v. 2, n. 26, 2022

Journal of
Engineering
Research

STRUCTURAL COMPARATIVE ANALYSIS BETWEEN CONVENTIONAL SOLID SLABS AND REINFORCED CONCRETE RIBBED SLABS THROUGH MANUAL CALCULATION AND TQS SOFTWARE

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Abstract: The proposed work consists in the elaboration of a structural calculation of conventional solid and ribbed reinforced concrete slabs of a five-story building, using the criteria of NBR 6118 (ABNT, 2014), and comparing the manual design with the TQS software (Software Definitive for Structural Engineering). The reinforced concrete structure was designed in massive plate-type slabs and ribbed slabs supported by beams. For this, the grid theory method was used under rigid supports, perpendicular to the results of the computer program. The calculation memorial and detailed plans of the structural elements were developed together with the diagnosis and final report of the program. In order to clarify the dimensioning, most of the calculations were performed manually where it is possible to identify the theories, applications and concepts of the criteria and methodology used. Microsoft Excel spreadsheets were also used to summarize and route the statistical and analytical information of the due project. At the end of the work, the results obtained in the detailing of the manual calculation were compared with the results obtained in the TQS computational system. Checking that there are differences in the dimensioning of the structural elements. However, the software presents artifices for the arrangement of structural compatibility arrangements, thus making the different verifications manifest the degree of interpretation of the professional based on the behavior of the structure.
Keywords: Structural calculation, slabs, reinforced concrete.

INTRODUCTION

Programs for structural design are classified into analysis, design, dimensioning and integrated system. Software of analysis has as a means the responsibility of the internal forces and the verification of the displacements of a certain structure; its function is not the dimensioning of reinforcement nor the generation of final blueprints with details of any section associated to the project. The software for drawing generic blueprints is CAD (computer aided design) type software, which are widely used not only by Civil Engineering, but also other professional areas. The dimensioning ones are ideal to perform structural verifications of the elements, besides measuring a structural element - be it a beam, column, or slab in a separate way. Integrated system is more usual in all aspects to design reinforced concrete buildings, due to the successful way of covering the project stages, starting from the structural calculation, detailing and reinforcement dimensioning, up to the plotting of the final plates (KIMURA, 2007).

For this study, there will be a manual design of conventional solid slabs and waffle slabs in reinforced concrete through an analogy of the grid theory and will be run the software TQS, AutoCAD. TQS is a software developed by civil engineers who develop and market software for structural and foundation design of buildings. The technological company applied to engineering, operates in Brazil since 1986 and is present in the day to day of more than 35 thousand professionals that use a set of softwares supporting files with extension DWG/DXF and generated by AutoCAD, performing import and export of records. The program does all the structural launching from the already defined architecture. After the structural projection, it starts the analysis of the results obtained on the processing, the dimensioning of the structural elements and the final detailing of the structure.

Finally, it is worth emphasizing that the use of computer programs in real structural design situations requires extreme responsibility and experience on the part of the professional engineer in their use. It is necessary the qualification of the professional who will handle the software, being recommended its use only as a project aid mechanism and not as a definitive structural solution.

METHODOLOGY

Initially, to meet the objectives proposed in this work, an architectural design of a multi-family building with a total height of 14.40m and 6 housing units, with an area per apartment of 145.16m² and a total building area of 1,565.50m² was prepared. The modulation of the arranged slabs was made to meet the massive and ribbed slabs, i.e., spans established within the structural limits of each arrangement, (Figure 01 presents the panoramic views of the project performed for suggested work).

Only the slabs of an entire floor were analyzed, with one verification using a conventional solid slab and another with a ribbed slab supported on beams. The dimensioning of reinforced concrete in the computer program will follow the requirements of NBR 6118 (ABNT, 2014), and the other standards for consideration of structural design.

For the structural launch in the TQS software, studies were conducted to adapt the architectural design to define and size the elements that make up the entire structure: foundations, columns, beams, and the main element of study, slabs.

RESULTS AND DISCUSSIONS

The panels chosen for the analysis and presentation of the results and consequent discussions refer to slabs 1,2,3,4,8,9,13,14 and 18. The hatches in Figure 02 indicate the designated elements.

The following table 1, spells out the permanent and accidental loads of the project raising the quasi-permanent service combination and the accidental loads according to ABNT NBR 6120 (rev. 2018). The loads arranged for design:

- Plaster lining (0.25kN/m²); Subfloor(1.2kN/m²); Coating (1kN/m²);
- Own Weight (For L18 = 2.75kN/m², and other slabs with 2.5kN/m²);
- Masonry Weight (L2=0.75kN/m², L3=0.80kN/m², L9=1.3kN/m²).

Table 02 presents the final total loads distributed on the slabs relating the final service load (*fd, ser*) to the reduction coefficient. *fd, ser*

The conference of loads in the TQS was developed from the plant of forms, figure 03 shows the exemplification of the so-called plastic hinges.

Chart 1 shows the result comparing the difference in the quasi-permanent service load with the respective reduction factors applied in manual design and the TQS software.

The analysis of the Non-Linear Grid is presented in figure 04, considering the physical non-linearity of the elements, taking as an example the typical floor of the building.

The verification of the slab deflections takes into account the maximum total displacement and limit displacement, Figure 05. Shows the values obtained in the TQS analysis justifying the instantaneous value of the displacement at the point of greatest displacement. It is verified the isovalues of the slabs in Figure 06, which have the largest displacements of deflections in the structure. Thus, the table 03, assesses the values of immediate deflections and total deflections comparing the manual design with TQS software, which in chart 2 checks the percentage discrepancy between the manual design (grid theory on rigid supports), and grid TQS admitting the physical nonlinearity of the elements.

With these results, it is summarized that the analysis of the debonding limit states for the solid slabs showed about 23% and for the

Figure 01 - Project View - Facade and Building Structure

Source: Author,2020

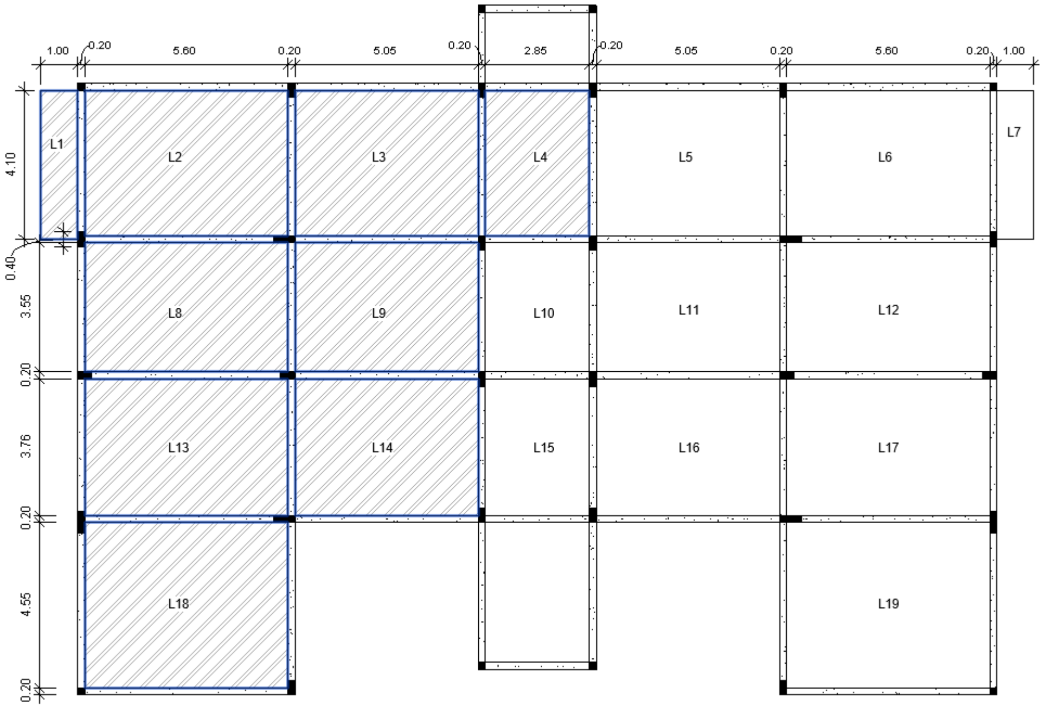


Figure 02 - Plan of Shapes of the Analyzed Slabs

Source: Author,2020

Slab	Permanent Loads (kN/m²)	Accidental Loads NBR 6120 (kN/m²)	Site Classification NBR 6120
L1	4.95	2.5	balconies
L2	5.70	1.50	dormitories
L3	5.75	2.00	Service area
L4	4.95	3.00	HALL Common Area
L8	4.95	1.50	dormitories
L9	6.30	1.50	Kitchen
L13	4.95	1.50	Living room
L14	4.95	1.50	Living room
L18	5.20	1.50	kitchen/terrace

Table 01 - Analysis of Project Loads Manual Dimensioning

Source: Author,2020

Slab	TQS (Tf/m²)	C. MANUAL (Tf/m²)
L1	0.75	0.57
L2	0.65	0.62
L3	0.70	0.65
L4	0.79	0.59
L8	0.65	0.54
L9	0.65	0.68
L13	0.65	0.54
L14	0.65	0.54
L18	0.70	0.57

Table 02 - Almost Permanent Service Load (*fd, ser*).

Source: Author, 2020.

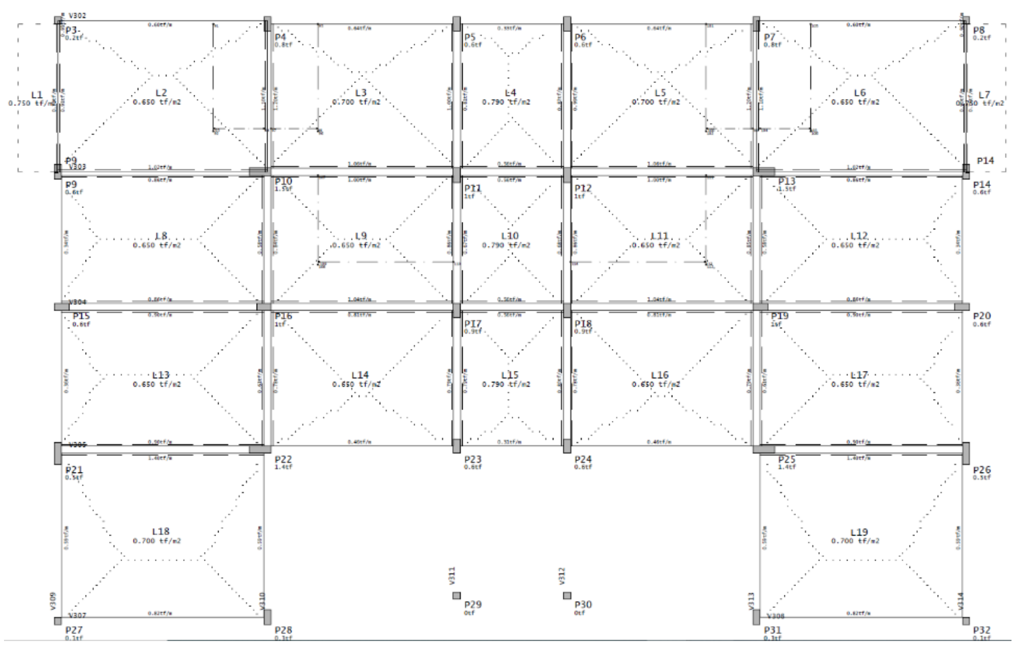


Figure 03 - TQ Plastic Hinges

Source: Author,2020

Journal of Engineering Research ISSN 2764-1317 DOI 10.22533/at.ed.3172262222113

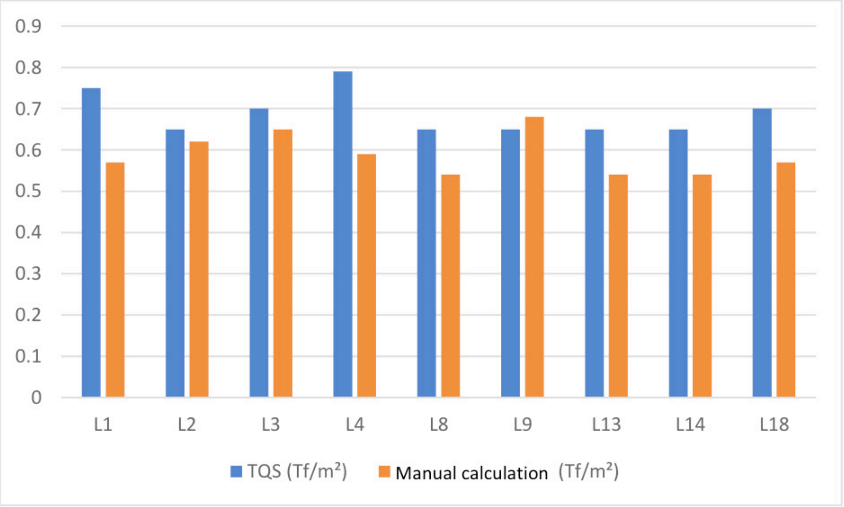


Chart1– Comparison (Fd, ser) Solid Slabs

Source: Author,2020

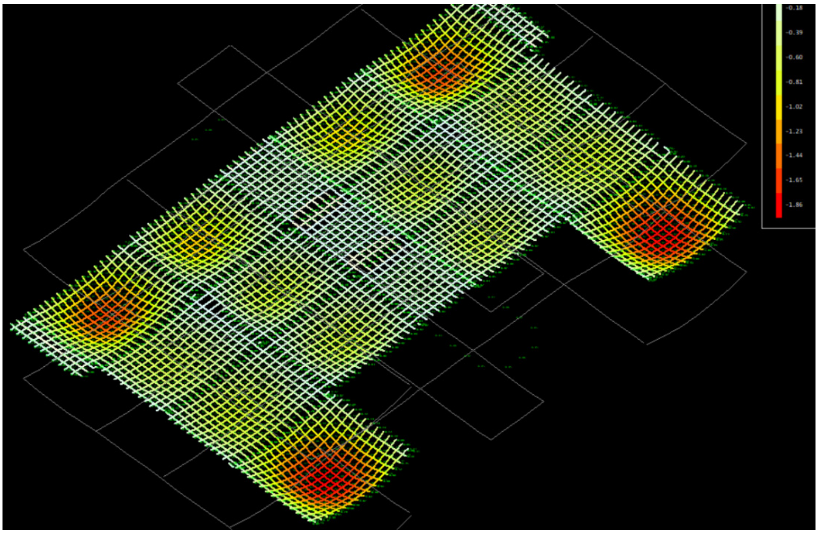
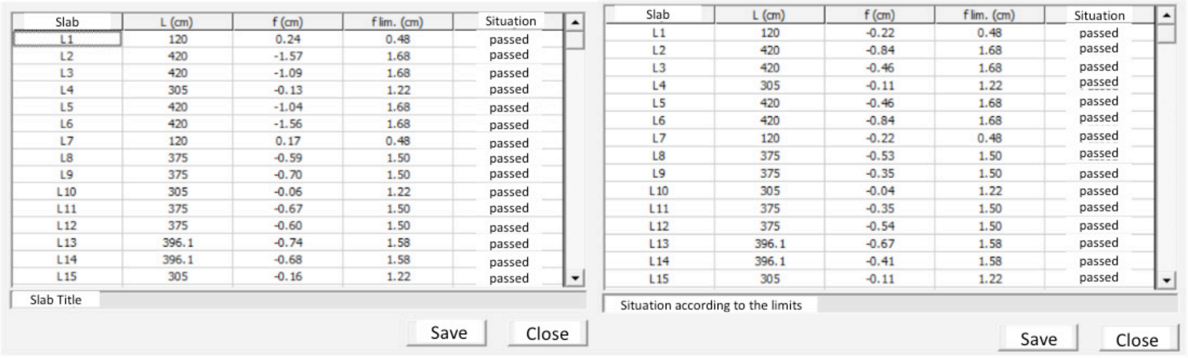


Figure 04 - Non-Linear Grid Total Arrows (Immediate + Progressive)

Source: Author,2020



Slab	L (cm)	f (cm)	f lim. (cm)	Situation
L1	120	0.24	0.48	passed
L2	420	-1.57	1.68	passed
L3	420	-1.09	1.68	passed
L4	305	-0.13	1.22	passed
L5	420	-1.04	1.68	passed
L6	420	-1.56	1.68	passed
L7	120	0.17	0.48	passed
L8	375	-0.59	1.50	passed
L9	375	-0.70	1.50	passed
L10	305	-0.06	1.22	passed
L11	375	-0.67	1.50	passed
L12	375	-0.60	1.50	passed
L13	396.1	-0.74	1.58	passed
L14	396.1	-0.68	1.58	passed
L15	305	-0.16	1.22	passed

Slab Title

Save Close

Slab	L (cm)	f (cm)	f lim. (cm)	Situation
L1	120	-0.22	0.48	passed
L2	420	-0.84	1.68	passed
L3	420	-0.46	1.68	passed
L4	305	-0.11	1.22	passed
L5	420	-0.46	1.68	passed
L6	420	-0.84	1.68	passed
L7	120	-0.22	0.48	passed
L8	375	-0.53	1.50	passed
L9	375	-0.35	1.50	passed
L10	305	-0.04	1.22	passed
L11	375	-0.35	1.50	passed
L12	375	-0.54	1.50	passed
L13	396.1	-0.67	1.58	passed
L14	396.1	-0.41	1.58	passed
L15	305	-0.11	1.22	passed

Situation according to the limits

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Figure 05 - Verification of Arrows in Solid and Ribbed Slabs TQS

Source: Author,2020

Journal of Engineering Research ISSN 2764-1317 DOI 10.22533/at.ed.3172262222113

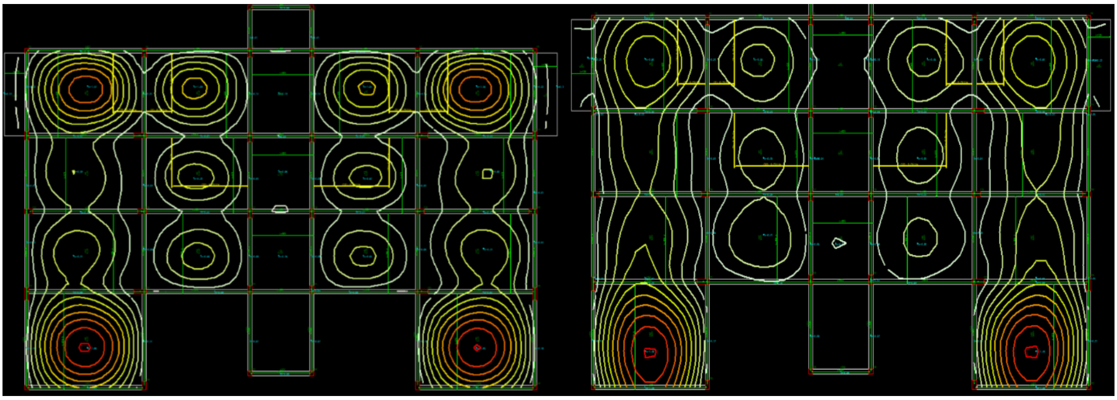


Figure 06 - TQS Solid and Ribbed Isovalues

Source: Author,2020

Slab	TQS	Non-linear grelah (cm)		Manual Dimensioning	Calculation of Arrows		Slab	TQS	Non-linear grelah (cm)		Manual Dimensioning	Calculation of Arrows(cm)	
		Arrows Total	Arrows Limite		Arrows Total	Arrows Limite			Arrows Total	Arrows Limite		Arrows Total	Arrows Limite
L1		0,24	0,48		0,15	0,8	L1		0,22	0,48		0,09	0,8
L2		1,57	1,68		1,31	1,68	L2		0,84	1,68		0,39	1,68
L3		1,09	1,68		0,94	1,68	L3		0,46	1,68		0,28	1,68
L4		0,13	1,22		0,19	1,22	L4		0,11	1,22		0,06	1,22
L8		0,59	1,50		0,43	1,50	L8		0,53	1,50		0,15	1,50
L9		0,70	1,50		0,46	1,50	L9		0,35	1,50		0,13	1,50
L13		0,74	1,58		0,52	1,58	L13		0,67	1,58		0,18	1,58
L14		0,68	1,58		0,70	1,58	L14		0,41	1,58		0,24	1,58
L18		1,86	1,90		1,59	1,90	L18		1,48	1,90		0,68	1,90

Table 03 - Analysis of Total Arrows Solid and Ribbed Slabs

Source: Author,2020

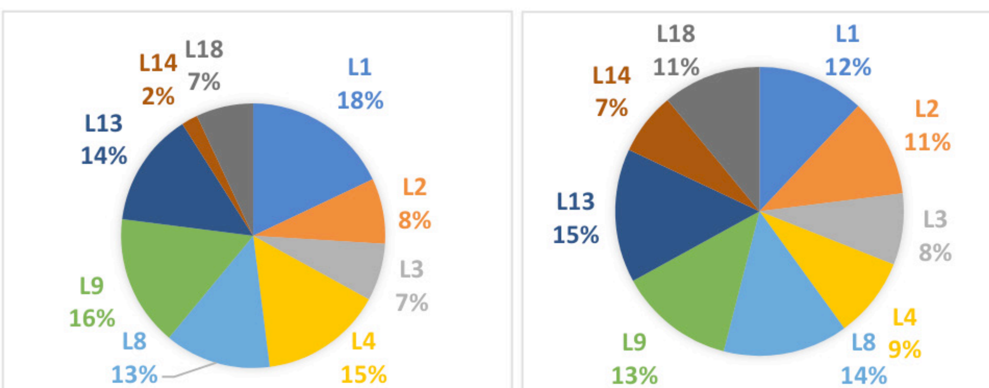


Chart 2– Comparison of Manual and Computational deflections

Fyesterday: Author, 2020.

waffle slabs 56% difference between the manual analysis and the TQS software. Moving on to the analysis of acting moments, determining bending moments and applying the theories of rigid body balance, it was identified in the TQS modeling through the grid viewer, as shown in Figure 07, that the distribution of calculations is visualized spatially. Thus, it is worth emphasizing the importance that the negative moments are practically zero and in the connections between one slab and another the moments are made compatible, for each grid bar.

Based on these results, it is resumed that the analysis of the debonding limit states showed about 23% difference between the manual analysis and the TQS software. Moving on to the analysis of acting moments, determining bending moments and applying the theories of rigid body balance, it was identified in the TQS modeling through the grid viewer, as shown in Figure 07, that the distribution of calculations is visualized spatially. Thus, it is worth emphasizing the importance that the negative moments are practically zero and in the connections between one slab and another the moments are made compatible, for each grid bar.

Proceeding with the TQS analysis criteria, it is possible to check these efforts in more detail in the reinforcement editing settings. Figure 09 shows the quick reinforcement editing tab where you can analyze each grid bar point by point. It is also possible to analyze an average of the bands, as shown in Figure 10.

Charts (3 and 4) below show the disproportions between the positive moments in directions X and Y of the manual analysis (of Solid and Waffle Slabs) and TQS. In consonance, it is also possible to open the discussions with Charts (5 and 6) showing the compatible negative bending moments in the X and Y directions.

Tables 04 and 05, present the summary of the positive reinforcement distribution and the respective detailing information of the slabs in the x-axis and tables 06 and 07 in the y-axis. The area of steel calculated by TQS, in solid slabs, presents superiority in the x-axis of the positive reinforcement, but in the Y direction there is equivalence of close areas and some slabs of the manual design excelling in the computational analysis as shown in Charts 7 and 8, Chart 9 shows the area of rib steel in the Y direction.

Tables 08 and 09, they show the relationship of negative moments in the Y direction of the slabs analyzed.

Chart10 shows the difference between the analyzes of negative reinforcement in the Y direction.

With the survey already described above, it is possible to take into account the manual and computational analyses, as shown in Chart 11, which shows the displacements of the slabs, and in Chart 12, which shows the difference between the negative and positive bending moments. This is presented with a maximum variation of 32.35% in solid slabs and 31.89% for waffle slabs, with respect to the manual calculation and computational design. The steel area shown in Chart 13, varies in its maximum point a value of 46.42% in the total positive reinforcement in the Y direction of the ribbed slabs, and 16.18% at the maximum point of analysis of the solid slabs.

The final amount of reinforcement in Kgf, was related to the result disregarding the anchorage and hook values. Due to their variation follow parameterization based on two fundamentals: adjacent slabs with straight anchorage and freeboard slabs with hook anchorage. Thus, in Chart 13 the summary of the final reinforcement of the slabs is presented. With this, it is possible to express in the Chart 14 the concrete consumption per m^3 of each slab.

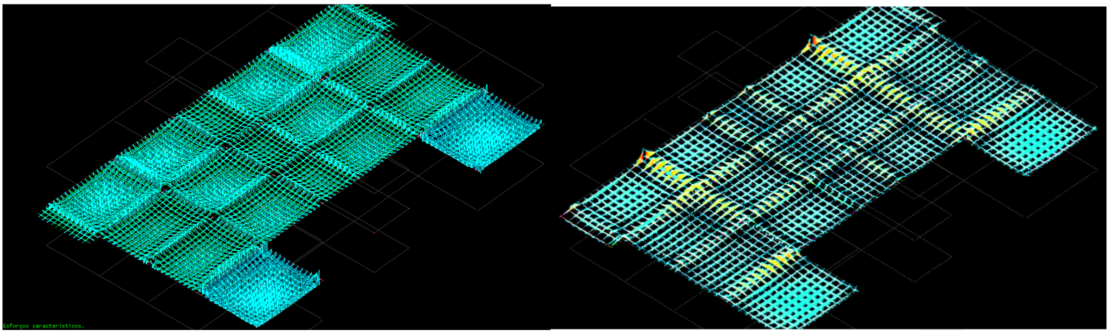


Figure 08 - Characteristic Bending Moments TQS Solid and Ribbed Slabs

Source: Author,2020

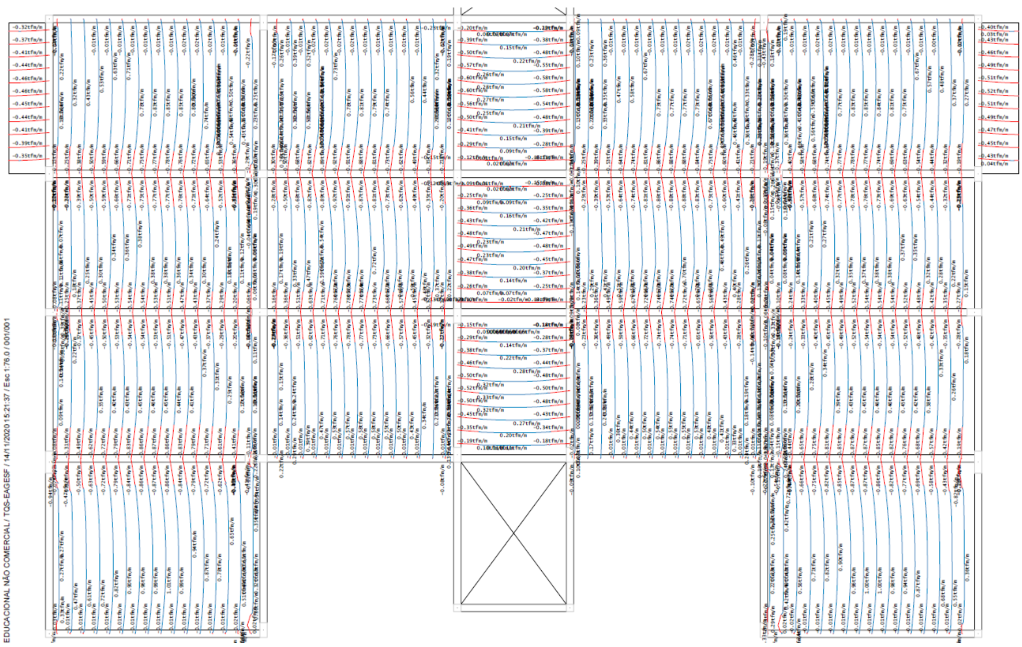


Figure 09 - TQS Bending Moments Diagram Viewer

Source: Author,2020

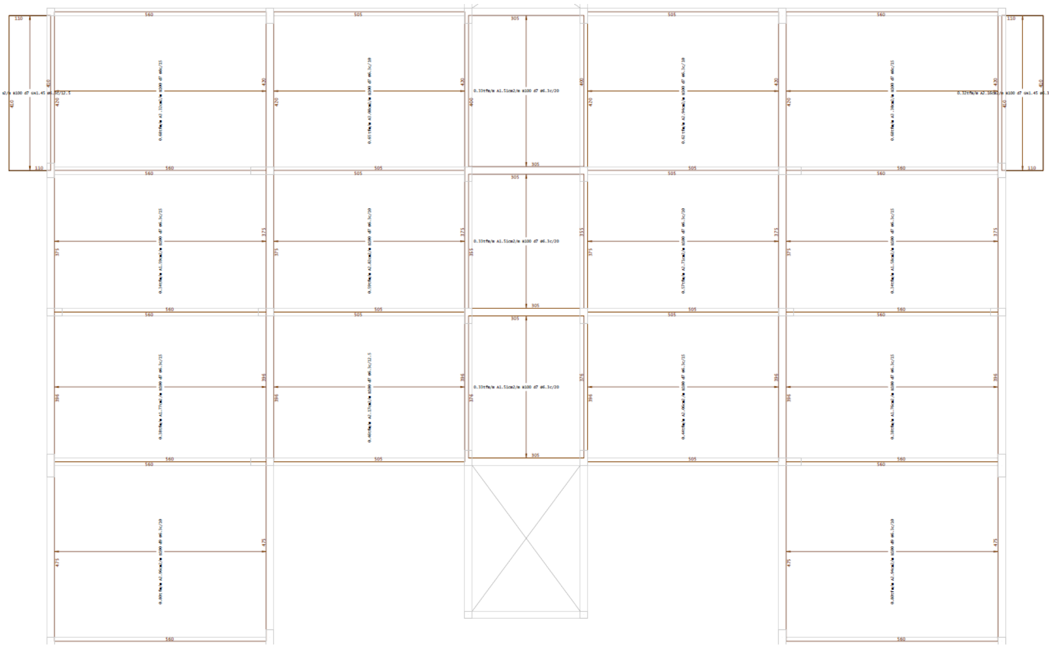
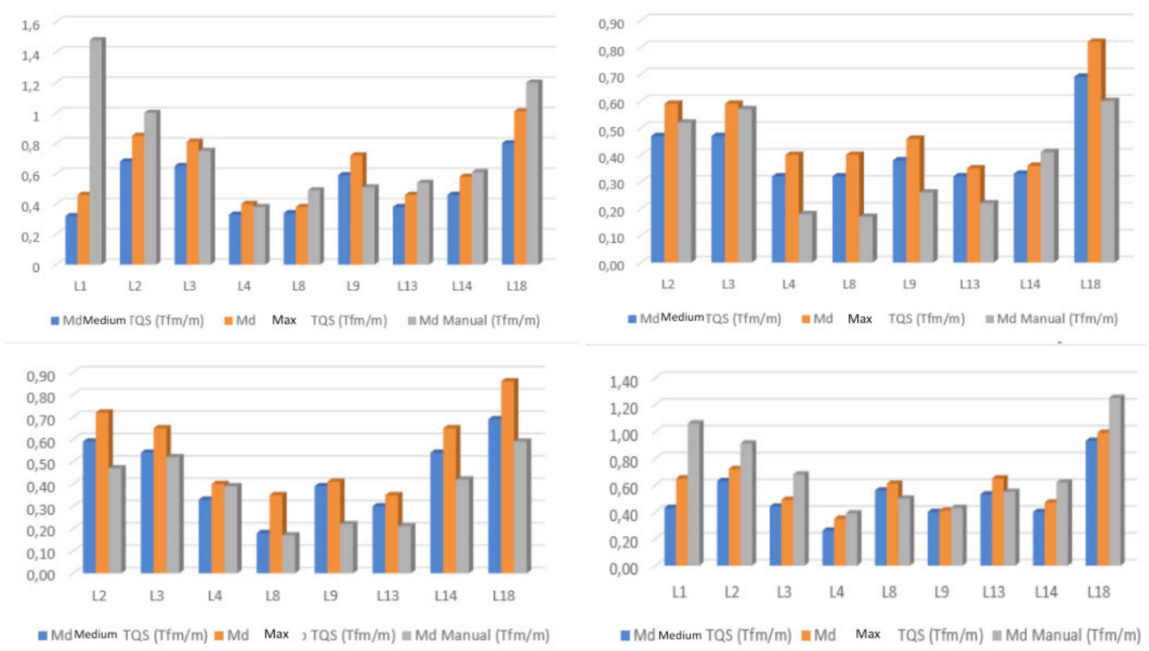


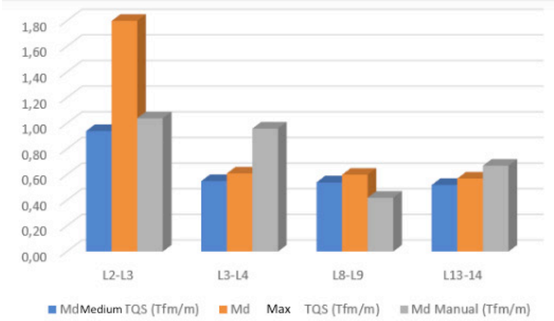
Figure 10 – TQS Bending Moment Range Diagram Viewer

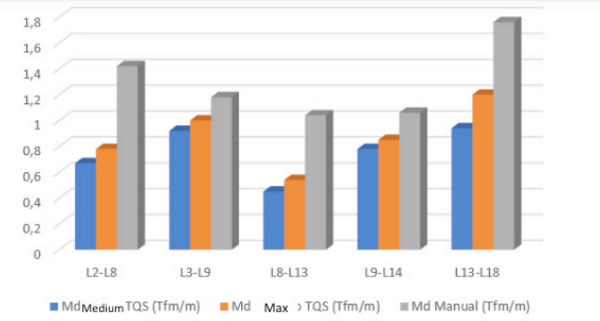
Source: Author,2020

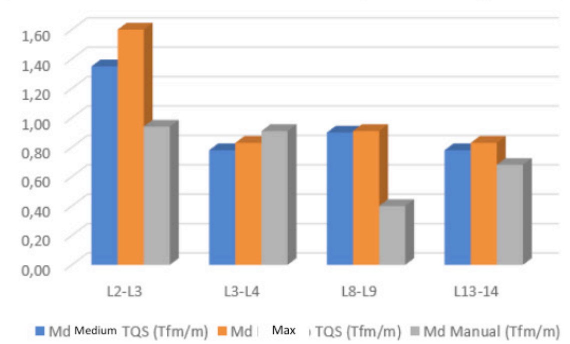


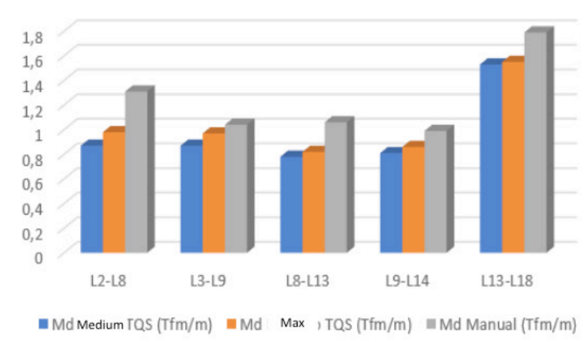
Graphic3– M. Positive Flexors at Dir. X LM and LNGráfico4– MF Positivos at Dir. Y LM and LN

Source: Author,2020









Graphic5– M. Negative Bending in the XGraphic Direction6– M. Negative Bending in the Y Direction

Source: Author,2020

Slab	Calculation ones (cm²/m)	Armor/Distribution	L Total	No. of bars
L1	4,56	Ø8.0 c/11cm	117,5	6
L2	1,90	Ø6.3 c/16cm	588,0	25
L3	2,08	Ø6.3 c/15cm	533,0	33
L4	1,40	Ø6.3 c/22cm	313,0	18
L8	1,00	Ø5.0 c/18cm	588,0	19
L9	1,00	Ø5.0 c/18cm	533,0	19
L13	1,00	Ø5.0 c/18cm	588,0	20
L14	1,49	Ø6.3 c/20cm	533,0	25

Slab	Calculation ones cm²/m)	Armor/Distribution	L Total	No. of bars
L1	2,55	Ø6.3 c/10cm	120,0	10
L2	2,59	Ø6.3 c/10cm	595,0	40
L3	2,60	Ø6.3 c/10cm	540,0	40
L4	1,51	Ø6.3 c/20cm	320,0	20
L8	1,72	Ø6.3 c/15cm	603,0	24
L9	2,07	Ø6.3 c/15cm	540,0	24
L13	1,73	Ø6.3 c/15cm	603,0	26
L14	1,78	Ø6.3 c/15cm	540,0	26
L18	2,86	Ø6.3 c/10cm	607,0	46

Slab	Calculation ones (cm²/m)	Armor/Distribution	L Total
L2	0,63	2 Ø8.0	625,0
L3	0,47	2 Ø6.3	530,0
L4	0,27	2 Ø6.3	435,0
L8	0,35	2 Ø6.3	595,0
L9	0,30	2 Ø6.3	555,0
L13	0,60	2 Ø6.3	595,0
L14	0,60	2 Ø6.3	555,0
L18	0,87	2 Ø8.0	580,0

Slab	Calculation ones (cm²/m)	Armor/Distribution	L Total
L2	1,03	1 Ø12.5	595,0
L3	0,44	1 Ø10.0	540,0
L4	0,36	1 Ø10.0	320,0
L8	0,57	2 Ø6.3	623,0
L9	0,40	1 Ø10.0	540,0
L13	0,71	1 Ø10.0	609,0
L14	0,86	2 Ø8.0	540,0
L18	0,95	2 Ø8.0	623,0

Table 04 and 05 - Manual and TQS Dimensioning of Positive Reinforcements in the Y Direction - LM and LN

Source: Author,2020

Slab	Calculation ones (cm²/m)	Armor/Distribution	L Total	No. of bars
L2-L3	3,62	Ø8.0 c/13cm	302,0	30
L3-L4	3,31	Ø8.0 c/15cm	274,5	26
L8-L9	1,50	Ø6.3 c/20cm	302,0	17
L13-14	2,25	Ø6.3 c/13cm	302,0	28

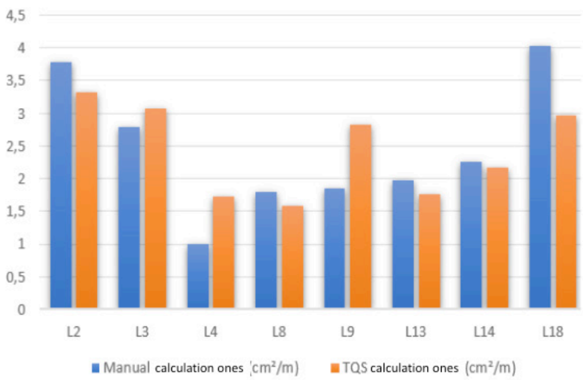
Slab	Calculation ones (cm²/m)	Armor/Distribution	L Total	No. of bars
L2-L3	4,78	Ø10.0 c/14.8cm	260,0	27
L3-L4	2,62	Ø6.3 c/10cm	225,0	40
L8-L9	2,53	Ø6.3 c/9.9cm	280,0	36
L13-14	2,46	Ø6.3 c/12.1cm	270,0	22

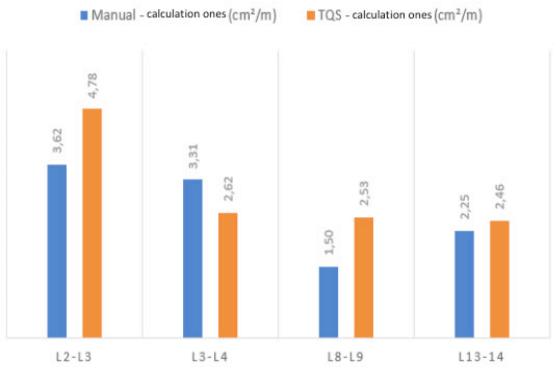
Slab	Calculation ones (cm²/m)	Armor/Distribution	L Total
L1	0,22	2 Ø6.3	430,0
L2	0,33	2 Ø6.3	435,0
L3	0,60	2 Ø6.3	435,0
L4	0,12	2 Ø6.3	335,0
L8	0,12	2 Ø6.3	405,0
L9	0,15	2 Ø6.3	405,0
L13	0,15	2 Ø6.3	425,0
L14	0,29	2 Ø6.3	410,0
L18	0,41	2 Ø6.3	490,0

Slab	Calculation ones cm²/m)	Armor/Distribution	L Total
L1	0,30	2 Ø6.3	450,0
L2	0,55	2 Ø6.3	450,0
L3	0,97	2 Ø8.0	450,0
L4	0,33	1 Ø8.0	320,0
L8	0,33	1 Ø8.0	390,0
L9	0,37	1 Ø8.0	390,0
L13	0,33	1 Ø8.0	411,0
L14	0,51	1 Ø8.0	426,0
L18	0,66	1 Ø10.0	505,0

Table 06 and 07 - Manual and TQS Dimensioning of Positive Reinforcements in X Direction - LM and LN

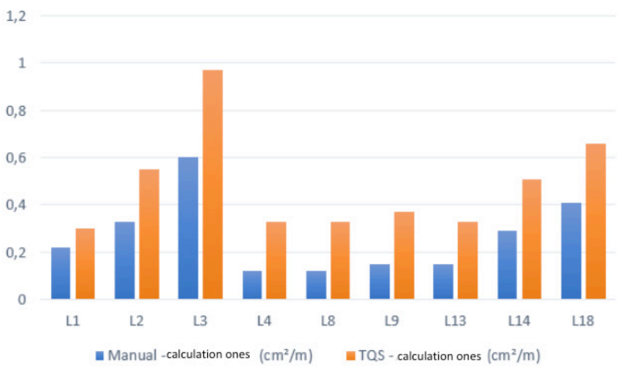
Source: Author,2020





Graph 7 – P. das Lajes Steel Areas in Dir. Y | Graph 8 – Negative Steel Areas of Lajes in Dir. X

Source: Author,2020



Graph 9 - Relation of the Steel Areas of the Ribs in the Y Direction

Source: Author, 2020.

Slab	Calculation ones (cm²/m)	Armor/Distribution	L Total	No. of bars
L2-L8	5,12	Ø10.0 c/15cm	222,0	37
L3-L9	4,17	Ø10.0 c/12cm	222,0	42
L8-L13	3,61	Ø8.0 c/13cm	210,1	43
L9-L14	3,70	Ø8.0 c/13cm	210,1	38
L13-L18	6,55	Ø10.0 c/13cm	250,0	43

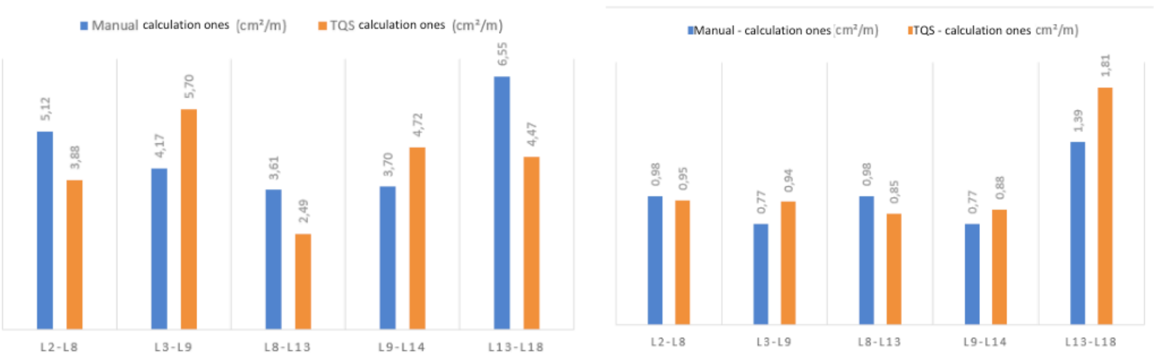
Slab	Calculation ones (cm²/m)	Armor/Distribution	L Total	No. of bars
L2-L8	3,88	Ø8.0 c/12.5cm	230,0	42
L3-L9	5,70	Ø10.0 c/12.3cm	235,0	41
L8-L13	2,49	Ø6.3 c/12,2cm	180,0	46
L9-L14	4,72	Ø10.0 c/14.9cm	235,0	34
L13-L18	4,47	Ø10.0 c/17.5cm	260,0	32

Slab	Calculation ones (cm²/m)	Armor/Distribution	L Total	No. of bars
L2-L8	0,98	Ø6.3 c/15cm	260,0	37
L3-L9	0,77	Ø6.3 c/20cm	260,0	25
L8-L13	0,98	Ø6.3 c/15cm	250,0	37
L9-L14	0,77	Ø6.3 c/20cm	250,0	25
L13-L18	1,39	Ø6.3 c/21cm	290,0	50

Slab	Calculation ones (cm²/m)	Armor/Distribution	L Total	No. of bars
L2-L8	0,95	Ø6.3 c/20cm	275,0	28
L3-L9	0,94	Ø6.3 c/19.4cm	255,0	26
L8-L13	0,85	Ø6.3 c/20cm	215,0	28
L9-L14	0,88	Ø6.3 c/19.4cm	205,0	26
L13-L18	1,81	Ø6.3 c/10cm	285,0	56

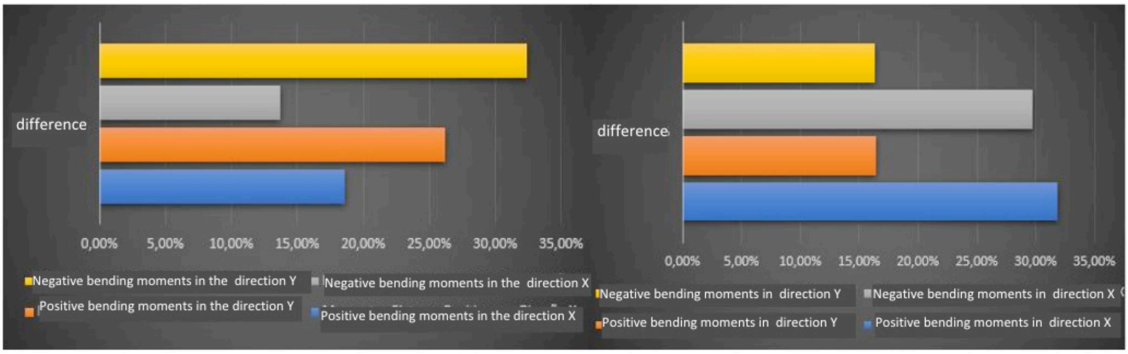
Table 08 and 09 - Manual and TQS Dimensioning of Negative Reinforcements in the Y Direction - LM and LN

Source: Author,2020



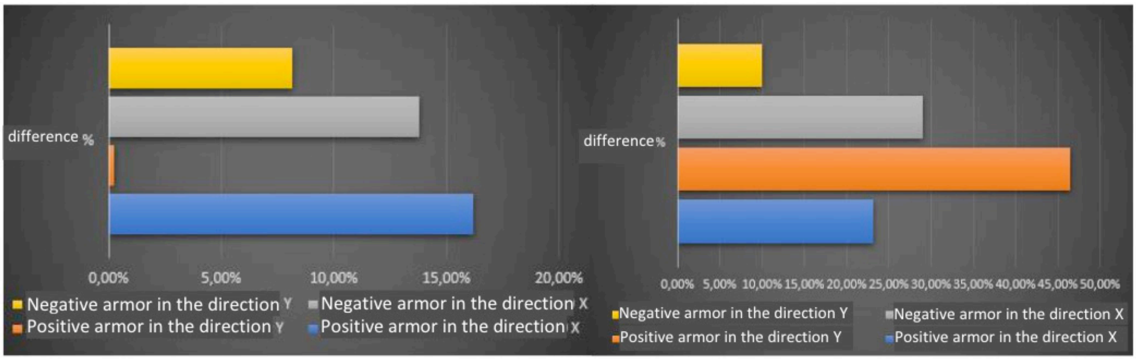
Graphic7– List of Negative Steel Areas of Slabs in the Y Direction – LM and LN

Source: Author,2020



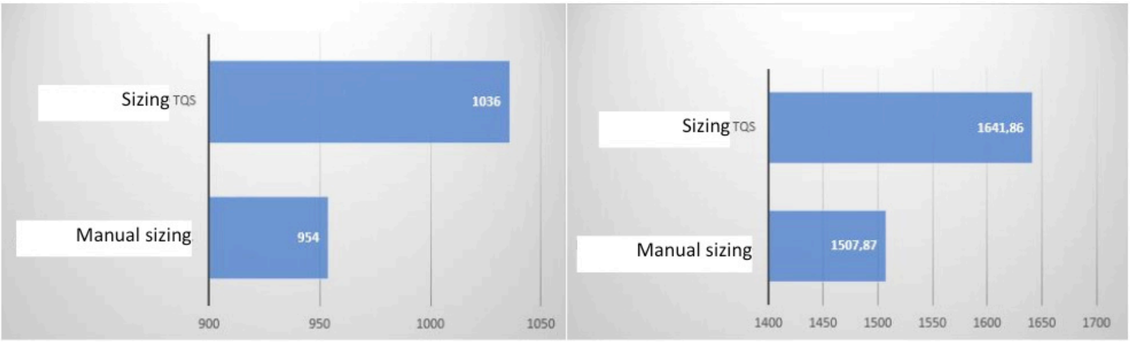
Graph 11 - Difference Between the Bending Moments of Calculation Solid and Ribbed Slabs

Source: Author,2020



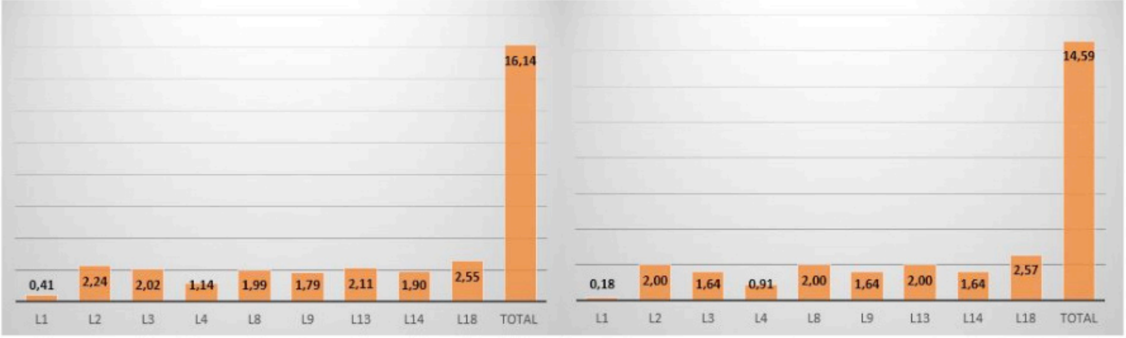
Graph 12 - Difference Between Steel Areas of Solid and Ribbed Slabs

Source: Author,2020



Graph 13 - Steel Consumption of Solid and Ribbed Slabs (Kgf)

Source: Author,2020



Graph 14 - Consumption of Concrete (m^3) Solid and Ribbed Slabs

Source: Author,2020

FINAL CONSIDERATIONS

Throughout this study, the handling of a software for the elaboration of a structural project was researched. Having in mind that, over the years several methods were developed for the design of structures in reinforced concrete. And with this technological evolution, the performance became more refined. The spread of software marks the construction industry, that is, the technologies applied in engineering works.

Regarding the methodology employed, in the verification phase of the service limit state, comparing the manual values of the slabs with TQS, the results obtained were relatively similar. A major difference was observed in the limit deflection, i.e., the admissible deflection. In the behavior of L1, because where there is discontinuity in the level of the elements in its adjacency, TQS redoes the grid values, the consideration and flexibilization at these points becomes more divergent.

Evaluating the slabs' grids generated in TQS, it is possible to verify the interaction of displacements well correlated to the manual calculation, the smaller detachments presented in the ribbed slabs compared to the solid slabs - this is due to the equivalence stiffness of the heights and weight of the slabs.

When considering the rigid body balance of the structural devices, dealing more specifically with the design bending moments, the manual design of the slabs showed mostly some higher points. Smaller values of the ribbed slabs, but the higher moment range of the TQS grids stood out mainly due to the interactive analysis integrated in the software.

Most of the calculated steel areas of the solid slabs according to TQS detailing showed a higher ratio in both positive and negative reinforcement. In the ribbed slabs TQS showed superiority in the positive reinforcement, and in the negative reinforcement the manual calculation - based on the adopted theory - showed high values compared to the computational analysis. In general, there is little variation in these results, but as these are values whose minimal variation can cause different details due to these differences, the spacing of the reinforcement along with the total lengths and types of anchorage used varied in all cross-sectional details. Not very far from what the solution of the structural elements presents, but values where they represent significant economic and beneficial actions to the structures.

In view of this, the study provided knowledge in the structural area in addition to the scientific technical teachings, learning to handle software for structural engineering and geotechnics, led to: the learning of more specific concepts of the behavior of structures through a spatial and integrated analysis, the relevance of considerations related to structural connections and links, and the search for professionals with experience to launch and analyze the behavior of a more complex structure, enabling interactivity with engineers who are references in the area of structures and contributing to the knowledge and performance of the work introduced.

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