Asociación Argentina
de Mecánica Computacional

Mecánica Computacional Vol XLII, pp. 289-298
A. Caggiano, G. Etse, P. Folino, M. Goldschmit, M. Pucheta, M. Storti (Eds.)
J. Ballaben, D. Felix, R. Jaca (Issue eds.)
Buenos Aires, November 11-14, 2025

GLOBAL STABILITY IN SHORT BUILDINGS: VALIDATION THROUGH COMPUTATIONAL MODELLING

Geandra S. Bitencourt, Nayra C. Fontoura, Alisson S. Milani, Jaelson Budny and Diego A. Hartmann

Grupo de Pesquisa em Geotecnia e Infraestrutura - GeoInfra, Universidade Federal do Pampa, Avenida Tiarajú, 810 – Alegrete, Rio Grande do Sul, Brasil

Keywords: Non-linear analysis, global instability, gamma Z, P delta, effective stiffness.

Abstract. The gamma-Z coefficient is a widely utilised metric in Brazil for the assessment of global stability in large structures, particularly buildings with more than four floors, as stipulated in the Brazilian standard NBR 6118 - Design of concrete structures - Procedure (2023). The standard under discussion permits the use of stiffness reducers, with the objective of estimating the effects of physical non-linearity (PNL). The objective of this study was to analyse the effectiveness of the gamma-Z in estimating second-order effects in two- and three-storey structures, investigating how different stiffness reduction criteria impact the results. To this end, modelling and simulations were carried out using the commercial software TQS for two different structural models, discretised as space frames. Subsequent to the design of the structures, the average stiffness coefficients were obtained by processing them using the Nonlinear Physical-Geometric Frame (NLPGF). The iterative process was repeated until the coefficients converged. The gamma-Z results were then compared with those obtained using the P-delta calculation method. The research demonstrated that the adoption of more accurate stiffness reducers, replacing the conventional values of the Brazilian standard, results in a significant improvement in the estimation of second-order effects in buildings with less than four floors.

ISSN: 2591-3522 DOI: 10.70567/mc.v42.ocsid8440

1 INTRODUCTION

The analysis of global stability is fundamental to ensuring structural safety, as it assesses the risk of loss of resistant capacity due to the influence of second-order effects arising from structural displacements.(Kimura, 2018). As established by Carvalho and Pinheiro (2009), the forces calculated based on the initial geometry of the structure, without considering deformations, are termed first-order effects. Subsequent to the occurrence of deformations, such forces, considered from the displacements of the structure, are designated as second-order effects.

In order to facilitate the consideration of these effects, ABNT NBR6118 (2023) classifies structures as either fixed nodes, when second-order forces are less than 10% of first-order forces and can be disregarded, or movable nodes, when they exceed 10%, requiring their consideration. In light of the intricacy embedded within second-order calculations, the prevailing consensus advocates the utilisation of stability parameters, such as the γz coefficient. This approach serves to streamline the identification of the structural configuration and the estimation of the final forces, a process that is facilitated by the employment of solely first-order results. However, it is imperative to note that the application of this method is constrained to structures comprising a minimum of four floors.

With the aim of investigating the application of the coefficient γz in small structures with less than four floors, a study was conducted using TQS® software to assess the influence of stiffness reduction on the estimation of second-order effects. In this study, two building models were analysed, using stiffness reduction factors proposed in the works of Bueno (2014), Moreira and Martins (2018), in ABNT NBR6118 (2023), and in the code ACI318 (2019). The structure was validated using the P-Δ method for estimating second-order effects, in which stiffness reducers obtained through the Physical Geometric Nonlinear Frame (PNLFG) were applied.

2 THEORETICAL BASIS

The stability coefficient γz was initially proposed by Franco and Vasconcellos (1991), and was intended to simplify the process of obtaining second-order stresses. ABNT NBR6118 (2023) indicates that the coefficient γz can be determined from the results of a second-order linear analysis for each loading case according to Eq. (1), being valid for structures with at least four floors.

$$\gamma_z = \frac{1}{1 - \frac{\Delta M_{\text{tot},d}}{M_{1,\text{tot},d}}} \tag{1}$$

$\Delta Mtot, d$ – This is defined as the sum of all horizontal forces of the combination considered, with their design values, in relation to the base of the structure (Overturning moment);

$M1, tot, d$ – It is the sum of the products of all vertical forces acting on the structure, in the combination considered, with their calculation values, by the horizontal displacements of their respective points of application obtained from first-order analysis.

In order to make an accurate assessment of second-order effects in reinforced concrete structures, it is necessary to take into account physical nonlinearity (PNL). This is due to the fact that PNL alters the stiffness of materials as a result of cracking, concrete creep and steel flow (Silva et al., 2020). Traditionally, the analysis of PNL has been undertaken by means of moment-curvature relationships, based on the secant stiffness of the sections.

As demonstrated in ABNT NBR6118 (2023), stiffness reduction coefficients are established for beams and columns (Table 1). However, the application of these coefficients is restricted to structures with more than four floors, necessitating a specific evaluation for smaller buildings.

This approach was first introduced in studies by MacGregor (1993) and has since been incorporated into the standard. In order to circumvent this limitation, Bueno (2014) and Moreira and Martins (2018) proposed the use of stiffness reduction factors adapted to small structures (Table 1).

References	2 Flooring		3 Flooring	
	α_v	α_p	α_v	α_p
NBR 6118 (2023)	0.40	0.80	0.40	0.80
Bueno (2014)	0.30	0.60	0.30	0.70
Moreira and Martins (2018)	0.15	0.71	0.14	0.72

Table 1: Stiffness reducers for structures with less than 4 floors.

Another method for achieving effective stiffness reduction in structural elements is to utilize the elastic analysis proposed by the code ACI318 (2019). This approach to calculating the moment of inertia is based on the parametric investigations of Khuntia and Ghosh (2004), who developed specific equations for stiffness reduction in beams and columns. These equations have been adapted in this study according to the guidelines of ACI318 (2019).

In the columns, stiffness was calculated individually for each element and floor using Eq. (2), applying the arithmetic mean of the results to the model, with limits from $0.35I_g$ to $0.85I_g$. The calculation for the beams follows a similar methodology, applying Eq. (3), using the average of the values obtained and restricting between $0.25I_g$ and $0.50I_g$.

$$EI_{V,ef} = (0.10 + 25\rho)\left(1.2 - 0.2\frac{b_w}{d}\right) I_g \tag{2}$$

$$EI_{P,ef} \left(0.80 + 25\frac{A_{st}}{A_g}\right)\left(1 - \frac{M_u}{P_{u,h}} - 0.5\frac{P_u}{P_0}\right) I_g \tag{3}$$

Eq. (2) and Eq. (3) take into account a range of parameters, including the steel area (A_ST), the design moment (M_u), the section width (b_w), and the steel ratio (ρ), in accordance with the detailed structural requirements.

Nonlinear analysis can be performed with tools such as the Nonlinear Physical and Geometric Portal (NLPGP), which discretises the structure into bars and calculates stiffnesses via moment–curvature relationships (TQS Informática, 2020). For this, it is necessary that the forces and the detailed sizing of the elements be processed. In parallel, the P-Δ process, which consists of an iterative method that adjusts the geometric stiffness matrix, quantifies second-order effects using the RM2M1 parameter proposed by TQS®, which reports second- and first-order moments (Eq. 4).

$$\mathrm{RM2M1} = \frac{\mathrm{M2}}{\mathrm{M1}} \tag{4}$$

3 METHODOLOGY

In order to evaluate the effectiveness of the coefficient z in estimating second-order effects in two- to four-story buildings, two building models (Models A and B) were analyzed with variations in the stiffness reduction method. The models were simulated using the TQS® system to consider physical and geometric nonlinearities, and divided into two study topics: Physical Nonlinearity (PNL) and Nonlinearity Geometric (NLG).

3.1 Structural models

As illustrated in Figure (1a), the Model A structure is a rectangular building composed of eight beams and twelve pillars, with a ceiling height of three metres. The majority of the beams had a base measuring 14 centimetres and a height ranging from 30 to 50 centimetres. With regard to the columns, the base varied between 14 and 19 centimetres in diameter, and the height between 30, 40, and 50 centimetres. As illustrated in Figure (1b), Model B Bacarji and Pinheiro (1996) comprises 11 beams and 12 columns, which vary in section according to the number of floors. The majority of the beams were found to have a base measuring 14 centimetres, with a height ranging between 35 and 50 centimetres, depending on the specific level. In the case of the columns, the base varied between 14 and 19 centimetres and underwent dimensional adjustments in height according to the number of floors, varying between 30, 40, 50, and 60 centimetres.

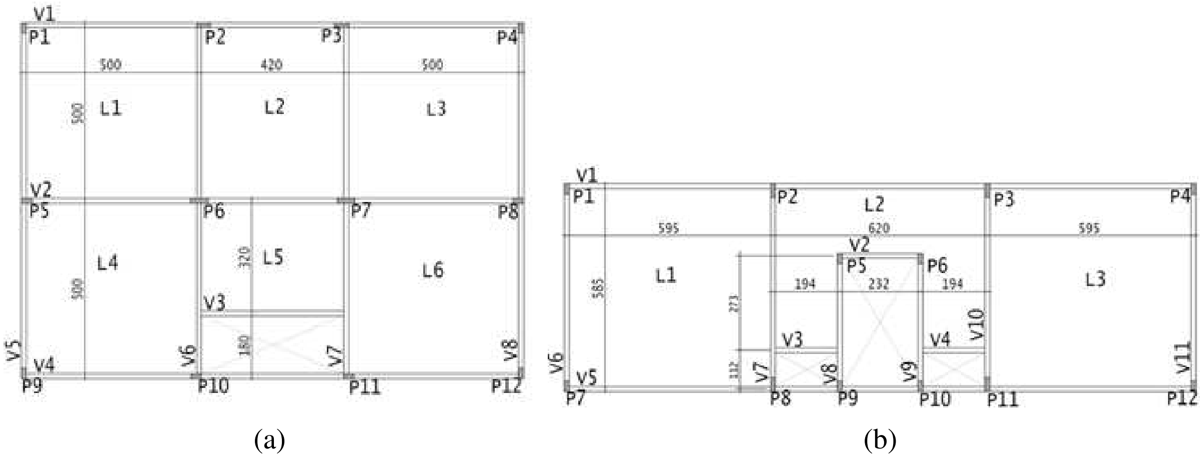

Figure 1: (a) Structural model A; (b) Structural model B.

3.2 Active Loads

According to ABNT NBR6118 (2023), the structural analysis process is required to encompass all potential actions that may exert an influence on the structure. This is to be achieved by giving due consideration to the ultimate and service limit states. As outlined in ABNT NBR6120 (2019), the self-weight of structural elements is one of the actions to be considered.

In the context of wind actions, the protocol outlined in ABNT NBR6123 (2023) was adhered to, with the TQS® software tool serving to facilitate the incorporation of data pertaining to the building in question and the subsequent determination of the static wind force. This determination was made with reference to a fundamental speed of 45 meters per second, as determined by the geographical location of the structure in proximity to Alegrete/RS, as depicted on the isopleth graph. In the models analysed, wind action prevailed, as 30% of wind action was greater than that of unsteadiness.

In concluding the assessment of overall model stability, eight combinations of actions, as specified by ABNT NBR6118 (2023), were utilised. The weighting coefficients assigned to these actions were 1.4 for permanent actions, with reduction coefficients of 1.5 and 0.5 for overloads and 1.4 an 0.6 for dynamic wind pressure.

3.3 Physical Nonlinearity

The influence of PNL variation was analysed through the variation of stiffness reduction factors. Initially, the factors recommended by ABNT NBR6118 (2023) were applied without consideration of the limitation provided for in the standard. Subsequently, the stiffness reducers proposed by Bueno (2014) and Moreira and Martins (2018) were tested, according to the values presented in (Table 1)

In order to validate the results, the Nonlinear Physical and Geometric Portal (NLPGP) method of the TQS® system was utilised. The spatial model under consideration comprised beams and columns discretised into bars of up to 50 centimetres. The stiffness of each bar was calculated on the basis of its geometry, detailed reinforcement, and applied forces, using moment-curvature relationships.

Subsequent to the initial dimensioning stage, the NLPGP was processed in order to obtain the average stiffness coefficients of the beams and columns. The coefficients were then adjusted in accordance with the system's predetermined criteria, and the structure underwent a resizing process. As illustrated in Figure (2), the procedural flowchart is presented.

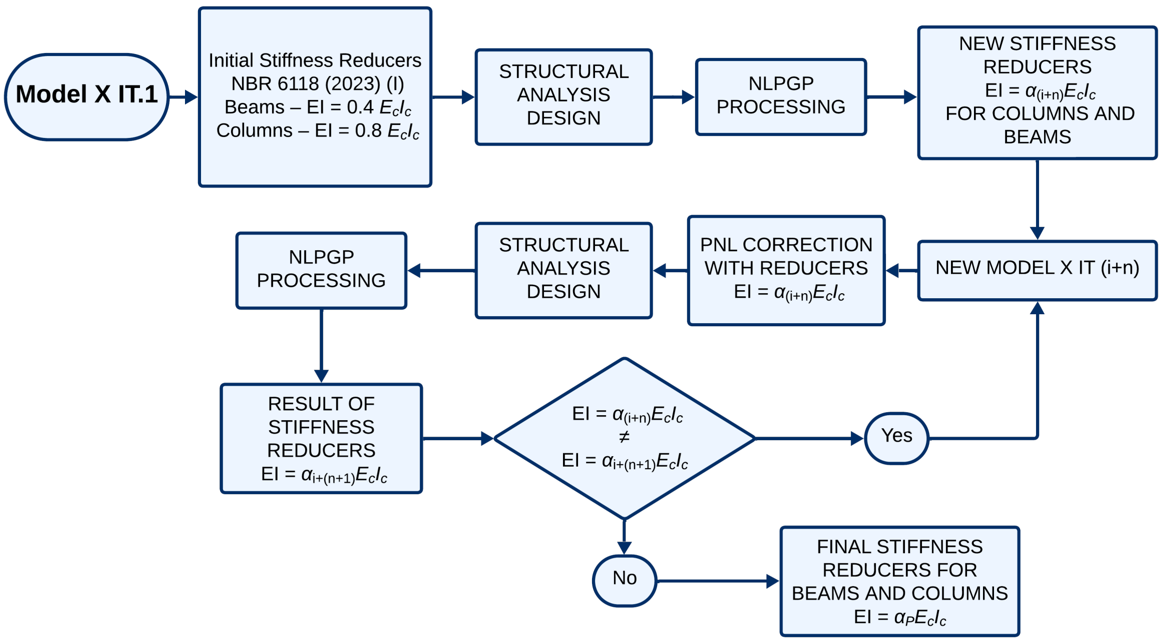

Figure 2: Flowchart of the methodology used in the NLPGP:

3.4 Global stability

Initially, the coefficient, designated as γz, was used as a metric for estimation, with systematic adjustments to the stiffness reducers implemented in accordance with a predetermined methodology. The modeling of the elements and the global processing followed the flow illustrated in Figure (3), with all variables kept constant except for the stiffness reducers.

The P-Δ numerical method was used to ascertain the ultimate equilibrium position of the structure through iterative corrections in the geometric stiffness matrix. Second-order effects were quantified on a global scale by employing the RM2M1 parameter, which serves to compare second- and first-order moments.

Following the global processing of the structure by the TQS® system, a global stability report was generated. This enabled the evaluation of the influence of the coefficient γz and the P-Δ process on the estimation of second-order effects.

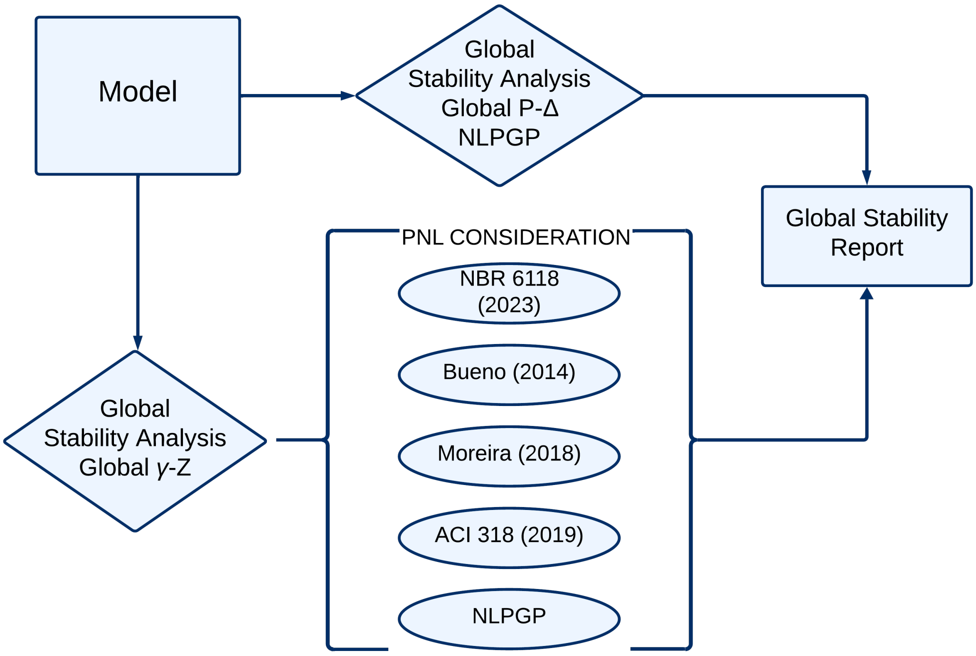

Figure 3: Flowchart of PNL analysis methodology

4 RESULTS

4.1 Results Physical Nonlinearity

As illustrated in Table (2), the stiffness reduction coefficients obtained by the NLPGP method and by Eq. (2) and Eq. (3) from ACI318 (2019) for beams and columns demonstrate that the differences are more pronounced in beams. For columns, the differences were less pronounced, with an average variation of less than 3%, suggesting enhanced precision in the ACI equations for these elements. The structural models were designated A and B, with the corresponding number of floors assigned P2, P3, and P4.

Model	NLPGP		ACI 318	
	Beams	Columns	Beams	Columns
AP2	0.172	0.718	0.278	0.726
BP2	0.192	0.708	0.288	0.665
AP3	0.161	0.725	0.287	0.679
BP3	0.159	0.672	0.286	0.674
AP4	0.150	0.695	0.301	0.673
BP4	0.168	0.701	0.297	0.676

Table 2: Stiffness reducers for structures with less than four floors.

4.2 Global stability analysis results

Figure (4) addresses the analysis of geometric nonlinearity in the structural models studied, evaluating the impact of stiffness reducers on the stability coefficients γz. The classifications between "fixed nodes" and "mobile nodes" vary according to the PNL methodology adopted, with greater instability observed in three- and four-story models.

Model A (1a), the vertical directions (90° and 270°) showed greater susceptibility to instability. Two-story models (AP2N and AP2ACI) were classified as "fixed nodes," with γz close to 1,10, while three-story (AP3) and four-story (AP4) models showed more flexible behavior, classified as "movable nodes." The variations between the methods based on ABNT NBR6118 (2023), ACI318 (2019), and the reducers of Bueno (2014) and Moreira and Martins (2018) were highlighted, especially in structures with up to three floors, since the factors in these studies do not apply to models with four floors.

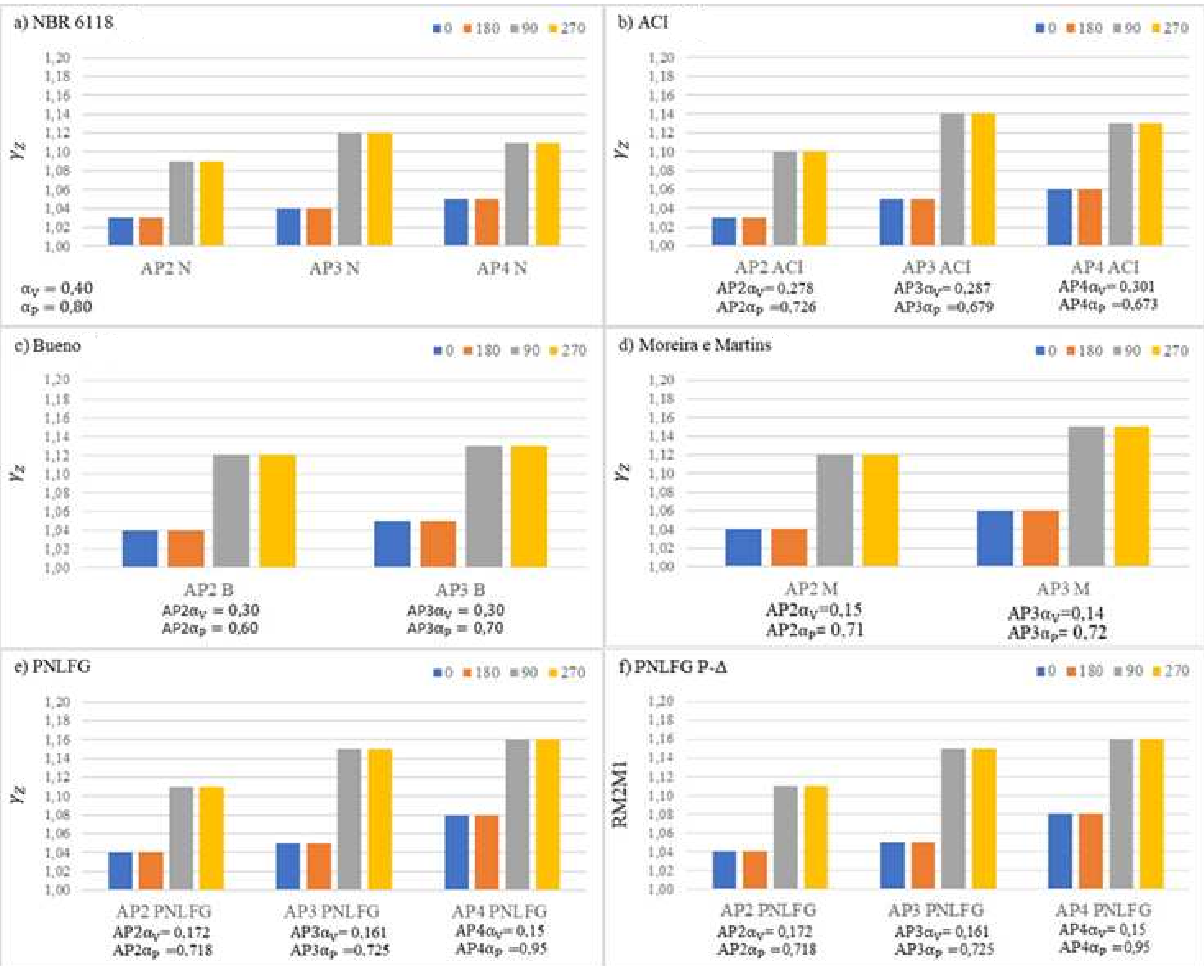

Figure 4: Global stability result model A

Model B Figure (5), instability was more pronounced in the horizontal directions (0° and 180°), and all models were classified as "mobile nodes." The dimensional adaptations of the columns in models BP3 and BP2 showed greater robustness in BP3. The coefficient γz varied according to the applied reducers, with the BPx-M and BPx-PNLFG models being the closest to the validation model (BPxP-Δ). The greatest discrepancy was recorded in the BP4N structure, with a variation of 3,85% in relation to the BP4 PNLFG P-Δ model.

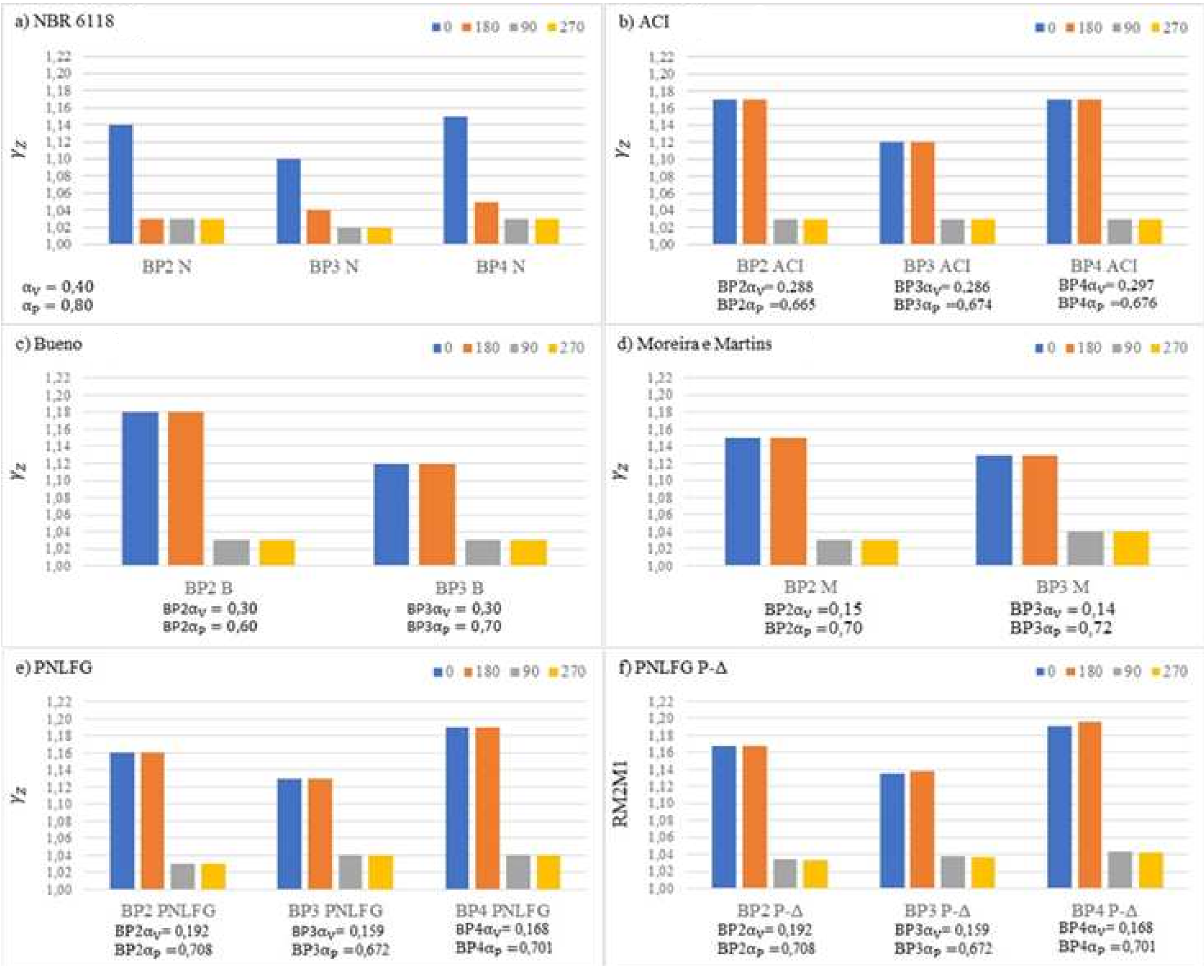

Figure 5: Global stability result model B

5 CONCLUSIONS

In this study, the performance of the γz coefficient was analyzed under various structural stiffness values using the P-Δ process combined with the Nonlinear Physical and Geometric Portal (NLPGP). The results obtained from this analysis demonstrated that:

- In the physical nonlinearity (PNL) analysis, the stiffness of the beams exhibited substantial variations (0,150 to 0,301) in relation to the reduction factors stipulated by ABNT NBR6118 (2023);
- The reduction in column stiffness exhibited a range from 0.665 to 0.726, exhibiting reduced discrepancy relative to the established normative values. It was determined that a decrease in reinforcement rates results in a reduction of beam stiffness, while the impact of the acting forces on columns is more pronounced;
- The values obtained by NLPGP were lower than those of ACI318 (2019), which indicated greater stiffness for beams and less for columns, as can be seen in models ACI AP3, AP4, BP2, and BP4;
- The coefficients proposed in ACI318 (2019) yielded estimates of γz that were lower than those of the reference model. This finding underscores the critical role of meticulous selection of stiffness factors in structural assessment;
- Preliminary findings from the Nonlinearity Geometric (NLG) analysis suggest that the coefficient γz, may serve as a reliable metric for estimating second-order effects in structures comprising up to four floors. However, it is crucial to note that the variability in structural stiffness exerts a substantial influence on the efficacy of this coefficient;
- A comparison was made of the coefficient γz with the P-Δ method, with both employing the same stiffness reducers. Variations of up to 5% in the coefficient were observed, depending on the model;
- The reducers proposed by Bueno (2014) and Moreira and Martins (2018) demonstrated greater adherence to the validation models, while those from ABNT NBR6118 (2023) and ACI318 (2019) exhibited greater discrepancies.

REFERENCES

ABNT NBR6118. Nbr 6118: Projeto de estruturas de concreto. Technical Report, ABNT, Rio de Janeiro, 2023.

ABNT NBR6120. Nbr 6120: Cargas para o cálculo de estruturas de edificações. Technical Report, ABNT, Rio de Janeiro, 2019.

ABNT NBR6123. Nbr 6123: Forças devidas ao vento em edificações. Technical Report, ABNT, Rio de Janeiro, 2023.

ACI318. Building code requirements for structural concrete (aci 318-19) and commentary. Technical Report, ACI, Farmington Hills, MI, 2019.

Bacarji E. and Pinheiro L.M. Estabilidade global de edifícios. In *Congresso de Engenharia Civil da UFJF*. Juiz de Fora, MG, Brasil, 1996.

Bueno M.M.E. *Evaluation of Global Instability Parameters in Reinforced Concrete Structures*. Ph.D. thesis, Universidade de Brasília, Brasília-DF, 2014.

Carvalho R. and Pinheiro L.M. *Cálculo e detalhamento de estruturas usuais de concreto armado: volume 2*. Pini, São Paulo, 2009. ISBN 9788552661881.

Franco M. and Vasconcellos A.C. Practical assessment of second order effects in tall buildings. In *Colloquium on the CEB-FIP MC90, Rio de Janeiro Proceedings*, pages 307–323. COPPE/UFRJ, Rio de Janeiro, 1991.

Khuntia M. and Ghosh S.K. Flexural stiffness of reinforced concrete columns and beams: analytical approach. *ACI Structural Journal*, 101(3):351–363, 2004.

Kimura A. *Informática aplicada a estruturas de concreto armado*. Oficina de Textos, São Paulo, 2018. ISBN 9788579753114.

MacGregor J.G. Design of slender concrete columns-revisited. *ACI Structural Journal*, 90(3):302–309, 1993.

Moreira L.M. and Martins C.H. Low-rise structures in reinforced concrete: approximation of material nonlinearity for global stability analysis. *IBRACON Structures and Materials Journal*, 11(1):1–25, 2018. http://doi.org/10.1590/S1983-41952018000100002.

Silva C.B.P.d., Mota A.G., Izquierdo O.S., Moraes M.A.F., Pinheiro A.d.S., and Izquierdo I.S. Influência da localização do núcleo rígido de edifícios de múltiplos pavimentos de concreto armado na estabilidade global das estruturas. *Brazilian Journal of Development*, 6(9):65574–65589, 2020. http://doi.org/10.34117/bjdv6n9-113.

TQS Informática. *Manual do usuário do CAD/TQS: análise estrutural*. São Paulo, SP, Brasil, 2020.