

Seismic evaluation of asymmetric reinforced concrete buildings using methods based on the performance design philosophy

Evaluación sísmica de edificios asimétricos de concreto reforzado utilizando métodos basados en la filosofía de diseño por desempeño

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Abstract

This article presents an approximate Performance-Based Seismic Design and its application to medium-rise buildings, characteristic of the Valley of Mexico and its metropolitan area. The proposed procedure considers the participation of the higher modes. This method considering displacements as damage indices and controls the global damage of the structure. To show its application and the validity of its results, 2 reinforced concrete buildings of medium height (8 and 15 stories), asymmetrical in plan were designed and evaluated. To avoid the uncertainties of the modal combination rules, a response spectrum was used as seismic demand. The seismic demand was applied orthogonally and simultaneously. The results obtained from the proposed approximate procedure were compared with those obtained from a step-by-step non-linear dynamic analysis, observing a congruence between both (displacement profiles and drift).

Resumen

En este artículo se presenta una metodología de diseño sísmico aproximado, basado en la filosofía de diseño por desempeño y su aplicación a edificios de mediana altura, característicos del valle de México y de su zona conurbada. El procedimiento propuesto considera la participación de los modos superiores y tiene un control de daño global de la estructura, considerando los desplazamientos como índices de daño. Para mostrar su aplicación y la validez de sus resultados se diseñaron y evaluaron de 2 edificios de concreto reforzado, de mediana altura, asimétricos en planta de 8 y 15 niveles. Para evitar las incertidumbres propias de las reglas de combinación modal se utilizó como demanda sísmica un espectro de respuesta. La demanda se aplicó de forma ortogonal y simultánea. Los resultados obtenidos del procedimiento aproximado propuesto se compararon con los obtenidos de un análisis dinámico no lineal paso a paso, observándose una congruencia entre ambos, perfil de desplazamientos y desplazamientos relativos.

Torsion, Seismic evaluation, Damage control

Torsión, Evaluación sísmica, Control de daño

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Introduction

At present most seismic design codes include torsional effects, with certain restrictions in the static method and none in the dynamic method, either spectral or dynamic modal analysis. In both cases the existence of asymmetries in plan is penalized by an increase in the spectral ordinate. Recent research has shown the limitations of these methods, particularly when used in the seismic design of buildings for boundary states where significant damage is accepted. Because of this, in recent years earthquake engineering has oriented part of its research to understand the nonlinear behavior of structures, particularly those considered irregular, using robust procedures. However, of these efforts, there is still no methodology, easy to implement, to ensure performance consistent with that established in the design.

Some "recent" research by different authors recommends the use of displacement-based procedures, since the effect of resistance distributions on the nonlinear torsional behavior of asymmetric buildings is explicitly considered. Paulay (2002) conducted research on the influence of torsion effects on the seismic performance of structures and proposed to reduce these effects through adequate control of stiffness and resistance distributions. However, most of these works have been validated in structures that do not enter the nonlinear range.

Due to the above, this article presents an approximate procedure for seismic design of buildings based on displacements and damage control, defined from the distribution of the resistances of the structural elements in plan and elevation. The results of this research emphasize the influence of torsion effects on the seismic performance of buildings, particularly in mezzanine drifts. The proposed methodology is based on the hypothesis that it is possible to approximate the seismic performance of a structure of multiple degrees of freedom (MDOF), through the response of a bilinear oscillator of a degree of freedom (SDOF), associated with a reference system, where the oscillator is defined by the properties of the modal form that contribute most to the inelastic response of the structure.

The fundamental principle of the proposed methodology is the validity of the capacity curve of the structure, which can be approximated by a curve bilinear, characterized by 2 stages and defined by the principle of equal energies between the "real" and bi-linear curves. From this one can construct the behavior curve (Sa-D) of the reference system of an oscillator (SDOF), using concepts of structural dynamics, and extract the seismic performance of the structure to a given seismic demand.

Background

Different investigations have shown that there is enough evidence to think that one of the main causes that cause severe damage to a structure after an earthquake of considerable magnitude are excessive rotations of the diaphragms. During the earthquake in Alaska (1964) damage was generated that reached the collapse of important buildings, e.g., J.C Penney building. In Mexico City, the 1985 earthquake caused severe damage to many structures, 42% of the buildings that collapsed or suffered serious damage were corner, which are susceptible to excessive rotations in the rigid diaphragms.

In the last 4 decades many investigations have been developed on the effects of torsion in the nonlinear response of buildings; However, there is still no single and/or accepted conclusion on how to consider its effects on the seismic design of structures. The progress of understanding the seismic behavior of asymmetric structures has been slow, which manifests itself with a paucity of methodologies and general conclusions, which makes us question. Do we really have a deep understanding of the behavior of ductile torsion systems? Are our element modeling hypotheses and therefore that of structural systems close enough to reality?

Paulay and currently some of his collaborators have shown a particular interest in understanding the seismic response considering the effects of torsion, particularly in ductile buildings. His contributions and views on this problem have been of great help in understanding the seismic response of asymmetric buildings. The following paragraph describes some of his contributions and comments:

The eccentricity of the rigidity is the parameter that most influences the response of the elastic systems, on the contrary, the eccentricity of the shear force is one of the parameters that most influences the response of ductile systems. Paulay (2002) showed that strength and stiffness systems are not independent parameters and that nominal yield displacements are a geometric property of materials, which is independent of force. He introduced the idea that the ductility displacement capacity of a system is based on the displacement capacity of its critical elements. He suggested that the elimination or reduction of system rotations, due to torsional effects, should not have to be the main design objective, instead system rotations should be accepted, when it is demonstrated that the displacement ductility criteria, for the different translation elements, are not violated. In this way we would have a greater dissipation of energy and consequent a more effective damping, among others.

Force-based seismic design method

This design philosophy has been adopted by most of the current regulations and consists of designing the structural elements using the results obtained from a linear elastic analysis, associated with a seismic demand characterized by a spectrum of elastic design smoothed and reduced by a ductility factor, R and / or Q . In this methodology, displacements are a secondary parameter that are only reviewed at the end of the design process, assuming that the rule of equal displacements is met for all cases. When the estimated displacements exceed the displacements established by the regulation then the rigidity of the structure is adjusted.

However, of the shortcomings observed in the application of this design philosophy, most current seismic design regulations continue to propose the use of force-based methods, accepting the validity of many assumptions, which do not have a rigorous foundation. The main inconsistencies found in the force-based method are related to the correlation between stiffness and strength, the relationship between strength and ductility, the choice of ductility of the structural system as the most important performance index, the validity of the equal displacement rule, among others.

Recent research has shown that any of these factors can lead designers to results inconsistent with those obtained from step-by-step nonlinear dynamic analysis.

Performance-based seismic design method

Due to the deficiencies observed in the force-based philosophy, some authors have directed efforts to develop "new" methods of seismic design, placing particular emphasis on the performance-based philosophy, which has as its main objective to design economical, safe structures with a seismic behavior consistent with the damages observed in previous experiences. This philosophy seeks to guarantee the stories of damage estimated in the structural design. It is established that in the event of a severe earthquake and with a low probability of occurrence, collapse must be avoided, but it is accepted that damage to the structural elements occurs, while for moderate earthquakes that have a high probability of occurrence, damage of any kind should be avoided, mainly in the main structural elements.

In recent years, many approximate methods based on the performance-based philosophy have emerged, mainly using displacements as a performance index, mainly because "recent" research has shown that displacements are the efficient way to assess damage to a structure, since the deformations produced by these displacements are directly related to the damage. Among the seismic design procedures based on displacements most referenced in the specialized literature are those proposed by Moehle (1992), Priestley et al., (2007), Ayala et al., (2012), among others.

Direct method based on displacements.

Priestley et al., (2007) proposes a direct method of seismic design (DDBD), based on the concept of the substitute structure proposed by Shibata and Sosen (1976). In this method, a structure of multiple degrees of freedom (MDOF) is idealized as an elastic system of an equivalent degree of freedom, which is associated with a viscous damping equal to the sum of the viscous damping of the system of multiple degrees of freedom and the hysterical corresponding to the non-linear behavior, and to a secant stiffness associated with a maximum displacement.

Method based on the validity of the capacity curve

Ayala et al., (2012) proposes an approximate seismic design method based on the assumption that the performance of a structure of multiple degrees of freedom can be approximated by the performance of a reference system, associated with the fundamental mode of the structure. The capacity curve of the structure is approximated by a bilinear capacity curve generated using the principle of equal energies. From this bilinear curve a capacity curve is defined in spectral coordinates (Sd-Sa) called the behavior curve, which offers the parameters for the seismic design of the structure.

The slope of the elastic branch of the behavior curve represents the rigidity of the structure in the elastic range while the second branch represents the post-yield or inelastic stiffness. Post-yield stiffness is defined using a structure with a damage distribution associated with a predefined maximum displacement, based on a performance index obtained from some regulation. The steps of the method (Ayala et al., 2012) are described in the following paragraphs.

1. Perform a preliminary design of the structure using a force-based method
2. Propose harm sharing
3. Define the dynamic properties of the structure without damage and the structure with damage
4. Define the target displacement of the structure
5. Calculate the yield displacement of the structure
6. Determine ductility, the relationship between initial stiffness and post-yield stiffness
7. Verify that the target displacement is consistent with an inelastic displacement, obtained from an inelastic spectrum
8. Calculate the resistance, R_y/m and R_u/m , of the capacity curve

9. Construction of the capacity curve
10. Obtain the design forces for the structural elements through spectral modal analysis
11. Design the structural elements

Formulation for estimating the reference system

The dynamic equilibrium equation, for a three-dimensional structure of multiple degrees of freedom, representing a building, subjected to a seismic demand at the base, is given by the following equation:

$$\{f_I\} + \{f_A\} + \{f_E\} = 0 \quad (1)$$

where:

$$\{f_I\} = \text{Inertia forces}$$

$$\{f_A\} = \text{Damping forces}$$

$$\{f_E\} = \text{Static forces}$$

$$\{f_I\} = [M]\{\ddot{u}^t\} \quad (2)$$

$$\{f_A\} = [C]\{\dot{u}\} \quad (3)$$

$$\{f_E\} = [K]\{u\} \quad (4)$$

Substituting 2, 3 and 4 into equation 1:

$$[M]\{\ddot{u}^t\} + [C]\{\dot{u}\} + [K]\{u\} = 0 \quad (5)$$

$$\{\ddot{u}^t\} = \{\ddot{u}\} + \{\ddot{u}_g\} \quad (6)$$

Where the matrix of mass, damping, rigidity and the vectors of displacements, velocities and accelerations are formed by submatrices which group all degrees of freedom of the structure:

$$[M] = \begin{bmatrix} M_x & 0 & 0 \\ 0 & M_y & 0 \\ 0 & 0 & I_0 \end{bmatrix}$$

$$[K] = \begin{bmatrix} K_{xx} & K_{xy} & K_{x\theta} \\ K_{yx} & K_{yy} & K_{y\theta} \\ K_{\theta x} & K_{\theta y} & K_{\theta\theta} \end{bmatrix}$$

$$[C] = \begin{bmatrix} C_{xx} & C_{xy} & C_{x\theta} \\ C_{yx} & C_{yy} & C_{y\theta} \\ C_{\theta x} & C_{\theta y} & C_{\theta\theta} \end{bmatrix}$$

$$\{u\} = \begin{Bmatrix} u_x \\ u_y \\ u_\theta \end{Bmatrix} \quad \{\dot{u}\} = \begin{Bmatrix} \dot{u}_x \\ \dot{u}_y \\ \dot{u}_\theta \end{Bmatrix} \quad \{\ddot{u}_g\} = \begin{Bmatrix} \ddot{u}_{gx} \\ \ddot{u}_{gy} \\ 0 \end{Bmatrix}$$

Substituting 6 in 5

$$[M]\{\ddot{u}\} + [M]\{\ddot{u}_g\} + [C]\{\dot{u}\} + [K]\{u\} = 0$$

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = -[M]\{\ddot{u}_g\} \quad (7)$$

Returning to the previous equation, the following modal coordinate transformation is applied:

$$\{u\} = [\Phi]\{v\}$$

$$\{\dot{u}\} = [\Phi]\{\dot{v}\}$$

$$\{\ddot{u}\} = [\Phi]\{\ddot{v}\}$$

The differential equation of motion of a system of various degrees of freedom can be expressed as "n" independent equations for systems with the properties of each of the modes. So, for the total response of the structure, we have:

$$[M][\Phi]\{\ddot{v}\} + [C][\Phi]\{\dot{v}\} + [K][\Phi]\{v\} = -[M]\{\ddot{u}_g\} \quad (8)$$

Multiplying both terms by $[\Phi]^T$

$$[\Phi]^T[M][\Phi]\{\ddot{v}\} + [\Phi]^T[C][\Phi]\{\dot{v}\} + [\Phi]^T[K][\Phi]\{v\} = -[\Phi]^T[M]\{\ddot{u}_g\} \quad (9)$$

Since vectors of modal forms are normalized to the mass, we have:

$$[\Phi]^T[M][\Phi] = [I] \quad (10)$$

$$[\Phi]^T[K][\Phi] = [\omega^2] \quad (11)$$

$$[\Phi]^T[M] = [\Gamma] \quad (12)$$

$$[\Phi]^T[C][\Phi] = [2\zeta\omega] \quad (13)$$

Substituting 10 to 13 into equation 9:

$$[I]\{\ddot{v}\} + [2\zeta\omega]\{\dot{v}\} + [\omega^2]\{v\} = -[\Gamma]\{\ddot{u}_g\} \quad (14)$$

Then the decoupled equation of motion for mode i is:

$$\ddot{v}_i + 2\zeta\omega_i\dot{v}_i + \omega_i^2v_i = -[\Gamma_{xi} \ \Gamma_{yi} \ \Gamma_{\theta i}] \begin{Bmatrix} \ddot{u}_{gx} \\ \ddot{u}_{gy} \\ 0 \end{Bmatrix}$$

$$\ddot{v}_i + 2\zeta\omega_i\dot{v}_i + \omega_i^2v_i = -\Gamma_{xi}\ddot{u}_{gx} - \Gamma_{yi}\ddot{u}_{gy}$$

If for validation purposes, it is considered $\ddot{u}_{gx} = \ddot{u}_{gy} = \ddot{u}_g$ then:

$$\ddot{v}_i + 2\zeta\omega_i\dot{v}_i + \omega_i^2v_i = -(\Gamma_{xi} + \Gamma_{yi})\ddot{u}_g \quad (15)$$

The decoupled equations of motion corresponding to systems of a degree of frequency freedom ω_i damping ζ_i , subject to a demand \ddot{u}_g is given by:

$$\ddot{D}_i + 2\zeta\omega_i\dot{D}_i + \omega_i^2D_i = -m\ddot{u}_g \quad (16)$$

Comparing equations 15 and 16 gives the following relationship between v_i and D_i :

$$v_i = (\Gamma_{xi} + \Gamma_{yi})D_i \quad (17)$$

Where D_i is the displacement of the oscillator in response to demand \ddot{u}_g , then the spectral shift of the oscillator $Sd(T, \zeta)$, It is directly related to the maximum modal shift of the structure, so the above equation can be written:

$$v_i = (\Gamma_{xi} + \Gamma_{yi})Sd(T_i, \zeta_i) \quad (18)$$

The displacement in the three directions in the center of mass of the roof of the building will be given by:

$$u_{iax} = \varphi_{iax}(\Gamma_{xi} + \Gamma_{yi})Sd(T_i, \zeta_i) \quad (19)$$

$$u_{iax} = \varphi_{iax}(\Gamma_{xi} + \Gamma_{yi})Sd(T_i, \zeta_i) \quad (20)$$

$$u_{ia\theta} = \varphi_{ia\theta}(\Gamma_{xi} + \Gamma_{yi})Sd(T_i, \zeta_i) \quad (21)$$

To find the structure reference frame for a mode i has:

$$Sd_i = \frac{u_{iax}}{\Phi_{ix}(\Gamma_{xi} + \Gamma_{yi})} \quad (22)$$

$$Sa_i = \omega_i^2 Sd_i \quad (23)$$

Proposed method

The seismic design method proposed in this article is an extension and/or modification of the procedure proposed by Ayala et al 2012 and is based mainly on the validity of the capacity curve, from which it is possible to extract the performance of the structure by constructing the behavior curve of the reference system expressed in spectral coordinates. The initial branch of the behavior curve represents the properties of the structure in the elastic range, and the slope of the second branch represents the properties of the structure in the inelastic range.

The characteristics of the second branch are defined from a damage distribution proposed by the analyst. The yield strength per unit mass (R_y/m) is associated with the story of demand for the structural elements that are assumed to have damage to design demands. The ultimate resistance per unit mass (R_u/m) is the story of demand for the structural elements that must remain elastic to such demands. Based on these fundamentals, the following paragraphs describe in detail the steps of the proposed design method to design asymmetrical buildings:

1. Build an elastic model and perform a pre-design of the structure. The pre-design is obtained according to a current force-based regulation either by static analysis under gravitational loads and equivalent lateral loads or by spectral modal analysis under the same demands.
2. Define the performance objective associated with a current seismic design regulation.
3. Propose a configuration of damage of the structure. The structural elements and sections in which damage resulting from the design demand is accepted to occur. The damage is characterized by plastic ball joints. This model is called "damaged".
4. Obtain the dynamic characteristics of structural models without and with damage. Modal analyses of both models are performed, from which the periods and modal forms are obtained and, from each of these analyses, the periods of the modes that most influence the response of the structure, T_1 and T_2 , are selected. These periods define the branches of the behavior curve of the reference frame of a degree of freedom; one for the elastic range and the other for the inelastic range, Fig. 1.

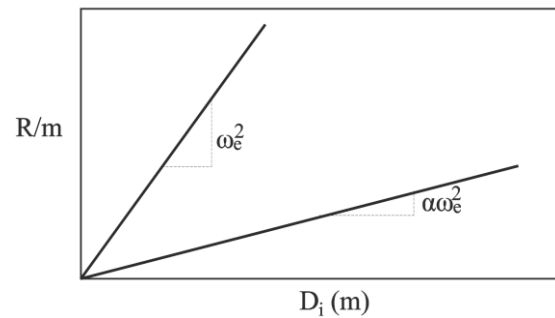


Figure 1 Branches of the behavior curve of the reference frame

5. Calculate yield displacement, \overline{D}_{11} of the behavior curve of the reference frame from the yield distortion of the structure, using expressions proposed by Priestley, (2000) that are a function of the geometry of the structure and the properties of the materials.
6. Get the target offset of the reference system. This offset is defined according to the maximum permissible values of the mezzanine drifts, corresponding to the design performance story. To calculate the objective displacement of the behavior curve, the following is used:

$$\delta_{dj} = \delta_{1dj} + \delta_{2dj} \quad (24)$$

where δ_{1dj} y δ_{2dj} They correspond to the mezzanine distortion of story j where it occurs, subscript 1 represents the elastic stage and subscript 2 represents the post-yield stage.

The contribution of the i th mode for each of the stages is defined by the following expressions:

$$\delta_{1dji} = \rho_1 \delta_{1j} \quad (25)$$

$$\delta_{2j} = \delta_{disj} - \delta_{1j} \quad (26)$$

$$\delta_{2dji} = \rho_2 (\delta_{disj} - \delta_{1j}) \quad (27)$$

Where δ_{disj} is the objective design distortion.

$$\rho_1 = \frac{\delta_{1ji}}{\sum_{i=1}^n \delta_{1ji}} \quad (28)$$

and

$$\rho_2 = \frac{\delta_{2ji}}{\sum_{i=1}^n \delta_{2ji}} \quad (29)$$

To calculate rooftop displacements for the mode that contributes most to the response (Δ_{A1i} and Δ_{A2i}), corresponding to each of the stages, the following equations are used:

$$\Delta_{A1i} = \frac{\delta_{1dji}}{\delta_{1ji}} \quad (30)$$

$$\Delta_{A2i} = \frac{\delta_{2dji}}{\delta_{2ji}} \quad (31)$$

Finally, the displacements of mode i (Projection X) are obtained for each of the stages

$$\overline{D}_{11x} = \frac{\Delta_{A1i}}{\phi_{iAx}(\Gamma_{xi} + \beta\Gamma_{yi})} \quad (32)$$

$$\overline{D}_{12x} = \frac{\Delta_{A2i}}{\phi_{iAx}(\Gamma_{xi} + \beta\Gamma_{yi})} \quad (33)$$

- Obtain the ductility corresponding to the design displacements. The ductility (μ), is calculated from the displacements defined in step 6.

$$\mu = \frac{\overline{D}_{12x}}{\overline{D}_{11x}} \quad (34)$$

- Calculate the offset of the reference system. From an inelastic spectrum of displacements, associated with the α value defined by the eq. 40 and from the ductility, μ , calculated in the previous step, the spectral displacement is obtained (D_{ux}), corresponding to the fundamental period of the elastic model, $T1$ (Fig. 2) of the reference system. This offset is compared to the target offset (\overline{D}_{12x}); if they are equal, the process continues; If not, the initial structure and/or the proposed damage distribution is modified and step 2 or 3 is returned, depending on what is decided to change, until the equality between these displacements is satisfied.

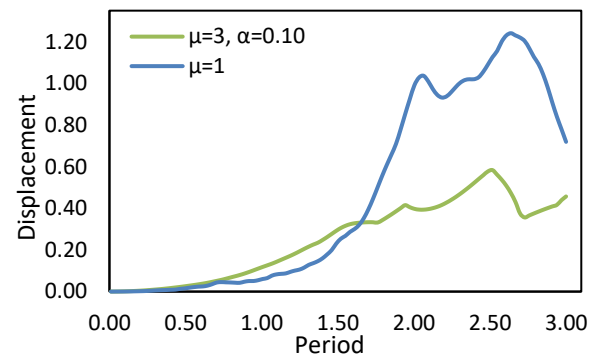


Figure 2 Elastic and inelastic displacement spectra

- Construct the behavior curve. With the parameters obtained in the previous steps, i.e., yield displacement, ultimate displacement, yield resistance, ultimate strength, initial stiffness, post-yield stiffness, ductility and the ratio of post-yield stiffness to initial stiffness, the behavior curve of the reference frame is constructed (Fig. 3).

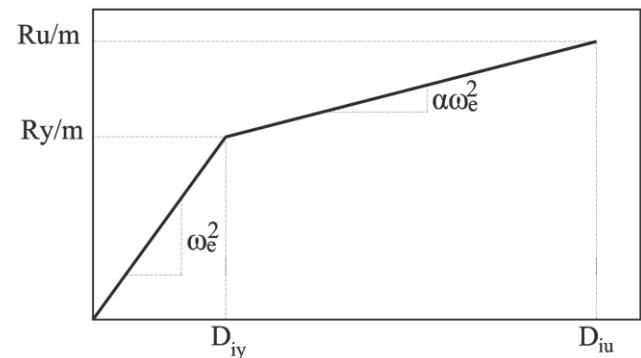


Figure 3 Behavior curve of the building reference system

- Calculate design forces. To obtain these forces, two spectral modal analyses are performed, one for the elastic model, which includes gravitational loads, and as seismic demand a spectrum scaled by the factor λ_1 is used, calculated as the quotient between the yield displacement of the oscillator and the maximum elastic displacement. The second analysis is performed for the model with damage, using as seismic demand the record scaled by the factor λ_2 , calculated as the quotient between the target displacement and the maximum elastic displacement corresponding to stage 2. The design forces for the elements that accept and do not accept damage are obtained by adding the two previous analyses.

$$\lambda_1 = \frac{\overline{D}_{11x}}{D_{1x}} \quad (35)$$

$$\lambda_2 = \frac{\overline{D_{12x}}}{D_{2x}} \quad (36)$$

Application example

To illustrate the application of the proposed procedure, two reinforced concrete buildings of 8 (B1) and 15 (B2) stories were designed, with 10% eccentricity in masses, using as demand, for comparative purposes, the records of a real earthquake. The results obtained were compared with those obtained from a nonlinear dynamic analysis step by step before the same seismic demand used in its design. For the structures used, the following considerations were considered:

1. Story diaphragms are considered infinitely rigid in their plane, i.e., three degrees of freedom per floor, two horizontal displacements and one rotation around the vertical axis are considered and the beams are considered as infinitely rigid for axial deformation purposes.
2. It is not considered damage to the base of the columns of the first story and nor to the beams of the last stories, 2 (B1) and 4 (B2).

Buildings B1 and B2 are rectangular with three bays of 7 m in direction X and four bays of 8 m in direction Y. The X1 and Y1 bays of the building. The thickness of the slab is 0.12 m, the height of all mezzanines is 3.3 m. In Fig. 4 The standard floor of the building is shown.

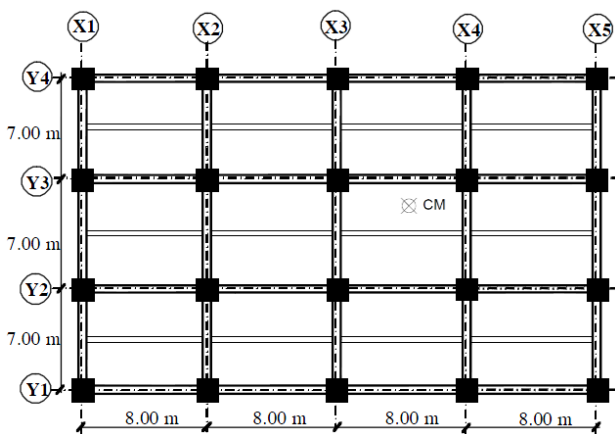


Figure 4 Story plan of the building with an eccentricity of 10% in each of its main axes

Analysis of results for building B1

For this example, a drift story of 0.02 and a design offset of 23 cm yield displacement (0.076), yield resistance (1.65 m/s²), ultimate resistance (2.029 m/s²), post-fluence ratio (11.3%) and a ductility of 3.

The mechanical design elements were calculated by 2 modal analyses in time, the first for the structure without damage (fact, λ1 = 0.54) and the second for the damaged structure (fact, λ2 = 0.32).

In Figure Fig. 5 The mezzanine distortions are observed in the "X" and "Y" directions of the frames that make up the building, as well as those of the center of mass. It is observed that the mezzanine distortions calculated with the proposed method are approximate to those obtained from a step-by-step dynamic analysis.

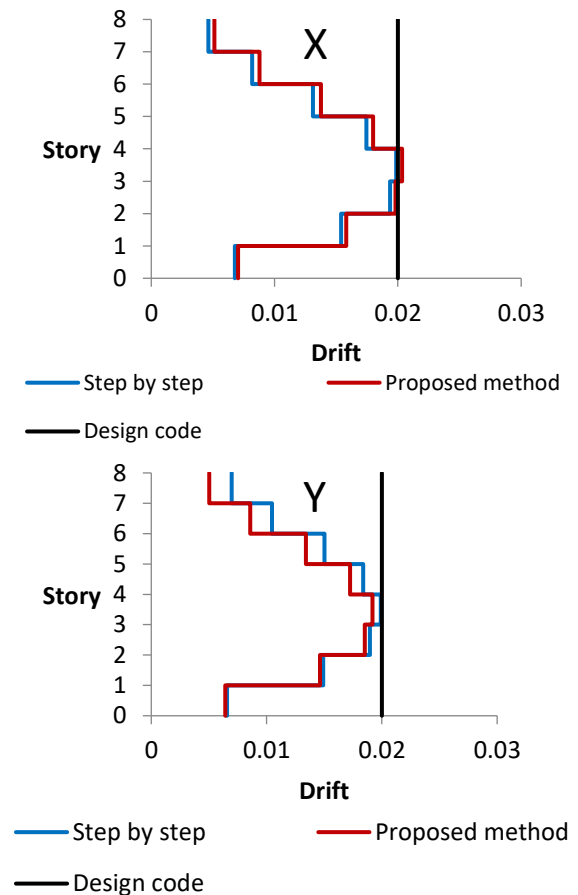


Figure 5 Drift story of building B1.

Analysis of results for building B2

The properties of the behavior curve of this structure are as follows:

Yield displacement (0.165), yield strength (1.438 m/s²), the ultimate resistance (1.774 m/s²), the post-fluence ratio ($\alpha=16.34\%$) and a ductility of 2.4.

The mechanical design elements were calculated by 2 modal analyses in time, the first for the structure without damage (fact, $\lambda_1 = 0.171$) and the second for the damaged structure (fact, $\lambda_2 = 1$).

Figure 6 shows the mezzanine distortions in the "X" and "Y" directions of the strongest frame. It is observed that the mezzanine distortions calculated with the proposed method are approximate to those obtained from a step-by-step dynamic analysis.

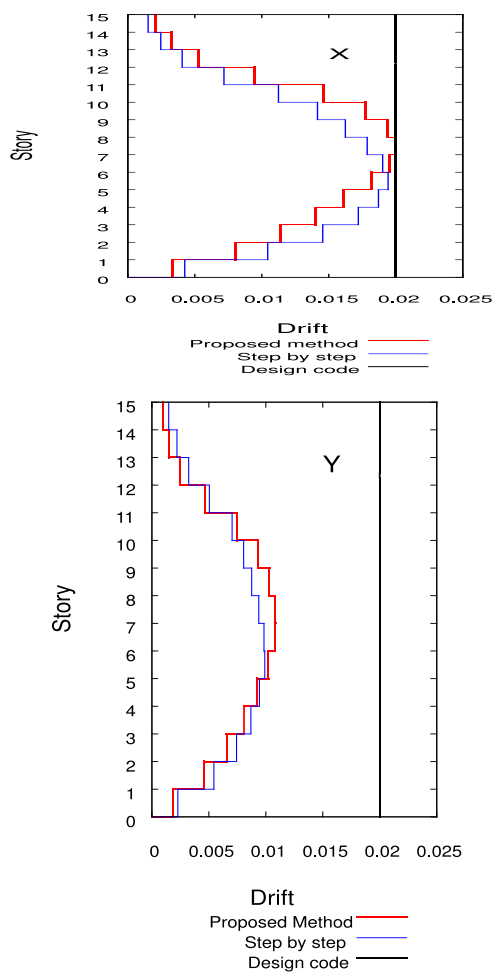


Figure 6 Drift story of building B2

Conclusions

From the results obtained in the 2 designs, where the application of the proposed adaptation to the original method of seismic design by displacements proposed by Ayala et. al (2012) and the estimated results of a step-by-step nonlinear dynamic analysis were compared, the following conclusions were obtained:

1. Archived good structural damage control. The differences between the damage distributions in the structures assumed as a design objective in the application of this method and those obtained from the nonlinear dynamic analysis step by step for the same seismic demand for which it was designed, are not significant.
2. The method proposed and/or modification of the original proposal in this research offers results comparable to those obtained from a step-by-step nonlinear dynamic analysis. This method guarantees that the estimated performance, derived maximum from mezzanine, using a reference system associated with the fundamental mode is consistent with that calculated of a numerically "accurate" method, under certain circumstances associated mainly with the influence of the higher modes on structural performance.

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