Assessment of the Torsion Effect in Asymmetric Buildings Under Seismic Load

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SUMMARY:
Irregular structures are more and more used in new architectural design. In these structures the torsion phenomenon can induce important stresses especially in the case of a seismic motion. The new seismic codes try to take into account this effect and during the modeling it is difficult to assess all the parameters that have an influence on the behavior of this kind of structures. In this work, a study on the influence of the torsion effects on the behavior of structures is done. Two types of buildings are considered, one symmetrical and the other asymmetrical in terms of rigidity. The proposed structures consist of a building in reinforced concrete with infinitely rigid slabs and frames. The use of a finite element code which takes into account the nonlinear behavior of structural elements allows temporal analysis. A database of 116 seismic records is used. These signals represent earthquakes with magnitude ranging between 6.2 and 7.7. The responses of the two buildings are compared in terms of maximum displacement at the top, ductility and reduction factor.

Keywords: Torsion, Earthquake, Buildings, Eccentricity, Non-linear behaviour

1. INTRODUCTION

The seismic response of asymmetric building subjected to ground motions may be significantly modified due to torsional effects. These effects arisen from non-uniform distribution of the mass, the stiffness, the strength and the torsional components of the ground movement.

Several studies have been conducted on the subject. Among them the influence of the lateral and torsional frequencies have been investigated by Goel and Chopra (1991) and the importance of adequate design of vertical resisting elements on both sides of centre of stiffness, accidental eccentricity effects due to a variety of causes and the effect of torsional and lateral coupling responses of asymmetric buildings have been studied by Ciongradi (2002), Stathopoulos (2010).

In fact, there are two major reasons for the occurrence of the torsion effect. The first is a non-uniform distribution in plan of the stiffness, mass or strength. The second is the rocking of foundation Crisafulli and Reboredo (2004). However, other factors have been considered in order to take into account the torsion effect, firstly in terms of ductility Fajfar (2005) concluded that the de-amplification of displacements on the stiff side due to torsion, typical for elastic torsionally stiff structures, usually decreases with increasing plastic deformations. He found also that the typical amplification for elastic torsionally flexible structures usually decreases with increasing plastic deformations. Secondly in terms of the strength reduction factor Newmark and Hall concluded that: in the middle, low and high frequency, spectral displacements and forces are the same for an elastic and inelastic system. By consequence for moderately high frequencies, the principle of conservation of energy is the same as that of an elastic perfectly plastic system Miranda (1994). Actually the formulation of the strength reduction factor combines the effect of over strength (Rs), ductility (Rμ) and redundancy (R_R) Bhavin (2010) concluded that in terms of demand the design reduction factor increases with increasing ductility and the lateral yielding strength of the structure decreases with increasing inelastic deformation in terms of capacity.

The main objective of the present work is to estimate the influence of torsion effects induced on the behaviour of an asymmetrical structure. Therefore we considered two types of structures: symmetrical and asymmetrical, in order to see the effects of some parameters previously cited. We focused our study specifically on some parameters such as: the displacement, the ductility, the reduction factor (Re) and the dynamic non accidental eccentricity. To do it, dynamic analyses using the finite elements software GEFDYN Aubry and Chouvet (1986), Aubry and Modaressi (1996) were performed.

2. DESCRIPTION OF THE STUDIED CASES

Dynamic analyses on a symmetrical and asymmetrical structure were performed using GEFDYN software.

2.1. Models characteristics

The transverse sections of the single story-frames chosen to represent the two types of structures (i.e. asymmetrical and symmetrical structures) are shown respectively in Fig.2.1a and 1b. The mass of the slab is assumed uniformly distributed along beam elements and the columns are supposed to be mass less. It is also assumed that the slab of the two structures is infinitely rigid in its own plane. Besides, the same rigidity is observed, for each column element in the symmetrical structure (i.e. $k_1 = k_2 = k_3 = k_4$) while in the flexible side of asymmetrical structure the rigidity for the elements E_{R1} and E_{R4} are $k_1 = k_4 = K$ and in the rigid side the rigidity of elements E_{F2} and E_{F3} are $k_2 = k_3 = 1.13K$. In this model the six degrees of freedom are considered.

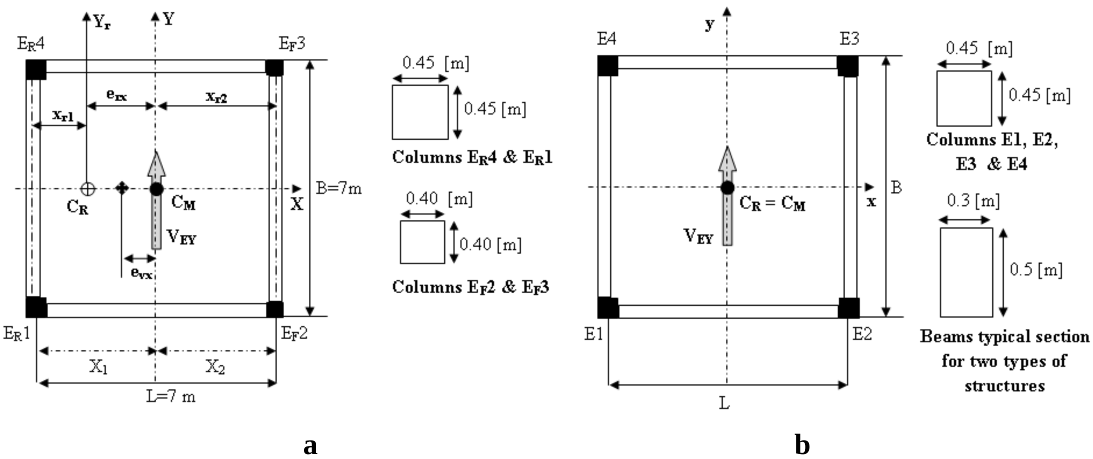


Figure 1. Geometry and transverse section description of structures

As regards the total masses 44 tones, the elastic modulus E of the two structures is equal to 33.4 GPa and the Poisson's ratio is ν =0.2. The dynamic elastic analysis on fixed base gives a fundamental frequency (f_{str}) of 6.32 Hz and 7.02 Hz for asymmetric and symmetric structures respectively. In order to introduce the non-linear properties of the column elements in the stiff and flexible side, a plastic hinge model has been used. Fig.2.2. displays axial force-bending moment (M-N) diagrams that control the yield function of the non-linear plastic hinge columns of the two structures.

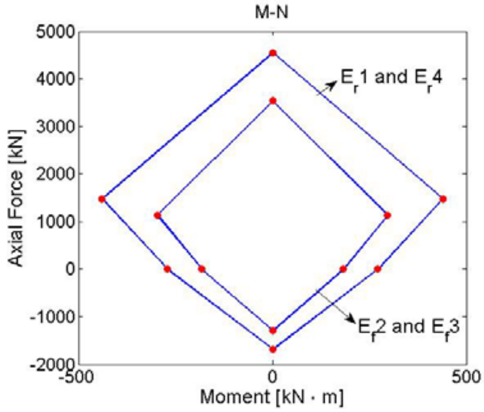


Figure 2. Axial force - bending moment interaction

The ductility was calculated for both structures considered. First, in the case of symmetrical structure the system displacement ductility demand was calculated by the following Eqn.2.1 Paulay (1999):

$$\mu_\Delta = \frac{\Delta_u}{\Delta_y} \tag{2.1}$$

Where (Δ_u) is the ultimate inelastic displacement and (Δ_y) is the yield displacement of the system. In the case of asymmetrical structure the ductility demand depends on the two angles of twist of the system (θ_{tu} and θ_{to}). The first is the ultimate angles of twist (θ_{tu}) which depends on the stiffness and moment of torsion of the system. It is defined as Eqn. 2.2:

$$\theta_{tu} = \frac{M_{tor}}{K_{tor}} = \frac{e_{vx} \sum_i V_{yi}}{\sum_i y_i^2 K_{xi} + \sum_i x_i^2 K_{yi}} \tag{2.2}$$

Where M_{tor} is the torsional moment; V_{yi} is the strength in y directions; e_{vx} is the strength eccentricity induced by the torsional moment and K_{tor} is the torsional stiffness of system; x_i and y_i are respectively the distance from each element (Column) to the centre of rigidity (or gravity).
Moreover, knowing that the ultimate displacement Δ_u obtained in the asymmetrical case is not necessarily identical in the stiff side Δ_{u1} compared to that in the flexible side Δ_{u2}, the optimal angle of twist θ_{to}, which corresponds to the strength eccentricity must be calculated by the following Eqn. 2.3:

$$\theta_{to} = \frac{\Delta_{u1} - \Delta_{u2}}{L} \tag{2.3}$$

L: is the length of structure.
Where the displacement ductility demand must be limited to Eqn. 2.4:

$$\mu_\Delta = \frac{\Delta_u}{\Delta_y} = \frac{(\Delta_{u1} + X_1 \theta_{tu})}{\Delta_y} \tag{2.4}$$

In which the angle of twist, θ_{tu}, is found to be less than the optimal value; given by Eqn.(2.2).
However, when $\theta_{tu} > \theta_{to}$, the system displacement ductility demand needs to be limited to Eqn. 2.5:

$$\mu_{\Delta} = \frac{\Delta_u}{\Delta_y} = \frac{(\Delta_{u2} - X_2\theta_{tu})}{\Delta_y} \quad (2.5)$$

Where X_1 is the distance from elements $E_R 1$ to the centre of mass and X_2 is the distance from elements $E_F 2$ to the centre of mass.
As regards to the strength reduction factor (Re) it reflects the capacity of the structure to dissipate energy through inelastic behavior. This does not depend only on the characteristics of the system, but also on the ground motion influenced by the period of vibration and the displacement ductility ratio Miranda (1994). This factor is defined as the ratio of the elastic strength demand to the inelastic one Eqn. 2.6.

$$R_e = \frac{F_{el}}{F_y} \quad (2.6)$$

Where (F_{el}) the maximum lateral elastic strength is obtained from linear analysis under ground motion, and (F_y) is the lateral yielding strength obtained from non-linear analysis and corresponding to the strength obtained at the ultimate capacity displacement under the same ground motion Miranda (1994).

2.2. Input ground motions

The study used 116 seismic records with a magnitude varying between 6.2 and 7.7. The parameters that incorporate the amplitude and duration of the ground motion are likely to be more reliable predictor of damage than parameters that capture only the amplitude of the earthquake. Arias intensity (Ia) is an earthquake severity measure that correlates well with several structural demand measures. This intensity is defined as follows Eqn. 2.7:

$$I_{Arias} = \frac{\pi}{2g} \int_0^{T_d} [a(t)]^2 dt \qquad [\text{m/s}] \quad (2.7)$$

Where: $a(t)$ is the ground acceleration T_d is the duration of the earthquake and g is the gravity acceleration Iervolino (2005).
The effect of the predominant period T_p (s) is also studied as the Arias intensity, the mean period (T_m) and the peak ground acceleration PGA (a_{gmax}) for the given input motion. The ranges of variation of these parameters for the input motions used are reported in Table 2.1.

Table 2.1. Characteristics of input motion data

Parameter	Range
a_{max} [g]	0.05-0.88
T_p [s]	0.08-1.15
I_a [m/s]	0.04-6.21

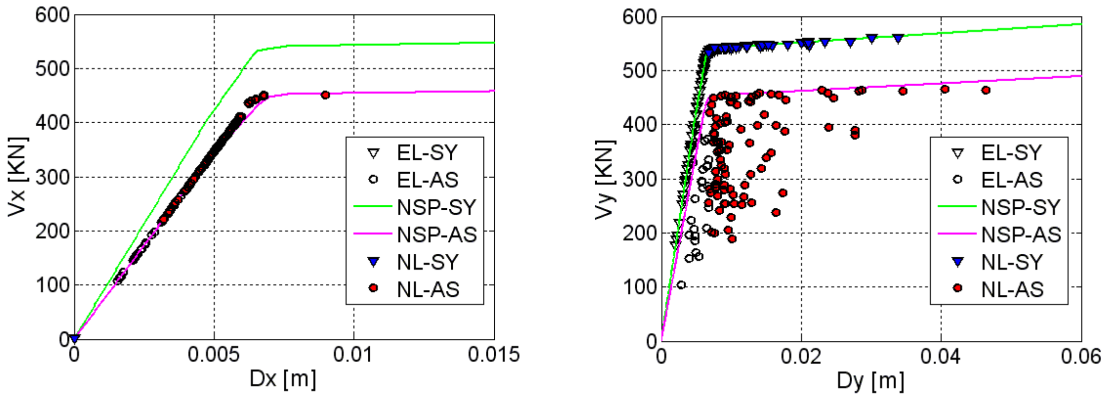
All signals are consistent with the response spectra of Type soil A of Eurocode8.

3. RESULTS AND DISCUSSION

Several analyses (linear dynamic (EL), nonlinear dynamic (NL) and Push over (NSP)) were performed. Then the results in terms of capacity curves (base shear/top displacement), ductility and reduction factor are presented.

3.1. Numerical simulations

The results obtained in terms of ultimate lateral strength (Vu) respectively in asymmetrical (A_S) and symmetrical (S_Y) structures are shown in Fig.3.3a and 3b. As it can be seen, the lateral strength in both directions X and Y (Vx and Vy respectively) for the symmetrical structure is greater than the one for the asymmetrical structure.



a b

Figure 3. Base shears versus Top displacements in both directions X and Y

Secondly, in terms of ductility μ_Δ versus respectively intensity arias and predominant period are shown in Fig.3.4 and Fig.3.5, As it can be seen, the ductility increases with increasing input motion (Arias intensity) and decrease with increasing predominant period respectively in asymmetrical (AS) and symmetrical (SY) structures. However the reduction factors' evolution is shown in Fig.3.6 and Fig.3.7 respectively. As it is shown in Fig.3.7, the reduction factor decreases when the dominant period of the earthquake increases. Unlike in the case of intensity arias variations Fig.3.6 the reduction factor increase with decreasing input motions.

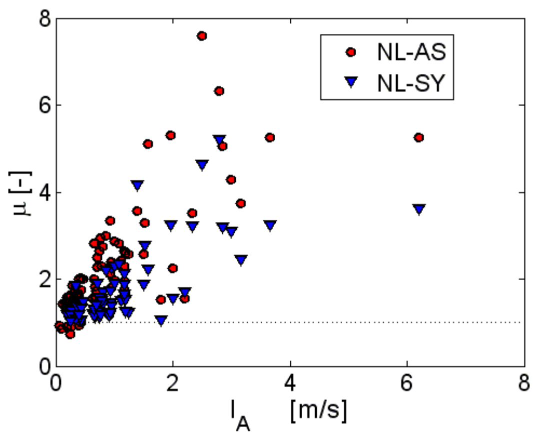


Figure 4 Ductility versus Intensity arias

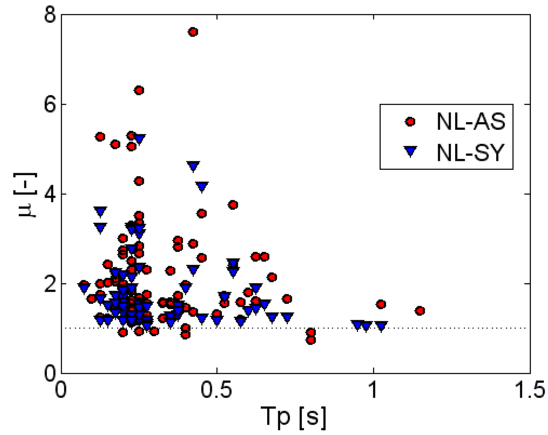


Figure 5. Ductility versus Predominant period

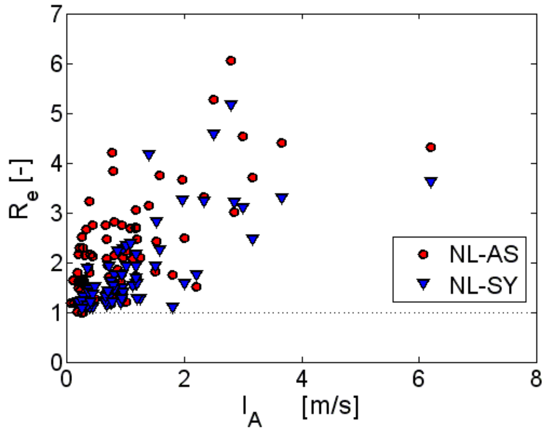


Figure 6. Reduction factor versus Intensity arias

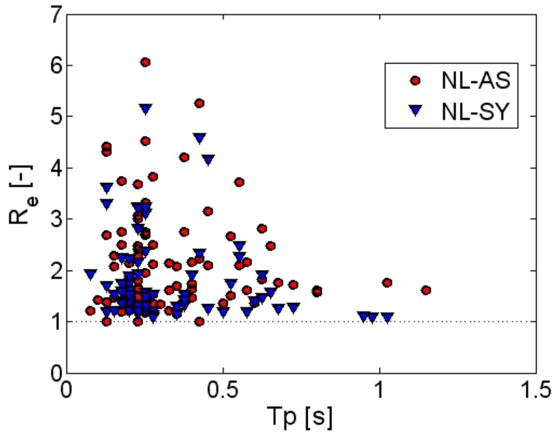


Figure 7. Reduction factor versus Predominant period

The results obtained in terms of the normalized dynamics eccentricity (defined as the dynamic eccentricity divided by the static eccentricity) are shown in Fig.3 8, it was observed an amplification of eccentricities in the elastic and plastic behavior on highly range of arias intensity, and its decrease on the non linear behavior on low arias intensity. These effects are due to the creation of plastic hinges.

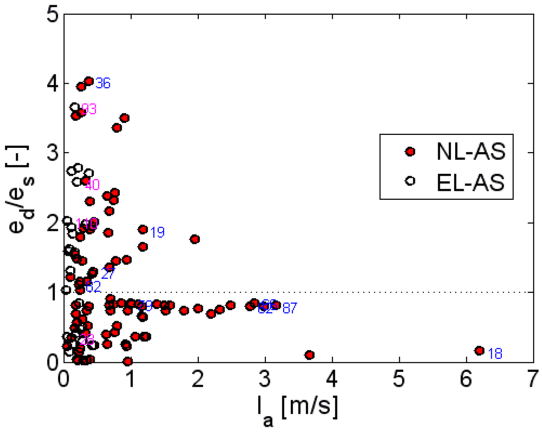


Figure 8. Normalized dynamics eccentricities versus Intensity arias

4. CONCLUSIONS

This work demonstrates that the torsional response in structures subjected to earthquake may be influenced by many parameters. Some of these effects as the ultimate top displacement, ductility, reduction factor and the dynamic eccentricity are presented. It was found that for the studied cases:

1. In terms of capacity the lateral yielding strength of the asymmetrical structure is higher than the one of the symmetrical structure in both directions.
2. The ductility increases with increasing input motion (Arias intensity) and decrease with increasing predominant period with significant variation in asymmetrical structure than those symmetrical structures.
3. The reduction factor decreases when the dominant period of the earthquake increases. Unlike the reduction factor increase with decreasing input motions.
4. The normalized eccentricity increase when Arias intensity is low on the elastic and inelastic domain and decrease when it is high.

To generalize the obtained results, and study the existence of correlations between the structural characteristics and the input motion parameters, the parametric study has to be pursued for other cases such as multistory models with bi-directionality of input motions.

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