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Displacement-based preliminary design of diagrid systems

A. Terán Gilmore[(1)], S. Roeslin[(2)] A. Quiroz Ramírez[(3)], E. Cuadros Hipólito[(4)], J. Olivera González[(5)]

[(1)] *Professor, Universidad Autónoma Metropolitana, tga@correo.azc.uam.mx*
[(2)] *Graduate Student, Ostbayerische Technische Hochschule, sroeslin@hotmail.com*
[(3)] *Postgraduate Student, Universidad Autónoma Metropolitana,aqr@correo.azc.uam.mx*
[(4)] *Graduate Student, Universidad Nacional Autónoma de México, shepsaline@yahoo.com.mx*
[(5)] *Undergraduate Student, Universidad Autónoma Metropolitana, js_og35@hotmail.com*

Abstract

In recent years, the diagrid (diagonal grid) system has offered an attractive option to carry the gravity and wind loads acting on tall buildings located in non-seismic zones. In spite of the possible advantages that this type of structural system can offer for tall buildings located in high seismicity zones, very few studies have been devoted to make possible this application. This paper describes a performance-based seismic design methodology for diagrid systems that contemplates two steps: A) *Global Predesign* and B) *Local Predesign.* The first step establishes, as a function of the required structural performance, a lateral roof displacement threshold. Then, the use of this threshold and of a design displacement spectrum allows for the estimation of the lateral stiffness required by the diagrid system in terms of a target value for its fundamental period of vibration. During the second step, the diagonals of the diagrid system are sized in such a manner as to satisfy its lateral stiffness requirements; that is, the area of the diagonals is estimated so that the building exhibits a fundamental period of vibration that matches its target value. The use of the methodology is illustrated during the predesign of a 24-story building having a circular plan and located in the Lake Zone of Mexico City. Then, the global mechanical characteristics of the building are determined through a nonlinear static analysis, and its structural performance evaluated through a series of nonlinear dynamic analysis.

Keywords: diagrid; displacement-based design; steel structures; tall buildings

1. Introduction

Several tall buildings around the world have used structural systems consisting of large perimetral steel frames arranged in triangular modules (diagrid). The horizontal elements of the triangular modules form perimetral rings that ensure the structural integrity of the diagrid. It is worth mentioning that the difference between a conventional perimetral braced system and a diagrid is that the second does not have vertical members (columns), since its diagonal members support simultaneously vertical and lateral loads. In general, the low consumption of structural material makes diagrid systems part of ambitious sustainable projects that have won major international recognition. The possibilities offered by diagrid systems in terms of combining aesthetic expression, versatility and structural efficiency, have been discussed thoroughly [1]. Despite the benefits that the use of the diagrid concept has represented from a sustainable point of view, its use has not been studied sufficiently for high seismicity areas. Nowadays, there is the need to develop conceptual tools to help the structural engineer during the conception and preliminary sizing of earthquake-resistant diagrid systems.

Innovation in earthquake-resistant design has been directed towards the conception of structural systems, either traditional or innovative, that are capable of adequately limiting their level of structural and nonstructural damage through the explicit control of their lateral deformation. Within this context, a displacement-based design methodology for the conception and preliminary seismic design of a diagrid is developed and illustrated. The methodology considers one performance level, and addresses the sizes (areas) and yield stress of the diagonal members, and the geometry and structural layout of the diagrid.

2. Design Methodology

The methodology offered in this paper is based on the conception of a building whose gravity forces are carried by flexible moment-resisting frames with standard detailing and, to a lesser extent, by a perimetral diagrid. Earthquake-resistance is provided in full by the latter. In the remainder of this paper, the moment-resisting frames will be referred as the *gravitational system*, and the perimetral diagrid as *diagrid*.

Regarding performance for severe ground motion (usually associated to an earthquake hazard level characterized by a probability of exceedance of 5% in 50 years), it will be considered that the building exhibits adequate performance if it satisfies the *Immediate Occupancy* performance level and it can be easily repaired. The design methodology can be readily modified to incorporate different or additional performance levels according to the project's needs. Within this context, it should be mentioned that the design objective under consideration in this paper is used for illustrative purposes.

In terms of modeling, the methodology assumes that: A) The slabs of the floor system act as rigid diaphragms; B) The total required lateral stiffness of the building is provided in full by the diagrid; and C) The global shear and flexural drifts of the diagrid can be estimated independently of each other. Under these three assumptions, it is possible to formulate the simple model shown in Fig. 1. For preliminary design purposes, the diagrid is modeled as an equivalent single-degree-of-freedom system that has two springs working in series: one that represents the global shear stiffness and another one that represents the global bending stiffness. In what follows, several subscripts are used to address the different sub-systems that integrate the structural system of the building. Subscripts *GS* and *D* refer to the gravitational system and the diagrid, respectively. Subscripts *S* and *B* will refer to the global shear and bending properties, respectively, of the diagrid.

The methodology introduced herein, applicable to standard occupation buildings and shown in Fig. 2, considers one intensity seismic level. Its first step implies establishing a qualitative definition of adequate performance. This is done through the explicit consideration of the acceptable levels of damage on the different sub-systems that compose the building (diagrid, gravitational and nonstructural). The second step consists in the quantification of adequate performance through establishing response thresholds. During the third step, the methodology establishes, through the use of a displacement spectrum, the design value for the fundamental period of vibration of the diagrid (which quantifies the design lateral stiffness). The sizes of the diagonal members of the diagrid are established according to the value of this period.

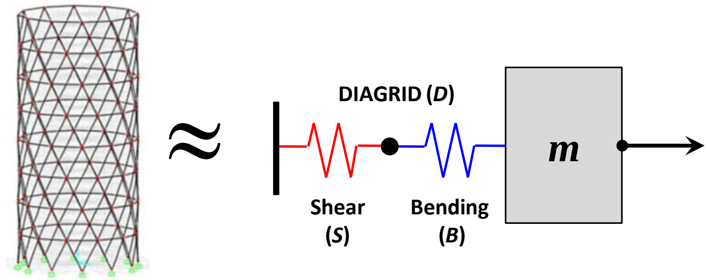

Fig.1 - Equivalent single-degree-of-freedom system

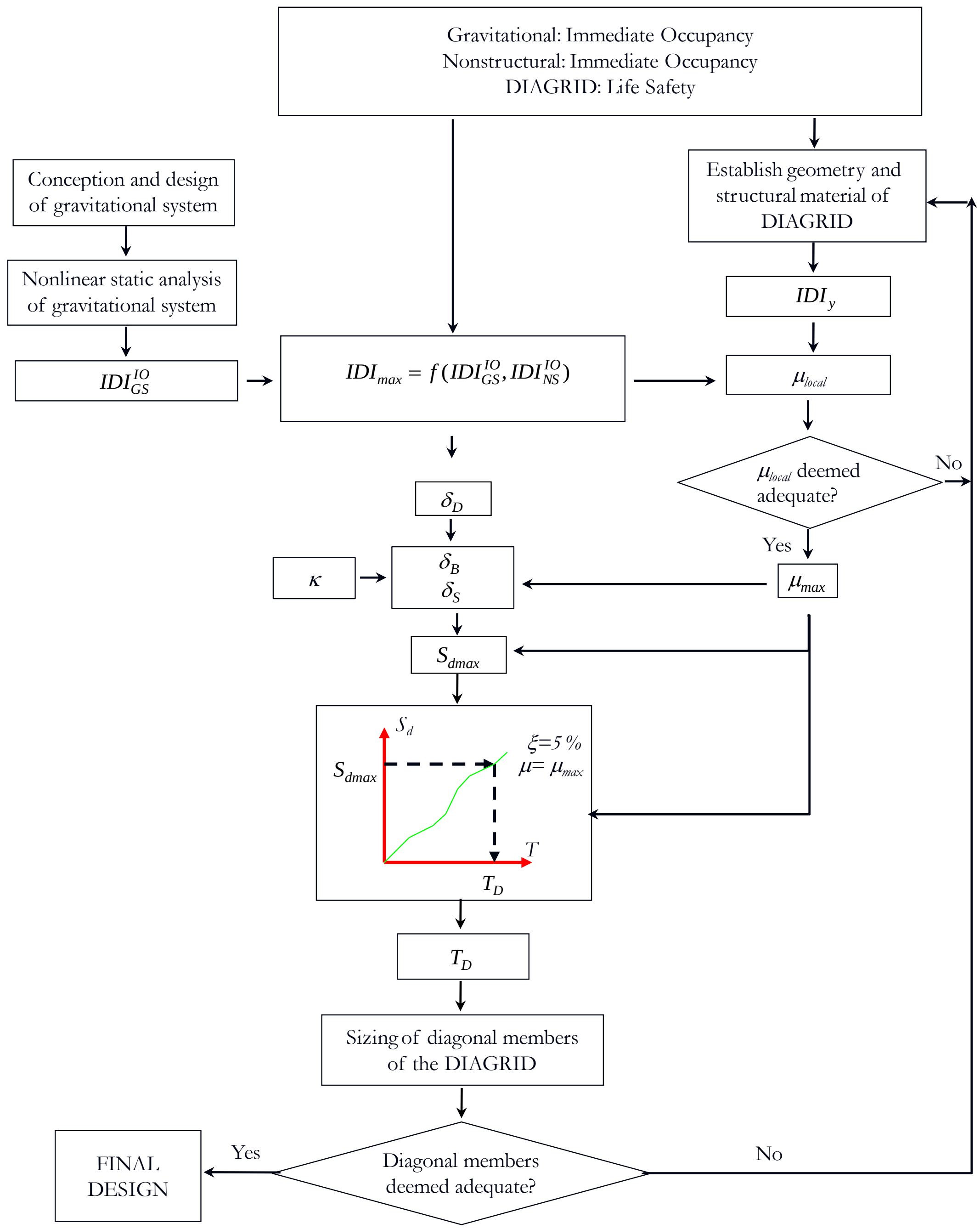

Fig.2 - Preliminary design methodology

In qualitative terms, the performance level under consideration is satisfied if the gravitational system and diagrid comply, respectively, with the *Immediate Occupancy* and *Life Safety* performance levels. The nonstructural system should satisfy *Immediate Occupancy*.

Regarding the quantification of performance, it is important to establish interstory drift index thresholds. Within this context, IDI_{GS}^{IO} and IDI_{NS}^{IO} denote the maximum interstory drift index demands allowed in the building so that the gravitational and nonstructural systems, respectively, are able to satisfy *Immediate Occupancy*. In the case of the diagrid, it is considered important to limit its maximum global ductility demand (μ_{max}) in such a manner as to control plastic deformation demands in its diagonal members, and thus, prevent or delay buckling. If large ductility demands are allowed, buckling-restrained braces can be used [2,3].

Numerical design starts with the conception and design of the gravitational system. The system is designed to exclusively resist the gravitational loads that are tributary to it. The gravitational loads taken by the diagrid should be ignored at this step. Within this context, it is recommended that the geometrical layout of the building is so, that only a small portion of the gravitational loads are tributary to the diagrid.

Once the gravitational system is designed, a nonlinear static analysis is carried out to establish IDI_{GS}^{IO}. For this purpose, an acceptable threshold for the plastic rotation in the structural members of the gravitational system can be defined (typically 0.005), and IDI_{GS}^{IO} defined as the interstory drift index at which those members reach it. Experience or experimental results can be used to establish IDI_{GS}^{IO}. For instance, IDI_{GS}^{IO} = 0.01 should yield reasonable design in a majority of cases. As shown in Fig. 2, the maximum interstory drift index demand allowed in the building (IDI_{max}) should be equal or smaller than the smallest of IDI_{GS}^{IO} and IDI_{NS}^{IO}.

Simultaneously to the design of the gravitational system, the structural characteristics of the diagrid should be established. This implies choosing the structural material (steel in the vast majority of cases) and defining the geometry and structural layout. Of particular importance is the angle that the diagonals form with respect to the plane of the horizontal floor systems (θ). This angle should be in a narrow range of values centered around 70^0 [4]. With the yield strength of the steel (f_y) and θ, it is possible to establish the interstory drift index at which the diagonal members of the diagrid yield:

$$IDI_y = \frac{f_y}{E \sin\theta \cos\theta} \tag{1}$$

where E is the modulus of elasticity of steel. With the value of IDI_y, it is possible to determine the local ductility demand acting on the diagonal members:

$$\mu_{local} = \frac{IDI_{max}}{IDI_y} \tag{2}$$

It is recommended to limit μ_{local} to values close to 1.5. This can be achieved, as discussed in the example presented later, by a careful selection of the values of f_y and θ. Then a global value of ductility is assigned to the diagrid as a function of μ_{local}:

$$\mu_{max} = \frac{\mu_{local}}{\beta} \tag{3}$$

where β is a correction factor larger than one that depends on the level of structural irregularity along height, and increases with increasing number of stories and the maximum ductility to be developed by the building [5,6]. An increase in post-yield stiffness reduces significantly the value of β, and decreases its dependence with respect to the number of stories and maximum ductility. If as suggested before, the ductility demand in the diagrid is tightly controlled; the value of β for a regular diagrid tends to be small, in such a manner that $\mu_{max} \approx \mu_{local}$.

The next step establishes a design threshold for the total roof displacement:

$$\delta_D = \frac{IDI_{max} H}{COD} \tag{4}$$

where δ_D is the maximum allowable roof displacement, which includes the contribution of the global shear and bending behaviors; IDI_{max} the design threshold for interstory drift index; H the total height of the building; and COD a coefficient of distortion that considers that interstory drift is not constant along height. Based on the results obtained by the authors, the use of a COD of 1.2 is suggested for the displacement-based preliminary design of slender diagrid systems. Strictly speaking, a COD of 1.2 works well for diagrid systems that exhibit elastic behavior. Nevertheless, if as suggested before, the local and global ductility demands are constrained to small values, the above value of COD results in reasonable preliminary design.

The fundamental period of vibration of the building can be estimated through the use of roof displacement thresholds corresponding to the global shear and bending behaviors of the diagrid, and a displacement spectrum corresponding to the design ground motion. Before the spectrum can be used, the roof displacements need to be corrected so that they represent those of an equivalent single-degree-of-freedom system:

$$S_d = \frac{\delta_{roof}}{\alpha} \tag{5}$$

where S_d denotes pseudo-displacement, δ_{roof} the roof displacement, and α a correction factor that transforms the roof displacement into an S_d demand.

Based on recommendations of FEMA 306 [7] and studies reported in [8,9], Table 1 presents values of α that can be used for the preliminary design of a diagrid that exhibits structural regularity along height. α_S and α_B denote the transformation factors for global shear and bending behaviors, respectively. Note that the correction factors associated to shear and bending behaviors are not necessarily equal.

Table 1 – Values of α_S and α_B to be used for preliminary design of regular diagrid systems

Stories	Shear (α_S)	Bending (α_B)
1	1.00	1.00
2	1.20	1.20
3	1.30	1.30
4	1.35	1.35
5	1.40	1.40
10	1.40	1.50
15	1.40	1.55
20+	1.40	1.60

To establish roof displacement thresholds corresponding to the global shear and bending behaviors (δ_S and δ_B, respectively), there is a need to assume a value for the ratio κ, defined as:

$$\kappa = \frac{S_{dS}}{S_{dB}} \tag{6}$$

where S_{dS} and S_{dB} are the lateral displacements due to global shear and bending behaviors of the single-degree-of-freedom representation of the diagrid. κ equal to 1 provides reasonable preliminary design.

Once a value of κ is assumed, the simplified model discussed by [10] yields:

$$\delta_S = \frac{1}{1+\frac{\alpha_B}{\alpha_S \kappa}} \delta_D \tag{7}$$

$$\delta_B = \frac{1}{1+\frac{\alpha_S \kappa}{\alpha_B}} \delta_D \tag{8}$$

where the values of α_S and α_B are established with Table 1 as a function of the number of stories in the building. The roof displacement threshold expressed in terms of pseudo-displacement is estimated as:

$$S_{dmax} = S_{dS} + S_{dB} = \frac{\delta_S}{\alpha_S} + \frac{\delta_B}{\alpha_B} \tag{9}$$

Pseudo-displacement will be used herein to denote a displacement demand or threshold formulated in terms of a single-degree-of-freedom system. Although Eq. (9) is not strictly applicable to a multi-degree-of-freedom system because the modal heights associated to the first modes of vibration corresponding to the global shear and flexural drift modes are not necessarily equal, this equation yield reasonable results for preliminary design. As illustrated in Fig. 2, with S_{dmax} and the design spectrum (which is established for ductility μ_{max} and a percentage of critical damping of 5%) the target value for the fundamental period of vibration of the diagrid (T_D) is determined. Recently, it has been suggested that tall buildings should be designed with design spectra corresponding to 2% of critical damping [11]. Note that the methodology can be easily adapted to any value of damping assumed to apply to the diagrid.

Under the assumption that the diagrid has to provide all the lateral stiffness of the building, the stiffness-based sizing of the diagonal members should result in that the actual fundamental period of vibration of the diagrid is as close as possible to T_D. To promote a stable behavior of the diagrid when it incurs in plastic behavior, it is strongly recommended that their areas are reduced along height according to a linear variation or to an assumed lateral shear distribution. In this paper, the following restrictions will be applied to the sizing procedure: A) All diagonal members that conform a triangular module have the same area; and B) The horizontal members of the triangular modules of the diagrid have the same area of the diagonal members located immediately under them.

Once the sizing of the diagonals is carried out, design proceeds to its final stage. Final design consists of two tasks: A) The verification of the preliminary design through a series of nonlinear time-history analysis; and B) If required, resizing of the structural members of the diagrid so that the building can meet adequately its performance level. The use of methodologies for preliminary design, such as the one introduced in this paper, should result in that the preliminary design converges into its final version with no or a few iterations.

3. Design Spectrum

To establish the design spectrum, a set of 10 ground motions was considered. The motions have a dominant period (T_S) of motion of 2s. The design spectrum corresponds to the mean plus one standard deviation *(σ)* spectrum corresponding to the motions included in the set. Because of the lack of motions recorded in the Lake Zone of Mexico City during severe earthquakes, a series of synthetic motions were generated. The motions, which intend to reflect the characteristics of the motion recorded during September 1985 at the *Secretaría de Comunicaciones y Transporte* (SCT) in the *E-W* direction, were generated through a two-stage simulation algorithm [12]. The seed motion used for this purpose was recorded during 1989 at the SCT site. The inelastic design spectrum was built from an elasto-perfectly-plastic model, which is considered to properly represent the *low-amplitude* cyclic lateral response of the diagrid.

4. Example

Figs. 3 and 4 show the geometrical and structural configurations of the building considered herein to illustrate the application of the displacement-based methodology. As shown, the building has a circular plan with a diameter of 34.2m for the gravitational system, and a distance of 18.25m from the centroid of the plan to the farthest point of the diagrid system. The usable area of the building is defined by that of the plans of the gravitational system. The building has 24 stories with a height of 3.5m. This results in a total height of 84m. The building has a core of 10m × 10m used to accommodate the elevators and other services. The total area of each floor of the gravitational system is 918m^2.

The choice for the module angle should consider the balance between two contradictory necessities [1,4]. On one hand, a small module angle provides a high shear rigidity. On the other hand, an angle equal to 90^0 delivers the maximum bending stiffness. Also and in terms of an earthquake-resisting diagrid, the angle has to be carefully chosen to control the local ductility demands on its diagonal members. To achieve simultaneously all these interlapping necessities, values of θ close to 70^0 should be used. Because of this, the 4-story triangular modules shown in Fig. 4b were used to configure the diagrid. The triangular module has a height of 14m, and a length at the base of 9.45m. Each diagonal member forms an angle θ of 71.4^0 with respect to the plane of the floor systems, and has a length of 3.69m in each story.

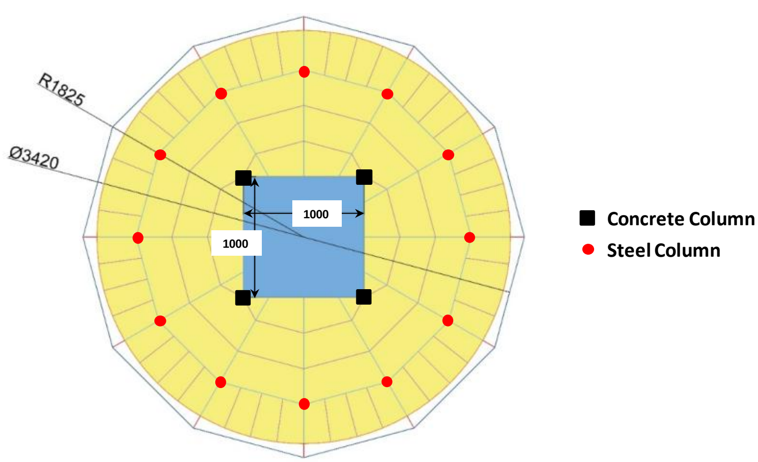

Fig.3 - Plan view of 24-story building

It was decided to use reinforced concrete frames to structure the service core of the building, and steel moment-resisting frames for the rest of the gravitational system. Standard detailing was used for the frames. It is important to mention that the internal core do not use concrete walls. Preliminary sizes were established by hand calculation for beams and columns. For the final design of these members, strength checks were carried out using a refined analytical model of the gravitational system. Finally, minor modifications were carried out on the properties of the members to promote a more stable behavior under lateral loading. Typically. these modifications followed a capacity design approach, and focused on providing the structural members of the frames with a capacity to develop plastic bending behavior before developing shear dominated structural damage.

Steel decks were provided in all stories to resist the gravitational loads. The only opening in the steel decks correspond to the service core of the building. A992Fy50 steel was used in the steel frames. W18×46, W18×40, W18×35 and W14×43 shapes were used in each floor for the steel beams (the frames have the same structural configuration in all floor systems). The columns used W14×283, W14×211 and W14×132 shapes, respectively, for the bottom, intermediate and top 8 stories.

Concrete with compressive strength (f_c') of 4200kg/cm^2 was used for the beams and columns of the reinforced concrete core. For reinforcement, A615Gr60 rebars were used. While the cross sections of the beams were 35.56cm×25.4cm, those of the columns were 67.31cm×67.31cm. As was the case for the steel frames, capacity design concepts were used to stabilize the lateral plastic behavior of the reinforced concrete core. The beams used #7 and #3 bars for their longitudinal and transverse reinforcement. In the case of the columns, #10 and #3 bars were used, respectively.

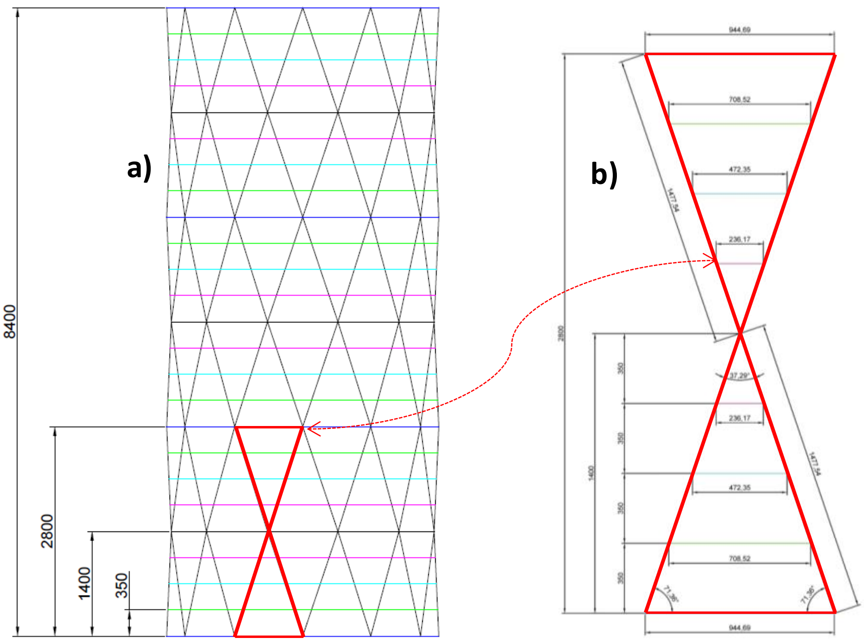

Fig.4 - Elevation views of 24-story building: a) Diagrid; b) Triangular module

In qualitative terms, the performance level under consideration is satisfied if the gravitational system and diagrid, respectively, comply with the *Immediate Occupancy* and *Life Safety* performance levels. As discussed before, it is recommended that the geometrical layout of the building is so that only a small portion of the gravitational loads are resisted by the diagrid. This has been achieved through the configuration provided to the gravitational system (see Fig. 3).

It was assumed that IDI_{GS}^{IO} = 0.01, and that nonstructural elements have been detailed in such a manner that nonstructural damage does not restrict the lateral deformation threshold of the diagrid. Under this circumstance, IDI_{max} = 0.01. At this point, the structural layout of the diagrid, illustrated in Figs. 3 and 4, has been established. In terms of structural material, it was decided to use A992Fy50 steel. An f_y of 3515kg/cm^2 and an overstrength factor of 1.2 are considered for this steel. As discussed before, the structural layout of the diagrid results in θ=71.4^0. The interstory drift index at which the diagonal members of the diagrid yield is:

$$IDI_y = \frac{3515 \times 1.2}{2'100{,}000\, sin(71.4^0)\, cos(71.4^0)} = 0.0066 \qquad (10)$$

The local ductility demand on the diagonal members is:

$$\mu_{local} = \frac{0.01}{0.0066} = 1.5 \qquad (11)$$

As discussed before, it is recommended to limit μ_{local} to values close of 1.5 through the careful selection of the values of f_y and θ. Due to the small plastic demands on the diagrid system, it is reasonable to assume that $\mu_{max} \approx \mu_{local}$ = 1.5. The design threshold for the total roof displacement is estimated as:

$$\delta_D = \frac{0.01 \times 84}{1.2} = 70cm \qquad (12)$$

Assuming that κ=1, the roof displacement thresholds corresponding to the global shear and bending behaviors are:

$$\delta_S = \frac{1}{1+\frac{1.6}{1.4}} 70 = 32.67cm \tag{13a}$$

$$\delta_B = \frac{1}{1+\frac{1.4}{1.6}} 70 = 37.33cm \tag{13b}$$

where the values of α_S and α_B are established from Table 1 by considering that the building has 24 stories. The roof displacement threshold expressed in terms of pseudo-displacement is estimated as:

$$S_{dmax} = \frac{32.67}{1.4} + \frac{37.33}{1.6} = 23.33 + 23.33 \approx 47cm \tag{14}$$

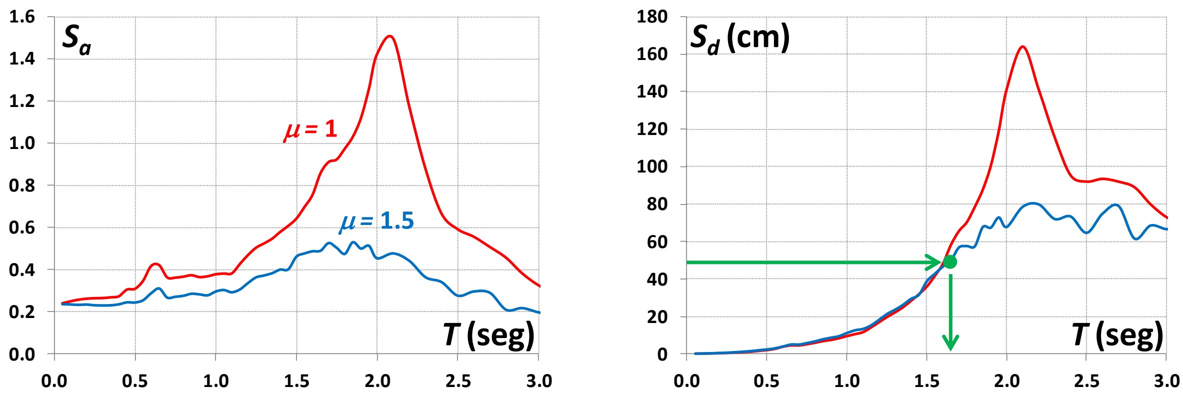

Fig.5 - Design spectra, ξ = 0.05: a) Strength; b) Displacement

Fig. 5 shows the design spectra. As shown in Fig. 5b, the target period is equal to 1.65s. A value of 1.6s was used for the stiffness-based sizing. Table 2 summarizes the areas established for the diagonal members of the diagrid. Note that a linear variation of areas along height was selected to promote a reasonable distribution of plastic demands along height. The third and fourth columns of the table are provided to give an idea of the sizes the diagonal members would have if solid square or circular cross sections were used.

Table 2 - Definitive areas for the diagonal members of the diagrid

Stories	Required Area (cm)	Side (square) (cm)	Diameter (circle) (cm)
21-24	146	12,1	13,6
17-20	291	17,1	19,2
13-16	436	20,9	23,6
9-12	582	24,1	27,2
5-8	727	27,0	30,4
1-4	873	29,5	33,3

5. Mechanical Characteristics

A nonlinear static analysis of a three-dimensional model of the 24-story building was carried out to evaluate its mechanical characteristics. The lateral force distribution along height used for this purpose was defined to be proportional to the first mode of vibration. The nonlinear model of the building, established with SAP2000, considered the structural members of the concrete core, the steel moment-resisting frames, and the diagrid.

Since the axial behavior of the diagonal members of the diagrid dominates their response to lateral loading, releases were introduced at their ends in order to simulate pin-end connections. The horizontal members of the diagrid considered continuity in terms of their bending behavior. An axial plastic hinge with elasto-perfectly-plastic behavior was provided to the diagonal members of the diagrid. To estimate their axial strength, the expected yield stress of steel was considered to be 20% larger than its nominal value. While the beams of the frames were assigned a bilinear behavior with 1% strain-hardening; the model of the columns considered the combined effect of biaxial-bending and axial load, and a bilinear behavior with no strain hardening. Expected material strengths were used to estimate the structural properties of beams and columns, particularly in terms of the bending strength of their rotational plastic hinges. In this respect, the expected yield stress of the steel and the compressive strength of concrete were considered to be 20 and 10% larger, respectively, than their nominal value. While the cyclic response of the members of the steel frames was modeled as elastoplastic, a stiffness degrading model was used for the concrete members.

Fig. 6 shows the capacity curve of the building. Inelastic behavior is first developed in the diagrid at a roof displacement of 43cm. The first plastic hinge in the gravitational system appears in the concrete beams of the service core at a roof displacement close to 70 cm. As shown in the figure with the red circle, the roof displacement at yield is estimated at 54cm. Note that the global ductility that the building develops when it reaches its design roof displacement is equal to $\mu_{max} = 70/54 \approx 1.3$, which is slightly smaller than the value of 1.5 estimated for μ_{local} at the beginning of the design process. It was discussed before that μ_{max} for a regular diagrid should be slightly smaller than its corresponding μ_{local}, and it was suggested that for practical purposes these two values should be considered equal as an alternative to the use of Eq. (3). As for the example developed herein, using a design spectra corresponding to μ_{max} of 1.5 practically yields the same target period as using the more refined estimation of 1.3.

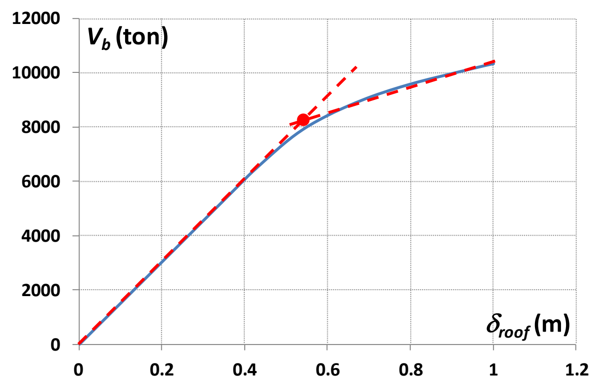

Fig.6 - Capacity curve of 24-story building

For the roof displacement threshold used for design purposes (0.70m), no plastic hinges have developed in the concrete core and steel frames, in such a manner that the gravitational system complies with the performance level of *Immediate Occupation*. Fig. 7 shows the distribution along height of lateral deformation for roof displacements of 0.20, 0.40, 0.60, 0.80 and 1m. It can be noted that the lateral deformation is spread in a practically uniform manner along height, and that this distribution is reasonably kept up to roof displacements of 1m. This occurs in spite of the fact that for roof displacements larger than 60cm, interstory drift index demands start accumulating on the bottom four stories. Although this suggests that nonlinear demands tend to accumulate in the triangular module located at the bottom part of the diagrid, it should be mentioned that this concentration is not excessive in such a manner that the building exhibits a notable stable behavior for a roof displacement of

1m (which exceeds by about 50% the roof displacement threshold used for design purposes). For a roof displacement of 70cm, the maximum intestory drift index demand is equal to 0.009, value that is very close to the value of 0.01 assumed for this roof displacement within the displacement-based format.

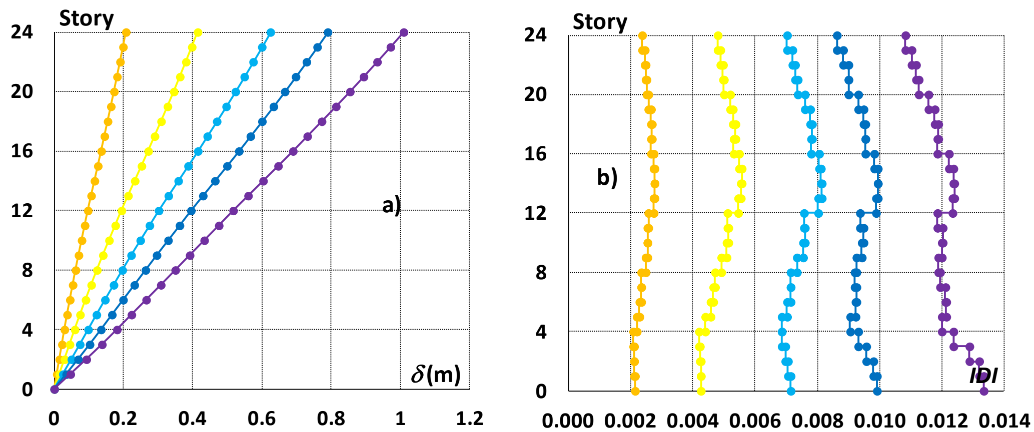

Fig.7 - Distributions of lateral deformation along height, nonlinear static analysis: a) Story displacement; b) Interstory drift index

6. Seismic Performance

To evaluate the seismic performance of the 24-story building, a series of nonlinear time-history analyses were carried out. The motions used for this purpose were those used to establish the design spectrum. The nonlinear model of the building considered 5% of critical damping. Viscous damping was considered through a Rayleigh matrix that assigned the indicated damping to the first two modes of the braced building. Fig. 8 shows, for each ground motion under consideration, envelopes for the lateral displacement and inter-story drift distributions along height. The thicker black lines correspond to the mean + σ demands. Regarding roof displacement demands, the nonlinear dynamic analyses estimate a mean + σ value of 68cm, which is slightly smaller than the design threshold of 70 cm. The largest value of the mean + σ interstory drift distribution is about 0.009, which is slightly smaller than its corresponding design threshold of 0.010. Note that the drift distributions along height shown in Fig. 7b for the nonlinear static analysis are similar to those shown in Fig. 8b. The design assumptions implied by the methodology have resulted in a building that has adequately controlled its lateral drift at the global and interstory levels. The relatively uniform distribution along height of interstory drift indicates a reasonable sizing of the members of the diagrid.

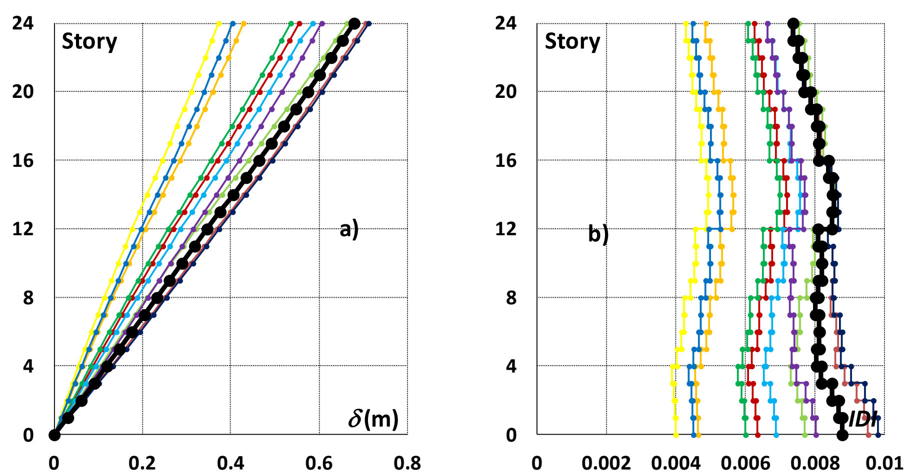

Fig.8 - Distributions of lateral deformation along height, nonlinear dynamic analyses: a) Story displacement; b) Interstory drift index

7. Conclusions

Diagrid systems exhibit a notable capacity to control the lateral response of earthquake-resistant buildings. In this sense, they constitute an attractive option, from the point of views of sustainability and structural security, to conform the structural system of tall buildings located in high seismicity zones.

A displacement-based methodology has been formulated to aid during the conception and preliminary design of diagrid systems. Such a methodology does not only provide a quantitative practical tool to size the members of the diagrid, but constitutes a conceptual basis that help understand the nature of the decisions that need to be taken to stabilize the lateral response of the system and optimize its design.

Within the context of the displacement-based seismic design methodology, the area of the structural members of the diagrid should be determined as a function of the fundamental period of vibration required by the building to adequately control the level of damage in all relevant sub-systems. An option to stabilize the global lateral response of the diagrid system is to provide its diagonal members with the capacity to undergo moderate nonlinear behavior without excessive structural degradation, and to tightly control their plastic deformation demands. In terms of control, it is important to use appropriate values for the yielding stress of the steel use to fabricate the diagrid and the angle its diagonal members form with respect to the plan of the floor systems.

The application of a displacement-based methodology to a 24-story building has given place to an adequate level of seismic design. The diagrid system that provides earthquake-resistance to the building exhibits a notable stability for roof displacements that are considerably larger than those considered during its design.

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