show that the bracings in triangular braces tend to increase the lateral rigidity of the structure vis-à-vis the horizontal seismic loads, which has the effect of limiting its displacements.

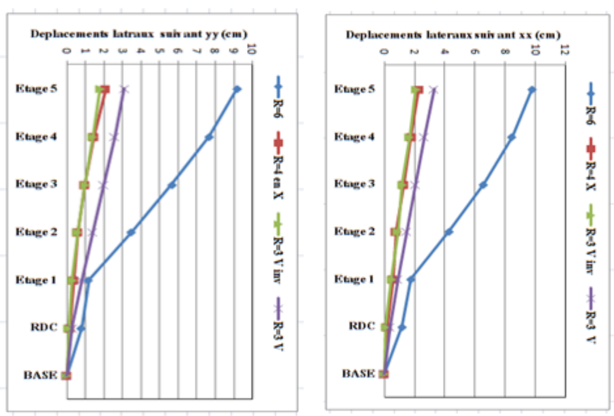

Fig. 7: Lateral displacements at each floor along the xx and yy axes.

- Relative displacements

The analysis of structures in terms of relative displacement is illustrated in Figure 8, 9. This figure clearly shows a significant deformation between floors of the freestanding gantry, in particular at the level of the intermediate floors, and particularly the 4th floor. On the other hand, structures braced by triangulated braces are characterized by a movement between floors that is quite low. Among these structures which have almost the same relative displacement, the one with centered V-bracing has a higher relative displacement. In the light of these findings, it is noted that the intermediate part of the self-stabilizing portal frame can be affected by damage, due to their significant flexibility, particularly in slender buildings. Through these results, it should be noted that the use of braces clearly shows their advantage on the behavior of structures in terms of displacement between floors

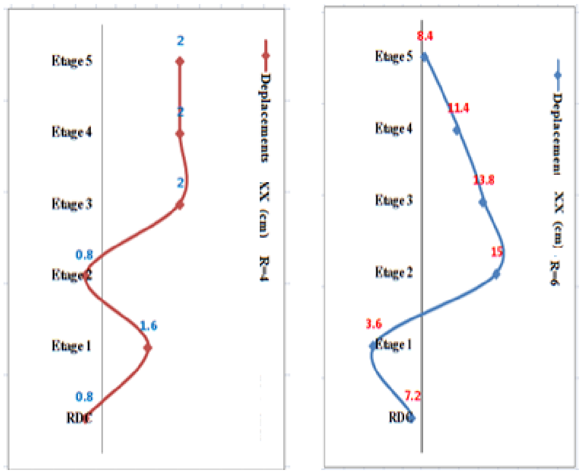

Fig. 8: The relative displacements of the different floors for self stabilizing and X-bracing portal frame.

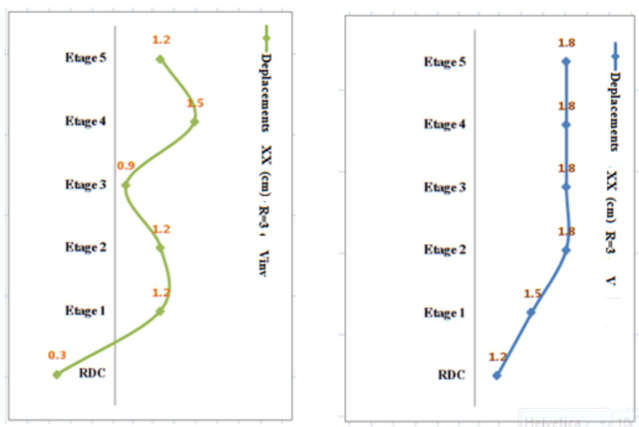

Fig. 9: The relative displacements of the different floors for V and Vinv.

To evaluate the seismic response of metal structures braced by triangulated and this with different bracing systems. From which we can conclude that: The self-stabilizing portal frame is more flexible under the effect of seismic actions, which leads to deformations in terms of very considerable lateral and relative displacement compared to that of other structures with centered X, V and inverted V bracing. Lateral stiffness is observed for structures with centered X and inverted V bracing compared to the V bracing system. The criterion of the shear and seismic force shows that the structures with triangulations centered in V and in V invert very high forces compared to the structures with a bracing in X and that because of their weak coefficient of behavior.

5. Conclusion

The work presented was devoted to the study of the effect of bracing systems on the seismic response of steel frame structures, namely, self-stabilizing portal frame, frames with centered triangulations in X, V and inverted V. The declared objectives were to evaluate the behavior of these structures with respect to seismic actions, in particular those defined in the Algerian paraseismic regulation (RPA2003), namely the equivalent static method by shear force at the base and dynamic by spectrum of elastic response. In light of the results obtained, the following conclusions can be drawn: self-stabilizing portal frame structures are more flexible under the effect of seismic actions, which leads to very considerable deformations in terms of lateral and relative displacement compared to that of other structures with centered X, V and inverted V bracing. Lateral stiffness is observed for structures with centered X and inverted V bracing compared to the V bracing system. The criterion of the shear and seismic force shows that the structures with triangulations centered in V and in inverted V have very high forces compared to the structures with a bracing in X and that because of their weak coefficient of behavior.

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