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A COMPARISON BETWEEN TWO BIM SOFTWARE FOR ANALYSIS AND CALCULATION IN REINFORCED CONCRETE STRUCTURES

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Glauco José de Oliveira Rodrigues[1], Alex Leandro de Lima[2], Stephàne Vannier Neto[3].

ABSTRACT

The objective of this work is to analyze the performance between two tools for structural analysis, analysis and detailing in a reinforced concrete structure, CYPECAD and EBERICK, in terms of material consumption suggested by the tools, also considering the numerical analysis methods used by both. For this analysis, the model of a linear residential building will be elaborated, with previously stipulated and identical shapes and loads in both tools, which will be analyzed using their standard installation configurations. After this process, the results of both tools, reinforcement rates and material consumption in the structure as a whole and in its individual elements, such as beams, columns and slabs, will be compared. A comparison will also be made between the results obtained through a similar article carried out in 2009, and the results of the present work in order to follow the evolution of the results of both tools mentioned above. It should be noted that the original article was based on the NBR 6118-2003 standard, and the present work with its 2014 revision.

Keywords: Structural Analysis, Reinforced concrete, Cypecad, Eberick, BIM.

[1] D.Sc.
Department of Structures and Foundations, UERJ
[2] M.Sc
Augusto Motta University Center, SUAM
[3] Eng
TESE Engenharia

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INTRODUCTION

Nowadays, the branch of activities related to the development of reinforced concrete structure projects is, almost entirely, dependent on commercial *software* intended for modeling, processing, analysis, dimensioning and structural detailing.

These *software* incorporate in their code structures, numerical analysis procedures, based on sophisticated methods, such as the finite element method, which constitutes the state of the art in terms of structural analysis. These and other benefits, combined with the less time invested in project design, have driven design engineers to use these tools more and more, and at the same time, have encouraged companies to develop and improve these tools, in such a way that they are robust and efficient in order to meet the demand for projects.

Among the users of these *softwares*, the issue of saving materials is often raised, which is a requirement of construction companies as a way of making their projects viable.

In this context, two of the commercial *software* most used by professionals in the field can be highlighted: Eberick 2019 (ALTOQI, 2018) and CYPECAD 2019.c (CYPE Ingenieros, 2018).

For comparison purposes, the present work will deal with the modeling of a simple residential building, composed of only one floor, which will be concomitantly analyzed by the two computational tools mentioned, with their previously defined and identical formwork and loads, in both tools, adopting their standard installation configurations.

This work aims to help clarify part of the doubts of the users of these *software* regarding the characteristics and specificities of each one, such as method of analysis, quantitative materials and efforts, as well as how these factors are related, despite any commercial aspects.

It is also noteworthy that the developers of the programs were not consulted about clarifications regarding the internal procedures of each program, only the "open" documentation of the respective *software*, as well as an iteration with an interface of the same, was consulted.

This work is a continuation of a similar article, already done in 2009, with only the formwork plan being changed, in order to compare the two tools once again, but with a different structure.

The motivation for this work is to analyze and collaborate so that these tools become increasingly efficient in the design of reinforced concrete structures

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STRUCTURE ANALYZED

The structure that was analyzed is based on a conventional construction system, with the slabs on the beams, which in turn are supported by pillars. As shown in the following figures:

Figure 1 – Ground floor form plan

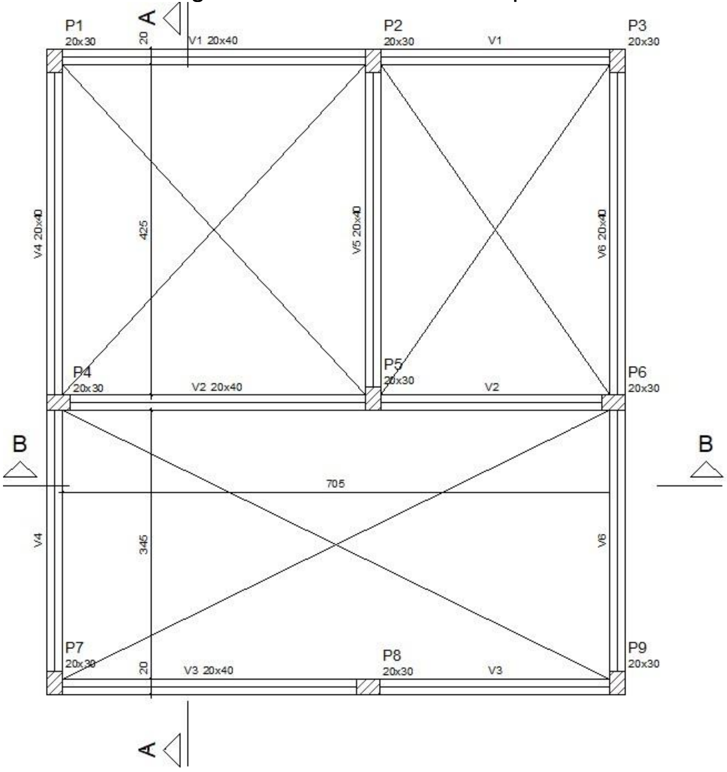

Figure 2 – Roof shape plan

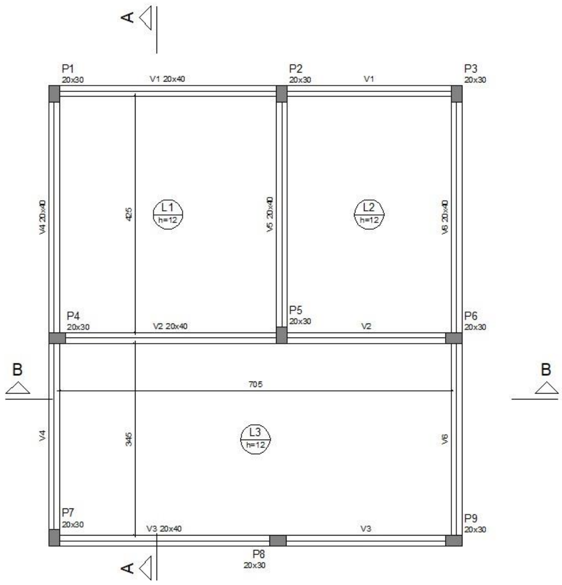

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Figure 3 – Court A-A

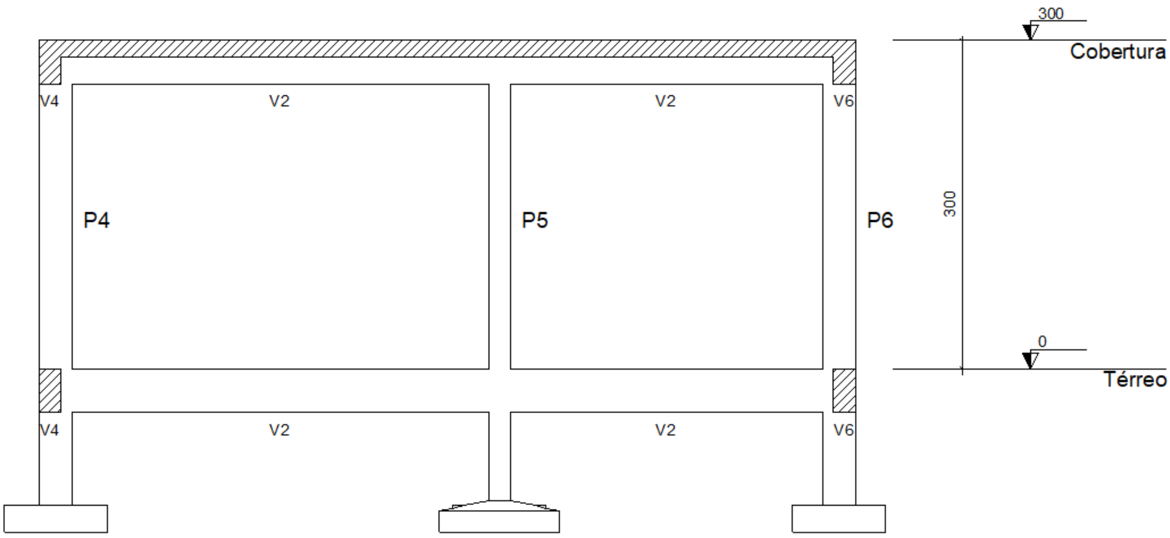
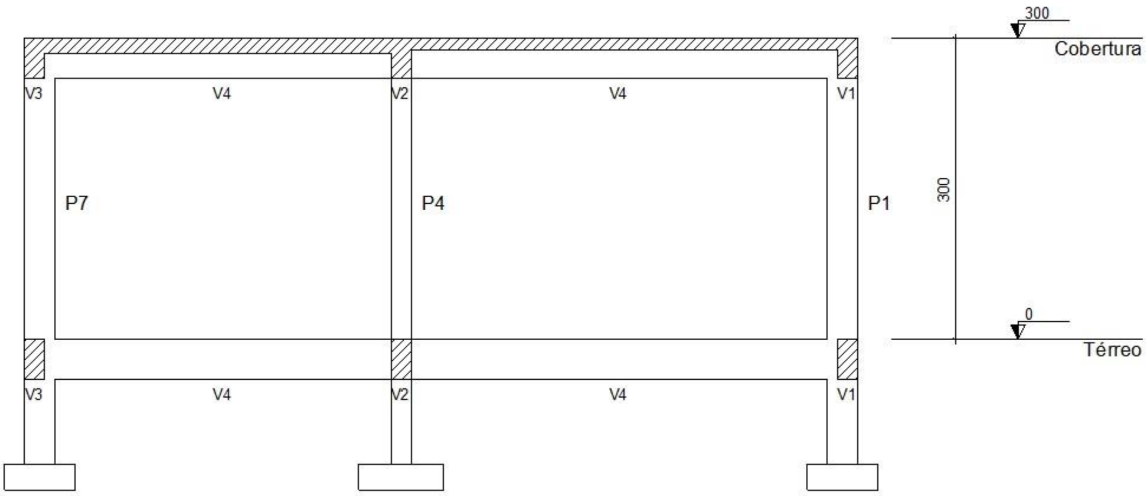


Figure 4 – B-B Cut



DATA AND ANALYSIS CONSIDERATIONS

The loading data and analysis considerations used in both programs are described below.

MATERIAL LOADS AND PROPERTIES

The loads used in the structure under study are described in table 1. Wind loading was not considered, nor masonry loading. The self-weight of the structure is calculated automatically by the programs, using the specific weight of 25 kN/m³.

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Table 1 – Loads used

Load	Value
Self-Weight	Automatic
Overload	1.5 kN/m²
Coating	1.0 kN/m²

Table 2 presents the strength characteristics of the concrete and steel used.

Table 2 – Characteristics of the Materials

Material	Value
Concrete	Class C25 - 25 Mpa
Steel	CA50 and CA60

CONSIDERATIONS OF THE ANALYSES

The following considerations were adopted in the analyses in both programs:

- The global second-order effect (P-delta) was disregarded, since horizontal actions were not considered.
- The connections of the columns with the foundation were considered labeled (the design of the foundations was not compared in this article)
- The slabs were considered to be set.

The steel gauges chosen for the design of the structure in each program are described below, in table 3.

Table 3 – Gauges chosen in the programs

Element	Gauges (mm)
Slabs	5,0 - 6,3 - 8,0 - 10,0
Beams (Longitudinal *Reinforcement*)	8,0 - 10,0 - 12,5 - 16,0 - 20,0
Beams (*Transverse Reinforcement*)	5,0 - 6,3 - 8,0 - 10,0
Pillars	10,0 - 12,5 - 16,0 - 20,0

Environmental aggressiveness class II (moderate) was determined, so a covering of 3.0 cm was used on the pillars and beams, and 2.5 cm on the slabs. With a limit opening for cracks of 0.3 mm.

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COMPARISON OF RESULTS

The following results were compared:

- Beam stress;
- Deformations in beams and slabs;
- Steel area in sections of slabs, beams and columns;
- Loads on the foundations;
- Shape area;
- Concrete volume;
- Total weight in steel bars.

Figure 5 presents the diagrams of bending moment and design shear force (stress envelopes) for beam V2 (figure 2), obtained with the Cypecad program; Figure 6 presents the diagrams of bending moment and shear force for this same beam, with the Eberick program. Table 4 presents a comparison between design forces, calculated reinforcements and maximum deferred deformation for beam V2.

Figure 5 – Bending Moment (kNm) and shear force (kN) beam V2 – Cypecad.

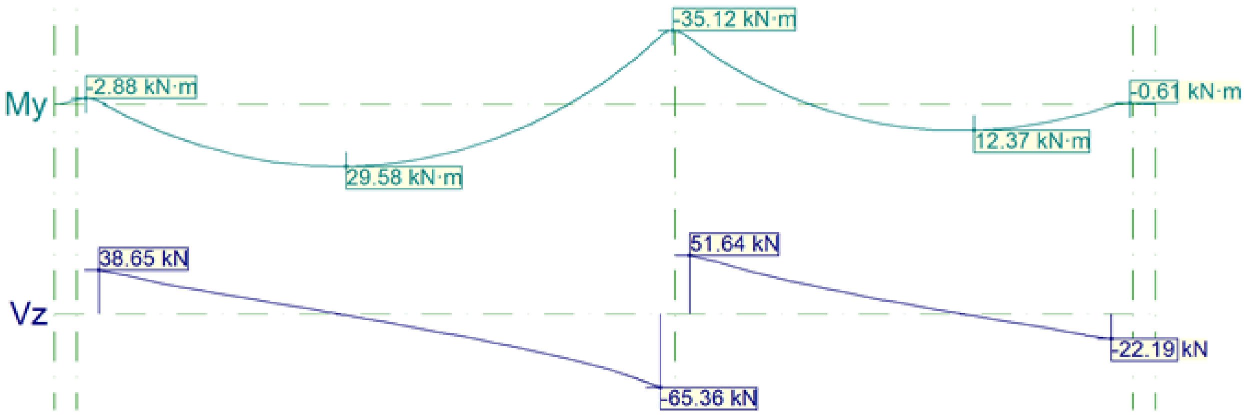

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Figure 6 – Bending Moment (kNm) and shear force (kN) beam V2 – Eberick

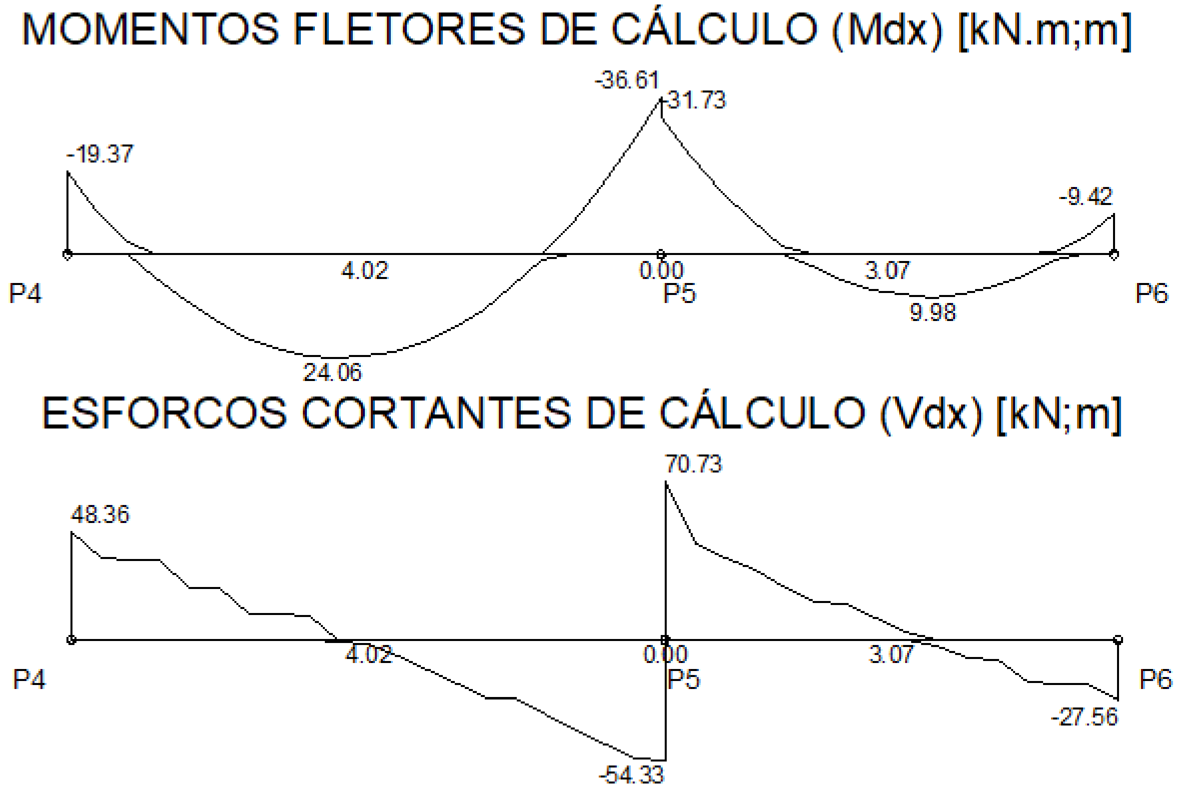

Table 4 – Comparison of design forces, reinforcement and deformation of beam V2.

Parameter	CYPECAD	EBERICK	Difference %	Difference % (Article 2009)
Maximum positive moment (kNm)	29,58	24,06	22,94	28,40
Maximum *positive* reinforcement (cm²)	2,36	1,59	48,43	39,00
Maximum negative moment (kNm)	35,12	36,61	4,07	1,50
Maximum negative reinforcement (cm²)	2,58	2,47	4,45	4,20
Maximum deflection between *pillars P4 and P5*(cm)	0,24	0,2	20,00	0,40
Maximum deflection between *pillars P5 and P6*(cm)	0,03	0,05	40,00	0,40
Maximum positive shear (kN)	51,64	70,73	27,00	3,00
Maximum positive shear reinforcement (cm²/m)	1,9	2,05	7,32	13,00

Figures 7 and 8 present, respectively, the details of beam V2 generated by the programs.

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Figure 7 – Beam V2 Detailing – Cypecad

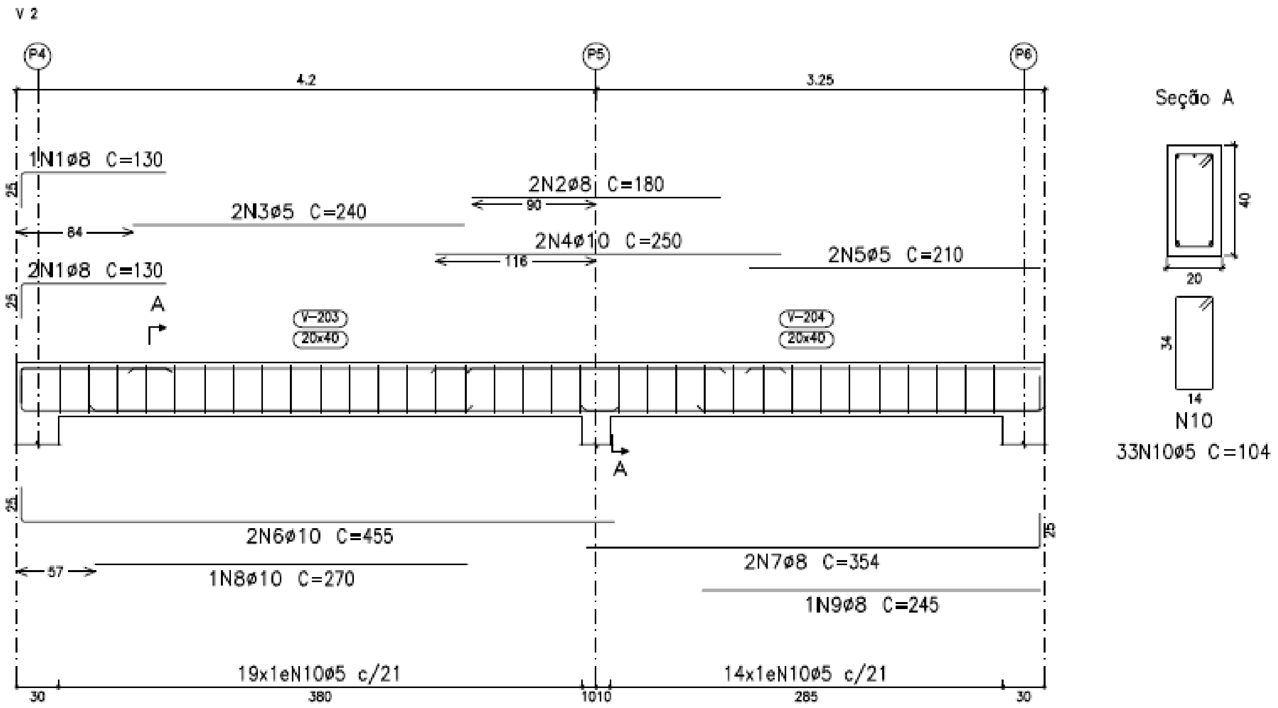

Figure 8 – Detailing beam V2 – Eberick

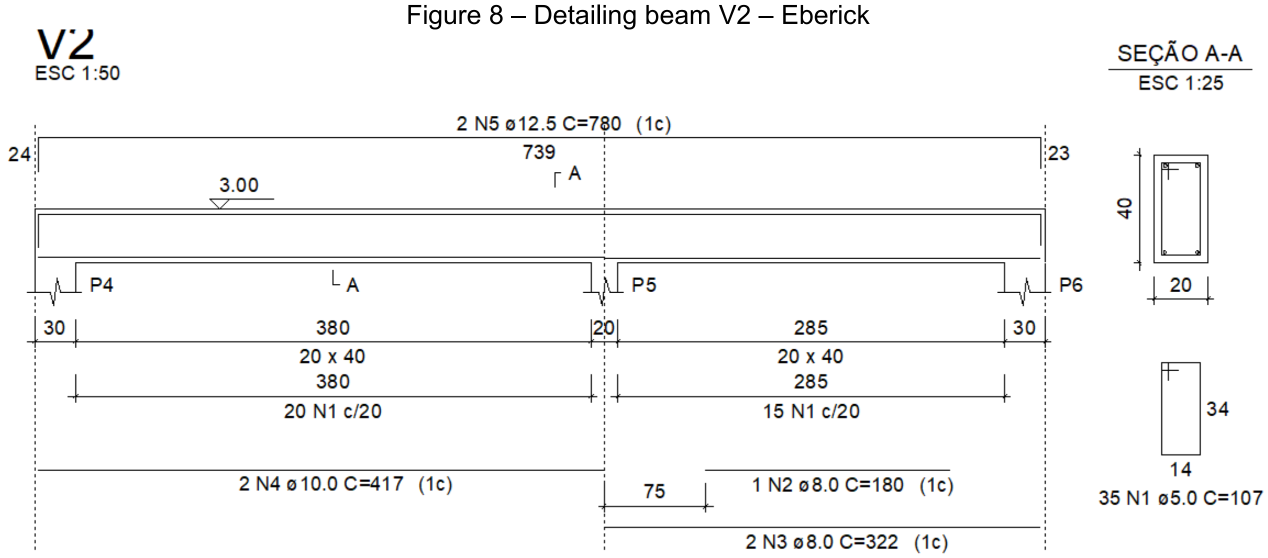

Table 5 presents a comparison between the steel areas adopted by both programs and the maximum deflection for L1 slab.

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Table 5 – Comparison of the adopted reinforcement and deformation in the L1 slab.

Parameter	CYPECAD	EBERICK	Difference %	% Difference (2009 Article)
Positive reinforcement adopted - x (cm²/m)	1,27	1,21	4,96	62,10
Positive reinforcement - y (cm²/m)	1,12	1,21	7,44	49,50
Negative reinforcement over V2 (cm²/m)	2,49	2,78	10,43	44,60
Negative reinforcement over V5 (cm²/m)	1,55	1,8	13,89	33,00
Maximum Deflection (cm)	0,26	0,37	29,73	60,70

Figures 9 and 10 show, respectively, bending moments of the roof slabs in the X direction and bending moments of the roof slabs in the Y direction, obtained through the Cypecad program, which uses the finite element method. Figure 11 shows bending moments of the roof slabs obtained through the Eberick program, which uses the grid analogy method.

Figure 9 – Bending moments of roof slabs in the X direction – Cypecad

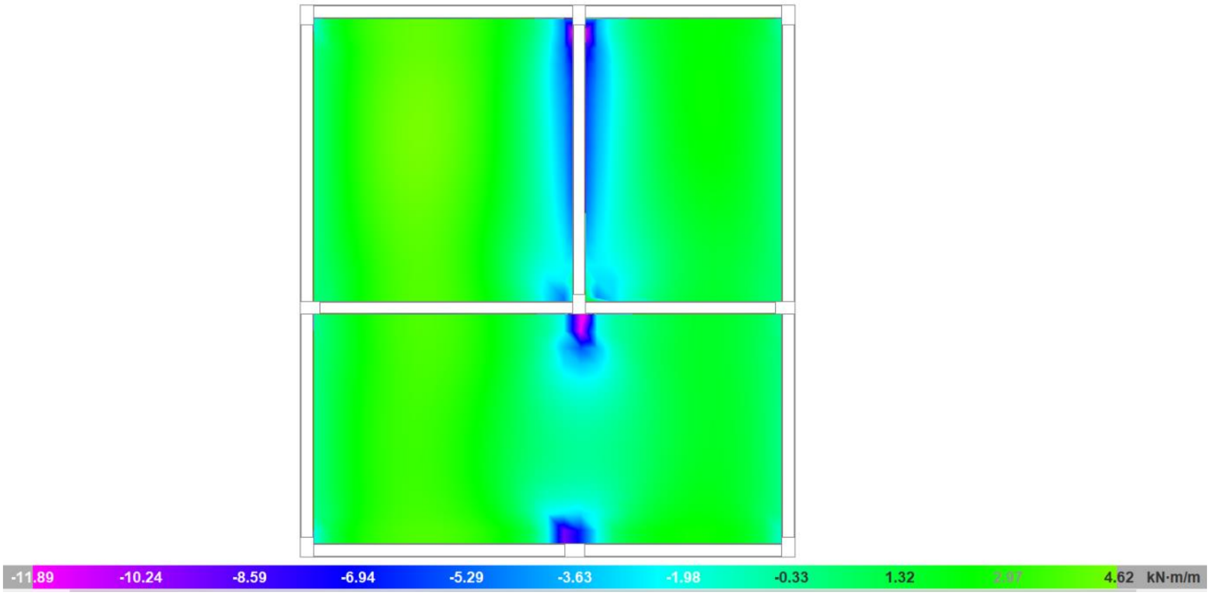

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Figure 10 – Bending moments of roof slabs in the Y direction – Cypecad

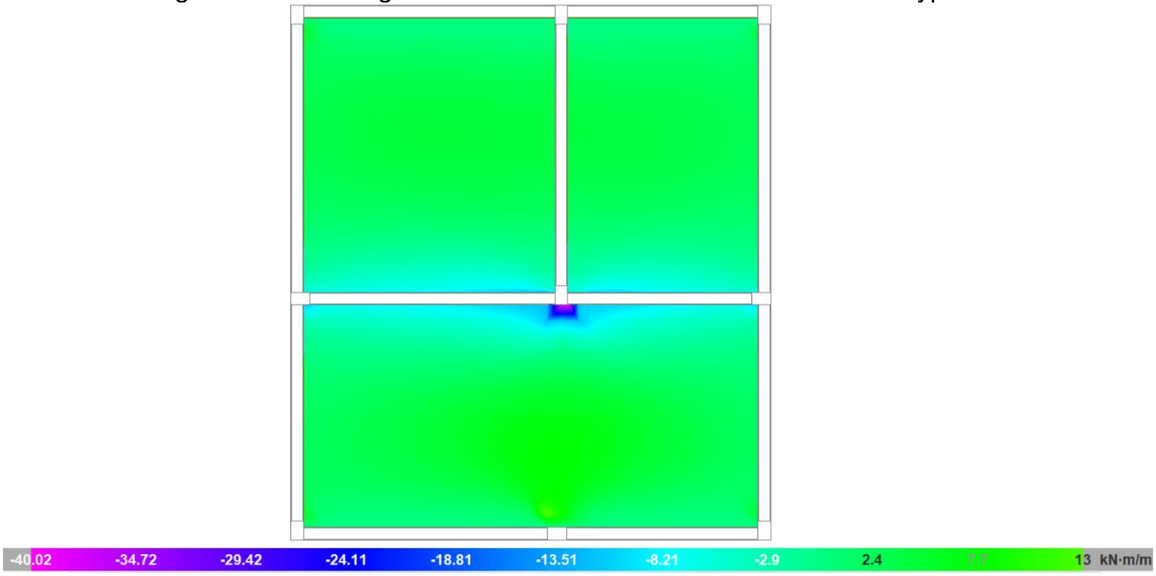

Figure 11 – Moments Freight Coverage Items – Eberick.

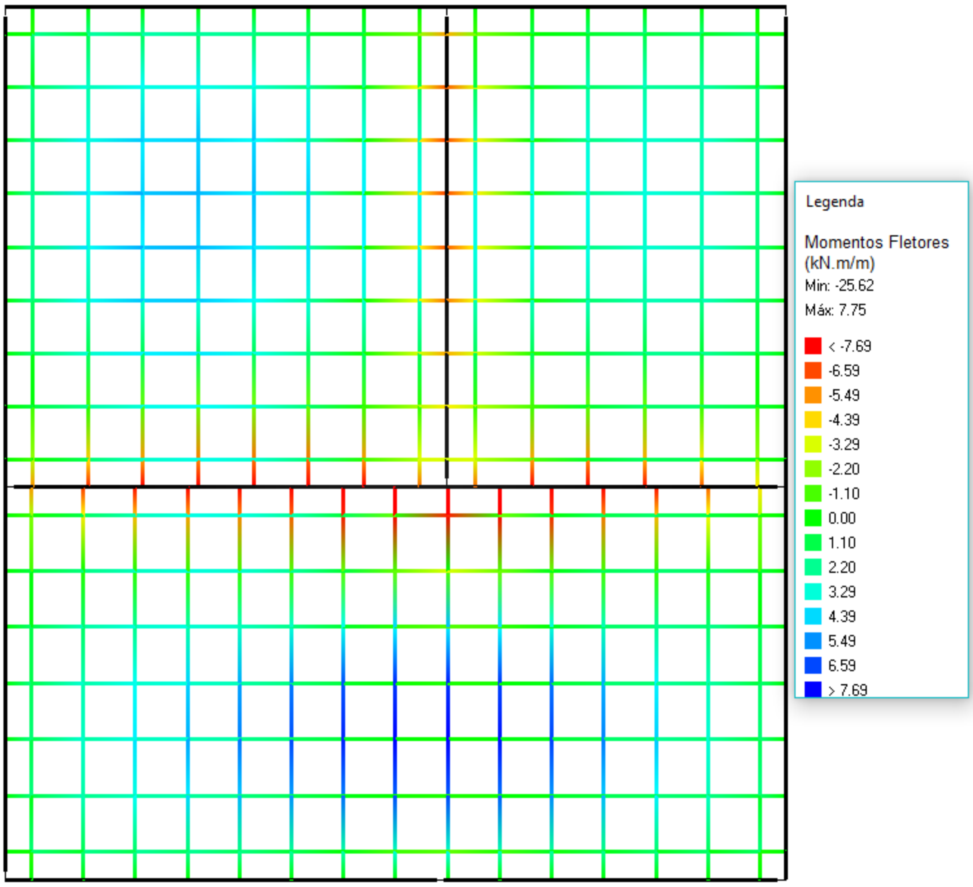

Table 6 presents a comparison between maximum design forces and steel areas of the P5 pillar.

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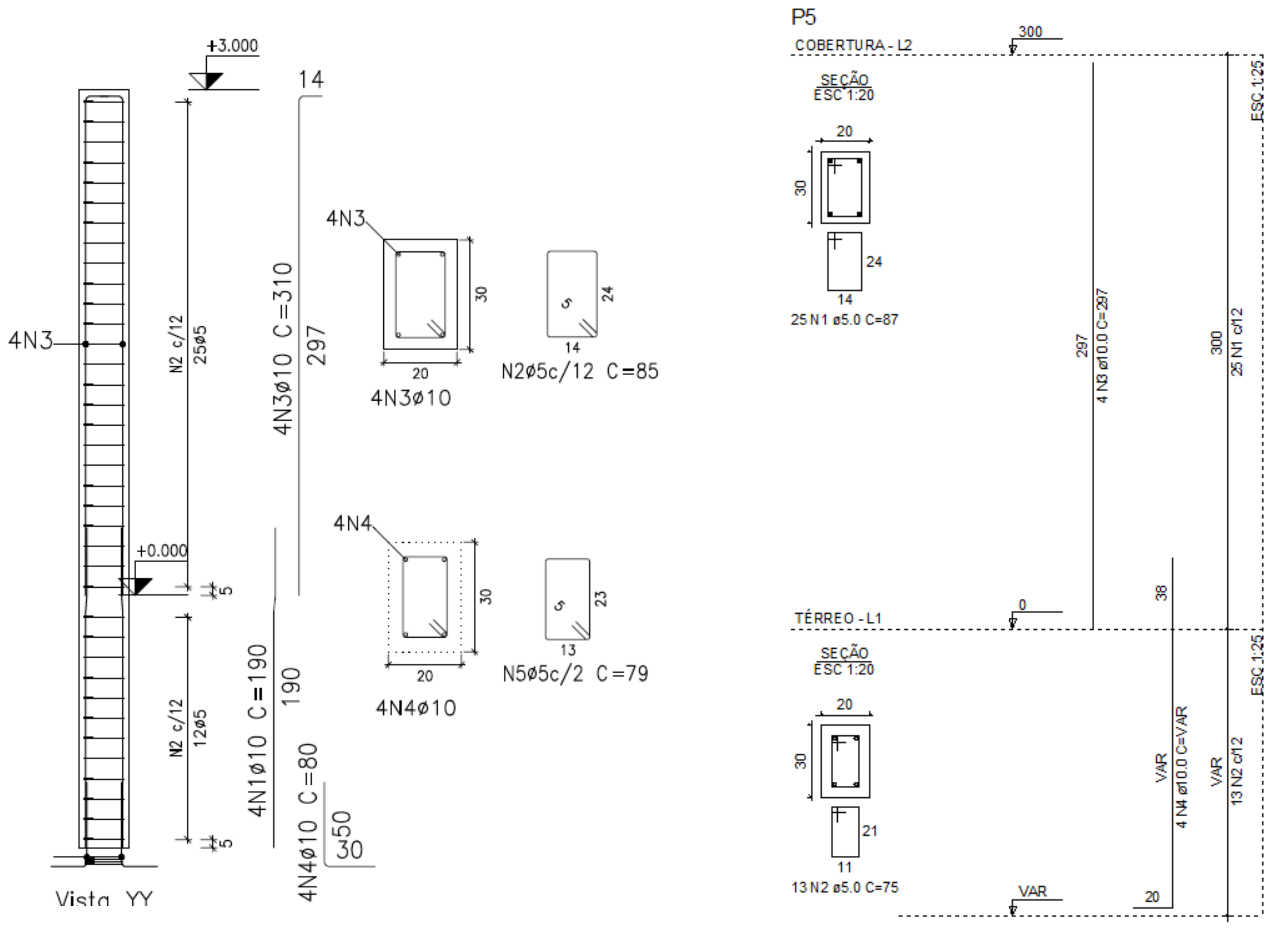
Table 6 – Steel forces and areas for the P5 pillar.

Parameter	CYPECAD	EBERICK	Difference %	% Difference (2009 Article)
Maximum peak moment (kNm)	4,6	8,78	47,61	30,00
Maximum Base Moment (kNm)	1,5	4,89	69,33	23,10
Maximum normal effort (kN)	177,43	166,57	6,52	6,60
Adopted reinforcement (cm²)	3,14	3,14	0,00	0,00

Figure 12 shows the breakdown of the P5 pillar in both programs.

Figure 12 – Details of the P5 pillar – (a) Cypecad (b) Eberick.



(a) (b)

Table 7 shows the loads on the foundations. The connection between the pillars and the footings were considered labeled.

Table 7 – Loads on the foundations (kN)

Pillar	CYPECAD	EBERICK	Difference %	% Difference (2009 Article)
P1	38,5	40,84	5,73	15,30
P2	75,9	78,77	3,64	1,60

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P3	30,4	32,81	7,35	15,30
P4	79,7	79,45	0,31	2,40
P5	141,7	136,61	3,73	-
P6	61,9	63,24	2,12	2,40
P7	31,9	34,82	8,39	12,50
P8	57,3	54,28	5,56	1,50
P9	26,7	29,73	10,19	12,50
Total	544,00	550,55	1,19	4,60

Table 8 presents the quantities of materials obtained by the programs, for each floor, and table 9 presents the total of the work.

Table 8 – Quantity of materials per floor.

Floor	Consumption	CYPECAD	EBERICK	Difference %	% Difference (2009 Article)
Coverage	Shape Area (m²)	110,14	124,20	11,32	7,00
	Concrete volume (m³)	11,34	11,50	1,39	3,00
	Weight of Steel Bars (kg)	505,00	504,70	0,06	10,70
Ground floor	Shape Area (m²)	49,20	57,10	13,84	23,40
	Concrete volume (m³)	4,12	4,30	4,19	13,20
	Weight of Steel Bars (kg)	194,00	199,10	2,56	32,30

Table 9 – Total quantity of the work.

Floor	Consumption	CYPECAD	EBERICK	Difference %	% Difference (2009 Article)
Total da Work	Shape Area (m²)	159,34	181,30	12,11	11,30
	Concrete volume (m³)	15,46	15,80	2,15	3,60
	Weight of Steel Bars (kg)	699,00	703,80	0,68	1,80
	Steel consumption (kg/m³)	45,21	44,54	1,50	1,70

CONCLUSIONS

As expected, it is observed that the results presented for the proposed comparisons are not identical. In some cases, they are very close, as in the case of the requesting force diagrams, as well as the maximum values for design, shown in figures 5 and 6, for bending moments in beam V2. The difference in moments in the supports, between the programs, can be justified by the fact that Cypecad uses as a crimping coefficient a value that varies from 0 to 1, where 0 is labeled support and 1 total crimping, being used as a standard value the coefficient 0.3 on the top floor, while in Eberick there are only 3 options, crimping, semi-rigid knots and labeled. As for the differences found in the steel areas, it can be attributed to the graduation of the default installation reinforcement tables . The graduation of steel areas is a function of the distribution quantity of the possibilities of combinations between

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steel bars in the beam sections. This option should be widely explored by the users of the tools, in order to cover the largest amount of sizing efforts possible, without compromising feasibility, and without burdening the workload of time in the editing of reinforcements in the preparation of the planks for execution. Also for beam V2, the maximum deflection obtained by Eberick had a difference of 20% in the section between pillars P4 and P5, and an even greater difference of 40% between pillars P5 and P6, this difference may be due to the fact that they are calculated by different shapes in the two programs.

Analyzing the results of the differences between the programs of the 2009 article and this one, we see a great similarity between the results of the maximum negative and positive moments, however, in the cutting efforts there is no follow-up of these results, as well as in the arrows, which are superior in this present work. This may be due to the analysis of a completely different structure from the old work.

In the case of the areas of steel for bending in slabs presented in table 5, it is observed that in terms of economy, the Cypecad program becomes more economical than the Eberick in terms of both positive and negative bending reinforcements, and in the latter the difference is even greater. These differences can be attributed to the graduation of the default reinforcement tables for installing the programs. It is also observed that the Eberick program presents a greater deflection than Cypecad, probably because the latter, by determining forces and displacements through the finite element method, does not contain the nonlinear formulation that considers the concrete in the cracked state and does not consider the deflection calculation deferred in time, such effects can be evaluated separately and, subsequently, make the comparison with the EBERICK results. In the comparison between the articles, a clear difference in the values was observed, which had their differences considerably reduced in the present study.

With regard to the columns, despite presenting bending moments with a marked difference, the reinforcement rates were identical in both programs, as well as the detailing of the longitudinal and transverse reinforcements, in the latter the small difference was in the stirrup length, which is 2cm shorter in the Cypecad program. Eberick adopts in its design method, an iterative process, or neutral line process, which takes into account the positioning of the reinforcements. In this method, diagrams of interaction between the resistant moments and calculation requesters are drawn for each combination, until a reinforcement configuration is reached that meets the design requests. The calculation method used in CYPECAD is to check the reinforcements of the selected column reinforcement table until a reinforcement configuration is found that meets all the combinations. In the case of the pillars, the differences between the normal forces are practically the same, as for the moments, there was an increase in the difference of the present work and the reinforcement adopted was exactly the same, as in the old article as well.

It is observed through the analysis of table 7 that the distribution of axial loads in the columns presents little difference, summarizing the comparison to the sum of loads in the columns, with a difference in the order of 1.2%. It is possible that this difference is related to the criteria adopted for the consideration of the portion due to the self-weight of the structural elements, which in turn is a direct function of the concrete volumes of the work. When comparing this result with that obtained in the 2009 article, we can see a decrease in the difference of almost 75% with that of the current year.

Analyzing tables 7 and 9, it is observed that the sum of the loads in the foundations, obtained by Eberick, is higher than that obtained by Cypecad. It is not by chance that the volume of concrete presented by Eberick is higher than that presented by Cypecad. Regarding the weight of the steel, it is observed that the summary of the calculation obtained from the use of the Cypecad program, presents a result of the order of 0.7% more economical than that obtained with the use of the Eberick program. But, when it comes to the consumption of steel per cubic meter of concrete, it shows that Eberick is more economical. This inversion of the result is explained by the fact that the volume of concrete is higher in the Eberick, than that calculated by Cypecad, causing this index to be reduced. This result was the same as that obtained in the 2009 article, and the difference between them is less than 12%.

As a difference was presented in the area of form used, being greater in the Eberick 12.1%, a manual calculation was made in order to elucidate such difference, and it was found that the results are closer to those obtained by the Cypecad program, and it is likely that in the calculation carried out by the Eberick program there is duplicity in the areas between the beams and columns. This same fact was found in the 2009 article, and remained practically the same difference, suggesting that there was no update in this item, but in the general consumption, making a comparison between the differences of the present study and the one carried out in 2009, a decrease in the differences between the programs is noticed.

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In summary, we can see, from the analyses made, that although the processes of structural analysis have their differences, the results in consumption are very equivalent. The Cypecad program adopts more steel in beams, and the Eberick program adopts more steel in slabs, however, by the criterion of material consumption, using the *default configuration*, as was also found in 2009, suggests the Cypecad software to be more economical.

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