MODELING, ANALYSIS AND STRUCTURAL DESIGN OF A MULTI-STORY REINFORCED CONCRETE HOUSE USING EBERICK SOFTWARE

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ABSTRACT

Despite the existence of multiple structural systems, reinforced concrete dominates Brazilian construction, specifically in the northeast region. This can be attributed to the availability of skilled labor, local materials and resources, as well as its versatility, adaptability, and durability, making it a more cost-effective choice compared to steel structures, which demand specialized skills and higher expenses. In this context, this study addresses the structural design of a multi-story reinforced concrete house, aiming at both technical and professional growth and the advancement of safe and efficient practices and methodologies. The step-by-step process of dimensioning using AltoQI's Eberick software was presented with careful adherence to all applicable standards. The study encompasses the design and analysis of beams, columns, slabs, and footings carried out in Eberick, as well as the detailing of reinforcements and solutions to identified structural problems. The outcomes of this project contribute to the professional field by providing insights into the capabilities of using the Eberick software.

KEYWORDS: *Structural Systems, Reinforced Concrete, Structural Design, Technical Development, Software Capabilities*

I. INTRODUCTION

Reinforced concrete is a composite material widely employed in civil construction, where addition of steel reinforcements is incorporated to increase its resistance to applied loads. [1] state that the annual production of reinforced concrete worldwide exceeded 10 billion cubic meters in 2012, leading to huge consumption of natural resources and resulting in considerable environmental impacts, as emphasized by [2].

Despite the spread of various structural systems in recent years, reinforced concrete remains the predominant system in the Brazilian construction sector. This predominance is justified by several factors, including the high compressive strength of concrete combined with the tensile strength of steel, versatility, durability, ease of production, resistance to fire and chemical agents, architectural flexibility, and, additionally, its deep-rooted historical tradition in the region as a fundamental material. Moreover, this predominance is fueled by the abundant and economically viable availability of labor for the implementation of related methodologies.

To that end, several studies have already been conducted with the intention of optimizing reinforced concrete structures to minimize weight and, consequently, reduce the amount of construction materials (steel reinforcement, concrete, labor, material manufacturing, transportation, installation, etc.) [3]-[8], improve environmental performance [9]-[15], and maximize overall multidisciplinary performance [16]-[21].

Most of the studies found on structural design in reinforced concrete adhere to specific guidelines for each region, aiming to meet minimum design requirements and ensure the necessary performance. Usually, engineering organizations and/or government agencies set specifications for structural design that must be followed during the dimensioning stages of a project. Some of the regional guidelines often adopted include the Brazilian Standards (NBR) [22].

Specifically in the Agreste region of Pernambuco and its surrounding areas, there has been an increase in both population and economic activity in recent years, significantly raising the demand for housing. Lately, there has been a noticeable increase in the emergence of high-end horizontal condominiums, which include single-family homes with one or more floors. The definition of a high-end residence, as stipulated by the ABNT NBR 12721:2006 standard [23], is characterized by comprising four bedrooms (including one with an en-suite bathroom and closet, as well as another with a bathroom), a guest bathroom, a living room, a dining room, an intimate room, circulation areas, a kitchen, a complete service area, and a balcony.

Therefore, this study focuses on developing the structural design in reinforced concrete of the multi-story house with the assistance of the Eberick structural analysis software, and encompasses the creation of its architectural design in CAD, the placement of columns, beams, slabs, and stairs, and the structural processing in accordance with ABNT NBR 6118:2014 [24] and other relevant standards. Furthermore, it includes the presentation of all details on project sheets. The project will be carried out with the aim of guaranteeing the structure's strength and safety, comfort and aesthetics for users, and economy and efficiency in the use of materials.

The relevance of this work for the technical and professional growth of a structural designer is substantial, as it plays a fundamental role in the dissemination of technical knowledge. Furthermore, the intention is to encourage the continuous development of more efficient and safer practices and methodologies, making the results of the structural design project using the Eberick software available to the job market. However, this research presents the following: the methodology (flowchart of project execution, structure modeling and launching, Eberick settings); results and discussions (solutions adopted to ensure stability); as well as the main conclusions of this study.

II. METHODOLOGY

This section describes the entire process of implementing the structural design proposed in this work, including the launching and modeling of formwork plans, the definition of construction materials and generated loads, the configuration of calculation parameters in the software, calculation execution, component adjustments, and final detailing. Figure 1 illustrates the flowchart of the steps followed throughout the project.

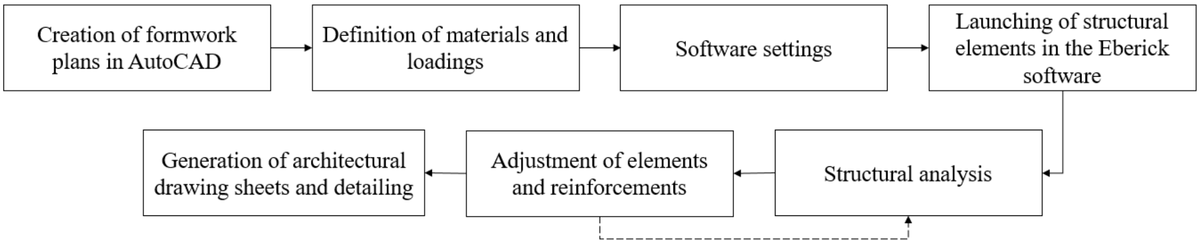

Figure 1. Structural project execution flowchart

2.1. Structural launch/modeling

The formwork plans were created using AutoCAD software. Beams and columns were launched in solid reinforced concrete. The slabs were launched in solid form only on the ground floor, while unidirectional trusses filled with expanded polystyrene (EPS) were adopted on the upper floors.

For the initial floor launching in the Eberick software, slab thicknesses of 18 cm and trusses of designation TR08645, as defined in ABNT NBR 14859-3:2017 [25], were adopted. All the columns were initially launched with cross-sections measuring 15 x 30 cm, and beams with cross-sections of 15 x 40 cm. These sections were eventually modified during the structural analysis and dimensioning process. Figure 2 illustrates the three-dimensional model of the final structure.

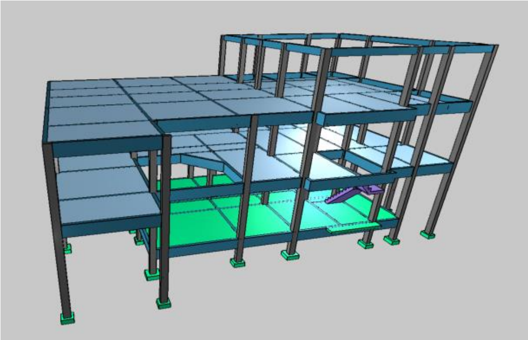

Figure 2. Three-dimensional model of the structure

2.2. Eberick settings

The Eberick software is a reinforced concrete structural design software developed by AltoQI. It provides advanced features that enable the execution of dimensioning calculations and analysis of various structural elements, including beams, columns, slabs, and reinforced concrete foundations. This software is widely employed in building design, assisting in making safe and efficient decisions throughout the entire structural design process.

2.2.1. Loads and combinations

All combinations of ultimate limit states (ULS) and serviceability limit states (SLS) are automatically generated by the Eberick software. The following load actions were adopted for the project: self-weight (G1), additional weight (G2), accidental load (Q), and wind load in four directions (V1, V2, V3, and V4). The combinations adopted for ULS and SLS are presented in Table 1 and Table 2, respectively.

Table 1. ULS load combinations

COMBINATION	TYPE	WEIGHTED LOADS
1	Normal	1.3G1 + 1.4G2
2		1.3G1 + 1.4G2 + 0.7Q + 1.4V1
3		1.3G1 + 1.4G2 + 0.7Q + 1.4V2
4		1.3G1 + 1.4G2 + 0.7Q + 1.4V3
5		1.3G1 + 1.4G2 + 0.7Q + 1.4V4
6		1.3G1 + 1.4G2 + 1.4Q
7		1.3G1 + 1.4G2 + 1.4Q + 0.84V1
8		1.3G1 + 1.4G2 + 1.4Q + 0.84V2
9		1.3G1 + 1.4G2 + 1.4Q + 0.84V3
10		1.3G1 + 1.4G2 + 1.4Q + 0.84V4
11		G1 + G2
12		G1 + G2 + 0.7Q + 1.4V1
13		G1 + G2 + 0.7Q + 1.4V2
14		G1 + G2 + 0.7Q + 1.4V3
15		G1 + G2 + 0.7Q + 1.4V4
16		G1 + G2 + 1.4Q
17		G1 + G2 + 1.4Q + 0.84V1
18		G1 + G2 + 1.4Q + 0.84V2
19		G1 + G2 + 1.4Q + 0.84V3
20		G1 + G2 + 1.4Q + 0.84V4

Table 2. SLS load combinations

COMBINATION	TYPE	WEIGHTED LOADS
21	Frequent	G1 + G2
22		G1 + G2 + 0.3Q + 0.3V1
23		G1 + G2 + 0.3Q + 0.3V2
24		G1 + G2 + 0.3Q + 0.3V3
25		G1 + G2 + 0.3Q + 0.3V4
26		G1 + G2 + 0.4Q
27	Quasi-permanent	G1 + G2
28		G1 + G2 + 0.3Q
29	Rare	G1 + G2 + 0.4Q + V1
30		G1 + G2 + 0.4Q + V2
31		G1 + G2 + 0.4Q + V3
32		G1 + G2 + 0.4Q + V4
33		G1 + G2 + Q
34		G1 + G2 + Q + 0.3V1
35		G1 + G2 + Q + 0.3V2
36		G1 + G2 + Q + 0.3V3
37		G1 + G2 + Q + 0.3V4

2.2.1.1 Permanent loads

In order to calculate the loads acting on the structure, the construction materials for the multi-story house were defined. For the project, the use of masonry with ceramic blocks for walls, porcelain tiles for flooring, and colonial roof tiles was adopted. The specific weights of all the materials used were consulted in accordance with ABNT NBR 6120:2019 [26].

The self-weight of the slabs, columns, and beams was considered by Eberick itself after launching the elements and defining the material properties. In addition to the self-weight, loads resulting from masonry, coverings, ceilings, and roofing were also calculated.

2.2.1.2 Accidental loads

The accidental loads for each room were also consulted in ABNT NBR 6120:2019 [26], with the minimum vertical loads for bedrooms, bathrooms, kitchens, and living rooms equal to 1.5 $kN{\cdot}m^{-2}$ and for the service area equal to 2 $kN{\cdot}m^{-2}$. For the library, a minimum value of 4 $kN{\cdot}m^{-2}$ was adopted for reading rooms with bookshelves.

2.2.2 Wind load

The calculation of wind-induced forces in Eberick is performed using wind speed data specific to the region, building dimensions, the number of neighboring buildings, and nearby vegetation that may block the direct incidence of the wind. Wind loads are applied in the four directions adopted for the combinations of ultimate limit state and serviceability limit state.

2.2.3 Global stability analysis considerations

In the analysis settings, users have the option to determine the percentage of restraint reduction for semi-rigid connections, with the limits specified by the standard [24] being up to 10% for structures with mobile nodes and up to 25% for structures with fixed nodes. Eberick employs the γ_z coefficient method for this analysis, where a structure can be considered to have fixed nodes when the γ_z coefficient is less than or equal to 1.1, or mobile nodes if it exceeds this limit. On the other hand, the P-Δ coefficient is a way to assess the influence of second-order effects concerning the first-order effects and is used for structures with mobile nodes.

In the same tab, it is also feasible to implement a reduction in the torsion of columns and beams, because whenever torsion is necessary for the stability of the structure, the effects of torsion must be considered, and the appropriate reinforcement must be adopted. However, in cases of compatibility torsion, where disregarding torsional effects (by applying a hinge connection, for example) does not compromise the structure's stability, the standard allows for the neglect of torsional efforts.

2.2.4 Detailing and dimensioning

In the detailing and dimensioning guides, it is possible to customize how the reinforcement drawings will be generated and how the program will apply reinforcements. Users can choose whether reinforcing bar anchors will be straight or curved, set the minimum spacing of vertical stirrups, stablish the limit length for uniformity of stirrup gauge, adjust priority coefficients for area, quantity, and diameter of bars, among other settings. These configurations allow for the compatibility of reinforcements between adjacent structural elements and facilitate the execution of the construction project.

2.2.5 Materials and durability

For the construction, C30 concrete was adopted, which is made with Portland cement CP-II and has an aggressiveness class (I - low) suitable for rural areas. The minimum steel bar diameters were set at 10 mm for columns, 8 mm for beams, 5 mm for slabs, and 5 mm for transverse reinforcements.
The project adopted a relative humidity of 60%, a concrete slump of 5 cm and a useful life of 50 years. This data is used to calculate the effects of concrete creep and shrinkage.

2.2.6 SLS verification

The adopted displacement limits were a maximum of L/250 for deflections in beams and slabs for visual sensory acceptability analysis, where L represents the span length of the beam or slab. Additionally, a limit of L/350 was adopted for counter-deflections in beams. These values were obtained from ABNT NBR 6118:2014 [24].

2.2.7 Loading

The self-weight loads of structural parts are automatically inserted when they are launched. Other loads taken into account were those of ceilings, subfloors, cladding, walls, roof tiles and tanks.

2.3 Launching of roof loads

The project includes two roofing systems, one with corrugated fiber cement boards and a second one with ceramic colonial tiles, supported by a wooden structure. The loading on the corrugated fiber cement roof is applied as a uniformly distributed load over the entire area of the roof slab, which means the load is evenly spread across the surface of the corrugated fiber cement roof. For the roof with ceramic colonial tiles, the approach is slightly different. The total load it supports, calculated based on the area of its horizontal surface, is divided among the four supporting beams. This division is done considering the influence area of each beam.

The weight on the horizontal surface from the corrugated fiber cement roof is 0.4 $kN \cdot m^{-2}$, while the ceramic colonial tile roof weighs 0.85 $kN \cdot m^{-2}$. Multiplying 0.85 by the influence areas of each beam results in a total load of 30.6 kN on the sides of 12 m and 28.1 kN on the sides of 11.5 m. The dimensions of the beams are approximately 10.7 m and 8.7 m in length, respectively (Figure 3). Dividing the total loads by the lengths, it is found that the linear loads are 2.9 $kN \cdot m^{-1}$ and 3.3 $kN \cdot m^{-1}$, respectively.

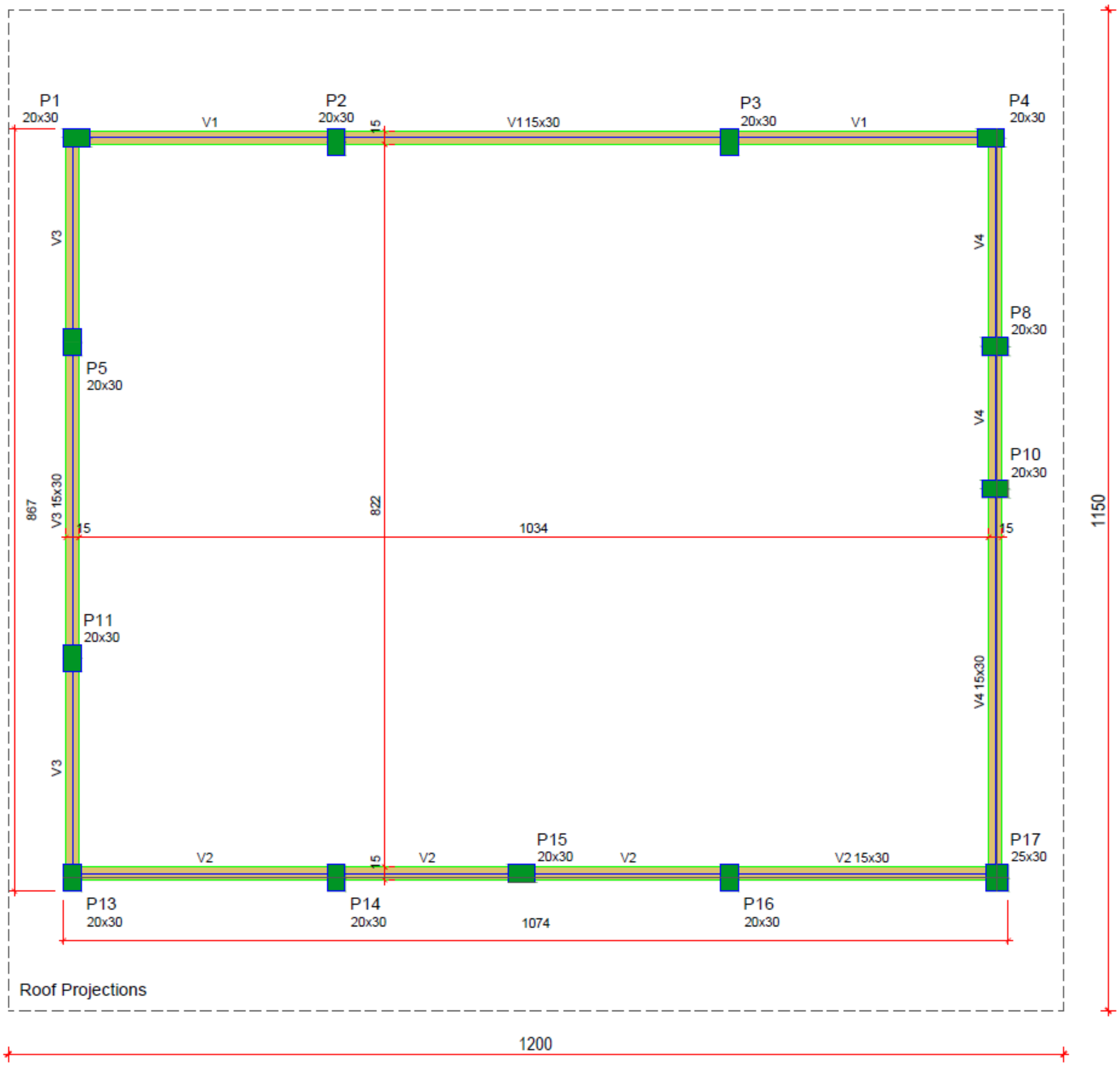

Figure 3 – Roof deck formwork and roof projection (dimensions in cm)

III. RESULTS AND DISCUSSIONS

This section encompasses the structural analysis of the house and the dimensioning of the beams, slabs, and columns. It also presents the solutions adopted to guarantee the stability of the structure after the analysis of the first structural design of the multi-story house.

3.1. First analysis

In the initial stage of the processing, the loads and displacements in the structural elements were calculated, and the preliminary design of foundations, columns, beams, and slabs was carried out. It is worth mentioning that during this initial process, error and warning messages that require resolution in subsequent stages were generated. It became evident that the largest displacements are concentrated in the central area of the roof, even considering the reduced presence of loads. This is due to the fact that there is a large span without the presence of columns in that region, resulting in greater bending and deformation in that part of the structure.

Table 3 and Table 4 show the stability results generated in the Eberick software reports.

Table 3. Global stability

Parameter	
Gama-Z	1.04 (1.10 as the limit)
Maximum column displacement (cm)*	0.23
Average column displacement (cm)*	0.08
Maximum column displacement */H_{total}	1/4255
Average column displacement */H_{total}	1/11678

*Displacement of top floor columns (Limit of H/1700 for effects on non-structural elements, where H is the total height of the building)

Table 4. Higher Gama-Z coefficient

Combination: 1.3G1 + 1.4G2 + 1.4Q + 0.84V2							
Floor	**Relative height (cm)**	**Vertical load (kN)**	**Horizontal load (kN)**	**Horizontal displacement (cm)**	**2nd order moment (kN.m)**	**Tipping point (kN.m)**	γ_z
Technical room	990	275.58	3.53	0.21	0.59	35.35	1.04 lim=1.1
Rooftop	740	2250.67	13.72	0.18	4.13	101.82	
1st Floor	435	2817.21	16.76	0.15	4.12	72.88	
Ground floor	150	506.07	1.76	0.06	0.29	2.70	
TOTAL					**9.13**	**212.74**	

According to [27], the parameter γ_z approximately relates the magnitude of global second-order effects in a structure, with values close to 1 indicating greater stability, while values above 1.5 suggest an unstable and impractical structure. Therefore, the outcomes obtained in Table 3 and Table 4 can be interpreted as favorable and indicative of a well-balanced structure in which second-order effects have a limited impact on structural forces.

After carrying out the initial analysis, multiple structural parts presented warnings or errors that needed to be corrected, many of them linked to excessive displacements. The most significant instances of these displacements are detailed in Table 5.

Table 5. Elements with excessive displacements (worst cases)

Sensory and visual acceptability (Beams)					
Floor	**Element**	**Deflection (cm)**	**Relation**	**Rotation**	**Limits**
Rooftop	V4 (span 1)	5.82	L/128	-	L/250
1st Floor	V4 (span 1)	1.91	L/234	-	L/250
Sensory and visual acceptability (Slabs)					
Floor	**Element**	**Deflection (cm)**	**Relation**	**Rotation**	**Limits**
Rooftop	L7 (span in the x-direction)	3.79	L/60	-	L/250
1st Floor	L11 (span in the x-direction)	1.77	L/105	-	L/250

In Figure 4, the beam and slab with the greatest displacements in the structure are presented. It is noticeable that there is a significant area lacking columns, primarily due to the fact that the floor immediately below has a large open area that does not allow for the placement of columns present on the ground floor. Beam V4 exhibited elevated displacements due to its length. To address this issue, it was necessary to increase the beam section to 15 x 50 cm. This modification, combined with alterations in the structural design, was sufficient to mitigate excessive displacements on the first floor and on the roof beams, significantly reducing displacements across the roof slabs.

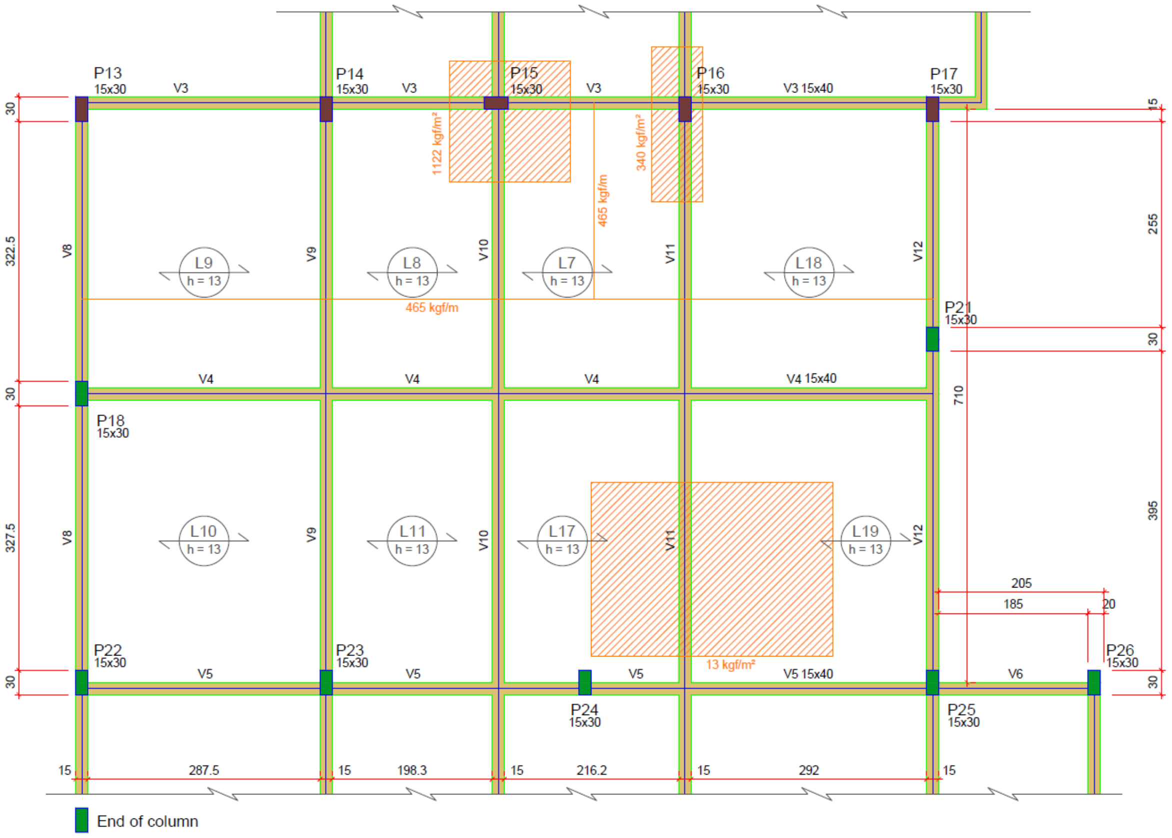

Figure 4. Structural elements with greater displacements

Table 6 provides a list of all the warning messages and errors encountered in this first processing, to be used as a reference in section 3.2, where the solutions adopted will be presented.

Table 6. Problems encountered

Code	Description	Element
Warning 98	Check the anchorage of the skin reinforcement.	Beam
Warning 26	Possible lateral instability.	Beam
Warning 101	Check displacements.	Beam/Slab
Error D11	Torsional stress TSd greater than TRd2.	Beam
Error D31	Error in calculating the main reinforcement (x-direction).	Slab
Warning 117	Slab in disagreement with ABNT NBR 14859:2016 [25].	Slab
Error D05	Slenderness greater than 140.	Column
Warning 10	Column with a smaller gauge or number of bars than in the bid above.	Column

3.2. Solutions adopted

Warning 98 – [28] discusses concepts related to skin reinforcement, highlighting that its primary role is to mitigate potential issues caused by cracking, shrinkage, and temperature fluctuations. Additionally, this shear reinforcement serves to prevent the opening of flexural cracks in the central part of beams. According to ABNT NBR 6118:2014 [24], the use of shear reinforcement is only mandatory in beams with heights greater than 60 cm, which suggests that the software inserted the side-facing reinforcement due to some torsional or tensile force acting on the beam. In Figure 5, a high torsional moment caused by beam 12 can be observed.

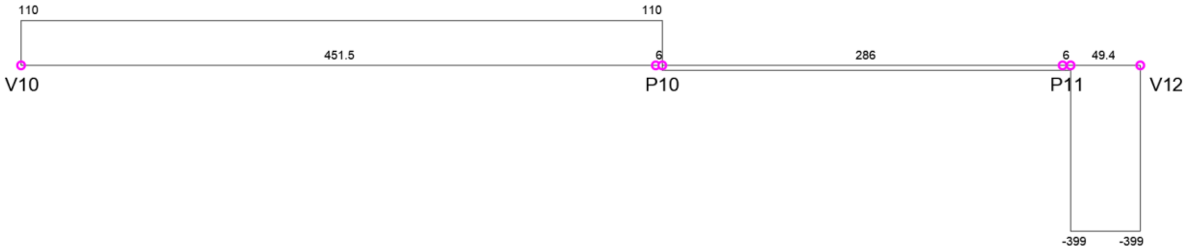

Figure 5. Calculation torque diagram (M_{td}) [kgf.m; cm] for the beam 3 (V3) of the first floor (dimensions in cm)

The torsion observed in Figure 5 is not necessary to maintain the stability of beam 12 (V12). As outlined by [29], compatibility torsion arises as a result of the restriction on deformation, while equilibrium torsion involves torsional moments necessary to fulfill the equilibrium conditions, potentially leading the structure to ruin if they are not considered.

Furthermore, according to [29], a straight bar subjected to torsion experiences a warping of its cross-sections, leading to normal tensile and compressive stresses along the bar. However, if such warping is prevented, in the case of concrete, these stresses dissipate through cracking. After cracking, the torsional moment decreases significantly, making it unnecessary to consider it in the design of the beam. Therefore, the effects of restraining warping at supports can be taken into account by including minimum shear reinforcement to limit cracking. Hence, it was necessary to introduce a hinge connection at the support of beam 12 on beam 3, thus disregarding the torsional moment due to concrete cracking without compromising the overall stability of the structure.

Warning 26 – Lateral instability can occur in slender beams in the compressed region. ABNT NBR 6118:2014 [24] provides a simplified check for the possibility of lateral instability presented in Equations 1 and 2, with the following conditions to be satisfied:

$$b \geq l_0/50 \tag{1}$$

$$b \geq \beta_{fl} \cdot h \tag{2}$$

in which: "b" is the height of the compressed zone, "h" is the total height of the beam, "l_0" is the length of the compressed flange, measured between supports that ensure lateral bracing, and "β_{fl}" is the coefficient that depends on the shape of the beam, being equal to 0.4 for rectangular sections.

If the beam does not pass this check, warning 26 is displayed, suggesting that a manual analysis be carried out or that the structural design of the beam be altered.

It is possible to estimate the critical moment for lateral instability using Equation 3, proposed by [31], according to [30].

$$M_{cr} = \frac{160 \cdot \varphi \cdot f_{ck} \cdot b^3 \cdot d}{l} \tag{3}$$

in which: ϕ is the coefficient that reduces the critical moment capacity due to uncertainties regarding the phenomenon of lateral instability. [31] suggest a value of 0.5. "b" is the width of the beam cross-section in meters, "d" is the useful height in meters, "l" is the free span in meters and f_{ck} is the characteristic compressive strength of the concrete, 30 MPa for this project.

In situations where the largest bending moment present in the beam (M_{dx}) is less than the calculated critical moment (M_{cr}), the warning can be ignored. However, if M_{dx} is greater than M_{cr}, actions should be implemented, such as modifying the section of the beam (increasing its base, for example) or reducing its span.

In Figure 6, it is shown that V3 triggered the warning indicating the possibility of lateral instability. After calculations, it was determined that for a 15 x 40 cm beam with a span of 2.62 cm, the M_{cr} is 1143.89 kN·m, while the M_{dx} value is 54.9 kN·m. As $M_{dx} \leq M_{cr}$, it can be concluded that the element will not experience lateral instability failure.

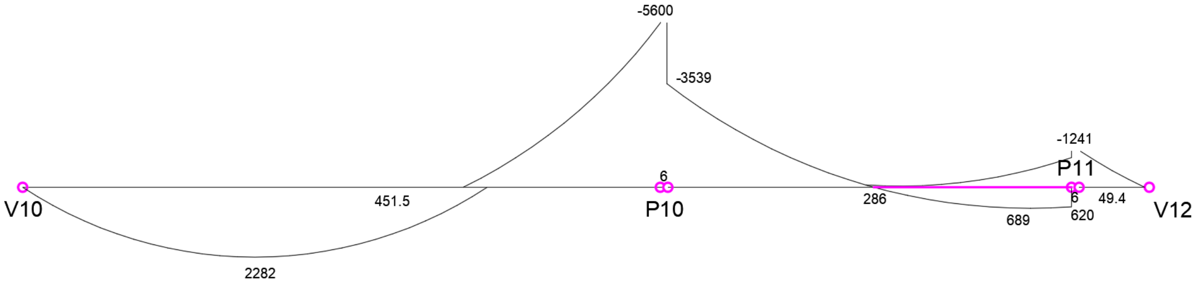

Figure 6. Calculation bending moment diagram (M_{dx}) [kgf.m; cm] for the beam 3 (V3) of the first floor (dimensions in cm)

Warning 101 – This message appears when the deformation of a beam or slab exceeds the configured limits. Elevated deformations can be reduced by applying fixed ends at the supports, increasing the stiffness of the analyzed element, or applying counter-deflections to the beams. To meet the deformation limits of some of the structural elements in the project, more robust sections were adopted for the beams on the first floor and the roof. The beams had their sections changed to 15 x 50 cm.

Error D11 - T_{Rd2} is related to the limit imposed by the strength of the compressed concrete diagonals in a beam that is subject to torsional stresses. This error was detected in beam V3 of the roof. Notably, the high torsion is caused by the bending of beam V7 which, because it is rigidly connected to beam V3, transfers this torsional stress. As this torsion is not an equilibrium torsion, it is possible to apply a joint (hinge) at the support point of V3, which allows the effect of the torsion to be disregarded.

Error D31 – This error occurs when the software cannot ensure the required spacings and coverings for any reinforcement bar size in a slab. For the truss slabs used, this indicates that despite the need for additional reinforcement in the trusses, there is not enough space in the adopted section for proper reinforcement. To address this issue, adjustments to the dimensions of the concrete base of the smaller beams are necessary to allow the software to incorporate additional reinforcement with the correct spacings. Alternatively, the need for such additional reinforcement can be reduced by increasing the dimensions of the trusses or adding more beams to the slab between the fillers. The resolution to this problem involved increasing the width of the concrete base from 12 cm to 15 cm and reducing the spacing between the smaller beams from 40 cm to 30 cm. These changes also allowed for a reduction in the total height of the slab from 18 cm to 13 cm. Figure 7 provides an example of the reinforcement detailing for a section of the roof slabs.

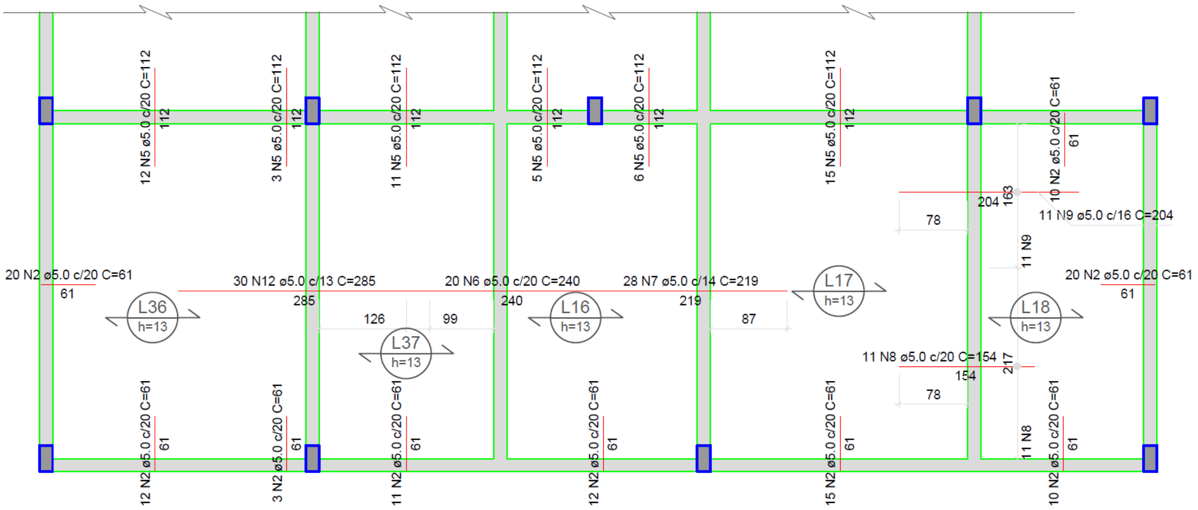

Figure 7. Example of reinforcement detailing for roof slabs

Warning 117 - This warning is displayed whenever any dimension of the smaller beams of a given slab does not meet the minimum requirements of ABNT NBR 14859:2016 [25]. In the case of unidirectional trussed slabs, such as those used in this project, this message is shown when:

- Concrete base height < 3.0 cm
- Concrete base width < 13.0 cm
- Concrete base width ≥ 40 cm and concrete base height < 4.0 cm (simultaneously)
- (Concrete base height /2 + H) < 7.5 cm
- (Concrete base width - e_{nx})/2 < 1.5 cm

in which: e_{nx} is the width of the ribs and H is the height of the adopted truss.

The warning can be corrected by adjusting the dimensions adopted for the beams.

Error D05 – Columns with high slenderness can be corrected by locking them laterally with beams or increasing the dimensions of the section. The columns that generated this error on the first-floor balcony were braced with beams in the direction of greatest slenderness, solving the error.

Warning 10 – This warning is triggered when an upper section of a column experiences high bending moment stresses, requiring more robust reinforcement, even though there is a reduced axial load compared to the lower section. The solution is to change the design of the structure to reduce the bending effects on the column or to standardize the reinforcement for the entire column plumb. The columns that had this warning had their reinforcement uniformized.

Columns with a high steel content – Some columns had a reinforcement arrangement that deviated from the minimum reinforcement required, which made it possible to reduce the reinforcement rate, as illustrated in the case of column P14. Figure 8 illustrates the modification in structural design and its consequent reduction in the bending moment in the column. This reduction was made possible by creating a continuity in the beam that originally generated a bending moment on only one side of the column. By continuing the beam, the bending moment was balanced, decreasing the need for reinforcement in the column. Beam V9 was removed and solid cantilevered slabs were added to beam V19. Figure 9 displays the reinforcement details for column P14 and beam V21, respectively.

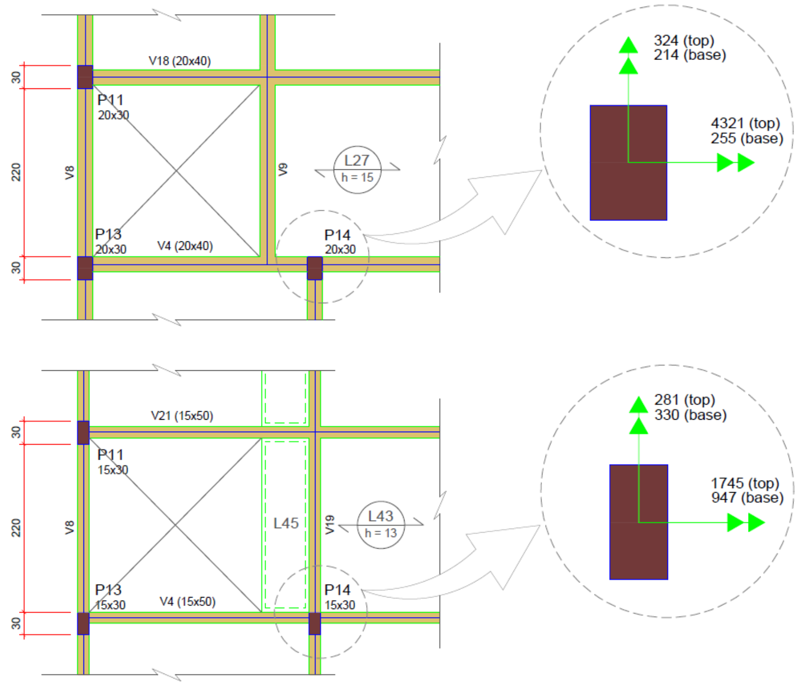

Figure 8. Column P14 before and after the continuity of the beam balancing the bending moment

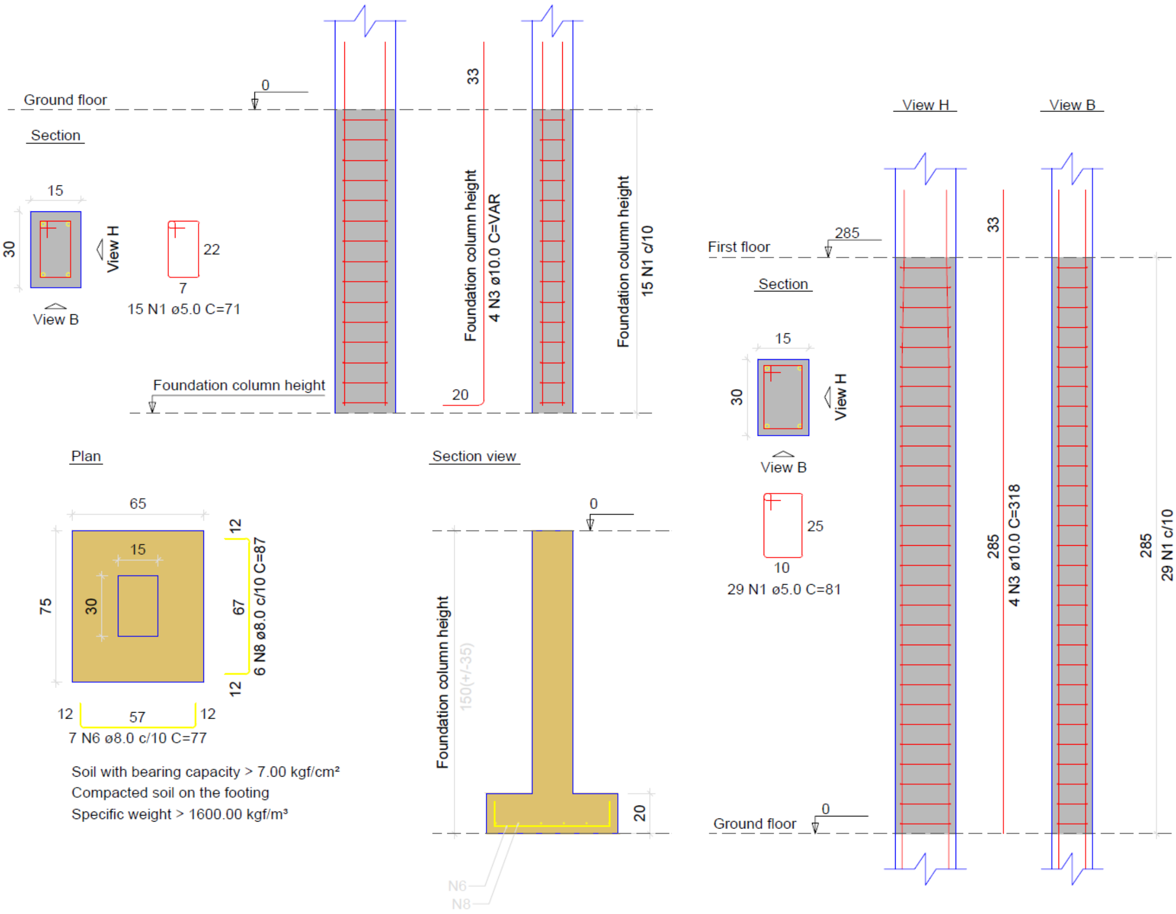

Figure 9. Reinforcement detailing for column P14 and its footing

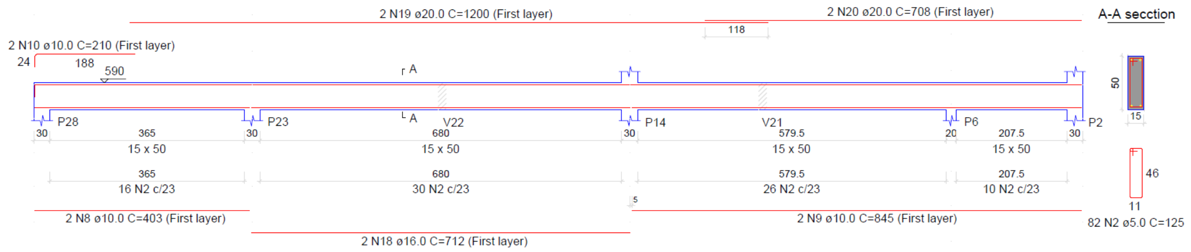

Figure 10. Beam V19 reinforcement detailing

3.3. Final launching

In the final analysis of the structure, after making the necessary corrections, the vertical loads outlined in Table 7 were obtained.

Table 7. Vertical loads

Type of load	Load (kN)
Self-weight	2172.17
Additional	2130.91
Accidental	903.17
Total	5206.25

The approximate area of the structure's slabs was 481.31 m², with a load/area ratio of 10.82 kN/m². Eberick recommends that this ratio should be between 8.8 kN/m² and 12.7 kN/m², but these values are not established by current standards, they are merely a convention obtained through usual design practices.

Almost all the beams underwent a section modification, increasing from 15 x 40 cm to 15 x 50 cm, except for the roof support beams of the technical room, which were reduced to 15 x 30 cm due to their lower load demands. This alteration was necessary due to the long spans in certain parts of the structure and the appearance of torsional moments resulting from the supports between beams, which were required due to the distribution of columns that could not be aligned optimally due to architectural constraints.

The truss slabs had the TR08645 trusses replaced with TR08646 trusses, and the spacing of the fillers was changed from 40 cm to 30 cm with the aim of reducing deflections and better distributing the load on the smaller beams to reduce shear forces at their support on the other beams.

The single-line displacement diagram for the final release was generated, as shown in Figure 11. It is possible to observe the reduction in maximum displacements, mainly in the roof area where the water tank is located and in the large central span.

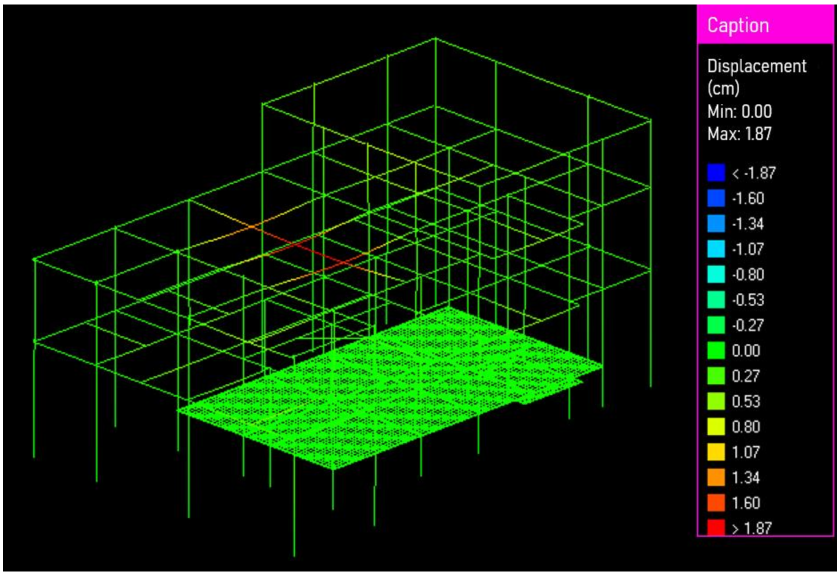

Figure 11. Single-line displacement frame of the final structure

Out of the 32 columns launched, it was possible to design 29 of them with minimum reinforcement after adopting solutions to reduce bending moments and buckling lengths in some of the columns.

Table 8 shows the summary of material consumption generated by the software.

Table 8. Summary of consumption by material and by element

Elements of the structure		**Beams**	**Columns**	**Slabs**	**Stairs**	**Foundation**	**Total**
Total weight 10% (kg)	**CA50**	1781.5	807.1	258.4	49.2	814.4	3710.6
	CA60	497.5	390.4	441.6	0	0	1336.8
	Total	2279.0	1197.5	699.9	49.2	821.8	5047.3
Concrete volume (m³) C30		34.1	15.2	19.0	0.9	10.9	80.2
Formwork area (m²)		575.2	258.1	11.9	9.9	14	869.1
Steel consumption (kg/m³)		66.7	78.8	36.8	55.6	75.3	63

IV. CONCLUSIONS

Within the scope of a structural project, it is crucial to meet all the needs of the end-user, ensuring a structure that encompasses safety, functionality, aesthetics, and economic viability. To fulfill these criteria in this project, several challenges were encountered, with a focus on the need to keep displacements within acceptable limits in extensive spans without oversizing the structural elements.

In the initial analysis, excessive displacements were observed, particularly in the beams and slabs of the roof and first-floor areas. These displacements were attributed to the lack of columns in certain regions and the length of the beams, resulting in significant torsional and bending forces. However, a series of adjustments and structural modifications were implemented to mitigate these issues. The adopted solutions involved adjustments to the sections of the elements, positions of beams and columns, the inclusion of skin reinforcement to reduce cracking, the use of hinges to consider the torsion effect due to cracking, reduction of spacing between the smaller beams to address reinforcement and spacing issues in truss slabs, among other structural modifications, until the adopted structural formulation was deemed suitable, meeting all the analyzed requirements.

However, it is to be hoped that with the acquisition of knowledge and experience, it will be possible to develop structural designs and solutions that could result in a reduction in the stresses on the structural elements and, consequently, lead to more compact dimensions and more economical consumption of materials. The consumption of materials, including concrete and steel, was detailed for different elements of the structure, helping to assess project cost and feasibility.

The use of software like Eberick, which is an indispensable tool for a structural engineer nowadays, requires attention and technical expertise. Throughout the course of this study, it became evident that it is not possible to rely solely on the software. Although Eberick can calculate and detail any structural design input by the user, it does not fully consider elements such as material optimization, efficient use of materials, and construction costs. As a result, the software may generate oversized or inefficient elements, leaving this analysis to the discretion of the user.

In this context, it is evident that the stipulated objectives, namely the development of practical skills and the acquisition of technical knowledge during the execution of a reinforced concrete structural project using the Eberick structural analysis software, have been achieved. The project was able to overcome the initial challenges, guaranteeing the stability, safety and efficiency of the multi-story house structure.

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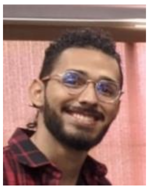

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