16th World Conference on Earthquake, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° XXXX

Registration Code: S-XXXXXXXX

A METHODOLOGY FOR PRELIMINARY SEISMIC DESIGN OF STRUCTURES WITH OR WITHOUT ENERGY DISSIPATION DEVICES

A. Giuliano(1), M. Rubinstein(2), O. Möller(3), J.P. Ascheri(4), M. Poliotti(5)

(1) *Director Instituto Nacional de Prevención Sísmica INPRES, San Juan, Argentina, giuliano@inpres.gov.ar*
(2) *Professor, IMAE, FCEIA, Universidad Nacional de Rosario, Argentina, marub@fceia.unr.edu.ar*
(3) *Professor, IMAE, FCEIA, CIUNR, Universidad Nacional de Rosario, Argentina, moller@fceia.unr.edu.ar*
(4) *Professor, IMAE, FCEIA, Universidad Nacional de Rosario, Argentina, jascheri@fceia.unr.edu.ar*
(5) *Professor, IMAE, FCEIA, Universidad Nacional de Rosario, Argentina, Poliotti@fceia.unr.edu.ar*

Abstract

It is generally accepted that structural design under seismic excitations must be displacement- rather than force-based with the guiding design variables being ductility limits, damage indices and inter-story drift. Further, more than one level of seismic demand must be considered, establishing performance requirements for each one, in what is known as "performance-based design".

Also, there are current techniques being developed for the application of passive control of structural responses, controls provided by energy dissipation devices. These act in response to relative displacements between structural elements. The objective of these replaceable devices is to concentrate the damage in the devices, avoiding or diminishing its occurrence in the rest of the structure (beams, columns, shear walls, etc.).

It is important to have a preliminary design methodology for the structure, with or without energy dissipation devices, a design that can later be improved by more detailed methods. The preliminary design should be clear in concept, and rely in as few simple calculation steps as possible. It must be displacement-based and be applicable to cases with or without devices.

This work presents such a method for preliminary design. It uses inelastic design spectra in the form of capacity diagrams or Yield Point Spectra (YPS). The method can be applied to structures for which the global response, in terms of the relationship between top displacement and base shear, can be represented by an equivalent system with a single degree of freedom. For such structures, the response is dominated by the first vibration mode.

The method is based on the calculation of the available ductility, starting from the limit displacement which is consistent with the required performance level and the yield displacement of either the structure or the energy dissipation devices (in case that controls are implemented). With the ductility and the yield displacements, the design spectra allow the determination of the required resistance. The proposed method represents an advance with respect to previous work, adding more clarity of concept and generalization of application to systems with or without devices.

Several numerical examples are presented corresponding to a building with different number of stories and different lay-out with and without vibration control. It is shown that the methodology is simple and consistent, and that is a useful tool for the preliminary design of seismic resistant structures.

Keywords: Performance-based seismic design, Passive control, Preliminary design.

1. Introduction

Performance-based seismic engineering philosophy [1, 2, 3, 4], involves the appropriate selection of design criteria concerning: the layout of the system, general configuration of structural elements, also the analysis, design and detailing of the structure, design of non-structural elements, in order to avoid damage of the structure beyond certain limit states defined for specified levels of ground motions and with defined levels of reliability.

It is necessary to start the design process with a preliminary step through a simple procedure, clear in concept, and orientated to satisfy multiple performance targets. A design that can later may be improved by more detailed method.

This paper presents a general methodology for preliminary design of structural systems with or without dissipation devices. It is displacement-based [5, 6, 7], with two performance levels and uses inelastic design spectra in the form of capacity diagrams or Yield Point Spectra [8]. The method can be applied to structures for which the global response, in terms of the relationship between top displacement and base shear, can be represented by an equivalent system with a single degree of freedom. For such structures, the response is dominated by the first vibration mode. Recently developed version of the method N2 yields results of reasonable accuracy if the structure oscillates predominantly in the first mode [9, 10].

The method is based on the evaluation of the limit displacement which is consistent with the required performance level and the yield displacement of either the structure or the energy dissipation devices (in case that controls are implemented). With both displacements, the systems ductility is calculated and finally the design spectra allow the determination of the required resistance.

An advantage of the proposed method is to include, in a unify framework, the passive control of the structure provided by energy dissipation devices [11, 12]. The objective of these replaceable devices is to concentrate the damage in the devices, avoiding or diminishing its occurrence in the rest of the structure (beams, columns, shear walls, etc.).

The work includes several numerical examples corresponding to a building with different number of stories and different lay-out with and without vibration control. It is shown that the methodology is simple and consistent, and that is a useful tool for the preliminary design of seismic resistant structures.

2. Methodology of preliminary design

The preliminary design methodology uses the push-over diagram, relating the base shear to the top displacement, in each resisting direction, of an equivalent single-degree-of-freedom system. It is assumed that the first mode of vibration governs the response and allows the further development of the capacity design.

The methodology is based on displacements, meeting the limit states corresponding to ductility, damage index and inter-story drift [5, 13, 14]. Further, the methodology considers more than one level of seismic demand and, for each one, establishes the performance level required, following the objectives of “performance-based design”.

In summary, the proposed method consists in the calculation of the resistance (base shear) for each direction of analysis, for the structural system and for each component, on the basis of the requirements imposed on the displacements. Finally, with the resistance known, torsional effects can be taken into account, verifying that the total displacements resulting from translation and rotations do not exceed the design limits. Fig.1 shows a flowchart for the procedure, valid for structural systems with or without energy dissipation devices, and a brief descripción of each blocks is as following.

The lay-out consists of an initial proposal for the structural system, indicating the number and distribution of components or planes of resistance, type of structure and the material to use. This initial proposal is the most important step in the preliminary design, and must take into account the architectural requirements, and fundamental concepts of earthquake engineering in accordance with the prescribed demands.

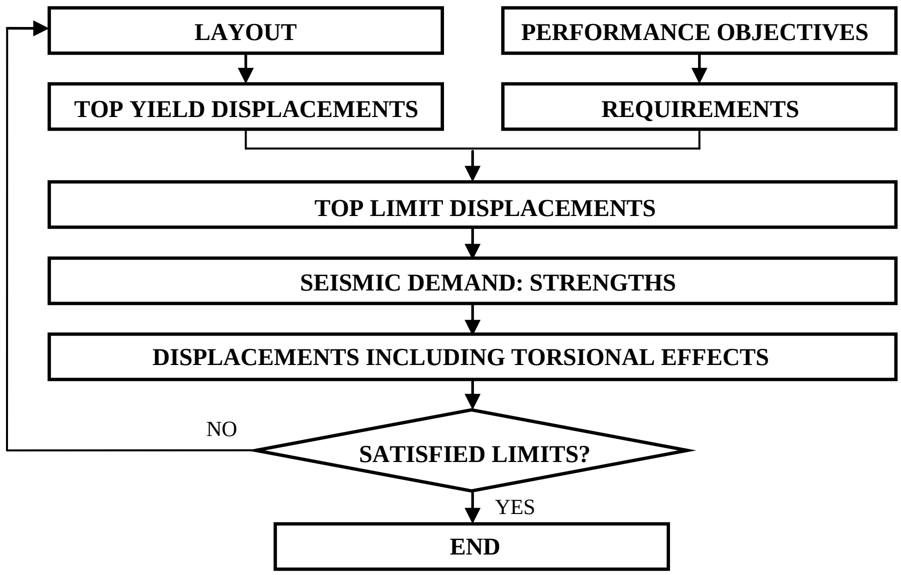


Fig. 1 – Flow-chart for the proposed procedure

2.1 Top yield displacement and push over diagram

a) Systems without control, shear walls: the top yield displacement, for a lateral load with triangular distribution approximately consistent with the first vibration mode, is [15, 16]

$$D_{Yj} = \frac{11}{40} \phi_{Yj} \, H^2 = \frac{11}{40} \frac{2\,\varepsilon_Y}{l_{Wj}} H^2 \tag{1}$$

Where D_{Yj} is the top yield displacement for the jth shear wall, ϕ_{Yj} is the yield curvature at a base, ε_Y is the yield deformation of the reinforcement, l_{Wj} is the shear wall length and H is the total height. Fig.2 shows a push-over diagram between base shear V and top displacement D of the system

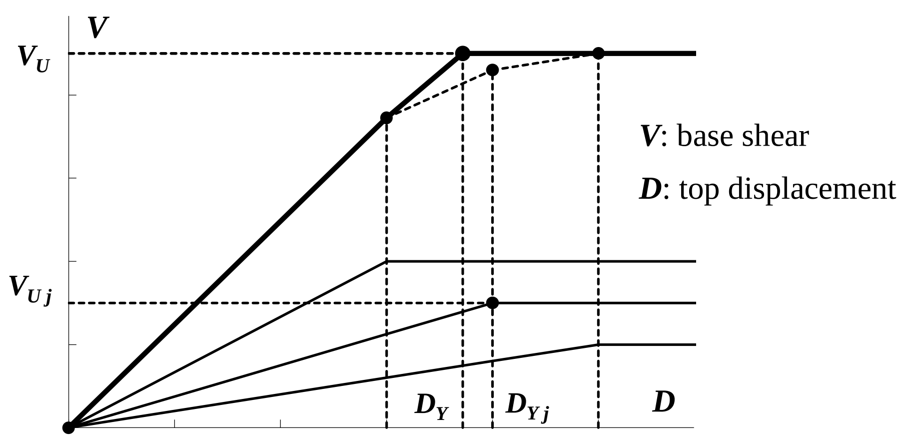


Fig. 2 – Push over diagram for a system without control

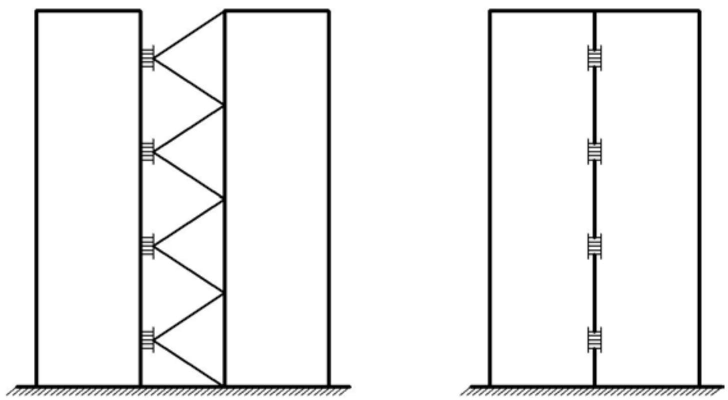
If n is the number of resistant planes or components in the system, then

$$V_U = \sum_{j=1}^{n} V_{U\,j} \;, \quad \frac{V_U}{D_Y} = \sum_{j=1}^{n} \frac{V_{U\,j}}{D_{Y\,j}} \tag{2}$$

As a design criterion, participation coefficients p_j are adopted and defined as

$$V_{U\,j} = p_j\, V_U \quad \text{with} \sum_{j=1}^{n} p_j = 1 \;\rightarrow\; D_Y = \left(\sum_{j=1}^{n} \frac{p_j}{D_{Y\,j}} \right)^{-1} \tag{3}$$

b) Systems with control: It is considered here seismic structural systems composed by plane structures incorporating passive energy dissipation devices. These are assumed to dissipate energy through yielding, and could be located as shown in Fig.3. These devices respond to vertical drift and can be related to top displacements trough de relationship defined in (4) and (5).



(a) Couple shear walls with linkage and energy dissipation devices

(b) Adjacent shear walls with and energy dissipation devices

Fig. 3 – Plane structures with energy dissipation devices

The push-over diagram for a component j is shown in Fig.4. It shows a first segment of elastic behavior, ending in point (D_{Ydj}, V_{Ydj}), point at which the devices reach yielding. Then, continues with another segment of elastic behavior for the main structure, until reaching its yield displacement D_{Yj}.

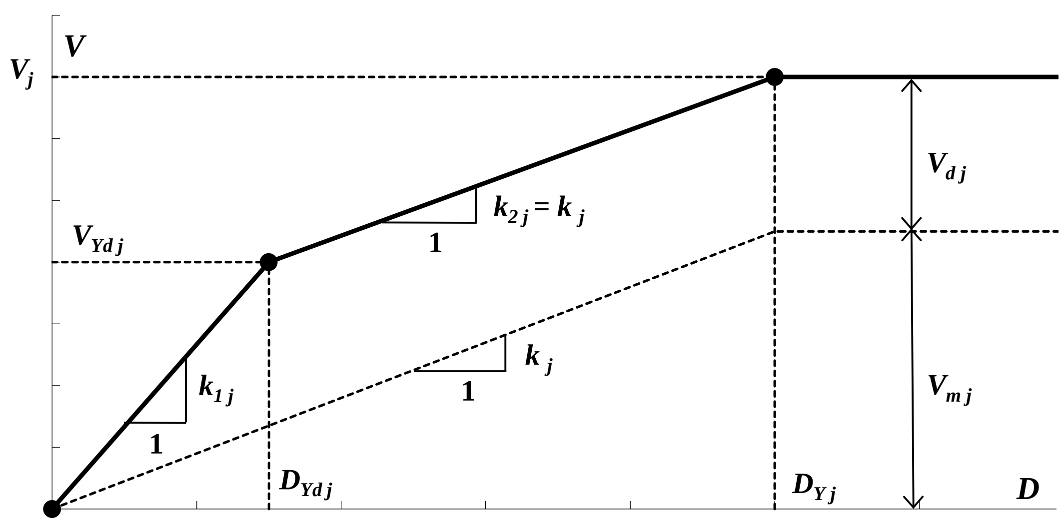


Fig. 4 – Push over diagram for a resistant plane with control devices

If the maximum shear force carried by the resistant plane is V_{mj} , and those by the devices V_{dj}, the following relations can be defined between strengths and stiffness.

$$v_j = \frac{V_{d\,j}}{V_{m\,j}}, \quad h_j = \frac{k_{2\,j}}{k_{1\,j}} \tag{4}$$

Then, the yield displacements for the dissipation devices D_{Ydj} , and for the resistant plane D_{Yj} can be obtained [16]

$$D_{Yd\,j} = D_{Y\,j}\ \frac{v_j\ h_j}{1-h_j}, \quad D_{Y\,j} = \frac{11-2.33\,v_j}{40}\ \frac{2\,\varepsilon_y}{l_{Wj}}\ H^2 \tag{5}$$

The push-over diagram for the structural system can be obtained by superposition of the respective diagrams from the resistant planes, as shown in Fig.5.

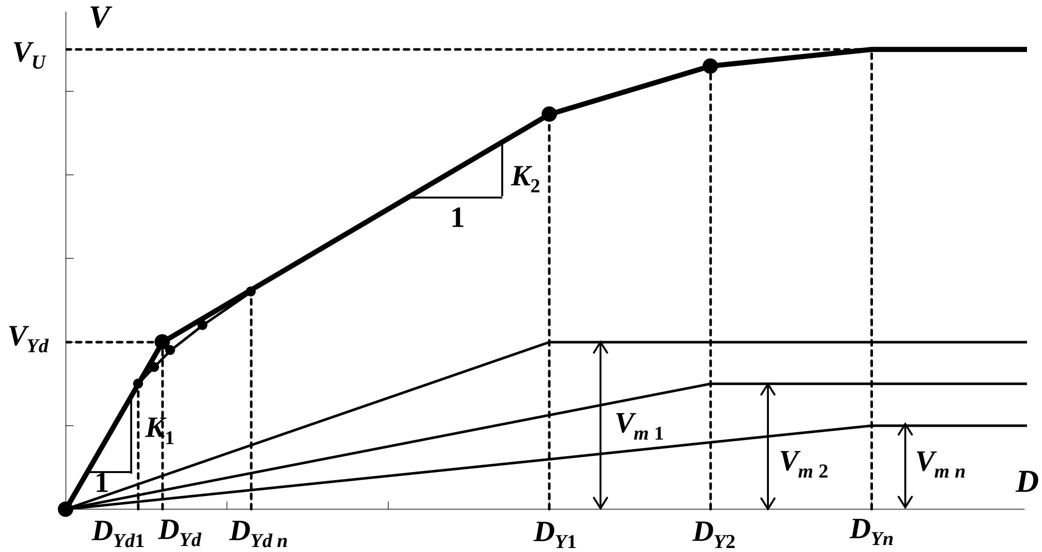


Fig. 5 – Push over diagram for a system with control devices

Approximately, the following relationships can be adopted

$$D_{Yd} = \frac{\sum_{j=1}^{n} D_{Yd\,j}}{n}, \quad h = \frac{K_2}{K_1} = \frac{\sum_{j=1}^{n} h_j}{n} \tag{6}$$

2.2 Performance objectives and requirements

For the examples in this work, each performance level is associated with an earthquake design level and with some requirements, which are shown in Table 1.

2.3 Top limit displacements

The top limit displacements can be calculated from the top yield displacements and the requirements from 2.2.

a) Systems without control:

– Rare earthquakes, life safety performance level

For each resistant plane j, and as a function of μ_j and the damage index DI_j , the equivalent ductility $\mu_{eq,j}$ and the corresponding top limit displacement $D_{\mu\,j}$ is calculated

Table 1 – Performance objectives and requirements

Performance level	Totally operational	Operational	Life safety
System without control devices		Frequent earthquake Requirements: Elastic shear walls Inter-story drift θ_{OP}	Rare earthquake Requirements: Ductility μ_j Inter-story drift θ_{LS}
System with control devices	Frequent earthquake Requirements: Elastic devices	Rare earthquake Requirements: Elastic shear walls Devices ductility μ_d Inter-story drift θ_{OP}	

$$\mu_{eq\,j} = f(\mu_j, DI_j) \quad \rightarrow \quad D_{\mu\,j} = \mu_{eq\,j}\; D_{Y\,j} \tag{7}$$

For the system, the ductility μ_s and then, with the damage index DI_s , the equivalent ductility $\mu_{eq\,s}$ are obtained. Finally, the top limit displacement result

$$\mu_s = \frac{\min\left(\mu_j\; D_{Y\,j}\right)}{D_Y} \quad \rightarrow \quad \mu_{eq\,s} = f(\mu_s, DI_s) \quad \rightarrow \quad D_{\mu\,s} = \mu_{eq\,s}\; D_Y \tag{8}$$

From de inter-story drift limit, for a generic shear wall j of total height H, and following a linear mode of lateral deformation, the top displacement is:

$$D_{\theta LS\,j} = \theta_{LS}\; H \tag{9}$$

For the system, the limit displacement $D_{\theta LS}$ is the weighted mean of the limit displacements of the component resistant planes, using the strength participation coefficients p_j. Finally, the top limit displacements for the resistant plane j and for the system are:

$$D^L_{LS\,j} = \min\left(D_{\mu\,j}, D_{\theta LS}\right), \quad D^L_{LS} = \min\left(D_{\mu\,s}\,, D_{\theta LS}\right) \tag{10}$$

– Frequent earthquakes, operational performance level

With the elastic response requirement, the top limit displacement for the resistant plane j will be $D_{Y\,j}$. The top limit displacement, associated with the maximum inter-story drift, is

$$D_{\theta OP} = \theta_{OP}\; H \tag{11}$$

Finally, for a generic plane j, the top limit displacement is:

$$D^L_{OP\,j} = \min\left(D_{Y\,j}, D_{\theta OP}\right) \tag{12}$$

b) Systems with control:

– Rare earthquakes, operational performance level

For each resistant plane j, the top limit displacement is the minimum between that from the ductility of the devices μ_d and that from the inter-story drift θ_{OP}

$$D_{\mu d\,j} = \mu_d\; D_{Yd\,j}\;, \quad D_{\theta OP} = \theta_{OP}\; H \quad \rightarrow \quad D^L_{OP\,j} = \min\left(D_{\mu d\,j}, D_{\theta OP}\right) \tag{13}$$

And for the system is

$$D_{OP}^{L} = \min\left(D_{OP\ j}^{L}\right) \tag{14}$$

– Frequent earthquakes, totally operational performance level

With the requirement of elastic response in the devices, the top limit displacement for the resistant plane j becomes

$$D_{TO,\,j}^{L} = D_{Yd,\,j} \tag{15}$$

2.4 Earthquake strength demand

a) Systems without control:

– Rare earthquakes, life safety performance level

The ductility capacity is calculated with

$$\mu_L = \frac{C_T\ D_{LS}^{L}}{D_Y} \tag{16}$$

in which C_T is a factor less than 1, that is enter at this stage to anticipate torsional displacements that are calculated later in the procedure. C_T can be iteratively adjusted, and for systems with limited rotation it is, generally, $C_T \geq 0.8$.

With the ductility capacity μ_L and the yield displacement D_Y converted to a system of one degree of freedom, the base shear V_{LS} per unit of effective weight is obtained from the inelastic capacity design spectrum (YPS) for rare earthquakes. Also the period is obtained. With V_{LS} known, it is made equivalent to V_U in the push-over diagram of Fig.2. Eq.(3) is then used to determine the strength in each resistant plane, $V_{U\ j}$, and the global stiffness $V_{U\,j}\ /\ D_{Y\,j}$.

– Frequent earthquakes, operational performance level

The period calculated previously is used with the elastic design strength spectrum, for frequent earthquakes, to calculate the top displacement D_{OP} and the base shear V_{OP}.

b) Systems with control:

– Rare earthquakes, operational performance level

The ductility capacity is calculated with

$$\mu_L = \frac{C_T\ D_{OP}^{L}}{D_Y} \tag{17}$$

in which C_T is a factor less than 1, to anticipate torsional displacements. With μ_L and D_{Yd} converted to a system of one degree of freedom, the base shear V_{OP} per unit of effective weight is obtained from the inelastic capacity design spectrum (YPS) for rare earthquakes, for the stiffness relations h defined in Eq.(4). With V_{OP}, the strength and stiffness for each resistant plane are calculated by using the following equations from the push-over diagrams in Figs.4-5.

$$k_1 = \frac{V_{OP}}{D_{Yd} + h\left(C_T\ D_{OP}^{L} - D_{Yd}\right)},\quad k_2 = h\,k_1\,,\quad \sum_{j=1}^{n} V_{m\,j} = \frac{k_2}{\displaystyle\sum_{j=1}^{n} \frac{p_j}{D_{Y\,j}}} \tag{18}$$

in which n is the number of resistant planes in the direction of interest, and p_j is the strength participation coefficient for the plane j in the sum of all the resistances, and adopted in a manner similar to that for systems without passive c ontrols (see Eq.(3)). Then

$$V_{m\,j} = p_j \sum_{j=1}^{n} V_{m\,j}\ , \quad k_{1j} = \frac{v_j\ p_j / \left(1 - h_j\right)}{D_{Yd\ j}} \sum_{j=1}^{n} V_{m\,j}\ , \quad k_{2j} = \frac{\left(1 + v_j\right) p_j - v_j\ p_j / \left(1 - h_j\right)}{D_{Y\,j} - D_{Yd\ j}} \sum_{j=1}^{n} V_{m\,j} \tag{19}$$

– Frequent earthquakes, totally operational performance level

The period T is first calculated with the stiffness k_1 and the mass associated with the first mode. From the strength design spectrum for frequent earthquakes and the period T, the top displacements D_{TO} and the base shear V_{TO} are obtained.

2.5 Displacements including torsional effects

For a generic resistant plane j with or without passive control and for each performance level considered, the top total displacement is calculated including translation and rotation

$$D_{Total\ j} = D_{Trans\ j} + D_{Rot\ j} = D_{Trans\ j} + \frac{M_T}{K_T} d_j \tag{20}$$

Where $D_{Trans\ j}$ is the translation top displacement for the resistant plane j calculated by the expressions developed in section 2.3 including the factor C_T explained in section 2.4. M_T is the torsional moment calculated with the shear base multiply by the eccentricity between the center of mass and the center of stiffness (frequent earthquake) or center of strengths (rare earthquakes), plus the accidental eccentricity required by code (if applicable). K_T is the sum of the stiffness multiplied by the square of its distance, provided by all resistant planes (frequent earthquakes) or only in the transverse direction to the analysis (rare earthquakes). d_j is the distance from the plane and the center of stiffness or resistance as appropriate.

2.6 Check limits

Finally, for a generic resistant plane j with or without passive control and for each performance level considered, the top total displacement Eq.(20) must be less than or equal to limit displacements developed in section 2.3. If these conditions are not satisfied, a modification of the structural layout would be indicated. The preliminary design is complete if the conditions are satisfied. Then, using the base shear $V_{m\ j}$ for each resistant plane, capacity-based design is applied and, with (D_{Ydj}, V_{Ydj}) the energy dissipation devices can be designed.

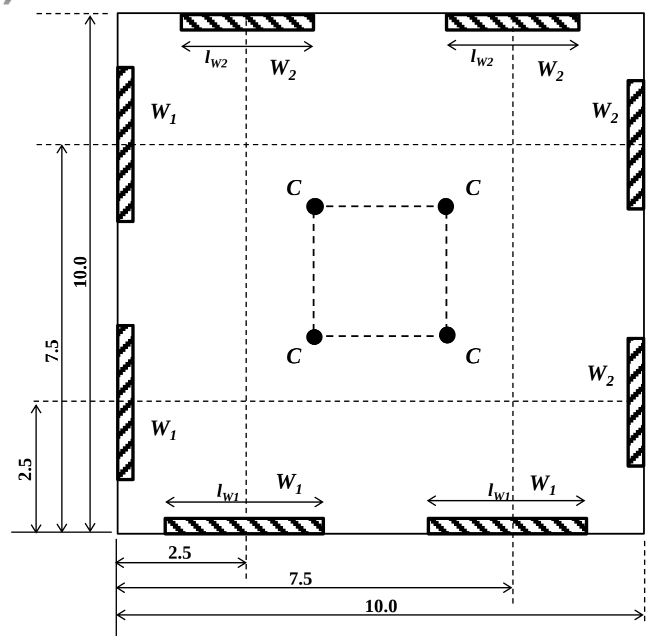
3. Numerical results and discussion

Five, eight and twelve story buildings located in Mendoza city, Argentina, are considered. Figs.6 and 7 show the arrangements of the seismic resistant planes for design with and without control devices. The Fig.8 shows the arrangement in elevation for de 5-story case, along with data for materials, gravitational loads and masses.

Table 2 contains the data used for the parameters intervening in the preliminary design. The seismic design spectra correspond to the study of microzoning for the city of Mendoza [17].

Table 2 – Performance objectives and requirements

Control		**Without**		**With**	
Earthquake		Rare	Frequent	Rare	Frequent
Performance		Life safe	Operational	Operational	Totally operational
REQUIREMENT	μ_j	μ_L	1	1	-
	ID_j	0.80	-	-	-
	θ	2.00%	0.70%	0.70%	-
	ID	0.60	-	-	-
	μ_d	-	-	8	1



Floor slab without beams.

C : Column, only for gravitational loads.

Dimensions in meters

Fig. 6 – Arrangement of resistant planes for design without control devices.

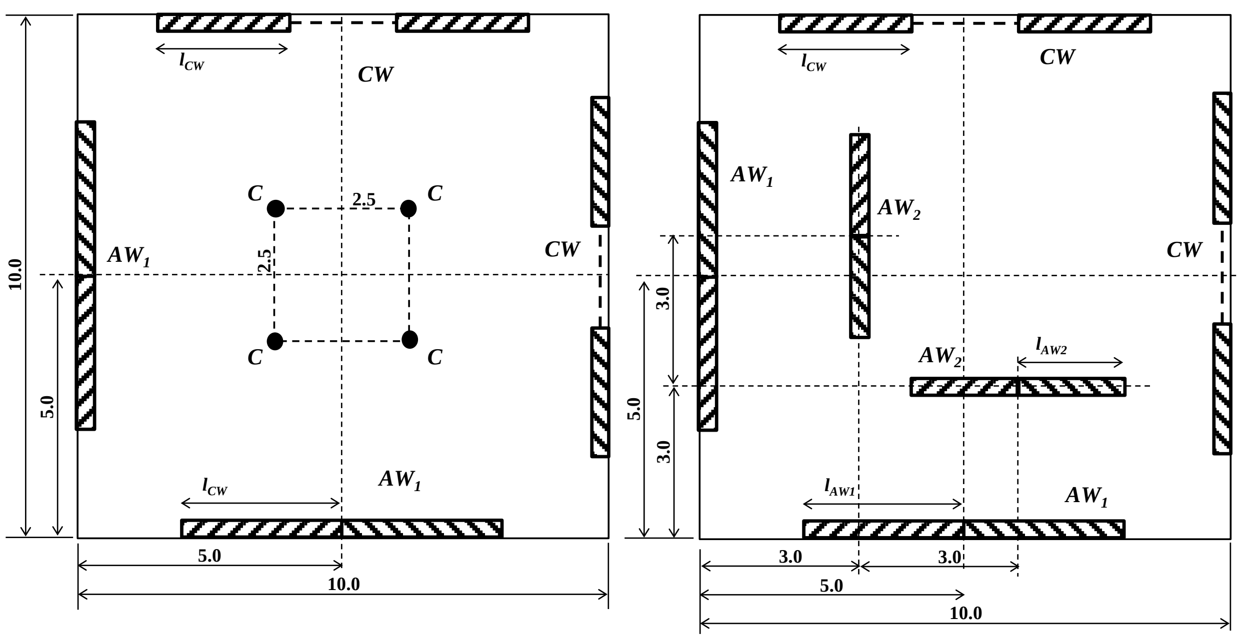


Fig. 7 – Arrangement of resistant planes for design with control devices.

The results from the preliminary design are shown in the push-over diagrams of Fig. 9 for the 8-story without control case where thick line represent the push over of the system consisting of the four walls of Fig. 6 in each direction, while Table 3 shows the total displacements $\boldsymbol{D^T}$, including torsional effects, and the corresponding limit displacements $\boldsymbol{D^L}$, for each performance level considered.

The following abbreviations have been used: ***W***: shear wall; ***l***: dimension of shear wall adopted; ***p***: strength participation coefficient for the plane in the sum of all the resistances; $\boldsymbol{V_{LS}}$: the strength in each resistant plane in life safety performance level.

Table 3 shows that the total displacements are closer to the limits for the life safety performance level than for the operational. In principle, this difference might be considered substantial, given that life safety performance is determinant for the design. The difference is due to the acceptance of a greater damage index for the resistant planes than for the system.

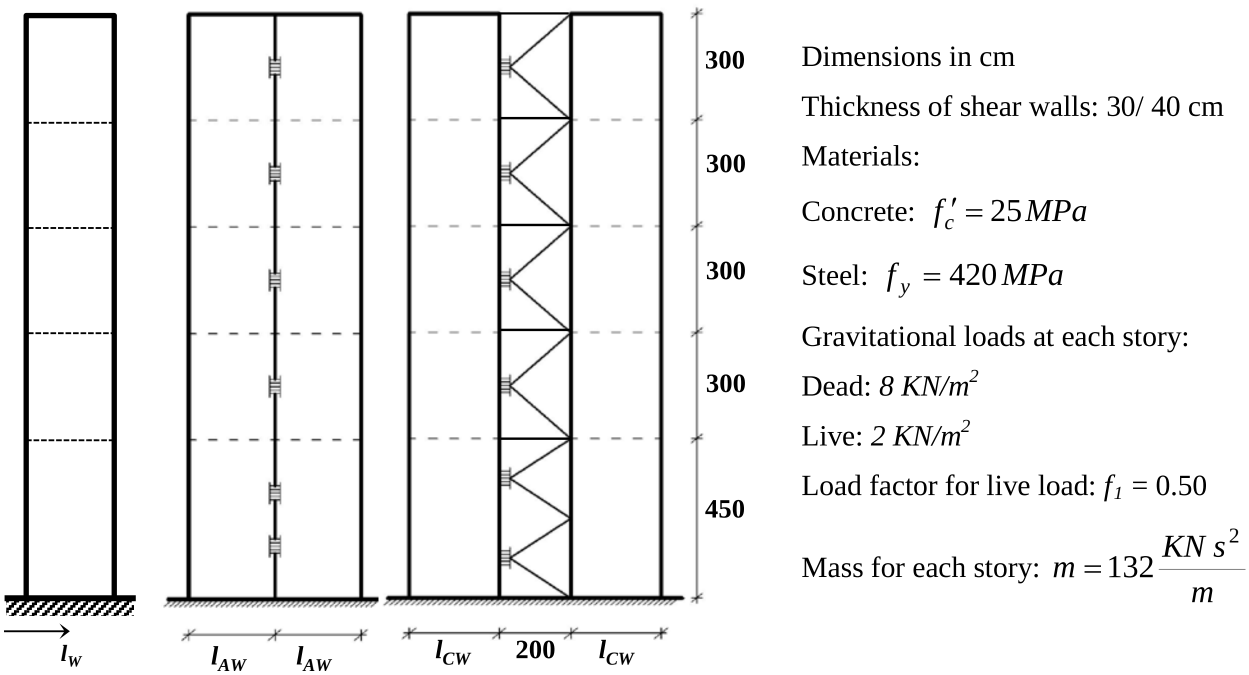


Fig. 8 – Elevation of the resistant planes

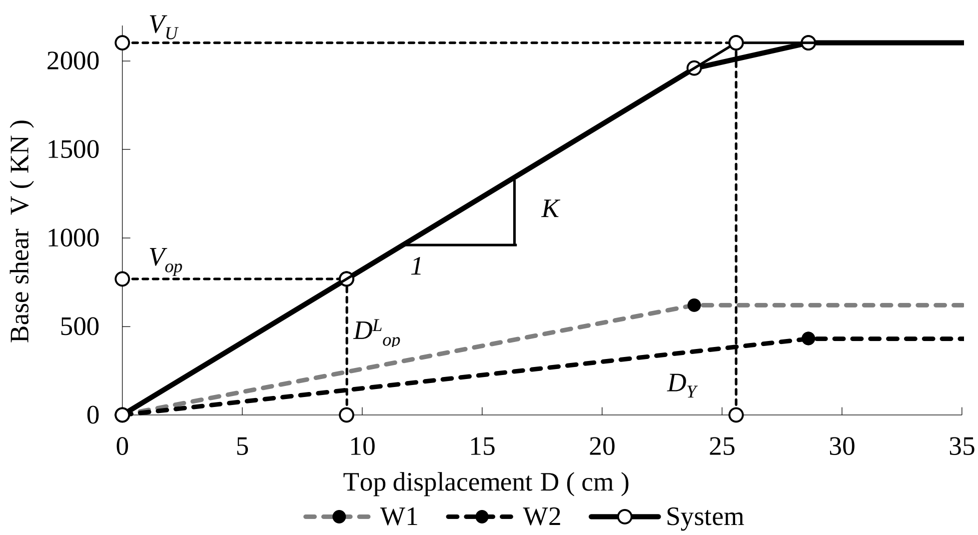


Fig. 9 – Push over diagram for the 8-story case and system without control devices

For the cases with control devices, the Fig. 10 shows the push-over for the 8-story building, while Table 4 shows the dimensions of shear wall $\boldsymbol{l}$, parameters of stiffness ratio $\boldsymbol{h}$, strength ratio $\boldsymbol{v}$ adopted and the shear force carried by the main structure $\boldsymbol{V_m}$ and those by the devices $\boldsymbol{V_d}$, the stiffness and the total displacements $\boldsymbol{D^T}$, including torsional effects, and the corresponding limit displacements $\boldsymbol{D^L}$, for each performance level considered.

h, ***v*** and ***l*** were adopted as a result of various combinations allowing verify total and limits displacements in each case, and choosing that combination that minimizes shear forces on the walls.

This whole procedure was performed with the implementation of a simple spreadsheet.

Table 3 – Performance objectives and requirements

Stories	***Dir.***	***P.***	***l (cm)***	***p***	***V_{LS} (KN)***	***Live safe***		***Operational***	
						D^L(cm)	***D^T(cm)***	***D^L(cm)***	***D^T(cm)***
5	X/Y	***W_1***	240	0.295	446	33.00	28.53	11.55	6.86
		W_2	200	0.205	310	33.00	29.47	11.55	7.32
8	X/Y	***W_1***	300	0.295	620	51.00	44.87	17.85	10.28
		W_2	250	0.205	431	51.00	46.66	17.85	10.95
12	X/Y	***W_1***	400	0.283	686	75.00	64.90	26.25	14.59
		W_2	350	0.217	525	75.00	66.40	26.25	15.10

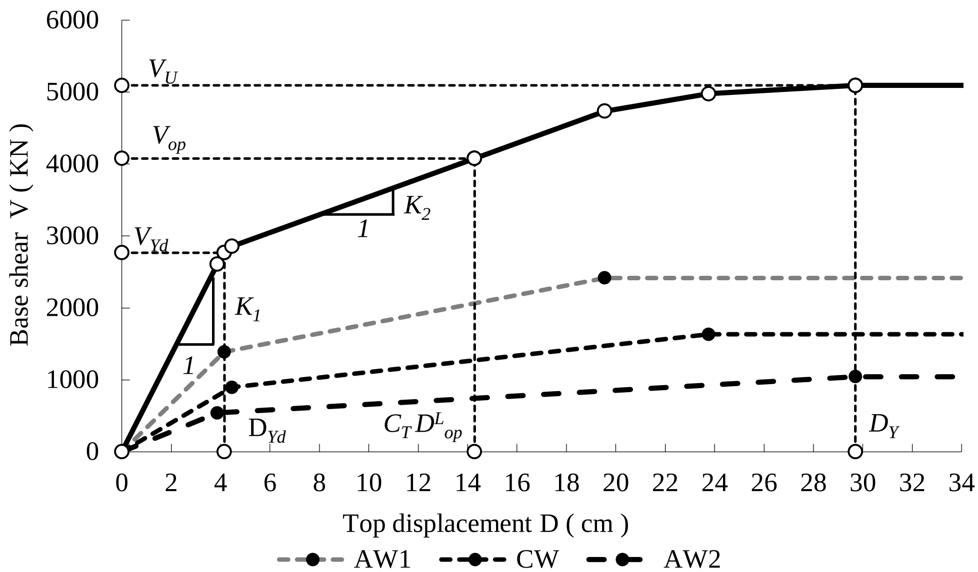


Fig. 10 – Push over diagram for the 8-story case and system with control devices, and its resistant planes, couple shear walls (CW) and adjacent shear walls (AW)

Table 4 – Performance objectives and requirements

Stories	***Dir.***	***Plane***	***l (cm)***	***v V_d/V_m***	***h k_2/k_1***	***V_m (KN)***	***V_d (KN)***	***K_1 (KN/cm)***	***K_2 (KN/cm)***	***Operational***		***Comp. Op.***	
										D^L(cm)	***D^T(cm)***	***D^L(cm)***	***D^T(cm)***
5	X/Y	AW_1	300	0.75	0.25	1480	1110	704.87	176.22	8.40	7.26	2.10	2.02
		CW	250	0.75	0.22	1028	771	463.54	101.98	10.08	7.65	2.13	2.08
8	X/Y	AW_1	300	0.85	0.20	1306	1110	334.09	66.82	17.85	15.73	4.15	4.04
		CW	250	0.80	0.19	907	726	200.92	38.17	17.85	16.94	4.46	4.33
		AW_2	200	0.80	0.14	581	464	139.61	19.55	17.85	14.52	3.87	3.73
12	X/Y	AW_1	300	0.80	0.16	1466	1173	213.97	34.23	26.25	23.20	6.53	6.38
		CW	250	0.70	0.16	1018	713	120.74	19.32	26.25	25.08	7.03	6.90
		AW_2	200	0.70	0.12	652	456	82.43	9.89	26.25	21.36	6.29	5.87

4. Conclusions

A methodology has been presented for the preliminary design of structures under earthquake demands. The structures are multi-story and may incorporate devices for energy dissipation. The procedure is based on displacements and takes into account different performance levels for different seismic demands. It is applicable to structures for which the first vibration mode is dominant.

The proposed methodology is conceptually clear, presents different blocks hinged together, related to capacity, demands and performance requirements, and the procedure is almost identical for structures with or without passive control.

The Codes could provide, without difficulties, the necessary design spectra in digital form.

Even when, in the case of energy dissipation devices, only those that work by steel yielding have been considered, the methodology is also directly applicable to other types of dissipation devices.

Similarly, even when only two levels of seismic demands and performance have been considered, the methodology can be readily extended to other levels of demand or performance.

5. References

[1] Hajirasouliha I, Asadi P, Pilakoutas K (2012): An efficient performance-based seismic design method for reinforced concrete frames, *Earthquake Engng. Struct. Dyn.*, **41**, 663–679.

[2] Wei L, Qing-Ning L (2012): Performance-based seismic design of complicated tall building structures beyond the code specification, *Struct. Design Tall Spec. Build.*, **21**, 578–591.

[3] Vamvatsikos D, Kazantzi A, Aschheim M (2015): *Performance-Based Seismic Design: Avant-Garde and Code-Compatible Approaches*, ASCE-ASME J. Risk Uncertainty Eng. Syst., Part A: Civ. Eng. C4015008.

[4] Catalán A, Foti D (2015): Multilevel performance-based procedure applied to moderate seismic zones in Europe, *Eartquakes and Structures*, **8** (1), 57-76.

[5] Paulay T (2002): An estimation of displacement limits for ductile systems, *Earthquake Engng. Struct. Dyn,* **31**, 583-599.

[6] Shabdin M, Soltani M (2012): Evaluation of direct displacement based method for seismic design of RC shear walls, *15th WCEE*, Lisboa, Portugal, ID 5237.

[7] Varughese JA, Menon D, Meher P (2015): Displacement-based seismic design of open ground story buildings, *Structural Engineering and Mechanics*, **54** (1), 19-33.

[8] Aschheim MA, Black EF (2000): Yield point spectra for seismic design and rehabilitation, *Earthquake Spectra*, EERI, **16** (2), 317–335.

[9] Dautaj A, Kabashi N, Sadiku H (2015): Method N2 according to Fajfar, *CSCE 2015, Regina Canada*. ISBN: 978-1-63248-042-2

[10] Kilar V, Koren D (2010): Simplified inelastic seismic analysis of base-isolated structures using the N2 method, *Earthquake Engng. Struct. Dyn.*, **39**, 967–989.

[11] Guo JW, Christopoulos C (2013): Performance spectra based method for the seismic design of structures equipped with passive supplemental damping systems, *Earthquake Engng. Struct. Dyn.*, **42**, 935–952.

[12] Wu CX, Zhou Y, Tong JG, Han J.J (2012): Study on the seismic performance of X-added damping and stiffness energy dissipation device, *15th WCEE*, Lisboa, Portugal, ID 331.

[13] Caterino N, Cosenza E, Azmoodeh BM (2013): Approximate methods to evaluate story stiffness and inter story drift of RC buildings in seismic area, *Structural Engineering and Mechanics*, **46** (2), 245-267.

[14] Ayala G, Castellanos H, Lopez S (2012): A displacement-based seismic design method with damage control for RC buildings, *Eartquakes and Structures*, **3** (3), 413-434.

[15] Rubinstein M, Möller O, Giuliano A (2007): Preliminary design and inelastic assessment of earthquake-resistant structural systems, *Structural Engineering and Mechanics*, **26** (3), 297-313.

[16] Rubinstein M, Möller O, Ascheri JP, Giuliano A (2012): Methodology for the seismic design of structural systems, including passive control, *15th WCEE*, Lisboa, Portugal, ID 1084.

[17] INPRES (1995): Microzonificación sísmica del Gran Mendoza, Publicación técnica N° 19, INTI.