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Considerations about the determination of γ_z coefficient

Considerações sobre a determinação do coeficiente γ_z

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Abstract

In this work, the γ_z coefficient, used to evaluate final second order effects in reinforced concrete structures, is studied. At the start, the influence of the structural model in determination of γ_z coefficient is evaluated. Next, a comparative analysis of γ_z and B_2 coefficient, usually employed to evaluate second order effects in steel structures, is performed. In order to develop the study, several reinforced concrete buildings of medium height are analysed using ANSYS-9.0 [1] software. The results show that simplified analysis provide more conservative values of γ_z. It means that, for structures analysed by simplified models, large values of γ_z don't imply, necessarily, in significant second order effects. Furthermore, it was checked that γ_z can be determinated from B_2 coefficients of each storey of the structures and that, for all the analysed buildings, the average values of the B_2 coefficients are similar to γ_z.

Keywords: reinforced concrete, structural model, γ_z Coefficient, B_2 Coefficient.

Resumo

Neste trabalho apresenta-se um estudo do coeficiente γ_z, empregado para indicar a necessidade ou não de se considerar os efeitos de segunda ordem globais na análise das estruturas de concreto armado. Inicialmente, procura-se avaliar a influência do modelo estrutural adotado no cálculo de γ_z. Em seguida, realiza-se uma análise comparativa do coeficiente γ_z e do coeficiente B_2, comumente empregado para avaliar os efeitos de segunda ordem em estruturas de aço. Para conduzir o estudo, diversos edifícios de médio porte de concreto armado são processados utilizando o programa computacional ANSYS-9.0 [1]. Os resultados obtidos permitem verificar que análises menos refinadas tendem a fornecer valores de γ_z mais conservadores. Isto significa que, para estruturas analisadas por meio de modelos simplificados, a obtenção de altos coeficientes γ_z não implica necessariamente em efeitos de segunda ordem significativos. Além disso, mostra-se que o γ_z pode ser calculado a partir dos coeficientes B_2 determinados para cada pavimento das estruturas, e que, para todos os edifícios analisados, os valores médios dos coeficientes B_2 apresentam boa proximidade em relação ao γ_z.

Palavras-chave: concreto armado, modelo estrutural, coeficiente γ_z, coeficiente B_2.

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1. Introduction

Of late, erecting more economical, slender structures and taller, bolder buildings has become increasingly common.
The taller and more slender the building, the greater the strains present, particularly those resulting from lateral actions. In these cases the stability analysis and evaluation of second order effects start taking on fundamental importance in the structural project.
Second order effects arise when the structure equilibrium considering the deformed configuration study is done. In this way, existing forces interact with displacements, thereby producing additional efforts. Second order efforts introduced by the structure joints moving horizontally, when subject to vertical and horizontal loads, are referred to as global second order effects.
It is well known that all structures are displaceable. However, horizontal joint displacements are small in some more stiff structures and, as a result, second order global effects have little influence on total efforts, and so can be ignored. These structures are referred to as nonsway structures. In these cases, bars can be sized separately, with their extremities tied, where efforts obtained by the first order analysis are applied.
On the other hand, some more flexible structures have significant horizontal displacements and therefore global second order effects depict an important part of final efforts and cannot be ignored. This is the case of sway structures for which a second order analysis must be done.
According to NBR 6118:2007 [2], if global second order effects are less than 10% of the respective first order efforts, the structure can be classified as being nonsway structure. Otherwise (that is, when global second order effects are over 10% higher than first order effects), the structure is classified as being sway structure.
NBR 6118:2007 [2] also establishes that structures can be classified using two approximate processes, the α instability parameter and the γ_z coefficient. However, the γ_z coefficient goes beyond the α parameter, since it can also be utilized to evaluate final efforts, which include second order efforts, as long as their value does not exceed 1.3. However, it is obvious that, for second effects to be evaluated satisfactorily, the γ_z coefficient needs to be calculated accurately.
It is worth noting that the γ_z coefficient must be employed in reinforced concrete structures. To assess second order effects on steel structures, the B_2 coefficient must be utilized. As with γ_z, this coefficient is also able to provide an estimate of a structure's final efforts, as long as their value does not go beyond a certain threshold.
Within this context, this paper's primary intention is to ascertain the adopted structural model's influence in calculating the γ_z coefficient. Thus, the γ_z values for two medium height reinforced concrete buildings are determined, considering five distinct three-dimensional models developed utilizing ANSYS-9.0 [1] software. The results obtained make it possible to identify the more adequate models for putting the project into practice, as well as those whose utilization could prove disadvantageous and uneconomical. Moreover, the attempt has been made to carry out a comparative study of coefficients γ_z and B_2. To conduct the study, first of all an expression associating these parameters is developed. Next, the γ_z and B_2 values for several medium height reinforced concrete buildings are calculated, utilizing ANSYS-9.0 [1] software.

2. Coefficient γ_z

NBR 6118:2007 [2] ordains that the γ_z coefficient, valid for reticulated structures at least four stories high, can be determined from a first order linear analysis, by reducing the structural elements' stiffness, in order to consider the physical non-linearity approximately. For each load combination, the γ_z value is calculated using the following expression:

$$\gamma_z = \frac{1}{1 - \dfrac{\Delta M_{tot,d}}{M_{1,tot,d}}} \quad (1)$$

- $M_{1,tot,d}$ (first order moment) being: a sum of the all the horizontal force moments (with their design values) of the considered combination relative to the structure base, which can be written as:

$$M_{1,tot,d} = \Sigma\,(F_{hid} \cdot h_i) \quad (2)$$

F_{hid} being the horizontal force applied to storey *i* (with its design value), and h_i being the height of storey *i*.
- $\Delta M_{tot,d}$ (increase in moments after the first order analysis) being: a sum of the products of all the vertical forces working on the structure (with their design values), in the considered combination, by the horizontal displacements of their respective application points:

$$\Delta M_{tot,d} = \Sigma\,(P_{id} \cdot u_i) \quad (3)$$

P_{id} being the vertical force working on storey *i* (with its design value), and u_i being the horizontal displacement of storey *i*.
Bearing in mind that second order effects can be ignored as long as they do not show a greater than 10% increase in the respective first order efforts, a structure may be classified as being nonsway structure if its $\gamma_z \leq 1.1$.
NBR 6118:2007 [2] establishes that final efforts (first order + second order) can be evaluated from the additional $0.95\gamma_z$ horizontal efforts magnification of the considered loading combination, as long as γ_z does not exceed 1.3. However, according to the NBR 6118:2000 [3] Revision Project, final efforts values could be obtained by multiplying the first order moments by $0.95\gamma_z$, also on the condition that $\gamma_z \leq 1.3$. It is therefore understood that γ_z ceased to be the first order moment magnifier coefficient and became the horizontal loads magnifier coefficient.
According to Franco &Vasconcelos [4], utilizing γ_z as a first order moments magnifier provides a good estimate for the second order analysis results; the method was applied successfully on tall buildings with γ_z in the region of 1.2 or more. Vasconcelos [5] adds that this process is valid even for γ_z values lower than 1.10, in which cases technical norms allow second order effects to be disregarded. It is also noted that, according to Vasconcelos [6], the process of eval-

uating second order effects by multiplying first order moments by γ_z is based on the assumption that the successive elastic lines produced by vertical force action on the structure with displaced joints follow in geometric progression. Indeed, it was seen in countless cases that up to the value $\gamma_z = 1.3$ this assumption is valid with less than 5% error. However, there are some particular situations where the assumption formulated in developing the method does not apply or applies with greater errors. As examples of these exceptional cases, Vasconcelos [6] quotes: when there is a sudden change in inertia between stories (in particular between the ground and first floor), where ceiling heights from one floor to the next are very different, cases of column transition in beams, when there is torsion in the spatial frame or uneven settling in the foundations, and others.
Oliveira [7] did an evaluation of the γ_z coefficient's efficiency as a first order efforts magnifier (for bending moments, axial and shearing forces) and as a horizontal loads magnifier, to obtain final, including second order, efforts. The study was carried out for structures with maximum γ_z values in the region of 1.3, that is, for which, according to NBR 6118:2007 [2], the simplified final efforts evaluation process employing the γ_z coefficient is still valid. It was found that the γ_z coefficient must be utilized as magnifier of first order moments (and not for horizontal loads) to obtain final moments. In the case of axial force on columns and shearing force on beams, magnification by the γ_z coefficient was not necessary, since the first and second order efforts values obtained in these cases were practically the same.

3. Coefficient B_2

To evaluate second order effects on steel structures, AISC/LRFD [8] adopts the approximate method of amplifying the first order moments by magnification factors B_1 and B_2. So the second order bending moment, M_{Sd}, must be determined by means of the following expression:

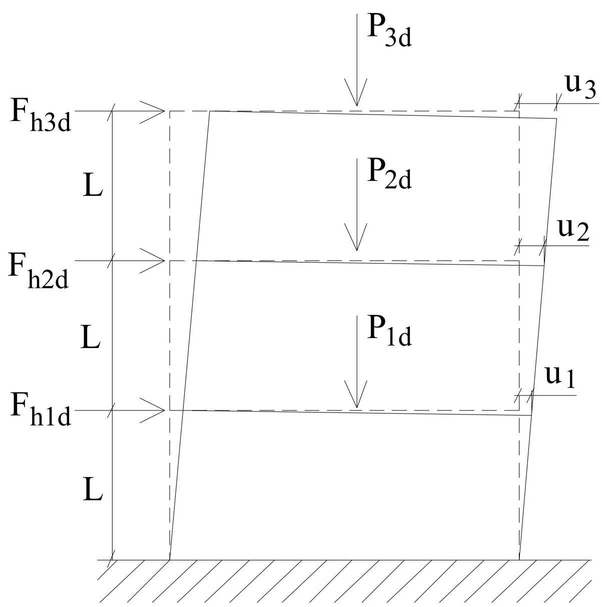
$$M_{Sd} = B_1.M_{nt} + B_2.M_{lt} \quad (4)$$

M_{nt} being the design bending moment, assuming there is no side sway in the structure, M_{lt} being the design bending moment due to the frame's side sway; both M_{nt} and M_{lt} are obtained by first order analyses. The B_1 amplification coefficient depicts the *P-δ* effect, relating to the instability of the bar, or to local second order effects; B_2 considers the *P-Δ* effect, relating to the instability of the frame, or to global second order effects.
The B_2 coefficient can be calculated for each storey of the structure, as:

$$B_2 = \frac{1}{1 - \frac{\Delta_{0h}}{L}\frac{\sum N_{Sd}}{\sum H_{Sd}}} \quad (5)$$

with ΣN_{Sd} as the summation of the design axial compression forces on all the columns and other elements resistant to the storey's vertical forces; Δ_{0h} as the relative horizontal displacement; L as the storey's length and ΣH_{Sd} as the summation of all the design horizontal forces on the storey producing Δ_{0h}.

Figure 1 – Three-storey structure subjected to vertical and horizontal forces



According to Silva [9], if the B_2 coefficient does not exceed the value of 1.1 on all storeys, the structure can be considered almost insensitive to horizontal movement and, in this case, global second order effects can be ignored. When the greater B_2 is situated between 1.1 and 1.4, the approximate B_1-B_2 method can be utilized for the bending moment, with the other efforts (axial and shearing forces) being directly obtained from the first order analysis. Lastly, when $B_2 > 1.40$, the recommendation is that a rigorous second order elastoplastic analysis be performed. Silva [9] also adds that, in the event $1.1 < B_2 \leq 1.2$, the bending moments can alternatively be based on a first order analysis performed with the magnified horizontal efforts by the greater B_2.
So it can be seen that, like the γ_z coefficient, the B_2 coefficient is an "indicator" of the importance of global second order effects on a structure. In this way, in the next item, an expression capable of relating these parameters will be obtained.

4. Relation between coefficients γ_z and B_2

Figure [1] shows a structure consisting of three storeys of equal length (L). In this figure the vertical (P_{id}) and horizontal (F_{hid}) design forces working on each storey i, along with their respective horizontal displacement (u_i) are also shown.
To calculate γ_z, equation (1), the values of $M_{1,tot,d}$ and $\Delta M_{tot,d}$ need to be determined. Through equations (2) and (3), we get, respectively:

$$M_{1,tot,d} = (F_{h1d} \cdot L + F_{h2d} \cdot 2L + F_{h3d} \cdot 3L) = F_{h1d} \cdot L + 2\, F_{h2d} \cdot L + 3\, F_{h3d} \cdot L \quad (6)$$

$$\Delta M_{tot,d} = P_{1d} \cdot u_1 + P_{2d} \cdot u_2 + P_{3d} \cdot u_3 \quad (7)$$

The B_2 coefficient, given by equation (5), shows distinct values for each storey of the structure. Thus, referring to the B_2 coefficient of storey i as $B_{2,i}$ and the parts $(L \cdot \Sigma H_{Sd})$ and $(\Delta_{0h} \cdot \Sigma N_{Sd})$ as M_i and ΔM_i, respectively, we get:

- 1st storey:

$$M_1 = L \cdot (F_{h1d} + F_{h2d} + F_{h3d}) = F_{h1d} \cdot L + F_{h2d} \cdot L + F_{h3d} \cdot L \quad (8)$$

$$\Delta M_1 = (u_1 - 0) \cdot (P_{1d} + P_{2d} + P_{3d}) = P_{1d} \cdot u_1 + P_{2d} \cdot u_1 + P_{3d} \cdot u_1 \quad (9)$$

$$B_{2,1} = \frac{1}{1 - \frac{\Delta M_1}{M_1}} \Rightarrow B_{2,1} = \frac{1}{\frac{M_1 - \Delta M_1}{M_1}} \Rightarrow (M_1 - \Delta M_1) = \frac{M_1}{B_{2,1}} \quad (10)$$

- 2nd storey:

$$M_2 = L \cdot (F_{h2d} + F_{h3d}) = F_{h2d} \cdot L + F_{h3d} \cdot L \quad (11)$$

$$\Delta M_2 = (u_2 - u_1) \cdot (P_{2d} + P_{3d}) = P_{2d} \cdot u_2 + P_{3d} \cdot u_2 - P_{2d} \cdot u_1 - P_{3d} \cdot u_1 \quad (12)$$

$$B_{2,2} = \frac{1}{1 - \frac{\Delta M_2}{M_2}} \Rightarrow B_{2,2} = \frac{1}{\frac{M_2 - \Delta M_2}{M_2}} \Rightarrow (M_2 - \Delta M_2) = \frac{M_2}{B_{2,2}} \quad (13)$$

- 3rd storey:

$$M_3 = L \cdot (F_{h3d}) = F_{h3d} \cdot L \quad (14)$$

$$\Delta M_3 = (u_3 - u_2) \cdot (P_{3d}) = P_{3d} \cdot u_3 - P_{3d} \cdot u_2 \quad (15)$$

$$B_{2,3} = \frac{1}{1 - \frac{\Delta M_3}{M_3}} \Rightarrow B_{2,3} = \frac{1}{\frac{M_3 - \Delta M_3}{M_3}} \Rightarrow (M_3 - \Delta M_3) = \frac{M_3}{B_{2,3}} \quad (16)$$

Adding up M_1, M_2 and M_3 equations (8), (11) and (14), and ΔM_1, ΔM_2 and ΔM_3, equations (9), (12) and (15) gives:

$$M_1 + M_2 + M_3 = F_{h1d} \cdot L + 2F_{h2d} \cdot L + 3F_{h3d} \cdot L \quad (17)$$

$$\Delta M_1 + \Delta M_2 + \Delta M_3 = P_{1d} \cdot u_1 + P_{2d} \cdot u_2 + P_{3d} \cdot u_3 \quad (18)$$

Comparing equations (17) and (18) with equations (6) and (7) we can write:

$$M_{1,tot,d} = M_1 + M_2 + M_3 \quad (19)$$

$$\Delta M_{tot,d} = \Delta M_1 + \Delta M_2 + \Delta M_3 \quad (20)$$

By substituting equations (19) and (20) in equation (1), the γ_z coefficient becomes defined as:

$$\gamma_z = \frac{1}{1 - \frac{\Delta M_1 + \Delta M_2 + \Delta M_3}{M_1 + M_2 + M_3}} = \frac{1}{\frac{(M_1 + M_2 + M_3) - (\Delta M_1 + \Delta M_2 + \Delta M_3)}{M_1 + M_2 + M_3}}$$

$$\gamma_z = \frac{M_1 + M_2 + M_3}{(M_1 - \Delta M_1) + (M_2 - \Delta M_2) + (M_3 - \Delta M_3)} \quad (21)$$

Inverting equation (21) gives:

$$\frac{1}{\gamma_z} = \frac{(M_1 - \Delta M_1) + (M_2 - \Delta M_2) + (M_3 - \Delta M_3)}{M_1 + M_2 + M_3} \quad (22)$$

Substituting equations (10), (13), (16) and (19) in equation (22), gives:

$$\frac{1}{\gamma_z} = \frac{\frac{M_1}{B_{2,1}} + \frac{M_2}{B_{2,2}} + \frac{M_3}{B_{2,3}}}{M_{1,tot,d}} \Rightarrow \frac{1}{\gamma_z} = \frac{M_1}{M_{1,tot,d} \cdot B_{2,1}} + \frac{M_2}{M_{1,tot,d} \cdot B_{2,2}} + \frac{M_3}{M_{1,tot,d} \cdot B_{2,3}} \quad (23)$$

Finally equation (23) can be written as:

$$\frac{1}{\gamma_z} = \frac{c_1}{B_{2,1}} + \frac{c_2}{B_{2,2}} + \frac{c_3}{B_{2,3}} \quad (24)$$

with constants c_1, c_2 and c_3 being given respectively through:

$$c_1 = \frac{M_1}{M_{1,tot,d}} = \frac{F_{h1d} \cdot L + F_{h2d} \cdot L + F_{h3d} \cdot L}{F_{h1d} \cdot L + 2F_{h2d} \cdot L + 3F_{h3d} \cdot L} = \frac{F_{h1d} + F_{h2d} + F_{h3d}}{F_{h1d} + 2F_{h2d} + 3F_{h3d}} \quad (25)$$

$$c_2 = \frac{M_2}{M_{1,tot,d}} = \frac{F_{h2d} \cdot L + F_{h3d} \cdot L}{F_{h1d} \cdot L + 2F_{h2d} \cdot L + 3F_{h3d} \cdot L} = \frac{F_{h2d} + F_{h3d}}{F_{h1d} + 2F_{h2d} + 3F_{h3d}} \quad (26)$$

$$c_3 = \frac{M_3}{M_{1,tot,d}} = \frac{F_{h3d} \cdot L}{F_{h1d} \cdot L + 2F_{h2d} \cdot L + 3F_{h3d} \cdot L} = \frac{F_{h3d}}{F_{h1d} + 2F_{h2d} + 3F_{h3d}} \quad (27)$$

As such, for a structure consisting of n storeys, the γ_z coefficient can be calculated by reference to the B_2 coefficient as:

$$\frac{1}{\gamma_z} = \sum_{i=1}^{n} \frac{c_i}{B_{2,i}} \quad (28)$$

and

$$c_i = \frac{\sum_{j=i}^{n} F_{hjd}}{\sum_{j=1}^{n} j \cdot F_{hjd}} \quad (29)$$

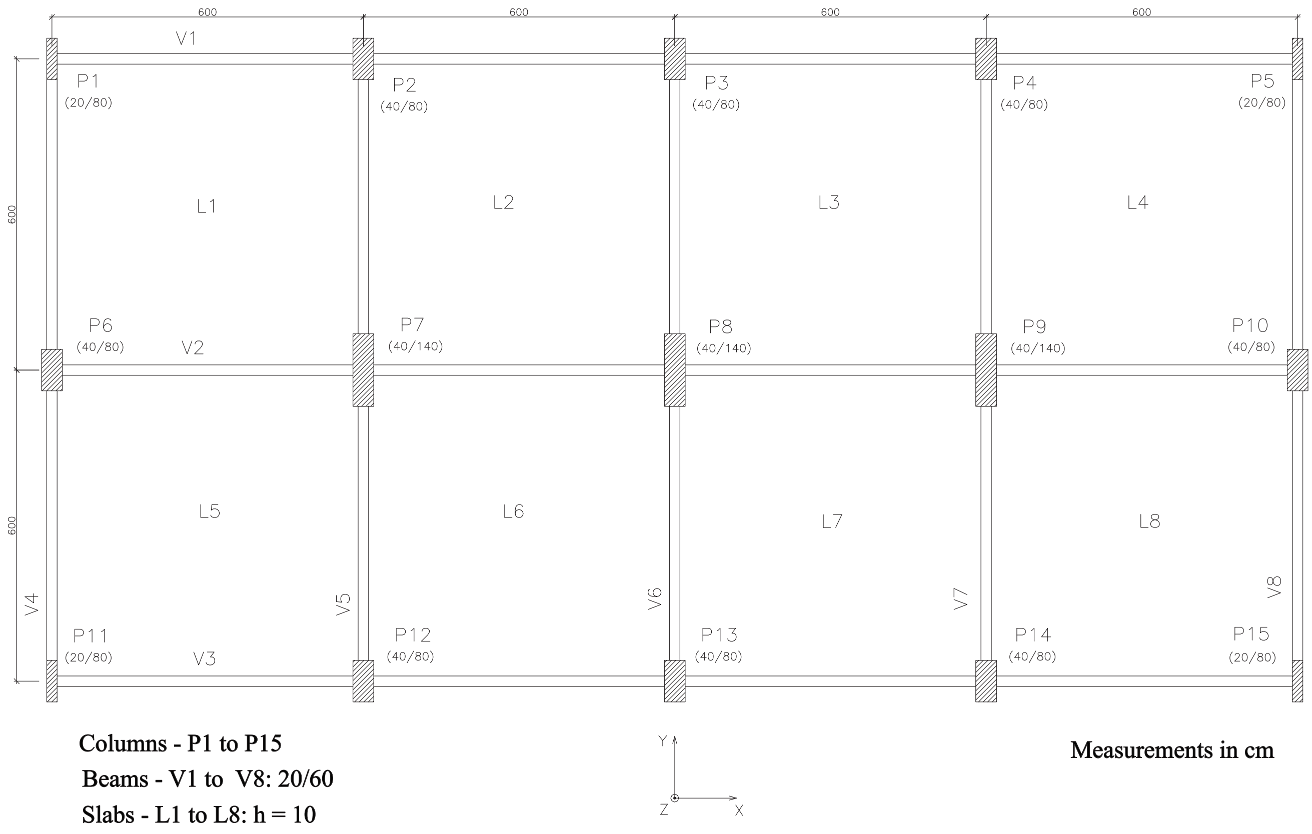
5. Influence of the structural model adopted to calculate γ_z

As commented previously, NBR 6118:2007 [2] establishes that the γ_z coefficient can be determined from a first order structure analysis. However, this analysis can be carried out utilizing various types of structural models. For example, a building can be modelled considering the slabs as rigid diaphragms or depicting them by means of shell elements. Additionally, the eccentricity existing between the beam axis and the average slab plane may or may not be taken into account. In this way, in order to evaluate the possible influence of the structural model on the value of γ_z, the γ_z coefficients will be determined for two reinforced concrete buildings, considering five distinct three-dimensional models developed utilizing ANSYS-9.0 [1] software. The results of these models will then be analyzed and compared.

5.1 Buildings and models analyzed

The first building analyzed, shown in figure [2], consists of sixteen storeys (with a 2.9 m ceiling height) and is symmetrical in both *X* and *Y* directions. 20 MPa for the characteristic strength of the concrete to compression and a Poisson coefficient equal to 0.2 were adopted.
The second building, depicted in figure [3], consists of eighteen storeys (with a ceiling height of 2.55 m) and has no symmetry. The concrete presents characteristic strength to compression and a Poisson coefficient equal to 30 MPa and 0.2, respectively.
Each building was analyzed utilizing five distinct three-dimensional models. In the first model the columns and beams are depicted by means of bar elements (defined in ANSYS-9.0 [1] as "beam 4"and "beam 44"respectively) and the slabs by means of shell elements (called "shell 63"). The "beam 4" and "beam 44" elements show six degrees of freedom at each node: three translations and three rotations, in directions *X, Y* and *Z*. The "shell 63" element has four nodes, each node presenting six degrees of freedom, the same as the bar elements. The "beam 44"element, utilized to represent the beams, enables the eccentricity existing between the beam axis and the average slab plane to be taken into account. Thus, this model simulates the real situation between the slabs and the beams, as depicted in figure [4]. It is worth commenting that, when their axes did not coincide, the connection between the beams and the columns was carried out using rigid bars, as figure [5] shows.
The second model only differs from the previous one by replacing the "beam 44" element with the "beam 4" element to depict the

Figure 2 – Typical storey of building I (adapted from Costa (10))



beams. In this way, in this model the average slab plane coincides with the beam axis, figure [6], since the "beam 4" element does not allow eccentricities to be considered.

In the third model, the columns and beams are depicted by means of the "beam 4" element and the slabs are treated as rigid diaphragms, that is, it is accepted that they have infinite stiffness on their own plane and nil stiffness crosswise. In the ANSYS-9.0 software [1], the hypothesis of a rigid diaphragm is embodied in the model by means of a specific command which relates the degrees of freedom of the nodes making up the slab plane. Thus, a "master" node, corresponding to the point representing all the storey's nodes is defined. The remaining nodes, called "slaves", have their own degrees of freedom and those represented by the "master" node.

The fourth model, like the previous one, is also made up of bars (depicting the columns and beams by means of the "beam4" element), but without considering the hypothesis of a rigid diaphragm.

Finally, the last model only differs from the previous one because the "beam4" element is replaced by the "beam44" element to depict the beams, whereby the eccentricity existing between the beam axis and the average slab plane can be considered.

It can be seen, then, that in models 3,4, and 5 the structural system just consists of bars, since the slabs are not modelled (unlike models 1 and 2 in which the slabs are depicted by means of shell elements). In all the models, the beams' torsional stiffness was reduced, by reproducing the cracking effect.

Table [1] sums up the main characteristics of the models employed.

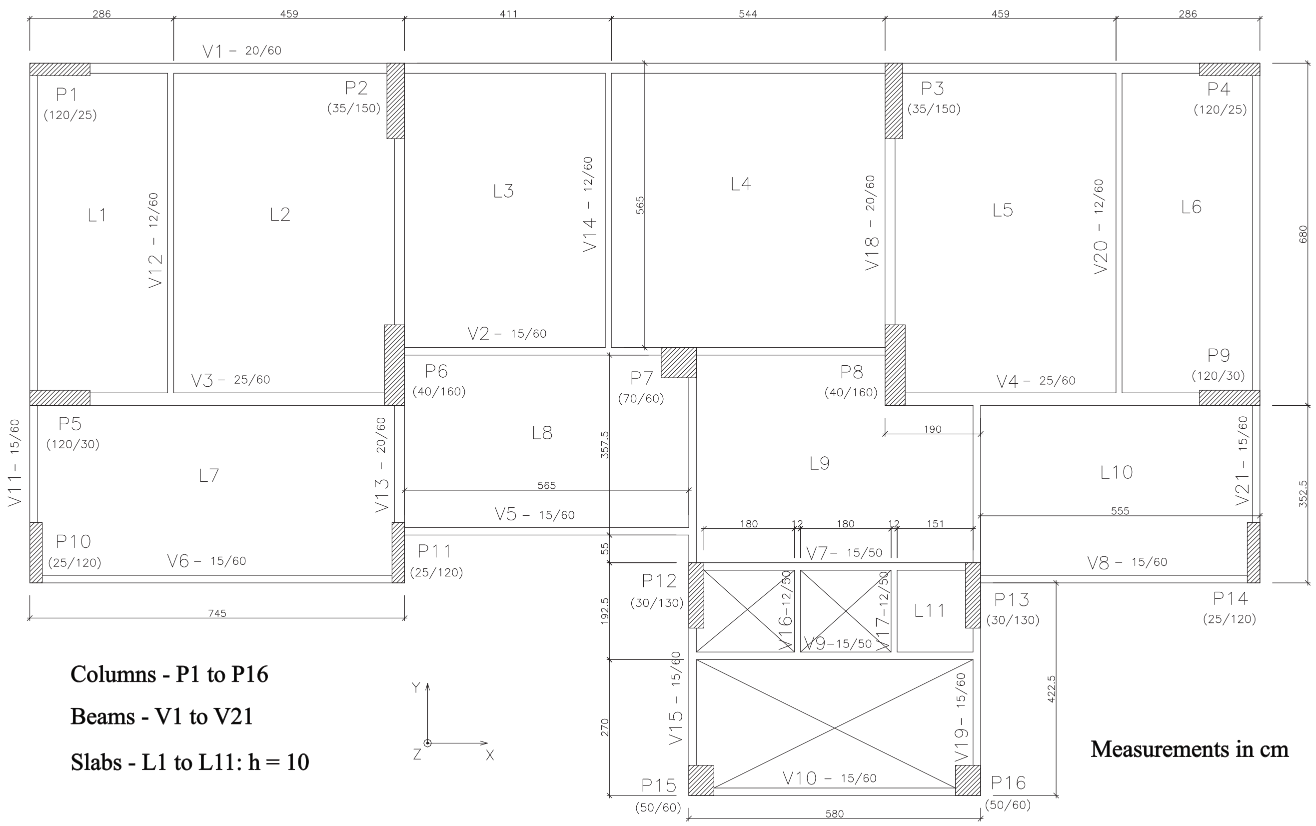
5.2 Design considerations

The actions working on the buildings are divided into two groups: vertical actions and horizontal actions.

Vertical actions consist of permanent loads and the accidental load. The permanent loads considered were the own weights of structures, the masonry loads and the slab coatings and finishings. The accidental loads were determined in accordance with the precepts of NBR 6120:1980 [12].

The chief horizontal actions that must be taken into account in the structural project are the forces due to the wind and those relating to geometric imperfections (out-of-plumb). However, according to NBR 6118:2007 [2], these loadings do not need to be overlapped and only the most unfavorable (the one causing the greatest total moment at the structure base) may be considered. According to Rodrigues Junior [13], for tall buildings, just as with the main variable load choice, it is possible to prove that, in most practical cases, the wind corresponds to the most unfavorable situation. In this way, in this paper, the horizontal loading applied to the structures

Figure 3 – Typical storey of building II (adapted from LOPES et al. (11))



was that corresponding to the action of the wind, considered more unfavorable than out-of-plumb, both for direction *X* and for direction *Y*. It is worth pointing out that the drag forces were calculated in accordance with the precepts of NBR 6123:1988 [14].
The coefficients applied to the actions, defined from the ultimate normal combination that considers the wind to be the main variable action, were determined as recommended by NBR 6118:2007[2].

Figure 4 – Slab-beam model utilizing the "beam 44" element

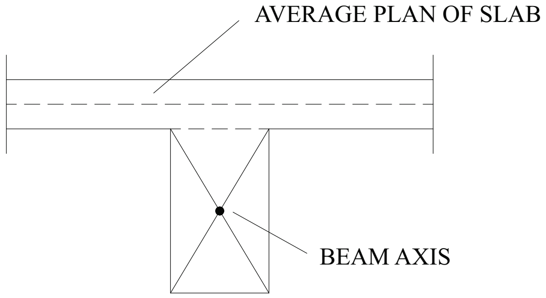


Figure 5 – Connection between the beams and the columns

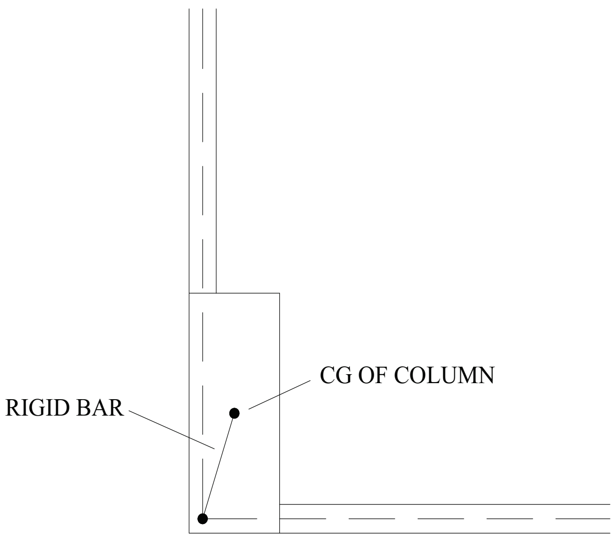
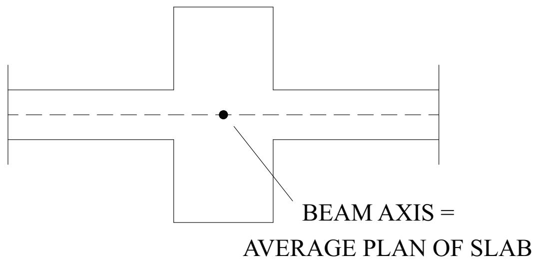


Figure 6 – Slab-beam model utilizing the "beam 4" element



5.3 Results obtained

The γ_z coefficient was calculated from the first order linear analysis of the structures, for the vertical loads acting simultaneously with the horizontal actions. In this analysis the physical non-linearity was considered in a simplified way, as established by NBR 6118:2007[2], reducing the stiffness of the structural elements.
The γ_z values (in directions *X* and *Y*) obtained for both buildings and considering all the models utilized, are shown in table [2].
In table [2] it can be seen that, with the exception of model 1, all the models provided practically the same γ_z values, for both buildings I and II. Therefore, the presence or lack of symmetry did not have any influence on the results obtained. Furthermore, the γ_z values calculated based on model 1, the most sophisticated (for it is the only one, among all the models adopted, that considers simultaneously the representation of the slabs as shell elements and the eccentricity existing between the beam's axis and the slab's average plane), are considerably inferior to the other models. This means that more simplified analyses tend to provide more conservative results. In this way, it can be claimed that, for structures analyzed by means of simplified models, obtaining high γ_z values does not necessarily mean significant second order effects: considering the results for model 1, building 1 would be classified as being nonsway structure in both directions, and building II in the direction of *Y*. However, according to the other models, both the structures would be classified as being sway structures in the directions of *X* and *Y*. So, from this point of view, utilization of less refined models proves disadvantageous and uneconomical, since it can result in quite relevant second order effects, when in fact they should not be so.
It is important to mention that, obviously, the smaller the γ_z coefficient value is, the more stiff the structure, which is easily found by analyzing equation (1). If the structure's horizontal displacements are fairly big, so that the increase in moments $\Delta M_{tot,d}$ becomes approximately equal to the $M_{1,tot,d}$ moment, that is, $\Delta M_{tot,d} / M_{1,tot,d} \cong 1$, the γ_z coefficient will tend to infinity. This would be the case of an infinitely flexible structure. On the other hand, for an infinitely stiff structure, that is, that does not shift under the action of loads, the $\Delta M_{tot,d}$ would be nil and consequently, the γ_z coefficient would be

Table 1 – Main characteristics of the models employed

Model	Elements adopted	Depiction of the slabs	Consideration of the eccentricity existing between the beam axis and the average plane of the slab
1	"beam 4", "beam 44" and "shell 63"	Shell elements	Yes
2	"beam 4" and "shell 63"	Shell elements	No
3	"beam 4"	Rigid diaphragm	No
4	"beam 4"	-	No
5	"beam 4" and "beam 44"	-	Yes

Table 2 – Values of γ_z for buildings I and II, considering all the models utilized

Model	Building I		Building II	
	Direction X	Direction Y	Direction X	Direction Y
1	1.09	1.06	1.20	1.08
2	1.18	1.14	1.31	1.15
3	1.19	1.14	1.32	1.16
4	1.19	1.14	1.32	1.16
5	1.19	1.14	1.32	1.16

Table 3 – Values of the γ_z and B_2 in directions X and Y, for building I

Storey	Direction X		Direction Y	
	$\gamma_{z,x}$	$B_{2,i,x}$	$\gamma_{z,y}$	$B_{2,i,y}$
1st	1.19	1.13	1.14	1.05
2nd		1.26		1.13
3rd		1.28		1.18
4th		1.26		1.19
5th		1.24		1.20
6th		1.22		1.19
7th		1.20		1.18
8th		1.17		1.16
9th		1.15		1.15
10th		1.13		1.13
11th		1.11		1.12
12th		1.09		1.10
13th		1.07		1.08
14th		1.06		1.07
15th		1.04		1.06
16th		1.03		1.08

equal to 1. Based on these considerations, it can be stated that, on observation of the γ_z values shown in table [2], the buildings, if analyzed utilizing model 1, appear much more stiff than if analyzed considering the other models. Furthermore, it can be seen that this considerable increase in stiffness is due to the representation of the slabs as shell elements associated with the consideration of the eccentricity existing between the beam axis and the average slab plane, and it is not sufficient to take only one of these factors into account, as can be found by observing the results of models 2 and 5. Thus, from tables [1] and [2], it can also be stated that the representation of the slabs by means of shell elements (model 2) or the consideration of the hypothesis of a rigid diaphragm (model 3) did not themselves contribute to the increase in stiffness of the structures, observed in model 1. In the same way, considering the eccentricity existing between the beam axis and the average slab plane in the bar model (model 5) did not alter the results previously obtained (model 4), indicating that substituting the "beam 4" element for the "beam 44" element to represent the beams did not prove advantageous in the absence of slabs.

Finally, based on the principle that model 1, the most sophisticated and which involves the most computer work, is not generally adopted by the technical medium, including calculating the γ_z coefficient, and considering that all the other models provide practically identical results, in the next item of this paper the buildings will be analyzed utilizing model 4, the simplest one. However, it is worth commenting that, in putting the project into practice, model 1 must be utilized for preference, since it represents the actual behaviour of the structure more accurately and provides much lower γ_z values to those obtained by the other models, which leads to greater savings and, in many cases, dispenses with carrying out analyses which consider, in a simplified way or otherwise, the second order effects.

6. Comparative study of the γ_z and B_2 coefficients

With the purpose of carrying out a comparative study of the γ_z and B_2 coefficients, the values of these parameters were calculated for several reinforced concrete buildings of medium height, including those that were the object of study in item 5.

The buildings were then first order processed, utilizing three-dimensional models on ANSYS-9.0 [1] software, with the columns and beams depicted by means of the "beam 4" element (according to model 4, described in the previous item).

As already mentioned, the actions working on the buildings are divided into two groups: vertical actions (consisting of permanent loads and accidental load) and horizontal actions (corresponding to the action of the wind in directions *X* and Y*).* The coefficients applied to the actions were defined from the ultimate normal combination considering the wind to be the main variable action, and determined according to NBR 6118:2007 [2] recommendations.

6.1 Results obtained

Table [3] shows the values of γ_z (the only one for the whole structure) and B_2 (determined for each storey) obtained for the first building analyzed ("building I"), in directions *X* and *Y*.

It can be seen in table [3] that, on several storeys of building I, the B_2 coefficient exceeds the value of 1.1 both in direction *X* and direction *Y*. In this way, the structure can be considered very sensitive to horizontal movement and, in this case, the global second order effects cannot be ignored. The γ_z coefficient provides a like classification, that is, it considers the structure as being sway structure in both directions *X* and *Y*.

It is worth remembering that the γ_z coefficient can be calculated from the values of B_2, utilizing equation (28). Thus, it is enough to determine the c_i constants for each storey, given by equation (29).
In this equation, the $\sum_{j=l}^{n} j \cdot F_{hjd}$ portion can be written as:

$$\sum_{j=l}^{n} j \cdot F_{hjd} = F_{h1d} + 2 \cdot F_{h2d} + 3 \cdot F_{h3d} + ... + 16 \cdot F_{h16d} \quad (30)$$

Substituting the F_{hid} values (design horizontal forces working on each storey of the structure), given in table [4] and [5], in equation (30), gives:

- Direction X: $\sum_{j=l}^{n} j \cdot F_{hjd} = 3164.13kN$
- Direction Y: $\sum_{j=l}^{n} j \cdot F_{hjd} = 7985.94kN$

Also considering equation (29), the $\sum_{j=i}^{n} F_{hjd}$ must be calculated for each storey of the structure; the results obtained are shown in tables [4] and [5], together with all the data needed to determine the c_i constants and γ_z coefficient, in directions X and Y.
It can be seen in tables [4] and [5] that, as expected, the γ_z values calculated from the B_2 coefficients coincide with those previously obtained, shown in table [3].
Table [6] shows the γ_z and B_2 parameter values for other buildings analyzed (whose characteristics can be found in Oliveira [7]), together with the classification of the structures, in directions X and Y. However, in the case of the B_2 coefficient, only the average ($B_{2,avg}$) and maximum ($B_{2,max}$) values of the storeys are shown. Note that, according to Silva [9], a structure can be considered almost insensitive to horizontal movement if, on all its storeys, the B_2 coefficient does not exceed the value of 1.1. If B_2 is greater than this value on at least one storey, the structure will be considered very sensitive to horizontal movement. In this way, classification of the buildings is carried out by analyzing the $B_{2,max}$ value obtained.
Table [6] shows that, in all cases, the γ_z and B_2 coefficients provide the same classification for the structures. Furthermore, the γ_z and $B_{2,avg}$ proved to be extremely close, the major difference, corresponding to direction X of building I, being around 3.4%. It is also worth commenting that, in the large majority of cases $B_{2,avg}$ was lower than γ_z.

Table 4 – Calculation of the γ_z coefficient, from the values of B_2, in direction X, for building I

Storey	$F_{hid,x}$ (kN)	$B_{2,i,x}$	$\sum_{j=i}^{n=16} F_{hjd,x}$ (kN)	$c_{i,x} = \frac{\sum_{j=i}^{n=16} F_{hjd,x}}{3164.13}$	$\frac{c_{i,x}}{B_{2,i,x}}$
1st	26.19	1.13	359.71	0.114	0.100
2nd	17.46	1.26	333.52	0.105	0.084
3rd	17.48	1.28	316.06	0.100	0.078
4th	18.24	1.26	298.58	0.094	0.075
5th	19.60	1.24	280.34	0.089	0.071
6th	20.79	1.22	260.73	0.082	0.068
7th	21.84	1.20	239.94	0.076	0.063
8th	22.80	1.17	218.10	0.069	0.059
9th	23.68	1.15	195.30	0.062	0.054
10th	24.49	1.13	171.62	0.054	0.048
11th	25.25	1.11	147.12	0.046	0.042
12th	25.97	1.09	121.87	0.039	0.035
13th	26.64	1.07	95.91	0.030	0.028
14th	27.28	1.06	69.26	0.022	0.021
15th	27.89	1.04	41.98	0.013	0.013
16th	14.09	1.03	14.09	0.004	0.004

$$\frac{1}{\gamma_{z,x}} = \sum_{i=1}^{n=16} \frac{c_{i,x}}{B_{2,i,x}} = 0.843$$

$$\gamma_{z,x} = 1.19$$

7. Final considerations

This paper sought to carry out a study of the γ_z coefficient, employed to indicate the need or otherwise to consider the global second order effects in the analysis of reinforced concrete structures. To conduct the study, several reinforced concrete buildings of medium height were processed utilizing ANSYS-9.0 [1] software.

Initially, the influence of the structural model adopted in calculating γ_z was evaluated. On the basis of the studies done, it was ascertained that less refined analyses tend to provide more conservative γ_z values. This means that, for structures analyzed by means of simplified models, obtaining high γ_z values does not necessarily mean significant second order effects. As such, on adopting simplified models, it is up to the technical medium to be aware that using them can, in many cases, prove disadvantageous and uneconomical, resulting in quite relevant second order effects, when in fact they should not be so.

On putting the project into practice, more sophisticated models (in which the slabs are depicted as shell elements and the eccentricity existing between the beam axis and the average slab plane is considered), although they involve more computer work, should be preferably be utilized, since they depict the actual behaviour of the structures more accurately and provide much lower γ_z values than those obtained by more simplified models, which leads to greater savings and, in many cases, dispenses with carrying out analyses that consider second order effects approximately or otherwise.

Next, a comparative analysis was done of the γ_z coefficient and the B_2 coefficient, commonly employed to evaluate second order effects on steel structures. To conduct the study, initially an equation relating these parameters was developed. Later, the values of γ_z and B_2 for several reinforced concrete buildings of medium height were calculated. From the results obtained, it was observed that the average values of the B_2 ($B_{2,avg}$) coefficients showed close proximity in relation to γ_z and that, in all cases, the γ_z and B_2 parameters provided the same classification as the structures.

However, an important aspect deserves to be highlighted concerning the γ_z coefficient: contrary to the B_2 coefficient, it presents a single value for the entire structure, although, as found in several works (Carmo [15], Lima & Guarda [16] and Oliveira [17]), second order effects suffer variations along the height of the buildings. This means that, should the γ_z coefficient be utilized as magnifier of first order moments, as Oliveira [7] suggests, the final moments at some storeys could be underestimated, and overestimated at others.

Thus, a better estimate of the final moments could be made utilizing both coefficients γ_z and B_2, which is calculated for each storey of the structure and whose average value is approximately γ_z. The magnifier of the first order moments would then be differentiated for each storey *i* of the structure, and given as $(B_{2,i}/B_{2,avg})\cdot\gamma_z$. Although more specific studies on the

Table 5 – Calculation of the γ_z coefficient, from the values of B_2, in direction Y, for building I

Storey	$F_{hid,y}$ (kN)	$B_{2,i,y}$	$\sum_{j=i}^{n=16} F_{hjd,y}$ (kN)	$c_{i,y} = \frac{\sum_{j=i}^{n=16} F_{hjd,y}}{7985.94}$	$\frac{c_{i,y}}{B_{2,i,y}}$
1st	66.10	1.05	907.87	0.114	0.108
2nd	44.07	1.13	841.77	0.105	0.093
3rd	44.13	1.18	797.71	0.100	0.085
4th	46.04	1.19	753.58	0.094	0.079
5th	49.48	1.20	707.54	0.089	0.074
6th	52.47	1.19	658.06	0.082	0.069
7th	55.13	1.18	605.59	0.076	0.064
8th	57.55	1.16	550.45	0.069	0.059
9th	59.76	1.15	492.91	0.062	0.054
10th	61.82	1.13	433.14	0.054	0.048
11th	63.73	1.12	371.33	0.046	0.042
12th	65.54	1.10	307.59	0.039	0.035
13th	67.24	1.08	242.06	0.030	0.028
14th	68.85	1.07	174.82	0.022	0.020
15th	70.39	1.06	105.96	0.013	0.012
16th	35.57	1.08	35.57	0.004	0.004

$$\frac{1}{\gamma_{z,y}} = \sum_{i=1}^{n=16} \frac{c_{i,y}}{B_{2,i,y}} = 0.875$$

$$\gamma_{z,y} = 1.14$$

subject have not been done, we believe this to be very logical and rational alternative for taking into account how second order effects vary according to how high storeys in reinforced concrete buildings are.

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Table 6 – Values obtained for the γ_z and B_2 coefficients and structure classification

Building	Direction	Parameter	Value	Classification
I	X	γ_z	1.19	Sway structure
		$B_{2,avg}$	1.15	Structure very sensitive
		$B_{2,max}$	1.28	to horizontal movement
	Y	γ_z	1.14	Sway structure
		$B_{2,avg}$	1.13	Structure very sensitive
		$B_{2,max}$	1.20	to horizontal movement
II	X	γ_z	1.32	Sway structure
		$B_{2,avg}$	1.29	Structure very sensitive
		$B_{2,max}$	1.47	to horizontal movement
	Y	γ_z	1.16	Sway structure
		$B_{2,avg}$	1.17	Structure very sensitive
		$B_{2,max}$	1.22	to horizontal movement
III	X	γ_z	1.06	Nonsway structure
		$B_{2,avg}$	1.05	Structure almost insensitive
		$B_{2,max}$	1.07	to horizontal movement
	Y	γ_z	1.32	Sway structure
		$B_{2,avg}$	1.29	Structure very sensitive
		$B_{2,max}$	1.44	to horizontal movement
IV	X = Y	γ_z	1.30	Sway structure
		$B_{2,avg}$	1.26	Structure very sensitive
		$B_{2,max}$	1.45	to horizontal movement
V	X	γ_z	1.17	Sway structure
		$B_{2,avg}$	1.15	Structure very sensitive
		$B_{2,max}$	1.23	to horizontal movement
	Y	γ_z	1.28	Sway structure
		$B_{2,avg}$	1.28	Structure very sensitive
		$B_{2,max}$	1.35	to horizontal movement
VI	X	γ_z	1.27	Sway structure
		$B_{2,avg}$	1.25	Structure very sensitive
		$B_{2,max}$	1.40	to horizontal movement
	Y	γ_z	1.14	Sway structure
		$B_{2,avg}$	1.14	Structure very sensitive
		$B_{2,max}$	1.18	to horizontal movement

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