AUTOMATED MODELING OF SLABS IN ANSYS USING GRILLAGE ANALOGY AND THE FINITE ELEMENT METHOD

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Abstract: Technological advances have fostered the widespread use of computational tools in structural engineering, enabling more representative and detailed analyses. The grillage analogy, applied through the Finite Element Method (FEM), is an effective approach for slab analysis. In ANSYS®, this technique can be implemented through APDL (ANSYS Parametric Design Language) input files; however, their manual generation is time-consuming and labor-intensive, often requiring thousands of command lines. This study developed a Python-based computational routine to automate the generation of APDL files for grillage-based analysis of slabs and edge beams in ANSYS®. The generated models were validated against slab analyses reported in the literature. Percentage differences in bending moments ranged from 0.21% to 5.09%. The expanded validation included torsional moments and vertical deflections. For torsional moments, differences of 14.44% and 17.53% were obtained for J = 100% and J = 15%, respectively, while reducing J from 100% to 15% decreased the torsional moment by 72.33% in the developed model and 73.06% in the reference study. Vertical deflections showed close agreement with reference values, with differences of 1.08% and 1.48% for the analyzed mesh discretizations. Overall, the APDL Generator provided consistent numerical results while automating the modeling process, supporting its applicability to grillage-based slab analysis in ANSYS®.

Keywords: APDL, Python programming, Structural engineering, Torsional stiffness, Numerical simulation.

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1. INTRODUCTION

In structural and biosystems engineering, structural analysis plays a fundamental role in ensuring the safety and performance of built facilities, ranging from urban infrastructure to specialized rural constructions. The evaluation of reinforced concrete slabs is particularly critical, as these elements are responsible for transferring loads to the supporting system while controlling serviceability and ultimate limit states. In practical design, however, slab analysis, especially in structures with complex geometries or boundary conditions, often requires significant computational effort and specialized expertise, particularly when advanced numerical tools are employed.

Within this context, the grillage analogy has long been recognized as an efficient and conceptually robust approach for slab analysis. In this method, a two-dimensional slab is idealized as an orthogonal grid of equivalent beams whose flexural and torsional properties reproduce, in an approximate but effective manner, the global behavior of the plate. This approach has been successfully applied in a wide range of structural engineering problems, from residential building slabs to bridge decks. Additionally, in the agricultural sector, this method is vital for the design of grain storage

floors and silo foundations, where accurate stress analysis is essential for structural integrity. Gordon and May (2004) discussed fundamental aspects of slab discretization using grillage models, highlighting both inherent limitations and recommended modeling practices. Similarly, Théoret, Massicotte, and Conciatori (2012) and Lu and Shao (2012) applied the grillage analogy to straight and skewed slab bridges, emphasizing the influence of mesh spacing and torsional stiffness calibration on the accuracy of the results.

More recent studies have confirmed the continued relevance of grillage-based models in structural analysis. Machado and Moura (2022) applied the grillage analogy to the numerical analysis of reinforced concrete solid slabs, while Lu, Judd, and Barker (2021) combined field testing with grillage analysis to assess the load-carrying capacity and system behavior of skewed steel-girder highway bridges. More recently, Subedi et al. (2024) employed finite element grillage models to investigate the influence of cross-girder configuration on bending moments, shear forces, torsion, and displacements in reinforced concrete T-beam bridges. These studies demonstrate that grillage-based modeling remains a relevant computational approach for evaluating load distribution and structural response, while also highlighting the importance of adequately representing stiffness and discretization parameters.

ANSYS® is a widely recognized engineering simulation platform capable of performing detailed structural analyses based on the finite element method. Nevertheless, the implementation of grillage models in ANSYS® through APDL (ANSYS Parametric Design Language) input files can be a delicate and time-consuming task. The manual preparation of these scripts requires careful definition of geometry, material properties, boundary conditions, and load cases, frequently resulting in input files with thousands of command lines. As a consequence, the modeling process becomes prone to human error and inefficient for parametric studies or routine design applications.

In recent years, several efforts have sought to automate structural modeling workflows in finite element software. The PyMAPDL project (2025), for instance, represents a significant milestone by enabling direct interaction between Python and ANSYS® MAPDL, allowing the automated generation and execution of input files. Along similar lines, Guo et al. (2025) proposed an automated methodology for the analysis of corroded pipelines by integrating MATLAB® and ANSYS®, demonstrating the potential of programming-based approaches to reduce modeling errors and improve computational efficiency.

To address the challenges associated with manual grillage modeling in ANSYS®, this study presents the development of a computational program written in Python aimed at automating the generation of APDL input files for the grillage-based analysis of solid slabs. The proposed routine systematically incorporates geometric parameters, material properties, mesh discretization, loading conditions, and boundary constraints, producing a ready-to-run APDL file with minimal user intervention. Beyond improving efficiency and reducing the likelihood of errors, this automation constitutes an original contribution to the structural engineering literature by formalizing a reproducible and extensible procedure for grillage modeling of slabs in ANSYS®.

The main objective of this paper is to evaluate the performance and reliability of the developed program through comparisons with classical analytical tables and well-established numerical studies reported in the literature. Special attention is given to the influence of torsional stiffness on the structural response, in line with the recommendations of design standards such as ABNT NBR 6118 (2023). By automating the analysis of solid slabs using the grillage analogy, the proposed approach seeks to enhance the efficiency, consistency, and reliability of structural analyses, thereby supporting safer and more rational engineering design.

2. MATERIALS AND METHODS

The research methodology consisted, in the first stage, of identifying and analyzing the variables and parameters required for the generation of input codes in ANSYS®, considering the grillage analogy for the analysis of solid slabs. Based

on the definition of these variables, a detailed study of the programming language Python was carried out in order to support the development of the computational program. Python was chosen over other programming languages due to its simple and intuitive syntax, which allows rapid implementation of routines and reduces the likelihood of coding errors. In addition, Python is an open-source, multiplatform language that does not require costly licensing, and it offers a wide range of scientific libraries suitable for numerical computation and structural analysis, such as NumPy, SciPy and Matplotlib.

After the completion of the computational code, slab examples previously studied by other authors were reanalyzed in order to compare the results obtained by the developed program with those reported in the literature, thereby validating the functionality of the code. In this validation process of the computational routine entitled "APDL Generator", bending moments were initially adopted as the primary response parameters for comparison. In order to expand the validation scope of the numerical model, additional comparisons were subsequently performed considering torsional moments and vertical deflections. Torsional moments were evaluated for Example 1, considering full torsional stiffness (J = 100%) and reduced torsional stiffness (J = 15%), using the results reported by Col Debella and Santos (2016) as reference values. Vertical deflections were evaluated for Example 2, considering grillage meshes of 10 × 10 cm and 80 × 80 cm, using the results reported by Stramandinoli and Loriggio (2003) as reference values. These additional response quantities were selected because they allow the validation to encompass not only the distribution of bending forces, but also the torsional response and the global stiffness of the numerical model.

Finally, after confirming the satisfactory performance of the routine, the graphical user interface of the program was improved to allow intuitive data input, enhancing usability and efficiency in practical applications.

As shown in Figure 1, the methodological procedure adopted in this study is structured into sequential stages, encompassing the definition of modeling parameters, development of the computational routine, numerical validation, and analysis of results.

2.1. Grillage analogy methodology and ANSYS® software

The grillage analogy method consists of discretizing a structural element into beam elements that form a reticulated system similar to a grid (Figure 2). This methodology allows the application of different types of loading, the consideration of various support conditions, and the representation of the geometrical and material properties, making it particularly suitable for the design of structural components and for studying the structural behavior of slabs.

ANSYS® is a widely used structural simulation tool that employs the finite element method to perform comprehensive analyses of complex structures. In this study, the BEAM4 element was adopted to model the beams of the grillage system (ANSYS, 2022). This element is uniaxial and has six degrees of freedom per node (three translations and three rotations), which enables consistent representation of bending, torsion, and shear effects along the bars that compose the grillage. This characteristic is particularly important in the present work, since the grillage

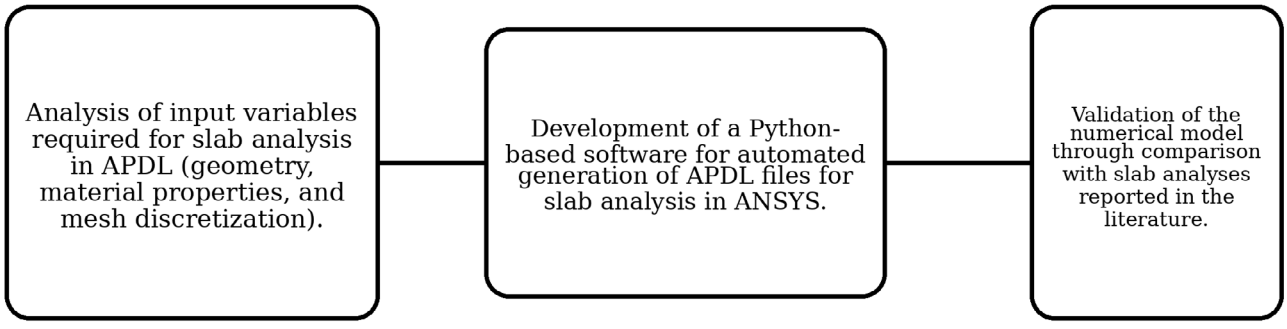


Figure 1: Research flowchart.

analogy strongly depends on an adequate representation of torsional stiffness, a key parameter in the structural response of slabs.

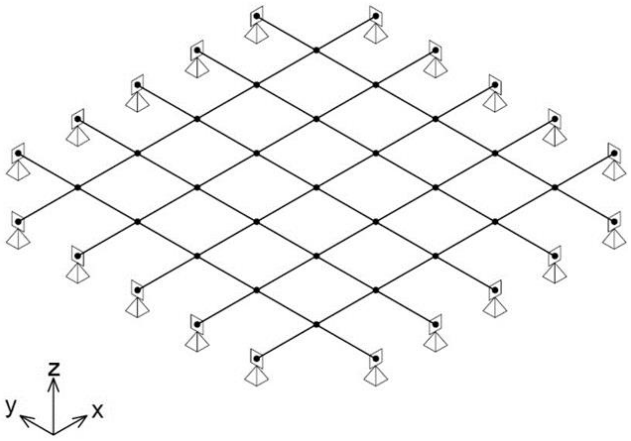


Figure 2: Representation of a slab discretized according to the grillage analogy (Machado, 2022).

However, because BEAM4 is a uniaxial element, it does not directly capture the two-dimensional effects typical of continuous plates. Therefore, the discretization of the slab into a grid of beams must be sufficiently refined in order to approximate the real structural behavior. Moreover, this element does not explicitly account for concrete cracking phenomena, and the analysis is thus restricted to Stage I behavior of reinforced concrete. Consequently, the present study is limited to a linear elastic analysis.

For the implementation of the APDL code applying the grillage analogy in ANSYS®, the following parameters must be defined:

- geometric properties of the beam elements;
- physical and mechanical properties of the materials;
- nodal mesh of the grillage in Cartesian coordinates;
- connectivity of nodes with assignment of geometric and material parameters;
- application of loads to nodes or beam elements;
- definition of support conditions.

2.2. Definition of geometric properties of the grillage and physical properties of the material

For the APDL input in ANSYS®, the geometric properties of the element cross sectional are first defined, including the moments of inertia about the X and Y axes, as well as the torsional stiffness. Considering an analysis restricted to Stage I of reinforced concrete behavior, without accounting for reinforcement, Equations (1) and (2) are used to calculate the moments of inertia of the beam sections in the structure:

$$I_x = \frac{b.h^3}{12} \tag{1}$$

$$I_y = \frac{\mathrm{h.b}^3}{12} \tag{2}$$

Another parameter employed in the grillage analogy is the torsional moment of inertia (J), defined according to Equations (3) and (4), as proposed by Gere and Weaver (1981):

$$\beta = \frac{1}{3} - (0.21\frac{e}{f})(1 - \frac{e^4}{12f^4}) \tag{3}$$

$$J = \beta.e^3.f \tag{4}$$

where:
e: smaller dimension of the cross section;
f: larger dimension of the cross section.

The material parameters adopted in the software are:

- modulus of elasticity (*E*);
- Poisson's ratio (ν) = 0.2 (concrete);
- shear modulus (*G*).

To obtain the modulus of elasticity of concrete using gneiss and granite as coarse aggregate, ABNT NBR 6118 (2023) prescribes the use of the following equation:

$$\alpha_i = 0.8 + 0.2\,\frac{f_{ck}}{80} \leq 1 \tag{5}$$

where:

$E_{cs} = \alpha_i\, 5600\sqrt{f_{ck}}$

f_{ck}: characteristic compressive strength of concrete (MPa).

The shear modulus (*G*) can be obtained using Equation (6):

$$G = \frac{E}{2(1+\nu)} \tag{6}$$

2.3. Definition of grillage mesh characteristics and applied loading

The grillage mesh is generated according to the spacing between beams, which determines the effective width of the equivalent beam sections. To generate the mesh, the total length of the structure is divided by the adopted mesh spacing.

In the analyzed system, the applied loads result from the combination of dead and live loads acting on the structure. Within the grillage analogy, these loads can be applied in two distinct ways: (i) by concentrating the loads at the connection points (nodes) of the grillage beams, or (ii) by distributing the loads uniformly along the beam segments connecting adjacent nodes. Both loading approaches are illustrated in Figure 3.

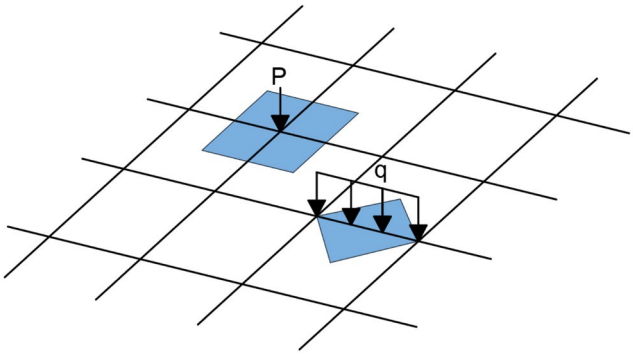


Figure 3: Types of loads applicable to the grillage system (adapted from Stramandinoli and Loriggio, 2003).

As depicted in Figure 3, the applied loads may be represented either as concentrated nodal forces or as uniformly distributed loads along the grillage beams, depending on the adopted modeling strategy. The support conditions of the analyzed slabs were considered in different configurations, depending on the slab type. In the analyses performed in this study, slabs simply supported along two adjacent edges and fixed along the other two edges were considered.

2.4. Program interface and input parameters

The developed program, named "APDL Generator," receives the variables required for the creation of the APDL code and outputs the corresponding input file for implementation in the structural simulation software, based on the following information:

- Inputs: slab dimensions, material properties, discretization mesh;
- Processing: generation of nodes, elements, boundary conditions, and loading;
- Output: APDL file ready for execution in ANSYS®.

Figure 4 presents the graphical user interface of the developed program, showing the main input fields used to define geometric characteristics, material properties, mesh discretization, and loading conditions. The interface was originally developed in Portuguese; the corresponding input parameters are identified in the figure caption.

2.5. Percentage differences

To evaluate the accuracy of the results obtained with the developed program, comparisons were carried out with reference values available in the literature and in classical structural design tables. Percentage differences were calculated by always considering the reference value (Vref) as the denominator, in order to express the relative deviation of the value obtained with the APDL Generator (Vobt) with respect to the consolidated solution, as defined in Equation (7):

$$\Delta\% = \frac{|V_{obt} - V_{ref}|}{V_{ref}} x100 \quad (7)$$

where:

- V_{ref} corresponds to the reference value obtained from the tables of Bares (1979) and Czerny (1932) or from the studies by Stramandinoli and Loriggio (2003) and Col Debella and Santos (2016);
- V_{obt} corresponds to the value resulting from the analysis performed using the developed program.

3. RESULTS AND DISCUSSIONS

This section presents the results obtained using the developed APDL Generator. In order to demonstrate the reliability and functionality of the proposed tool, the results

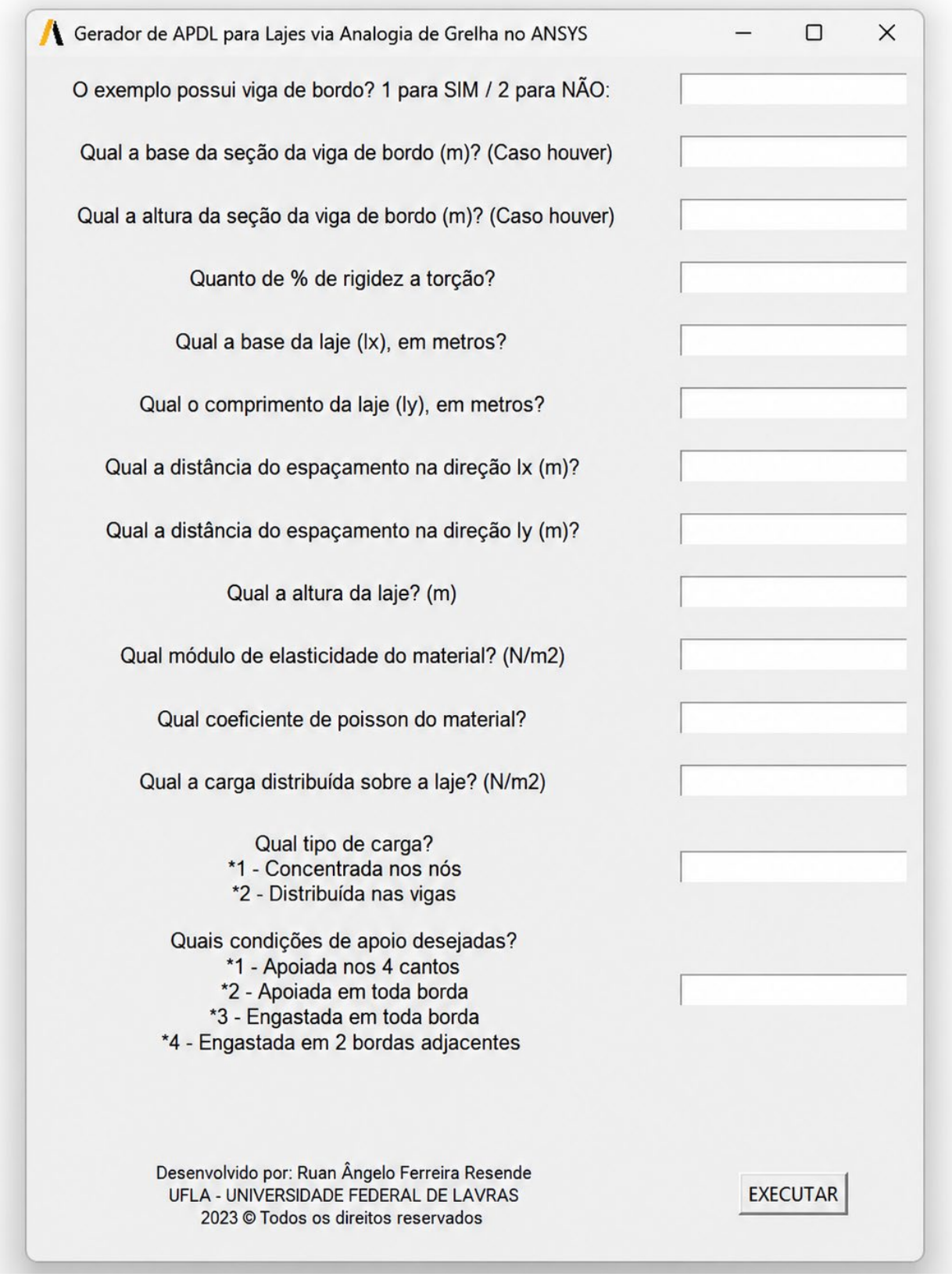


Figure 4: Interface and input parameters of the "APDL Generator" software. The software interface was originally developed in Portuguese. The displayed input fields correspond, respectively, to the presence of edge beams; edge-beam cross-sectional dimensions; percentage of torsional stiffness; slab width and length; grillage spacing in the x and y directions; slab thickness; material elastic modulus; Poisson's ratio; distributed load; load application type; and support conditions.

were systematically compared with multiple reference solutions available in the literature. Validation was carried out against classical analytical tables by Bares (1979) and Czerny (1932), which are widely used references in the structural analysis of reinforced concrete slabs. In parallel, the results were also compared with numerical models developed by Stramandinoli and Loriggio (2003) and Col Debella and Santos (2016), both of which employed the grillage analogy in their analyses. This comparative approach allows a consistent assessment of the accuracy of the developed program and its adherence to established structural analysis methods.

3.1. Example 1 – Square slab fixed along adjacent edges

Col Debella and Santos (2016) analyzed a solid square slab fixed along two adjacent edges and simply supported along the remaining edges, with a span of 4 m. The slab included edge beams with a cross section of 12 × 30 cm, and the study investigated variations in grillage spacing and torsional stiffness of the structural system. In the present work, bending moments obtained using the APDL Generator were compared considering grillage strips 40 cm wide and adopting both the full torsional stiffness and a reduced value equal to 15% of the original stiffness, as recommended by ABNT NBR 6118 (2023). The remaining slab parameters are summarized as follows:

- Modulus of elasticity: E_{ci} = 2.8 × 10^7 kN/m² (concrete with f_{ck} = 25 MPa);
- Poisson's ratio: v = 0.2;
- Slab thickness: h = 8 cm;
- Two adjacent edges fixed and the other two simply supported;
- Total load = 750 kgf/m² = 7.355 kN/m².

As shown in Figure 5, sagging bending moments occur at the center of the slab, whereas the largest hogging moments develop along the fixed edges, which is consistent with the expected structural behavior.

The numerical results obtained, as well as their comparison with the results reported by Col Debella and Santos (2016) and the Bares Tables (1979), are presented in Table 1.

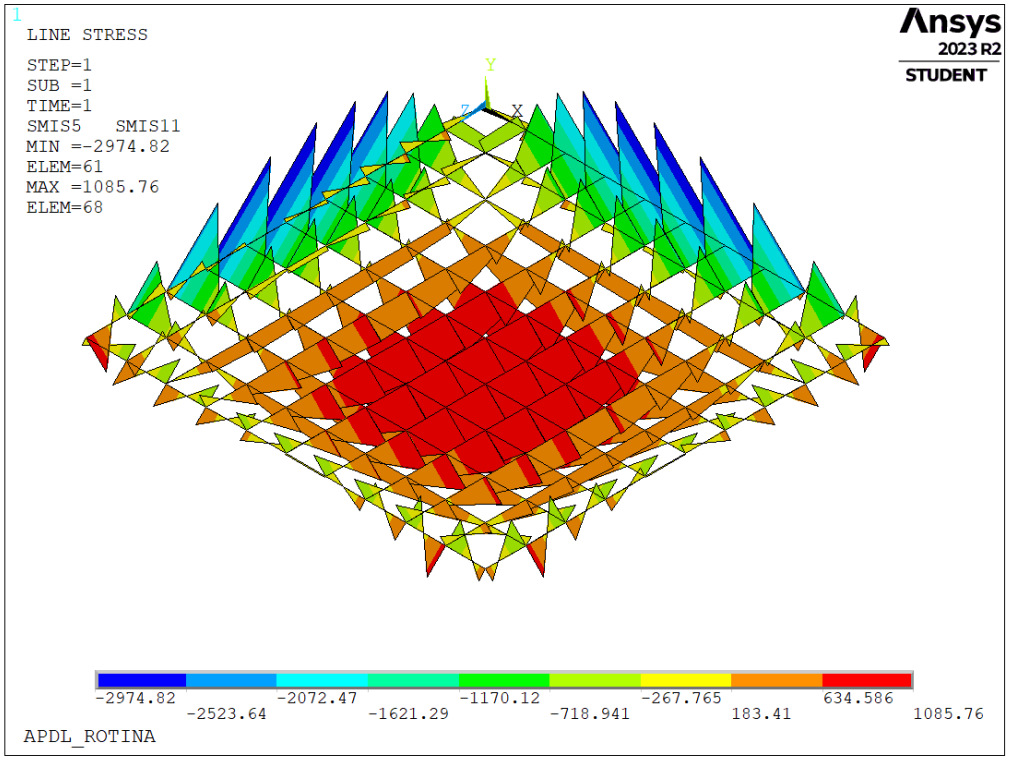


Figure 5: Bending moment diagram for Example 1 obtained in ANSYS®, considering full torsional stiffness (J = 100%).

The comparison for the reduced torsional stiffness case (J = 15%) is presented in Table 2.

The numerical results were compared with those obtained by Col Debella and Santos (2016), who used the SAP2000 software, as well as with the Bares Tables (1979), as shown in Table 1 for full torsional stiffness (J = 100%) and in Table 2 for the reduced stiffness case (J = 15%), as recommended by ABNT NBR 6118 (2023). It can be observed that the percentage differences between the developed program and Col Debella and Santos (2016) were lower than 1% in the first situation (0.53% for Mx^+ and 0.47% for Mx^-, Table 1, row Author × Col Debella), and close to this range in the second case (1.06% for Mx^+ and 1.41% for Mx^-, Table 2, row Author × Col Debella). This confirms that the computational model provides results that are coherent and adequate for the structural behavior of reinforced concrete slabs under the studied condition, in addition to demonstrating the high accuracy of the APDL Generator.

In contrast, when compared with the Bares Tables (1979), the results obtained using the Generator exhibited larger discrepancies (12.83% for Mx^+ and 9.06% for Mx^-, Table 1, row Author × Bares; and 39.14% for Mx^+ and 14.44% for Mx^-, Table 2, row Author × Bares). These differences follow the same trend as those also observed by Col Debella and Santos (2016) in comparison with Bares (1979) (13.29% for Mx^+ and 8.64% for Mx^-, Table 1, row Col Debella × Bares; and 40.63% for Mx^+ and 16.05% for Mx^-, Table 2, row Col Debella × Bares), which was expected given the approximate and simplified nature of these tables when compared with numerical models.

Another relevant aspect highlighted by the analysis was the sensitivity of the model to torsional stiffness (J). Reducing J to 15% resulted in significant increases in bending moments, reaching approximately 60% to 62% for Mx^+ and 26% to 27% for Mx^-, depending on the reference dataset (Author or Col Debella), when compared with the values obtained for J = 100% (Tables 1 and 2). These results confirm the high sensitivity of the structural response to torsional stiffness and are fully consistent with the literature and with the fundamentals of the grillage analogy, demonstrating that the developed program is capable of adequately capturing the effects of torsional stiffness on slab behavior. Nevertheless, both the APDL Generator analysis and the study by Col Debella and Santos (2016) presented significant discrepancies in relation to the Bares Tables (1979) when torsional stiffness was reduced. This behavior arises from the fact that the reduction

Table 1: Comparison of results obtained with the developed program and those reported by Col Debella and Santos (2016) and Bares (1979) for full torsional stiffness (J = 100%).

Calculation Model:	M_x^+ (kNm)	M_x^- (kNm)
Author	2.755	7.475
Col Debella and Santos (2016)	2.740	7.510
Bares Table (1979)	3.160	8.220
Percentage difference - Col Debella and Santos (2016) x Bares (1979)	13.29 %	8.64 %
Percentage difference - Author x Col Debella and Santos (2016)	0.53 %	0.47 %
Percentage difference - Author x Bares (1979)	12.83 %	9.06 %

Table 2: Comparison of results obtained with the developed program and those reported by Col Debella and Santos (2016) and Bares (1979) for reduced torsional stiffness (J = 15%).

Calculation Model:	M_x^+ (kNm)	M_x^- (kNm)
Author	4.397	9.407
Col Debella and Santos (2016)	4.444	9.540
Bares Table (1979)	3.160	8.220
Percentage difference - Col Debella and Santos (2016) x Bares (1979)	40.63 %	16.05 %
Percentage difference - Autor x Col Debella and Santos (2016)	1.06 %	1.41 %
Percentage difference - Autor x Bares (1979)	39.14 %	14.44 %

of J intensifies slab bending moments, which are captured by the numerical model but not represented by the tabulated approximations.

In addition to the bending-moment comparison, the validation of Example 1 was expanded to include the torsional moment, considering the two torsional stiffness conditions adopted in the analysis, J = 100% and J = 15%. The results obtained with the APDL Generator were compared with those reported by Col Debella and Santos (2016), as presented in Table 3.

Table 3: Comparison of torsional moments obtained with the APDL Generator and those reported by Col Debella and Santos (2016) for different torsional stiffness values.

Torsional stiffness	APDL Generator, Mt (kN·m/m)	Col Debella and Santos (2016), Mt (kN·m/m)	Percentage difference (%)
J=100%	412	360	14.44
J=15%	114	97	17.53

The torsional-moment comparison resulted in percentage differences of 14.44% for J = 100% and 17.53% for J = 15% relative to the values reported by Col Debella and Santos (2016). Although these differences are higher than those observed for the bending moments, both analyses reproduced a very similar response to the reduction in torsional stiffness. When J was reduced from 100% to 15%, the torsional moment decreased by 72.33% in the APDL Generator model and by 73.06% in the reference study. This close agreement in the relative variation demonstrates that the generated model consistently reproduces the sensitivity of the torsional response to changes in torsional stiffness.

Thus, Example 1 validates the APDL Generator in three aspects: (i) numerical accuracy, due to the proximity of the bending-moment results to those obtained by Col Debella and Santos (2016); (ii) physical adherence, due to the correct representation of the influence of torsional stiffness on the redistribution of internal forces; and (iii) consistency of the torsional response, demonstrated by the close agreement between the relative reductions in torsional moment obtained with the APDL Generator and reported in the reference study when J was reduced from 100% to 15%.

3.2. Example 2 – Square solid slab fixed along adjacent edges

In this second validation model, a solid square slab with a side length of 4 m, studied by Stramandinoli and Loriggio (2003), was analyzed. The slab was fixed along two adjacent edges and simply supported along the remaining edges, without edge beams along its perimeter. The main objective was to evaluate the influence of grillage mesh spacing (10 cm and 80 cm) on the accuracy of the results, while maintaining constant torsional stiffness (J = 100%). The remaining parameters adopted in the analysis are:

- Modulus of elasticity: E_{ci} = 2.1 × 10^7 kN/m² (concrete with f_{ck} = 15 MPa);
- Poisson's ratio: ν = 0.2;
- Thickness: h = 8 cm;
- Total load = 10 kN/m².

Figures 6 and 7 illustrate the bending moment diagrams obtained for the analyzed structure, considering grillage meshes of 80 × 80 cm and 10 × 10 cm, respectively. In both cases, a pattern is observed in which negative bending moments are more intense near the fixed edges, while sagging bending moments occur in the central region of the slab.

Quantitative comparisons for the assessment of torsional stiffness kept constant and the sensitivity to mesh discretization are presented in Tables 4 (mesh of 80 × 80 cm) and 5 (mesh of 10 × 10 cm). It is observed that, for the coarser mesh (80 cm), the results obtained using the APDL Generator were closer to those reported by Stramandinoli and Loriggio (2003) (0.36% for Mx^+ and 1.54% for Mx^-, Table 4, row Author × Stramandinoli) and also to the Czerny Tables (1932) (1.66% for Mx^+ and 4.71% for Mx^-, Table 4, row Author × Czerny). When the mesh was refined to 10 cm while maintaining full torsional stiffness, the differences increased: relative to Stramandinoli and Loriggio (2003), they increased to 5.09% for Mx^+ and 4.84% for Mx^- (Table 5, row Author × Stramandinoli); and relative to the Czerny Tables (1932), they reached 12.04% for Mx^+ and 10.05% for Mx^- (Table 5, row Author × Czerny). It is important to note that the results reported by Stramandinoli and Loriggio (2003) also diverge further from the Czerny Tables (1932) when the mesh is refined (from 1.29% to

7.33% for Mx^+ and from 6.34% to 14.21% for Mx^-, as shown in Tables 4 and 5, row Stramandinoli × Czerny), which indicates that conventional tables, due to their simplified nature, do not constitute a reference solution toward which the mesh should necessarily converge.

In addition to the bending-moment comparison, the validation of Example 2 was expanded to include vertical deflections, using the results reported by Stramandinoli and Loriggio (2003) as reference values. The comparison was performed for the same two grillage discretizations previously considered, with mesh spacings of 80 × 80 cm and 10 × 10 cm. The results are presented in Table 6.

As shown in Table 6, the vertical deflections obtained with the APDL Generator were in close agreement with the reference values for both

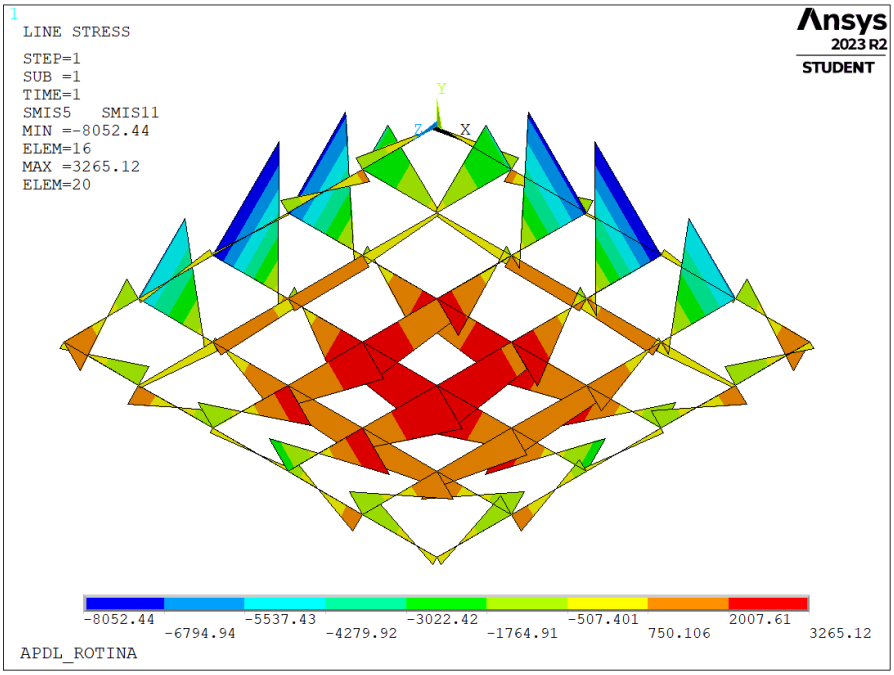


Figure 6: Bending moment diagram for Example 2 obtained in ANSYS® for a grillage mesh of 80 × 80 cm.

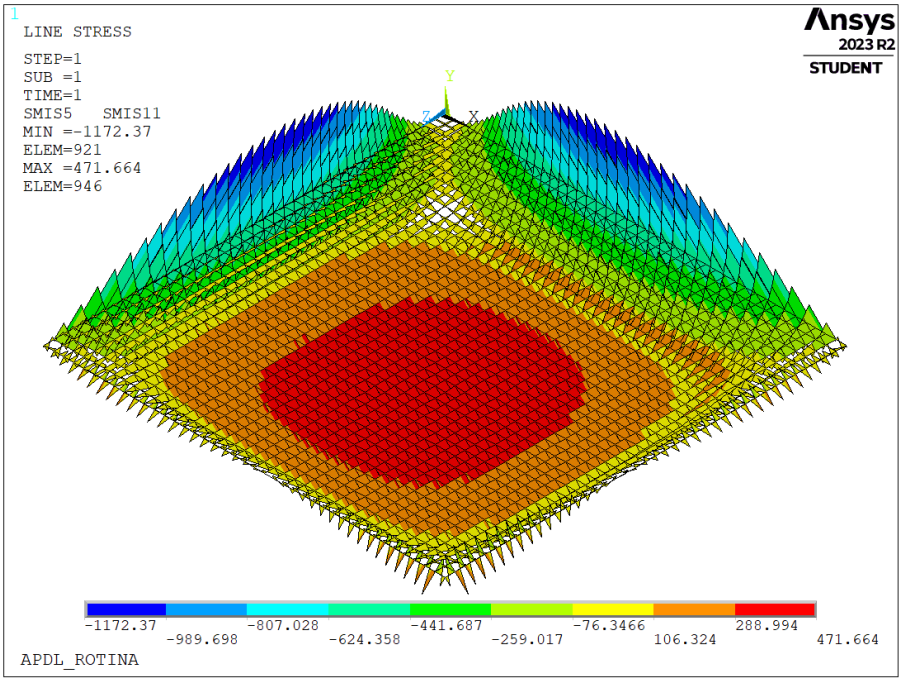


Figure 7: Bending moment diagram for Example 2 obtained in ANSYS® for a grillage mesh of 10 × 10 cm.

Table 4: Comparison of the results obtained by the software with those reported by Stramandinoli and Loriggio (2003) and the Czerny Tables (1932) (80 × 80 cm mesh, torsional stiffness *J* equal to 100% of its total value).

Calculation Model:	M_x^+ (kNm)	M_x^- (kNm)
Author	4.717	11.717
Stramandinoli and Loriggio (2003)	4.700	11.900
Czerny Table (1932)	4.640	11.190
Percentage Difference - Stramandinoli and Loriggio (2003) x Czerny (1932)	1.29 %	6.34 %
Percentage Difference - Author x Stramandinoli and Loriggio (2003)	0.36 %	1.54 %
Percentage Difference - Author x Czerny (1932)	1.66 %	4.71 %

Table 5: Comparison of the results obtained by the software with those reported by Stramandinoli and Loriggio (2003) and the Czerny Tables (1932) (10 × 10 cm mesh, torsional stiffness *J* equal to 100% of its total value).

Calculation Model:	M_x^+ (kNm)	M_x^- (kNm)
Author	4.081	10.065
Stramandinoli and Loriggio (2003)	4.300	9.600
Czerny Table (1932)	4.640	11.190
Percentage Difference - Stramandinoli and Loriggio (2003) x Czerny (1932)	7.33 %	14.21 %
Percentage Difference - Author x Stramandinoli and Loriggio (2003)	5.09 %	4.84 %
Percentage Difference - Author x Czerny (1932)	12.04 %	10.05 %

mesh discretizations. For the 80 × 80 cm mesh, the calculated deflection was 0.366 cm, compared with 0.370 cm reported by Stramandinoli and Loriggio (2003), corresponding to a difference of 1.08%. For the refined 10 × 10 cm mesh, the respective values were 0.266 cm and 0.270 cm, resulting in a difference of 1.48%. These small differences indicate that, in addition to reproducing bending-moment distributions, the generated model also provides a consistent representation of the global deformational response of the slab for the analyzed cases.

Table 6: Comparison of vertical deflections obtained with the APDL Generator and those reported by Stramandinoli and Loriggio (2003) for different grillage mesh spacings.

Grillage mesh	APDL Generator (cm)	Stramandinoli and Loriggio (2003) (cm)	Percentage difference (%)
80 x 80 cm	0.366	0.370	1.08
10 x 10 cm	0.266	0.270	1.48

In summary, mesh refinement promotes stabilization (convergence) of the numerical solution of the grillage model, but it does not imply convergence toward tabulated solutions. On the contrary, the refined solution may reveal structural effects not captured by the tables, such as a more realistic distribution of internal forces, which explains the greater deviation relative to Czerny (1932). Even so, the differences relative to Stramandinoli and Loriggio (2003) remain moderate (ranging from approximately 0.3% to 5.1%, Tables 4 and 5, row Author × Stramandinoli), indicating that the solution converges to a stable and physically consistent regime. Together with the close agreement observed for vertical deflections (Table 6), these results strengthen the validation of the APDL Generator by demonstrating consistency in both bending-moment response and global slab deformation for the analyzed cases.

3.3. Example 3 – Rectangular slab fixed along adjacent edges

Col Debella and Santos (2016) analyzed a rectangular solid slab measuring 4 × 8 m, fixed along two adjacent edges and simply supported along the remaining edges, with edge beams having a cross section of 12 × 30 cm. In that study, parameters such as the spacing between

the axes of the beams representing the slab grillage and the torsional stiffness of the model were varied. Using the APDL Generator, a comparison was carried out considering a grillage mesh spacing of 40 cm and torsional stiffness equal to its full value and to only 15% of its total value, as suggested by ABNT NBR 6118 (2023). The remaining structural parameters adopted in the analysis are:

- Modulus of elasticity: $E_{ci} = 2.8 \times 10^7$ kN/m²;
- Poisson's ratio: v = 0.2;
- Thickness: h = 8 cm;
- Total load = 750 kgf/m² = 7.355 kN/m².

The bending moment diagrams obtained (Figures 8 and 9) show different structural behavior depending on torsional stiffness. For J = 100%, higher concentrations of sagging and hogging bending moments are observed in the edge beams, resulting from the restriction of torsion in the grillage beams. In this case, part of the slab's tendency to twist is converted into additional bending moment in the peripheral beams, which is a typical boundary effect that is more pronounced along the longer span. When torsional stiffness is reduced to 15%, internal forces are redistributed toward the interior of the slab, resulting in higher bending moments in the central span and lower demand on the edge beams, which is physically consistent with the grillage analogy.

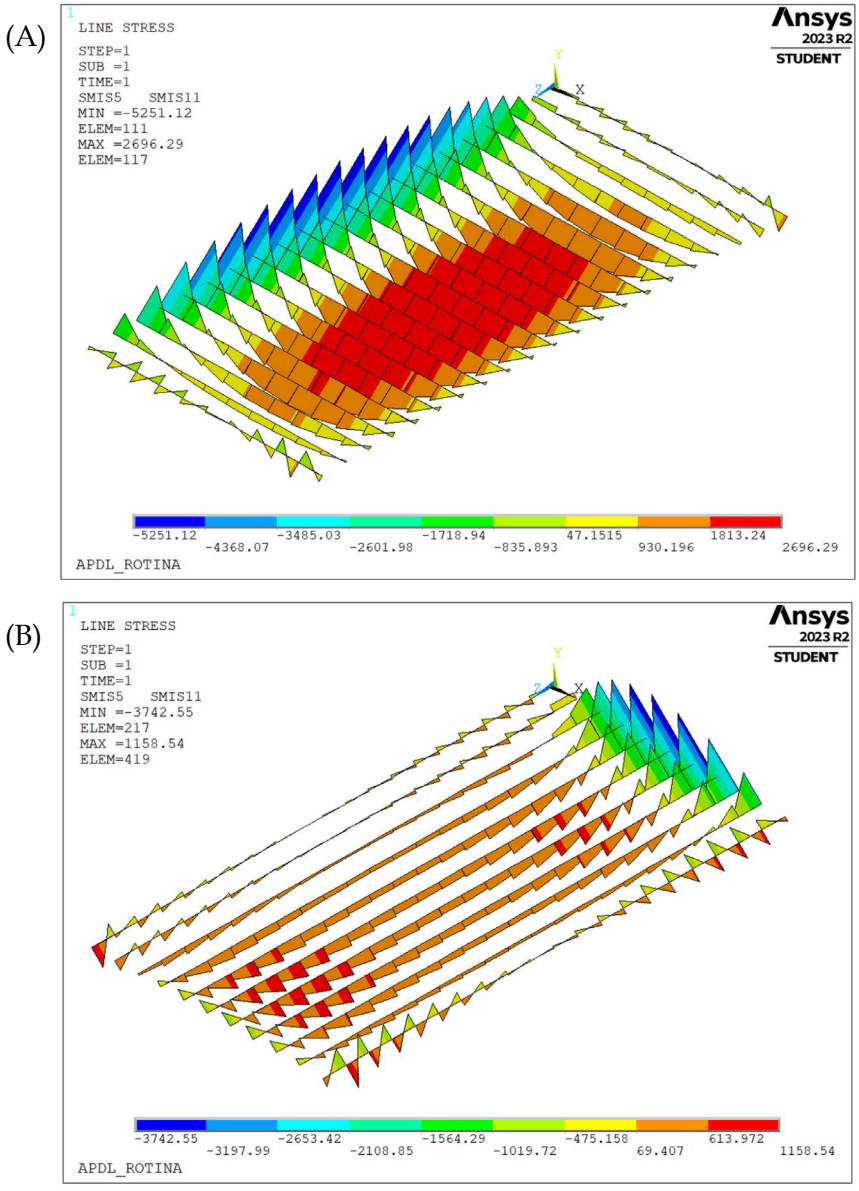


Figure 8: (A) Bending moment diagram along the direction of the shorter span (J = 100% of its total value); (B) Bending moment diagram along the direction of the longer span (J = 100% of its total value).

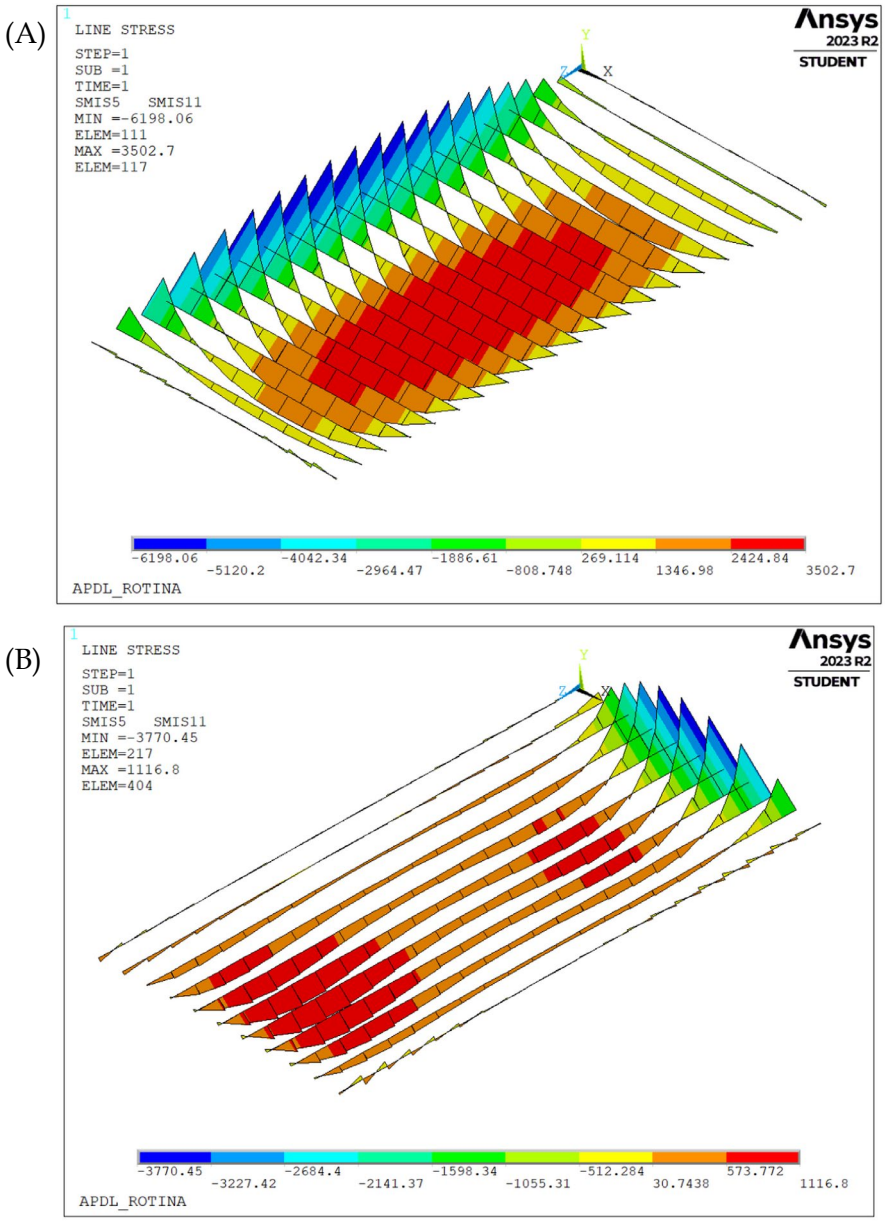


Figure 9: (A) Bending moment diagram along the direction of the shorter span (J = 15% of its total value); (B) Bending moment diagram along the direction of the longer span (J = 15% of its total value).

The bending moment in the edge beam due to the high torsional stiffness of the grillage beams is illustrated in Figure 10.

When the bending moment diagram of the same slab is evaluated considering only 15% of torsional stiffness, as illustrated in Figure 9 (B), it can be observed that, as there is no significant restraint of beam torsion, this torsion is transferred to the edge beams to a lesser extent in the form of bending moment.

The numerical comparisons presented in Tables 7 and 8 confirm the good agreement between the results obtained using the developed program and those reported by Col Debella and Santos (2016). For J = 100%, the differences relative to that author were small (below 5% in almost all cases), with the largest discrepancy occurring for My□ when the peak value in the edge beam is considered (20.66%). However, when only the bending moment in the slab span is analyzed, the difference is reduced to 1.94%, demonstrating that the deviation arises from a local boundary effect rather than from inconsistency in the model. For J = 15%, the differences relative to Col Debella remained low (ranging from 1.63% to 4.59%), reinforcing the reliability of the APDL Generator.

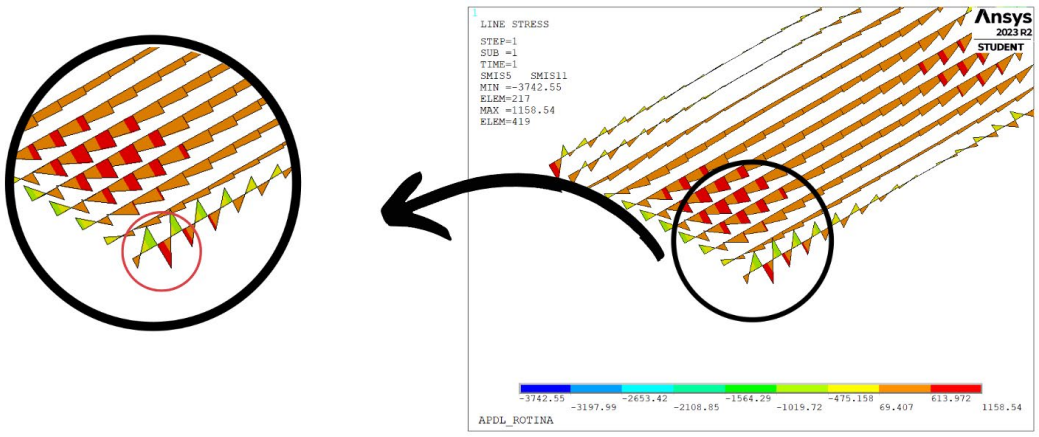


Figure 10: Bending moment transferred from the slab to the edge beams due to the high torsional stiffness of the grillage beams (J = 100% of its total value).

Table 7: Comparison of the results obtained in Example 3 with those reported by Col Debella and Santos (2016) and the Bares Tables (1979) (torsional stiffness J equal to 100% of its total value).

Calculation Model:	M_x^+ (kNm)	M_x^- (kNm)	M_y^+ (kNm)	M_y^- (kNm)
Author	6.740	13.127	2.896* 2.353**	9.356
Col Debella and Santos (2016)	7.000	13.100	2.400	9.800
Bares Table (1979)	6.890	14.270	2.260	9.840
Percentage Difference - Col Debella and Santos (2016) x Bares (1979)	1.59 %	8.20 %	6.19 %	0.41 %
Percentage Difference - Author x Col Debella and Santos (2016)	3.71 %	0.21 %	20.66 %* 1.94 %**	4.53 %
Percentage Difference - Author x Bares (1979)	2.18 %	8.01 %	4.12 %	4.92 %

* Considering the bending moment in the edge beam (maximum positive value observed in the grillage, in the Y direction).
** Considering the maximum bending moment in the slab (value observed in the slab span, in the Y direction).

Table 8: Comparison of the results obtained in Example 3 with those reported by Col Debella and Santos (2016) and the Bares Tables (1979) (torsional stiffness J equal to 15% of its total value).

Calculation Model:	M_x^+ (kNm)	M_x^- (kNm)	M_y^+ (kNm)	M_y^- (kNm)
Author	8.755	15.495	2.790	9.350
Col Debella and Santos (2016)	8.900	15.800	2.900	9.800
Bares Table (1979)	6.890	14.270	2.260	9.840
Percentage Difference - Col Debella and Santos (2016) x Bares (1979)	29.17 %	10.72 %	28.32 %	0.41 %
Percentage Difference - Author x Col Debella and Santos (2016)	1.63 %	1.93 %	3.79 %	4.59 %
Percentage Difference - Author x Bares (1979)	27.07 %	8.58 %	23.45 %	4.98 %

When compared with the Bares Tables (1979), the results show more significant deviations, especially for the case J = 15% (differences greater than 20% in some cases). This behavior had already been identified by Col Debella and Santos (2016) and results from the approximate and simplified nature of the tables, which do not adequately capture the redistribution of internal forces when torsional stiffness is reduced.

By evaluating the average percentage error (%) of the APDL Generator relative to Col Debella and Santos (2016) and to the Bares Tables (1979) as a function of the variation in J (100% and 15%), it is observed that, when J = 100% is considered, the value of My^+ in the slab (and not the peak value in the edge beam) results in an average error of approximately 2.6% relative to Col Debella and Santos (Table

7, row Author × Col Debella – My^+). When J = 15% is considered, the differences remain low, ranging from 1.6% to 4.6% (Table 8, rows Author × Col Debella – Mx^+, Mx^-, My^+, My^-). Relative to the Bares Tables, the deviations were on the order of 4.8% for J = 100% (Table 7, row Author × Bares – My^+) and reached approximately 16% for J = 15% (Table 8, rows Author × Bares – Mx^+ and My^+), reflecting the limitations of the tables with respect to the redistribution of internal forces captured by numerical models. Additionally, if the peak value in the edge beam is considered for My^+ (local boundary effect), for J = 100% the isolated error reaches 20.7% relative to Col Debella (Table 7, row Author × Col Debella – My^+ considering the edge beam peak) and 28.1% relative to Bares (Table 7, row Author × Bares – My^+ considering the edge beam peak). This assessment demonstrates that the APDL Generator adequately captures both the sensitivity of the results to torsional stiffness and the physical consistency of force redistribution.

In summary, Example 3 shows that the developed program adequately reproduces the influence of torsional stiffness and boundary effects in rectangular slabs. The percentage differences relative to Col Debella were generally low, mostly below 5%, and the trends observed when torsional stiffness is reduced are consistent with the expected physical behavior. Thus, the consistency and accuracy of the APDL Generator in the analysis of slabs using the grillage analogy are confirmed, including situations that are highly sensitive to torsional stiffness.

4. CONCLUSION

The APDL Generator developed in this study proved to be a reliable computational tool for automating the generation of grillage models of reinforced concrete slabs in ANSYS. The comparisons with established numerical studies and classical analytical references demonstrated that the generated models consistently reproduce the structural response of the analyzed slabs.

The validation showed that the program adequately represents bending behavior, the influence of torsional stiffness on the redistribution of internal forces, and the global deformational response of the slabs. The analyses also highlighted the relevance of appropriate mesh discretization and torsional-stiffness definition, particularly in models containing edge beams and pronounced boundary effects.

Within the adopted assumptions, the proposed computational routine therefore provides a reproducible and efficient alternative to the manual generation of APDL input files for grillage-based slab analysis. Its applicability is currently limited to linear elastic behavior and to the assumptions inherent to the grillage analogy and the BEAM4 element.

Future developments may extend the program to nonlinear concrete behavior, additional structural response quantities, equivalent orthotropic properties, adaptive mesh generation, and parametric sensitivity analyses. Overall, the developed tool constitutes an applied computational contribution to slab analysis by combining automated model generation with numerical validation and reducing the manual effort associated with APDL modeling.

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