PAVPLUS SYSTEM

THE EVOLUTION OF FLAT SLAB AND WAFFLE SLAB

BEST PRACTICES GUIDELINES

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TITLE
PAVPLUS SYSTEM
BEST PRACTICES GUIDELINES

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SUMMARY

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1. INTRODUCTION

The post-tensioning system applied to residential and commercial buildings in Brazil has gained great prominence in just over 20 years. Mainly when the system, previously almost completely restricted to bridge constructions, was applied to conventional buildings.

In 1996, Impacto was founded and began work aimed at disseminating the unbonded post-tensioning in buildings, present in the United States since 1960. As a result, buildings with post-tensioned slabs that are 35% thinner and beams that are 50% smaller began to be developed when compared to the conventional system of reinforced concrete.

In 1997, the first commercial building using unbonded post-tensioning was built in the city of Fortaleza, Figure 1. The result of a partnership between Impacto and the steel company ArcelorMittal.

Figure 1 - 1st Work in Brazil using non-adherent prestressing - Torre Santos Dumont, 1997

Brazilian civil construction, despite being one of the largest construction markets in Latin America, is historically known for its unskilled labor and outdated construction methods, which create major obstacles to the implementation of new technologies. Thus, dissatisfied with the low efficiency of construction processes and the low use of new technologies, inspired by LEGO® buildable toys, Impacto developed reusable plastic moulds, with standardized dimensions that are easily fitted into modular metallic structures. This modularized system replaces up to 80% of improvised wooden structures, which is a very

expensive job, without assembly standards, which generates extreme waste of materials and requires more specialized labor.

"Productivity is not the responsibility of the labor, but of its processes" (CARACAS, Joaquim)

In this sense, Impacto began to offer an integrated solution to the construction companies, offering multiple products such as scaffolding, plastic formwork and post-tensioning services.

After 21 years of the foundation of the company, the Brazilian market was immersed in one of the biggest financial crises in its history, with the construction sector as one of the pivots of this scenario, in the strategic scope, aiming to expand its operations in the market and thinking in the long term, Impacto concentrated its efforts in this stagnant period to develop a new disruptive system, and it was there, that in the year 2017, a type of slab was developed that correlates concepts of post-tensioned flat slabs and post-tensioned ribbed slabs, the PavPlus system.

When you want to save on the structure, the following question comes: what would be the structure of an ideal slab?

1) Is it the one that save concrete and rebar?
2) Is it the one that save labor?

When you think of a material economy, the answer would be to use the ribbed slab system, as it saves around 40-50% of concrete, relieves the weight of the structure itself, consequently, saves on rebar.

But the moment you wanted productivity, you migrated to the post-tensioned flat slabs, welded steel mesh of minimal rebar and with cables concentrated in one direction and distributed in the other.

Considering that around 50% of the cost of a structure is formwork and labor, the whole concept of the flat slab was transported to the ribbed slab, forming the PavPlus System, from there the calculation of the ribbed slab began to be calculated all as a flat slab.

So, this new slab system, the PavPlus system, combined the   lower concrete consumption and higher productivity, previously seen in ribbed systems and flat slabs respectively, in a single structural system industrializing the system of formworks, shorings and post-tensioning.

This material aims to present the construction system and project guidelines of PavPlus. For this, the material is presented in Six parts: (1) Characteristics of the system; (2)

Construction processes; (3) Pre-sdimensioning processes; (4) modeling, (5) analysis and detailing, linked to the NBR 6118/2014 standard using the commercial *software* TQS and ADAPT covering most of the processes linked to this construction system; And finally, (6) presentations of designs of a work using the system.

2. UNBONDED POST-TENSIONED SLABS

2.1 History

Giordano, 2013, points out that the use of post-tensioned slabs with unbonded tendons have been used in the United States, especially in California, since the 50's. In Brazil, it was only in 1997, with the production of greased and plasticized tendons by Belgo Mineira and in 1998 with the partnership Impacto and ArcelorMittal, that the post-tensioned slabs gained representation in the Brazilian construction of buildings.

Giordano, 2013, also addresses that the guidelines used by designers during the years 1997 to 2004 were in function of the American standards of the ACI – American Concrete Institute and the recommendations of the PTI Post-Tensioning Institut and, because NBR 6118/2003 only allowed the use of greased tendons with full post-tensioning, making it impossible to use the slabs in economic aspects. However, with the revision of NBR 6118 in 2014, the use of limited post-tensioning for flat slabs and other points, which made the use of post-tension standardized in several aspects, enabling its use in structural systems of buildings.

2.2 Main Advantages

2.2.1 Structural Focus

Among the main ones of the post-tensioned structure in relation to the reinforced concrete with structural point of view can be presented:

1. Overcome large spans using small thicknesses in the slabs, beams and with cracking and reduced deformations;
2. Increased in-service performance and greater endurance in the ultimate limit state;

2.2.2 Constructive Focus

One of the main constructive points of post-tensioned slabs is the possibility of designing cleaner *layouts* and a greater amount of floors, due to a more effective gain in reducing the thickness of the slabs.

In commercial and residential buildings, one of the great advantages is the reduction of the number of columns, enabling a greater number of parking spaces, a need that in recent years has become paramount for customers.

Along with this, the possibility of floors with lengths of 72 m without the use of expansion joints, due to the pre-compression forces introduced by the post-tensioning that combat the cracks of retraction of the concrete.

Post-tensioning can be presented in two types, bonded and unbonded. With a focus on productivity gain, the use of unbonded with monostrand is the best choice, due to its easier handling of monostrand and their smaller equipment, compared to the bonded system, presents several advantages when the question is productivity, example is the reduction of handling teams, enabling faster execution, with well-defined processes.

2.2.3 Economic Focus

The use of theseand system becomes an extremely competitive structural alternative with the reinforced concrete solution for spans from 6.5 m, even without considering the qualitative advantages listed above. Another point to take into consideration is its durability and service conditions, influenced by the use of higher strength concretes and a small amount of cracks, in addition to significantly reducing the consumption of passive steel, a very costly input in a structure.

In summary, the unbonded post-tensioning enables cleaner constructions that reduce the consumption of concrete, rebar and formwork, and the use of labor, resulting in material savings and higher productivity.

2.3 Impacts in Productivity and Economics

One of the costliest factors in civil construction is labor, Figure Figure 2, and in this context it is noted that productivity is directly related to the efficiency of the construction system and formwork. Reiterating the data presented in Figure 2it can be observed that until March 2020 the labor within the civil construction scenario presents a representativeness of 50% of the total costs, including all social charges, and in a survey developed in the period after March 2020 and the beginning of the year 2021, even with the relative increase in the price of steel, labor still presents a relevant part of the costs, Figure 3. These data prove that even with an increase in the prices of material inputs, labor remains a preponderant portion

of the total cost in civil construction, noting that materials are not limiting factors to save on the structure but its processes.
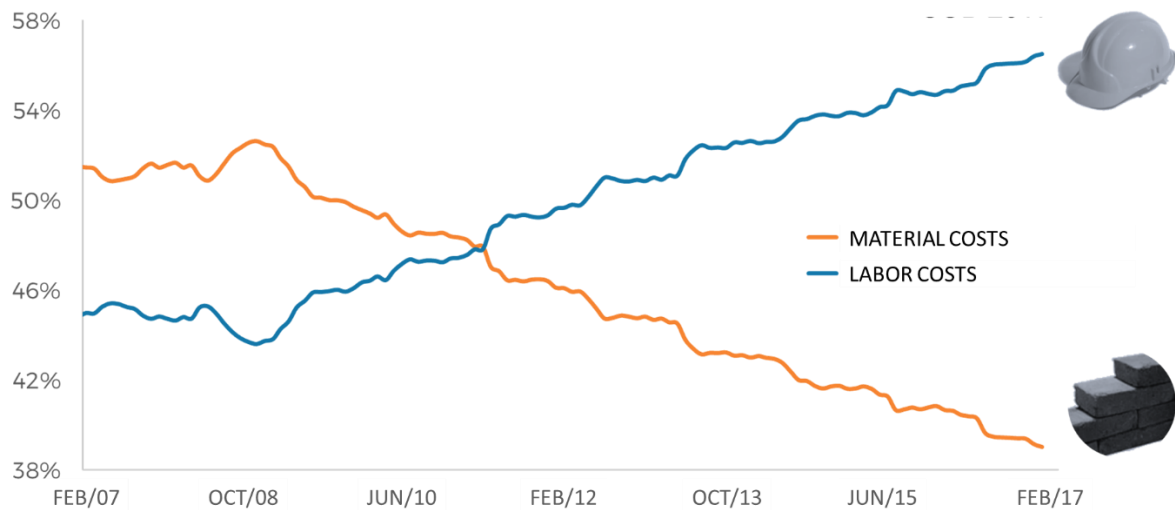
LABOR COST INDICATORS (CBIC-2017)

Figure 2 - Civil construction scenario, cost indexes. Source: CBIC-CUB 2017

Composition of costs in civil construction until March 2021

1 M³ of CONCRETE ——— R$ 300,00
100 kg of STEEL / m³ ——— R$ 700,00
LABOR + FORMWORKS ——— R$ 750,00
R$ 1750,00 / M³

± 10% CONCRETE = ± 1,72% STRUCTURE
± 10% AÇO = ± 4,00% STRUCTURE
± 5,72%

MATERIALS ARE NOT LIMITING FACTORS TO SAVE ON THE STRUCTUR, BUT ITS PROCESSES

17,15% 1 m³ CONCRETE
40,0% 100kg STEEL/m3
42,85% LABOR + FORMWORKS
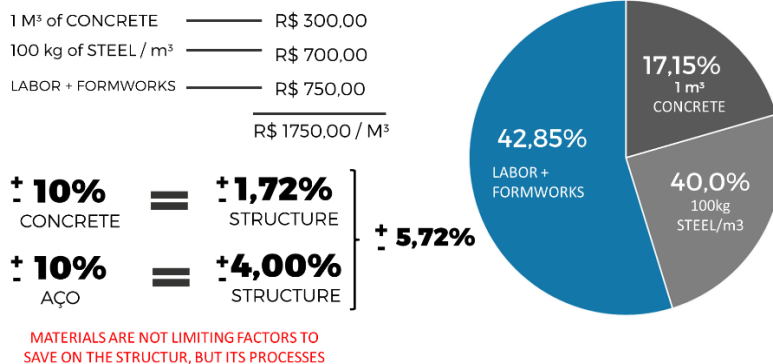
Figure 3 - Composition of costs in civil construction

Due to these economic aspects and always seeking continuous improvement focused on greater productivity and process development, Impacto, analyzing this scenario, where more than 40% of expenses are related to labor, Figure 3, developed a system of Modular formwork and schorings. Figure 4 shows the conventional system and the modularized system, which reduces the wood area on the slab by up to 93%, using less specialized labor.

Figure 4 - Formwork systems for slabs.

It is also notorious that the architectural geometry of the floors influences the economic performance of the structural system, according to the study presented in Figure 5. And the floors that privilege the ease of execution, with reduction of beams and columns, as intended by the post-tensioned and modularized systems of Impacto will obtain excellent results.

The evolution of Brazilian standards, with a more rigorous look at durability and performance has imposed minimum dimensions for the elements, which are also already incorporated into the Impacto system. It is mentioned, for example, the dimensions of the ribs and cover in ribbed slabs, where the ribs are at least 12 cm wide and the cover above ribs is at least 10 cm thick (and can count on the subfloor mortar), to meet the fire standard NBR 15200 of 2012.
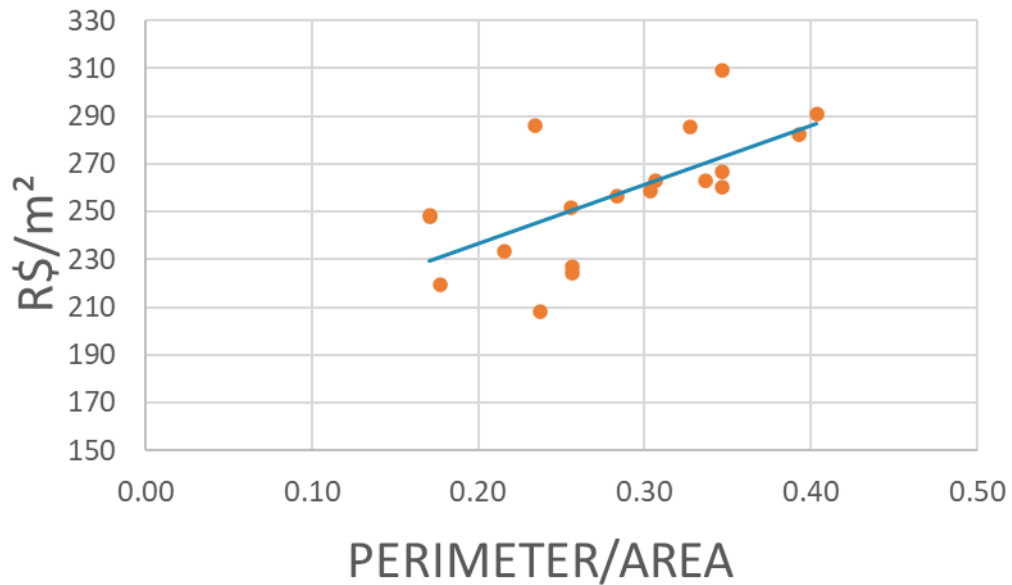
Figure 5 – Ratio perimeter/area x cost/square meter. Source: BURLAMARQUI, P.T.

2.3.1 Decisive aspects for post-tensioning and modularized system

Especially in the economic sphere, the use of post-tensioned slab systems presents a reduction in several aspects. Among these, we can highlight some points that are decisive for the choice of this structural solution.

- **More efficiency of steel in tensile combat**
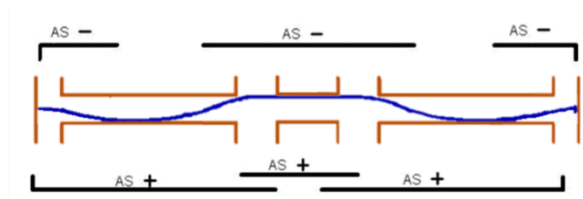
STEEL CA-50

$$RESISTANCE = \frac{5000Kgf/cm^2}{1,15} = 4348Kgf/cm^2$$

STEEL CP-190RB

$$RESISTANCE = \frac{19.000Kgf/cm^2}{FS + Lost} \triangleq 12.500Kgf/cm^2$$

RELATION CP190 x CA50

$$\frac{CP190}{CA50} = \frac{12.500Kgf}{4348Kgf} = 2,87$$

PRICE $CA50$ + M.O

$$CA50 = R\$6,00 + R\$2,50 = \mathbf{R\$8,50}$$

PRICE CP190 + M.O

$$CP190 = R\$11,00 + R\$6,00 = \mathbf{R\$17,00}$$

EFFICIENCY CP190 x CA50

$$CP190 = 2,87 * CA50$$
$$2,87 * R\$8,50 = \mathbf{R\$24,40}$$

R\$17,00 vs R\$24,40

$$= \mathbf{43,53\%}$$

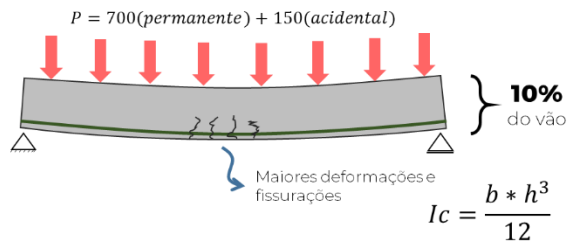POST-TENSIONING STRUCTURE CREATES 43.53% SAVINGS IN THE VALUE OF STEEL

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- **Minor deformations**

COM PROTENSÃO, PEÇAS MAIS ESBELTAS PARA OS MESMOS VÃOS

$$D = k * q * \frac{L^4}{E * I}$$

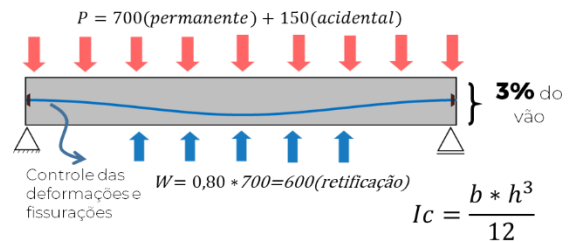HOJE, COM AS NOVAS NORMAS, A DEFORMAÇÃO DE LAJE COM ALVENARIA É LIMITADA A **10mm**, ENQUANTO **ANTES**, ERA **L/300**

VIGA DE CONCRETO ARMADO
(TRABALHA FISSURADO – ESTÁDIO II)

$P = 700(permanente) + 150(acidental)$

10% do vão

Maiores deformações e fissurações

$$Ic = \frac{b * h^3}{12}$$

$$I = 70\% * Ic \rightarrow$$ *Perda da Inércia por fissuração*

$$Di > 0 \quad Df = 5 * Di \rightarrow$$ *Se Di for após retirar escoras com 28 dias*

VIGA DE CONCRETO PROTENDIDO
(TRABALHA COMPRIMIDO)

$P = 700(permanente) + 150(acidental)$

3% do vão

Controle das deformações e fissurações

$W = 0,80 * 700 = 600 (retificação)$

$$Ic = \frac{b * h^3}{12}$$

$$I = 100\% * Ic \rightarrow ACI\ 318$$

$$Di \approx 0 \quad Df = 2 * Di$$

- **Less formworks, shorings and labor**

CP ALÉM DE COMBATER A TRAÇÃO, AGREGA ECONOMIAS RELACIONADAS COM MÃO DE OBRA, FÔRMA E ESCORAMENTO

VIGAS ALTAS

Índice de Forma $= 1,80\% * m^2/m^2$

Plano de Escoramento
$= 100\% - 70\% - 50\% - 50\%$ (28 dias)

VIGAS FAIXAS / LAJES LISAS

36% ↓ Índice de fôrma $= 1,15\% * m^2/m^2$

Plano de Escoramento
$= 100\% - 50\% - 30\%$ (Sem limite de dias)

In addition to lighter structures and with less amount rebar.

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2.3.2 Impacts of the PavPlus System as a function of productivity

When compared to other modularized slab systems, the PavPlus system presents a gain in cost and productivity. This can be seen by observing the Ranking of Productivity developed by Impacto.

In this ranking is presented the R$ / m2 of labor of the works. The data is provided directly by the builders of each project, providing information regarding the slab cycle, floor area, number of labors and their functions working directly on the pavement.

Until the edition of this material the productivity ranking that can be obtained on the Impacto Protensão website (link: http://rankingdaprodutividade.com.br/) presents the works with the PavPlus system being champions and occupying the seven best classified as to the price per square meter of labor. Table **Erro! Autoreferência de indicador não válida.** presents the results of the Productivity Ranking of the works executed with the systems provided by Impacto, all modularized. In the Ranking it can be observed that the PavPlus system occupies the first positions regarding the cost per square meter of labor.

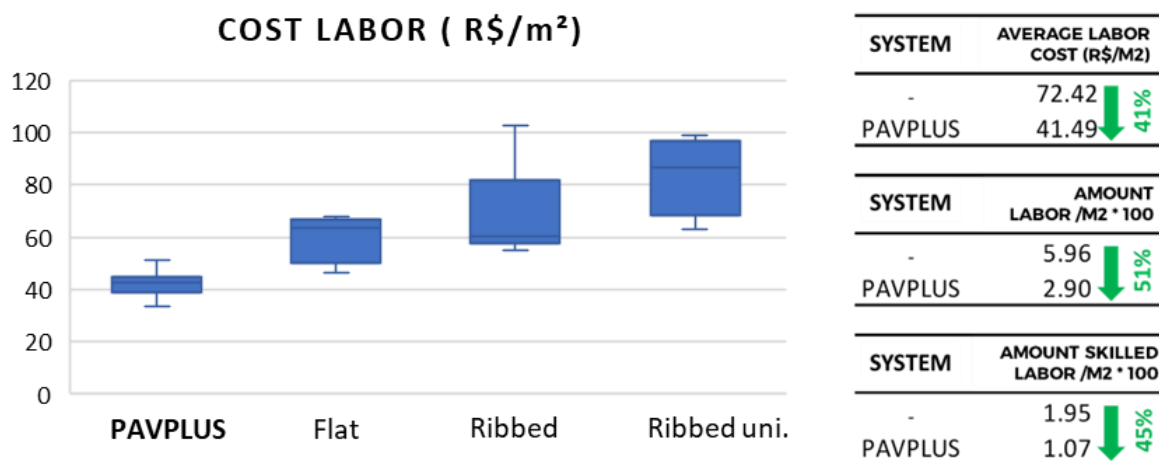**Tabela 1 - Ranking Produtividade. Fonte: Impacto Protensão**

POSITION	SYSTEM	Nº FLOORS	AREA (M²)	DAYS	QTY LABOR	QTY REBAR LABOR	COST (R$/M²)
1	PAVPLUS	2	837.79	10	18	6	24.54
2	PAVPLUS	13	379.49	5	17	5.5	27.08
3	PAVPLUS	12	462.48	10	12	5.5	33.77
4	PAVPLUS	13	392.03	9	13	6.5	36.04
5	PAVPLUS	1	951	28	12	3	38.74
6	PAVPLUS	1	951	28	12	3	39.7
7	PAVPLUS	13	348.53	5	24	9.5	41.14
8	-	1	485.99	6	30	9.5	43.4
9	-	3	1605.51	21	30	6.5	44.2
10	-	1	576.91	8	29	8.5	46.53
11	PAVPLUS	4	731.63	7	43	16.5	49.26
12	-	1	768.24	12	29	6.5	51.4
13	-	11	731.7	12	30.5	11.25	55.05
14	-	20	622.66	12	26.5	10.25	60.05
15	-	4	469.61	10	26	9.5	62.51
16	-	7	288.6	6	26	7.5	63.85
17	-	14	411.45	11	20	6.5	64.06

18	-	3	236.06	8	20	7.5	79.23
19	*PAVPLUS*	1	1426.46	29	37	14	83.16
20	-	21	519.95	7	51	18.5	83.19
21	-	11	668.5	10	55	21.5	90.18
22	-	13	482.84	10	37	11.5	90.73
23	-	2	371.96	14	21	7.5	92.38
24	-	30	906.85	10	80	26.5	95.89
25	-	28	600.97	10	55	15.5	102.05
26	-	23	512.15	11	45	15.5	106.44

Based on these data,Figure 66 jobsites, their costs and the system adopted. From this diagram it is noted that the works using the PavPlus system are the most economical when compared to the others using the other types of slab systems. In this diagram is represented the variation of the data contained in the ranking by means of quartiles indicating where 50% of the most probable values are located, the median and the extreme values presented in the ranking for each types of slabs. In addition to presenting comparisons with the data in Until the edition of this material the productivity ranking that can be obtained on the Impacto Protensão website (link: http://rankingdaprodutividade.com.br/) presents the works with the PavPlus system being champions and occupying the seven best classified as to the price per square meter of labor. Table **Erro! Autoreferência de indicador não válida.** presents the results of the Productivity Ranking of the works executed with the systems provided by Impacto, all modularized. In the Ranking it can be observed that the PavPlus system occupies the first positions regarding the cost per square meter of labor.

Tabela 1system and the other systems used in the jobsites, Figure Figure 6showing a preponderant economy when using PavPlus. It is worth mentioning that the comparisons are between modularized systems of Impacto, which already proves a great economy in relation to the conventional non-modularized system.

SYSTEM	AVERAGE LABOR COST (R$/M2)	
-	72.42	41%
PAVPLUS	41.49	

SYSTEM	AMOUNT LABOR /M2 * 100	
-	5.96	51%
PAVPLUS	2.90	

SYSTEM	AMOUNT SKILLED LABOR /M2 * 100	
-	1.95	45%
PAVPLUS	1.07	

Figure 6 - Box diagram of post-tensioned slab systems according to the Productivity Ranking of Impacto Protension.

Over five years more than 300 jobsites were developed using the PavPlus system throughout Brazil. This amount of works in a short period highlights the acceptance of the system by builders and designers, Figure 7.

Figure 7 - Survey of Jobsites over the last five years using the PavPlus system.

3. PAVPLUS SYSTEM

Combining the Flat Slab concept of adopting a structure easy to be executed in massive slabs without beams, and the concept of ribbed slabs, so used in Brazil due to the undeniable reduction of materials (concrete and rebar), Impacto developed a structural system without beams, but with the use of waffle mould in delimited regions of positive moments. The whole system is based on a modularization concept, further implementing the productivity aspect observed in the post-tensioned flat slab system.
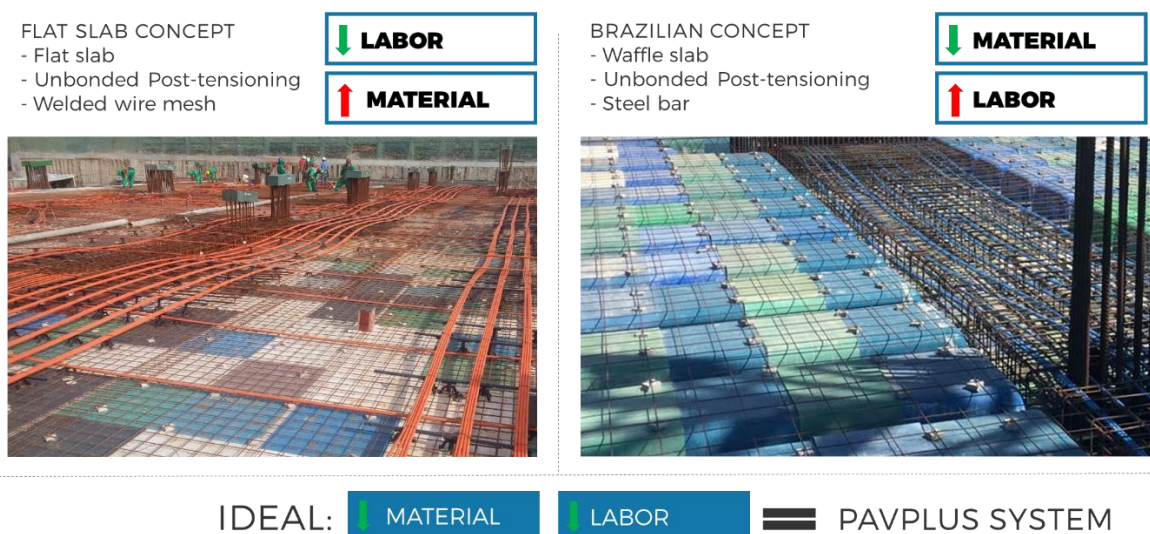

Figure 8 – Post-tensioned slabs.

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The PavPlus system unifies in a structural solution the main advantages of the post-tensioned flat slab, enabling a faster assembly process and increasing productivity, with the economic gain of concrete and rebar of the ribbed slab, as mentioned above.

Aiming at greater efficiency in all structural elements, and using a concept of modularization in all phases of the construction of a slab, it makes the process easier and minimizes the requirement of a specialized workforce, in order to reduce labor costs.

When compared to the post-tensioned flat slab, the PavPlus system presents a gain in the material cost for the removal of concrete and steel in the ribbed region. To achieve the productivity of the flat slab concept, it was developed together with ArcelorMittal a machine to make modularized steel mesh with customization of gauges and variation of meshes to meet the ribbed slabs, because until then, in Brazil there were only screens with meshes of 10x10cm, 15x15cm, etc., and cannot be used as a positive and negative armor screen in ribbed slabs, adding the use of Impacto's modular formwork and scaffolding system.

When compared to the conventional ribbed system, the PavPlus reduces the material cost by the use of concentrated regions of cables and dispenses with the use of banded beams with stirrups, in addition to not requiring the use of rebar above ribs and its positive ribbing reinforcement can be used by loose rebars or modular steel mesh, FigurE 9.
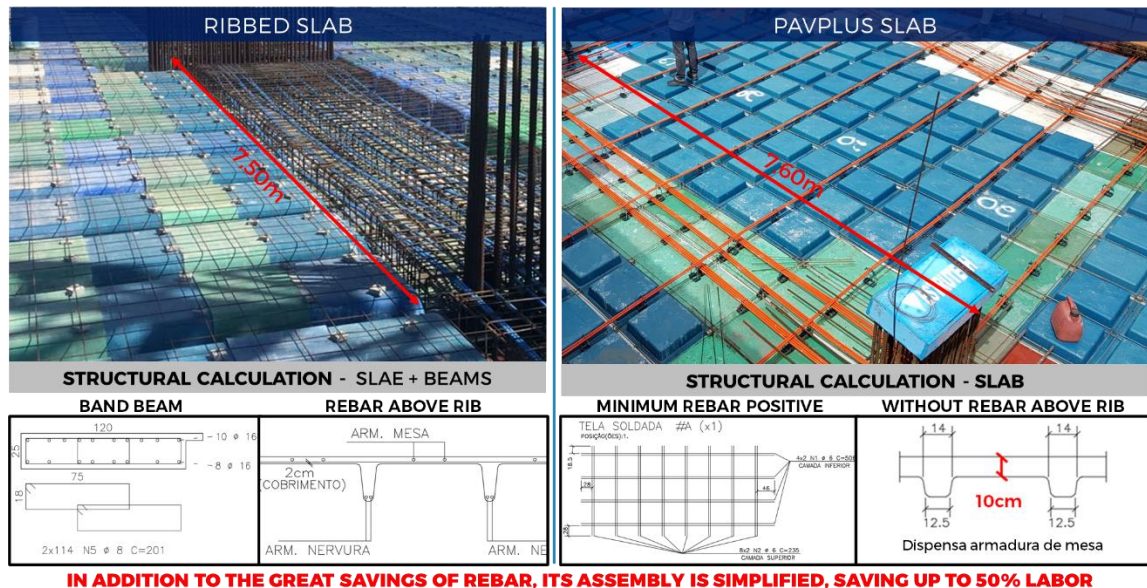

FigurE 9 – Comparison between the conventional ribbed system and the PavPlus.

Pavplus' Formwork Design uses a combination of Plasterit, which is the flat mould, with the waffle mould. The system is all modularized, multiple of 61 cmx61 cm, with the possibility

of adjustment on the edges of the slab, so the entire floor must follow the modulation in order to increase productivity and reduce the use of wood, Figure 10.
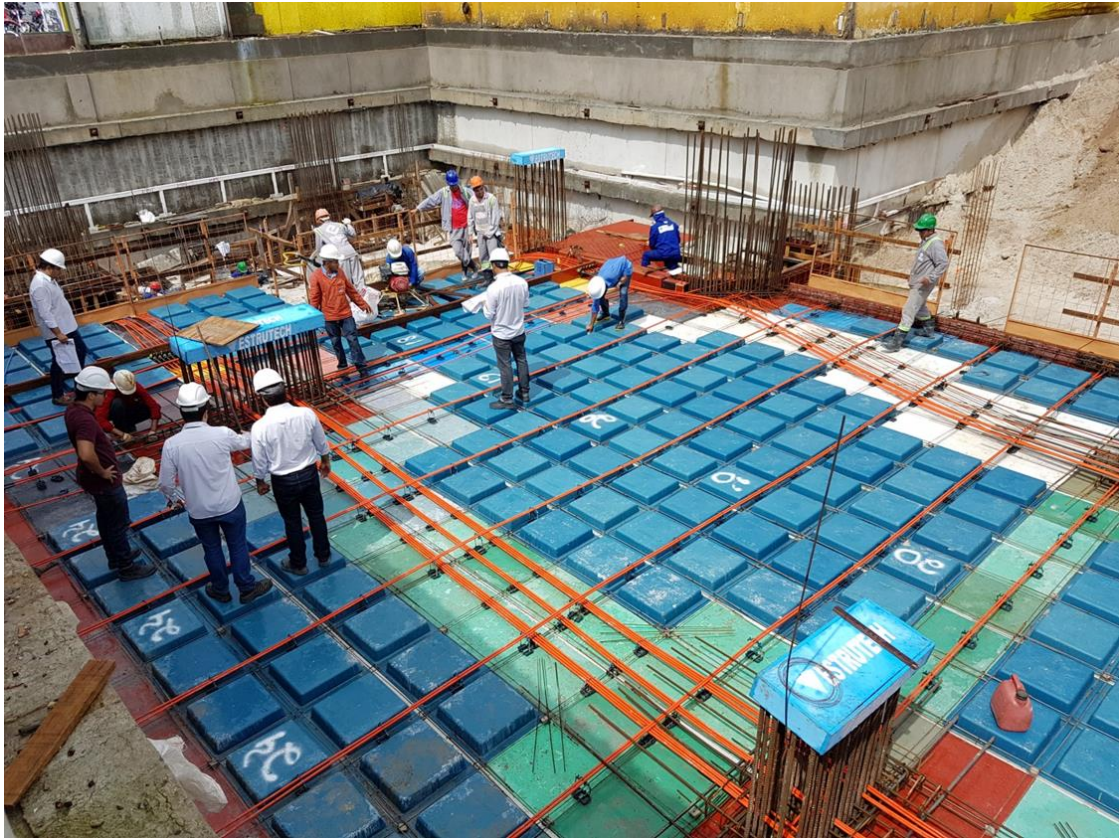

Figure 10 - PavPlus System. Source: Folder PavPlus Impacto

The Figure 11 show that the PavPlus System which allied to the modularized system (formwork, rebar and post-tensioning), easily achieve the highest degree of productivity and savings of material and labor in a structure.

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Figure 11 - PavPlus System, the modularized system. Source: Impacto

The PavPlus system is based on a ribbed slab system with massive regions over the supports. These systems can be used in expressive spans and enable an economy in the consumption of concrete, due to the use of ribs and only regions with concentrated tendons with massive stretches, this causes a reduction in the volume of concrete in the slab and with this, a reduction of its own weight. The massive regions are concentrated in and around the columns and are responsible for resisting the negative moments and effects of punchings on the supports.

In the system with the regions of massive regions, the post-tension is with concentrated tendons in one or two directions of the slab. This refers to a post-tensioning system most often with tendons concentrated in one direction and distributed in the other, increasing the efficiency of the post-tension in the system. When necessary, the concentration of post-tension in both directions is used.

The PTI recommends a ratio of thickness in the slabs for the case of continuous spans of L/h=35 and L/h=40, respectively for conventional floors; and in the case of a single span L/h=30 and L/h=35, respectively for conventional floors (Giordano, 2013).

3.1 Particularities of the PavPlus System

As mentioned above, the PavPlus system is based on the ideas of using ribbed slabs with massive bands and has some particularities regarding its executive and structural design standards, which may vary according to architectural projects.

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The system consists of: plastic molds in the form of waffle mold and flat molds, unbonded post-tensioning tendon elevations defined by Caderix, modularized welded steel mesh fabric to compose the passive reinforcement and horizontal shoring for assembly of the formwork and modularization of the system, Figure Figure 12.
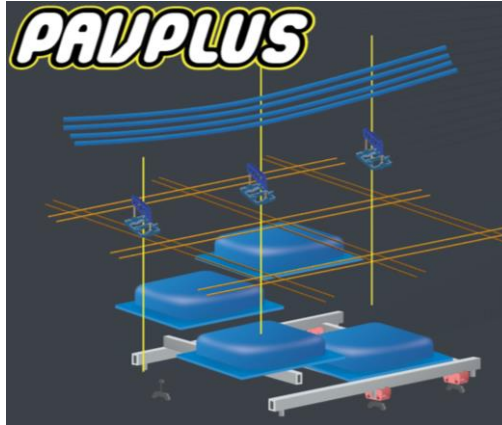

Figure 12 - Representative schematic of the parts of the PavPlus system. Source: Impacto Protension.

3.1.1 Plastic formwork

The plastic formworks in the form of waffle mold have dimensions of 61 cm x 61 cm, as well as the flat mold (Plasterit). Another factor of great relevance is the geometry of the rib that fit perfectly in the horizontal shoring, facilitating its assembly. For ribbed regions, waffle mold is used and for flat regions, Plasterit is used.

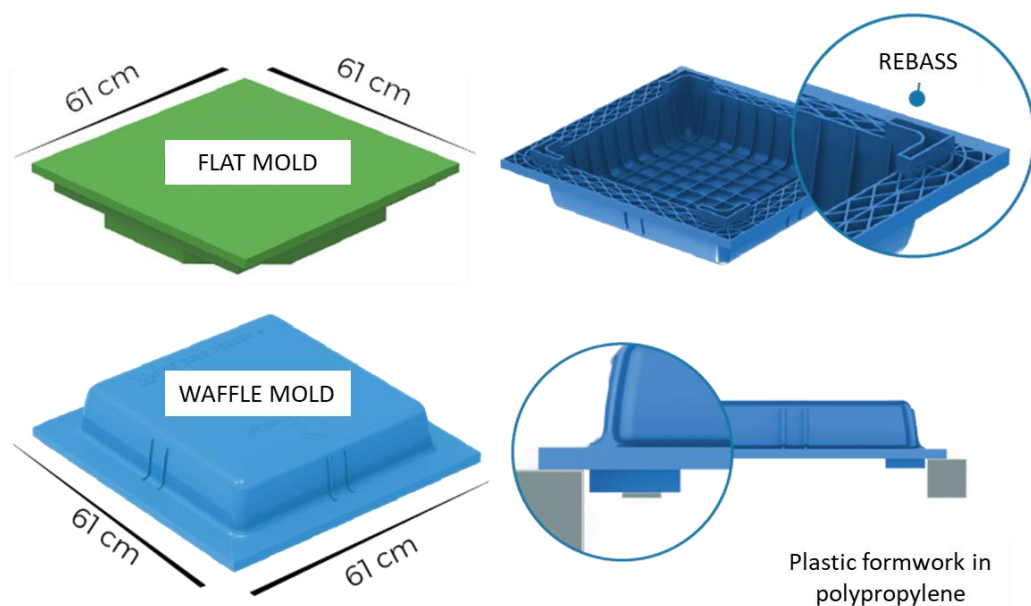Figure 13in the horizontal shoring, avoiding accidents and assembly errors.

Figure 13 – Waffle Mold and Plasterits. Source: Folder PavPlus Impacto.

The formwork has technical specifications that are presented in Table

. And the rib geometry is represented by a schematic cut in Figure Figure 14.

H = Molds's height	hm = Blade thickness	ht = Total height	Ac = Section Area
Ycg = C.G's height t the bottom face	bi = inferior	bm = mid	bs = superior

Table 2 - Technical Specifications PavPlus Formwork. Source: Impacto

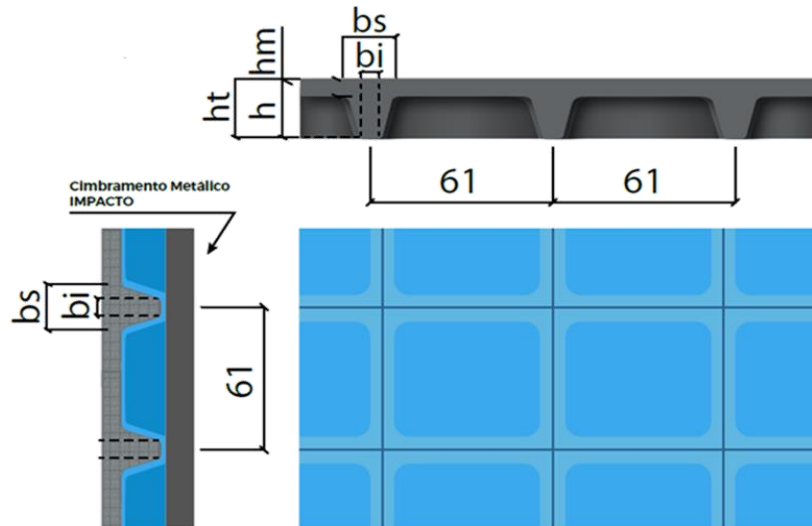| H	hm	ht	Ac	Ycg	Rib width			Inertia Equivalent	Concrete consumption equivalent	Weight
					bi	bm	bs			
(cm)	(cm)	(cm)	(cm²)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(Kg/m²)
10	10	20	750	13.2	12.5	14	15.5	15.0	14.1	352
	12	22	872	14.3	12.5	14	15.5	16.7	16.1	402
15	10	25	835	16.7	12.5	15	17.5	18.7	16.5	412
	12	27	957	17.9	12.5	15	17.5	20.3	18.5	462
20	10	30	930	20.1	12.5	16	19.5	22.6	19.1	477
	12	32	1052	21.4	12.5	16	19.5	24.1	21.1	527

Obs: Table for slabs only.

Figure 14 -Geometry of the slab

The use of the waffle mold provides greater rigidity to the slab than in conventional systems. With ribs of 10 cm in height, the PavPlus slab with 20 cm has a consumption similar to a massive slab of 14 cm and with inertia equivalent to a massive slab of 15 cm.
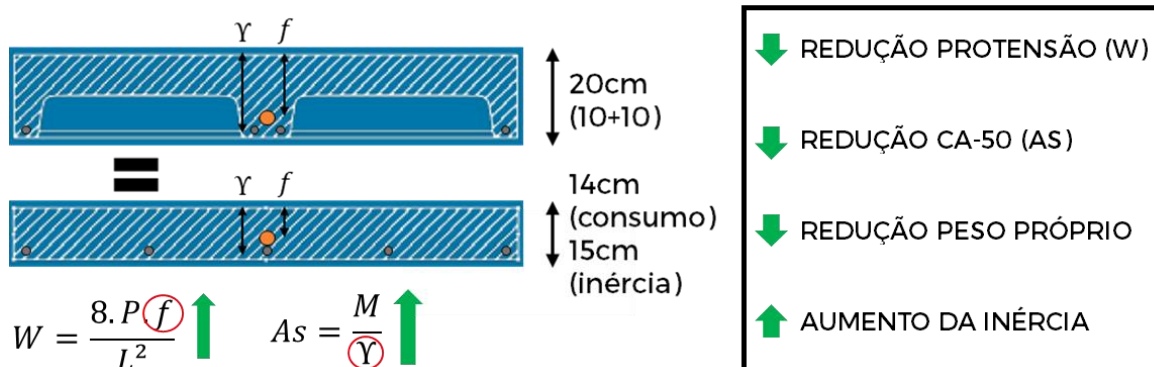

Figure 15 - Equivalence and comparisons between the ribbed system and massive slabs.

3.1.2 Welded steel mesh

The PavPlus system was designed for greater material efficiency and, in general, the passive rib reinforcements are the minimum provided for by standard, due to the post-tensioning efforts applied to the pavement. In addition, there is the offer of specific screens for this system, with appropriate modulations that greatly facilitate the assembly.

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Figure 16an example of a project in which the passive reinforcement demanded was the minimum inboth directions, and was designed using welded steel mesh specific to this system.
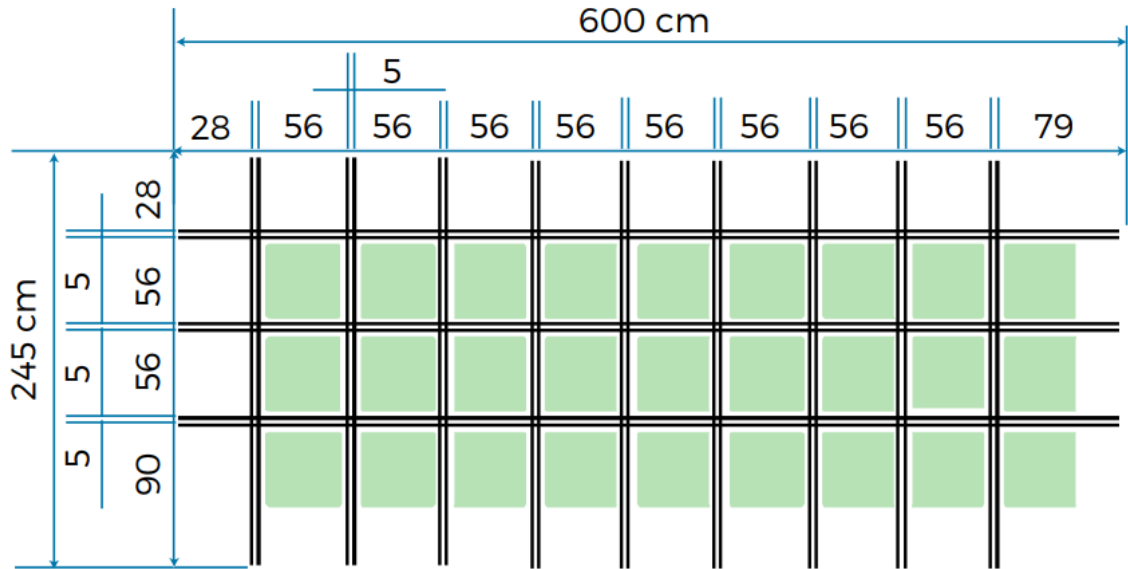

Figure 16 - PavPlus Steel Mesh Details

Figure

case in which the rebar is in the ribs.

Figure 17 - Practical application of the minimum reinforcement in the ribs

Based on item 17.3.5.2.1 and Table 19.1 of NBR 6118:2014, **Erro! Autoreferência de indicador não válida.** containing the minimum reinforcement values for the main forms usually used in the PavPlus system for 30MPa concrete. It is noteworthy that for the calculations, it was adopted that the ribs have a cable (CP190 RB 12.7) passing through it and the value of the "As" presented in the table already has the discount of the influence of the post-tension.

Table 3 - The minimum for the main forms of PavPlus using concrete of 30 MPa and CP 190 RB 12.7

h	hm	ht	Ac	Ycg	Rib width			"As" minimum
					bi	bm	bs	
(cm)	(cm)	(cm)	(cm²)	(cm)	(cm)	(cm)	(cm)	(cm²)
10	10	20	750	13.2	12.5	14	15.5	0,63
	12	22	872	14.3	12.5	14	15.5	0,81
15	10	25	835	16.7	12.5	15	17.5	0,75
	12	27	957	17.9	12.5	15	17.5	0,94
20	10	30	930	20.1	12.5	16	19.5	0,90

12	32	1052	21.4	12.5	16	19.5	1,08

3.1.3 Modularized Post-tensioning

The process of launching the tendons on the slab requires a lot of attention and a specialized labor to allocate the cable according to the parabolic trace calculated in the structural design. Aiming at an increase in productivity and greater reliability of this process, Impacto, in partnership with the company Termite, has developed some accessories that minimize the error during this stage of the execution of the system.

Previously, tendon lifting was done using tape to gauge elevations and individually bent rebar to keep cables at proper design heights. Aiming at greater productivity and efficiency, Termite together with Impacto have developed a system that enables the conference and fast execution, without the need for specialized labor and ensuring that the elevations of the tendons are in accordance with the project, in addition to a greater agility of execution.

In the PavPlus system, processes were also created in the assembly and conference of the tendons. The system includes the MasterCable solution, Figure Figure 18tendon with all the design information printed on its own plastic sheath, serving as a guide for the assembly and differentiated color for easier identification in the work, and the Caderix solution, Figure Figure 19an industrial manufacturing lifting accessory that has height indication, numbered and marked by bar code on its own part. Thus, in the assembly of thetendons just beat the information of the solution of the MasterCable with Caderix, dispensing with the use of tapes and opening of designs, making the process simple, 4x faster and with less specialized labor.

PavPlus

✓ FASTER

✓ LESS SKILLED LABOR

✓ 100% RELIABLE

✓ EXEMPTS   DESIGN OPENING

REQUIRED PATENTS

Figure 18 – MasterCable System

- **MANUFACTURED**
- **NUMBERED** WITH THE VALUES OF THE **DESIGNED HEIGHTS**
- **SETS READY FOR INSTALLATION**
- **BAR CODE** FOR **INFORMATIZED CONFERENCE** BY PAVSCAN **MOBILE APP**

Figure 19 - Caderix General Schematic

In addition to the MasterCable and Caderix solution, which simplifies assembly, the PavPlus System also includes the conference and assembly application, the world's first computerized process for unbonded post-tensioning. The application is patented in Brazil, with registration in deposit in the USA, which by reading the bar code of Caderix, assembled according to the information of the MasterCable, records the state of how the cable is assembled on site, identifying nonconformities instantly and issuing reports, in a transparent and 100% reliable way.

IMPACTO PROTENSÃO

PavPlus

FIRST INFORMATIZED SYSTEM IN THE WORLD FOR INSTALLATION & INSPECTION OF UNBONDED POST-TENSIONING

Figure 20 – PavScan Mobile Application.

With all these artifices for the arrangement, assembly and conference of the tendons, the execution of the   unbonded post-tensioning in slab becomes easier, faster and safer. FigureFigure 21 shows the distribution scheme of the tendons on a slab, already using all the artifices of execution and conference of the partnership Impacto and Termite.

Figure 21 PavPlus system with unbonded post-tensioning with orders and tendons using the rental and verification system developed by TERMITE.

3.2 Criteria according to Standards

3.2.1 Dimensioning criteria

The entire PavPlus system has been designed to meet current technical standards. (NBR 15200, NBR 6118:2014 and NBR 15575 :2013).

In addition, understood that the requirement of a minimum height of 20 cm for flat slabs (NBR 15200), without the possibility of considering the adherent subfloor for vertical compartmentalization, is due to the issue of sudden failure by punch. It is considered, then, that the PavPlus system meets this premise, because the transfer regions for the columns are massive, and with a minimum thickness of 20cm.

According to NBR 15200:2012 in Table Table 5TRRF of 90 min defines for b_{min} (rib width) and c_1 (distance between the center of gravity of the main reinforcement to the nearest face exposed to heat), respectively, the minimum values of 120 and 35 millimeters. For the Cover above ribs, minimum values of 100 mm are defined for the height of the slab.

Table 4 - Minimum dimensions for flat slabs

TRRF (min)	h (mm)	c_1 (mm)
30	150	10
60	180	15
90	**200**	**25**
120	200	35
180	200	45

Table 5 - Minimum dimensions for continuous ribbed slab on at least one of the edges.

TRRF (min)	Ribbing Combinations of b_{min}/c_1 (mm)			Cover ** h/c_1 (mm/mm)
	1	2	3	
30	80/10			60/10
60	100/25	120/18	190/10	80/10
90	120/35	160/15	250/15	100/15
120	160/45	190/40	300/30	120/20
180	310/60	600/50		150/30

Based on these points, it is necessary to determine the technical specifications used for the design and choice of the best PavPlus slab configuration to be used in the project. The choice of the modulation 61 cm x61cm was based on item 13.2.4.2 of NBR 6118:2014, where, "*For slabs with spacing between ribbing axes smaller or equal to 65cm, the verification of the flexion of the table can be dispensed with, and for the verification of the shear of the ribbed*

region, the consideration of the slab criteria is allowed" and in function of the modulated measure with the plywood sheets, which have dimensions of 122 cm x244 cm.

3.2.2 Punch and Negatives Reinforcements

Following item 20.3.2.6 of NBR 6118:2014 regarding negative rebar:

- On the support of flat slabs, at least four rebars shall be arranged on the drawn face in a band not exceeding the width of the support plus 1,5times the height of the slab on each side.
- The rebars should be spaced no more than 30cm apart and extended to a minimum distance of 1/6 of the free span in the direction of the reinforcement considered, from the face of the support.

Following item 20.4 of NBR 6118:2014 regarding punch reinforcements:

When necessary, the reinforcements to resist the punch should be constituted by vertical stirrups or connectors (studs), with preference for the use of the latter. The diameter of the stirrup armature cannot exceed h/20 and there must be mechanical contact of the longitudinal bars with the corners of the stirrups (mechanical anchorage).

3.2.3 Shear Reinforcement

According to item 13.2.4.2 of NBR 6118:2014, for slabs with spacing between ribbing axes less than or equal to 65 cm, the verification of shear is allowed to consider the slab criteria, following item 19.4 of NBR 6118:2014 regarding cutting force on slabs.

3.3 Overview

With the application of all these elements presented in the PavPlus system and with the modularization of the assembly of the ropes it is even more practical to use the unbonded post-tensioning. With welded steel mesh, or loose bars, but following a standardization, the assembly time decreases, reducing the days of service.

Figure Figure 22 shows the first jobsite executed using the PavPlus system in 2017. This work served as a starting point for the use of this system in buildings.

PavPlus

Figure 22 - Slab using the PavPlus system of the COIGMA – Du Louvre

4. DESIGN MANUAL – TQS

In this section will be presented the procedures necessary for the development of a project using the PavPlus system modeled, analyzed and detailed in the commercial software TQS.

4.1 Edition of the Prestressed Slab Criteria – TQS

Before entering the structural design and modeling phase, it is necessary to adjust the criteria of the program. In this material will be used the criteria of prestressed slabs adopted by the Center for Consulting in Protension (CCP), partner of Impacto Protensão in relation to the studies and feasibility analysis of projects using the post-tensioned systems and mainly, the PavPlus system.

i. There are two ways to access the criteria editor for post-tensioned slabs in TQS:

    a. The first it is during the creation of the building, in the Criteria tab and entering the Slabs option, as presented.
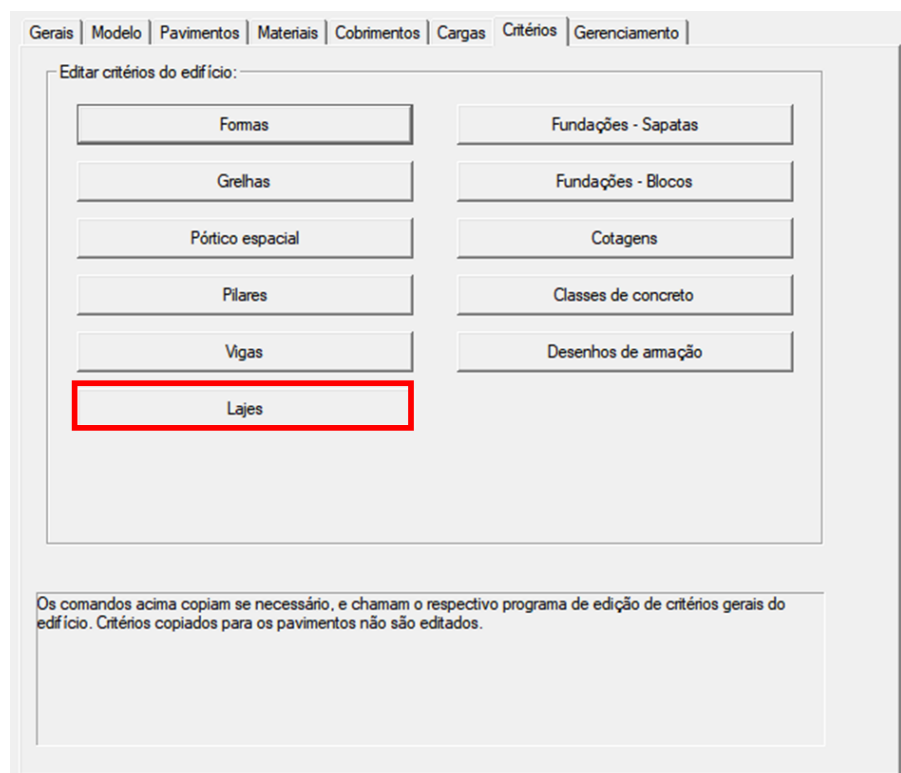
    b. The second is by going straight to the TQS toolbar, where there is the TQS "Lajes" (Slabs) option and in it are the criteria option that when selected opens a tab with three more options: design, drawing and data, simplified process. In this case, you must select the projects option and with that a window indicating the editing of the criteria will be opened, just by pressing "OK".
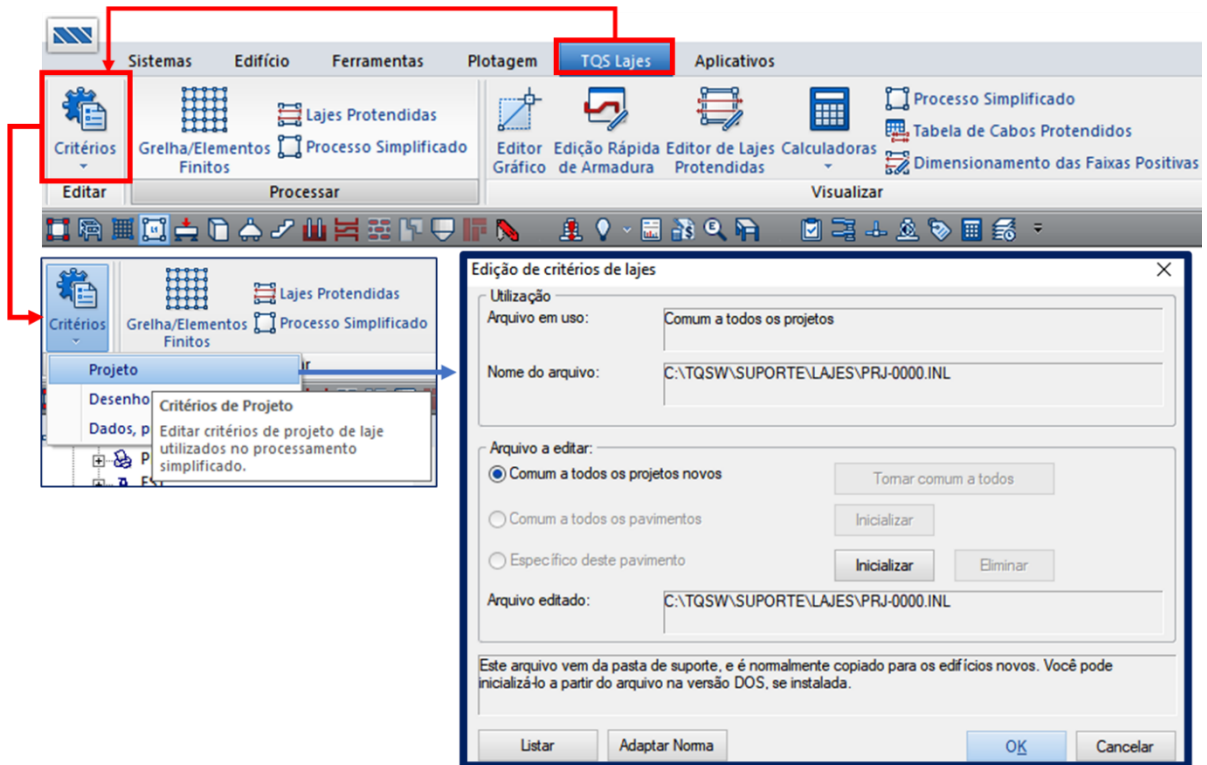
ii.   Within the slab editor appear several criteria within slabs, which can be edited and configured by the designer. The criteria that will be configured for the processing and sizing of the PavPlus slab will be the criteria of post-tensioned slabs.
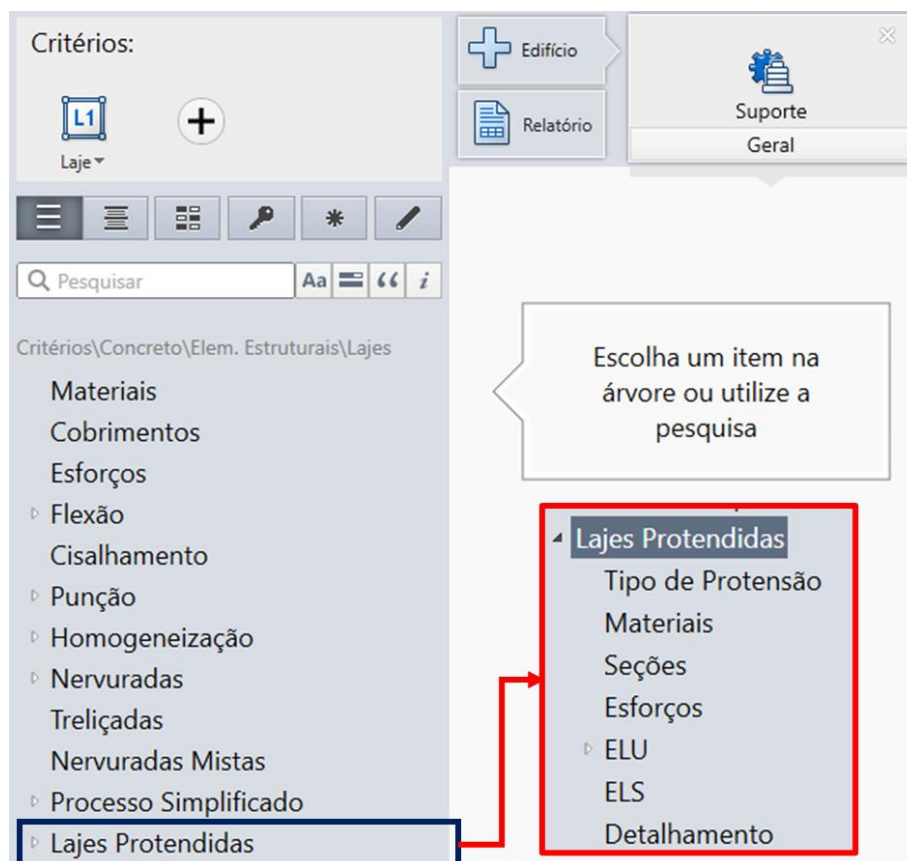
iii.   **Type of Pretension:** The first criterion to be edited will be the criterion of the type of post-tensioning, which can be with bonded and unbonded tendons, in our case it will be the unbonded (greased) tendons.

iv.   **Materials:** The material data is imputed when the building is created , and can be changed within this option.

   c. **Concreto**

   d. **Reinforcement**

   Reinforcement is divided into two options, passive (rebar) and active (post-tensioning) reinforcement, commonly does not change the passive reinforcement data and uses the default provided by TQS.

   i. **Passive reinforcement (rebar) – default TQS**

   ii. **Active reinforcement (post-tension)**

Diameter (mm)	Category	Denomination	Weight (kg/m)	Area (mm²)
12.7	190	CP 190 RB 7 12.7	0.890	100
15.2	190	CP 190 RB 7 15.2	1.226	145

   The most used is 12.7 and will be indicated for use in the models and procedures presented in this material.

   iii. **Post-tensioning (forces and losses)**

Standard	D (mm)	Pinitial (tf)	Pt=0 (tf)	Pinfin (tf)	Prupt (tf)	Pescda (tf)	%Lost	Fpyk (Mpa)	Fptk (MPa)	Dw(mm)
CCP	12.7	15.00	13.5	12.02	18.70	16.83	11	16830	18700	7.00

The values that are presented as default in TQS are different from this presented configuration, and should be edited. Most of the information is presented in the ArcelorMittal Table and the rest is used by the Center for Consulting in Protension (CCP).

  iv. Young's Modulus of post-tensioning tendon:

  E_p **(ELU) –** 1.96E+07 tf/m²

  E_p **(ELS) –** 1.96E+07 tf/m²

  Young's Modulus of rebar steel

  E_s **–** 2,10E+07 tf/m²

e. Friction and losses

The values of this parameter directly influence the calculation of immediate losses.

  i. Coefficient of friction (bonded tendon) – 0.02

This case does not apply to the proposed slab type.

  ii. Coefficient of friction (unbonded tendon) – 0.07

  iii. Coefficient of loss/meter (unbonded tendon) – 0.0035

v. Sections

As configurações desses pontos são importantes para que se analisem de modo adequados as seções geradas pelo programa.

f. Maximum spacing - 50 cm

vi. Stresses

g. Bending moments

Negative moment - medium

Positive momentum - medium

h. Hyperstatic

  i. Hyperstatic – Applies to RPUs (Uniform Protension Region) and RTEs (Effort Transfer Regions)

For, in addition to considering the values generated by the redistribution of efforts in RPUs, it also recognizes those of RTEs;

  ii. Additional width of RPUs - 0 cm

It is indicated to zero this value, so that there is no interference by non-compatible model of the grid.

i. Normal stress

i. Post-tension – from the forces defined in the criteria

In this option it is indicated for use when calculating the building by model IV.

If the model VI is chosen for the analyses, one can opt for either of the two options presented for this item.

vii.   ELU

j. Weighters

i. Act of Post-tension

It must be analyzed so that there is no excess of tensile and compression stresses.

γ_c – 1.2

γ_p – 1.1

γ_f – 1

γ_{hiper}favourable – 0.9

γ_{hiper}adverse – 1.2

Maximum compression stress – $0.7*fck_j$

Maximum tensile stress – $1.2*fctk_j$

ii. Infinite

γ_{hiper}favourable – 0.9

γ_{hiper}adverse – 1.2

Values according to NBR 6118:2014

k. Passive reinforcement

i. General crtieria

1. Calculate in the act of post-tension – No

It is indicated that in this item it is marked as no, and if it exceeds the limit in the act, it is proceeded in two stages. Only in conditions that require the slab or element to be fully post-tensioned should these reinforcement be calculated.

2. **Gauge for useful height** – 10 mm

3. **Increased tension in post-tensioning** – NBR 6118

   ii. **Minimum reinforcement**

1. **Processo of calculation of $A_{s,mín}$** – $A_{S_{mín}}$ according to NBR6118, table 19.1

However, the table calculates for an approximation of a rectangular section and in this case the section is T taking into account the rib, so the minimum moment of cracking should be used. It is indicated to use the $A_{S_{min}}$ option defined by the Engineer and impute the value of 0%.

2. **For unbonded tendon, include $A_{S_{min}}$ negative in the supports** - No

It is indicated to mark as not to include, leaving it free for the designer to calculate from outside the system and include in the model.

   iii. **Double reinforcement**

1. **% of limit traction reinforcement** - 4 %

2. **% compression reinforcement** – 0.5 %

3. **Values for the Default TQS.**

  viii.   **ELS (Service Limit States)**

   l. Cracking

     i. **$W_{k,lim}$** – 0.2 mm

     ii. **η_b** – 1.5

   m. Strains

This item is configured according to the level of post-tension limited to where there is traction in the part, however there is no cracking.

     i. **Maximum compression stress (almost permanent)** – 0.6*fck

     ii. **Maximum tensile strength (almost permanent)** – 1.2*fctk

- **Coefficient according to the type of section:**
  - **Rectangular** – 1.5
  - **I ou T inverted** – 1.3
  - **T ou double T** – 1.2

As the case is for the PavPlus system so 1.2 is used.

  iii. **Maximum compression stress (frequent combination)** – 0.6*fck

  iv. **Maximum tensile strength (frequent combination)** – 1.2*fctk

   ▪ **Coefficient according to the type of section:**

    • **Rectangular** – 1.5

    • **I ou T inverted** – 1.3

    • **T ou double T** – 1.2

As the case is for the PavPlus system so 1.2 is used.

ix. **Detailing**

 n. Supports

  i. **Automatic creation** - Yes, making the projection of the pillars that are inside the UPR.

 o. Concrete cover

  i. **Use the Standard**

 p. Spacing

  i. **Maxima between central tendons** – $6*h_{slab}$

  ii. **Minimum between central tendons** – 5 cm

  iii. **Maximum between ropes on columns** – $6*h_{slab}$

  iv. **Minimum between cables on columns** – 5 cm

  v. **Minimum between anchorages** – 7 cm

 q. Tendon geometry

  i. **Tendon is born and dies in the CG of the slab** – yes

  ii. **Straight length of live anchorage** – 50 cm

  iii. **Straight length at dead-end anchorage** – 50 cm

  iv. **Extension of the straight stretch in the spans (%A)** – 0%

  v. **Extension of the semi-pairtothe ball in the spans extrows (%B)** – 50%

  vi. **Extension of the semi-pairtothe ball on internal supports (%C)** – 10%

  vii. **Minimum distance for cable curvature** – 200 cm

  viii. **%p/ consideration of M (+) in cable detailing** – 15%

1. **Tipping points –** Locations of the tipping points is exactly where the moment of the slab cancels out **(YES)**

   ix. **Minimum radius of curvature**

D (mm)	Radius (cm)
12.7	100

r. **Anchorage**

   i. **Rebar covering –** 5 cm (no mínimo)

   ii. **Anchorage lengths**

	Bitola (mm)	Live (cm)	Dead-end (cm)	Intermediate (cm)	Inter bigger (cm)	Inter minor (cm)	Desc Sheath (cm)
CCP	12.7	60	0	0	0	0	0

So that in the table of post-tensioning tendon, the lengths resulting from the losses by the parabolas are included and 40cm necessary for the jack to be able to pull the strand. This is necessary because TQS recognizes only the straight length in plan of the tendon.

s. **Other criteria**

   i. **Standard number of tendons per bundle –** 1

   ii. **Standard gauge for detailing –** 12.7 mm

   iii. **Reducer initial amount of tendon –** 0%

4.2 Editing of the Design Criteria of Post-tensioned Slabs – TQS

After editing the design analysis criteria, we move on to editing the design criteria.

At this point the changes are very direct, and the items of criteria of Levels, Texts and dimensions are selected, at the sole discretion of the designer, because they are quite characteristic items of each professional and their standards of layout of presentation of the project.

Only the criteria settings for the Controls items will be indicated.

PavPlus
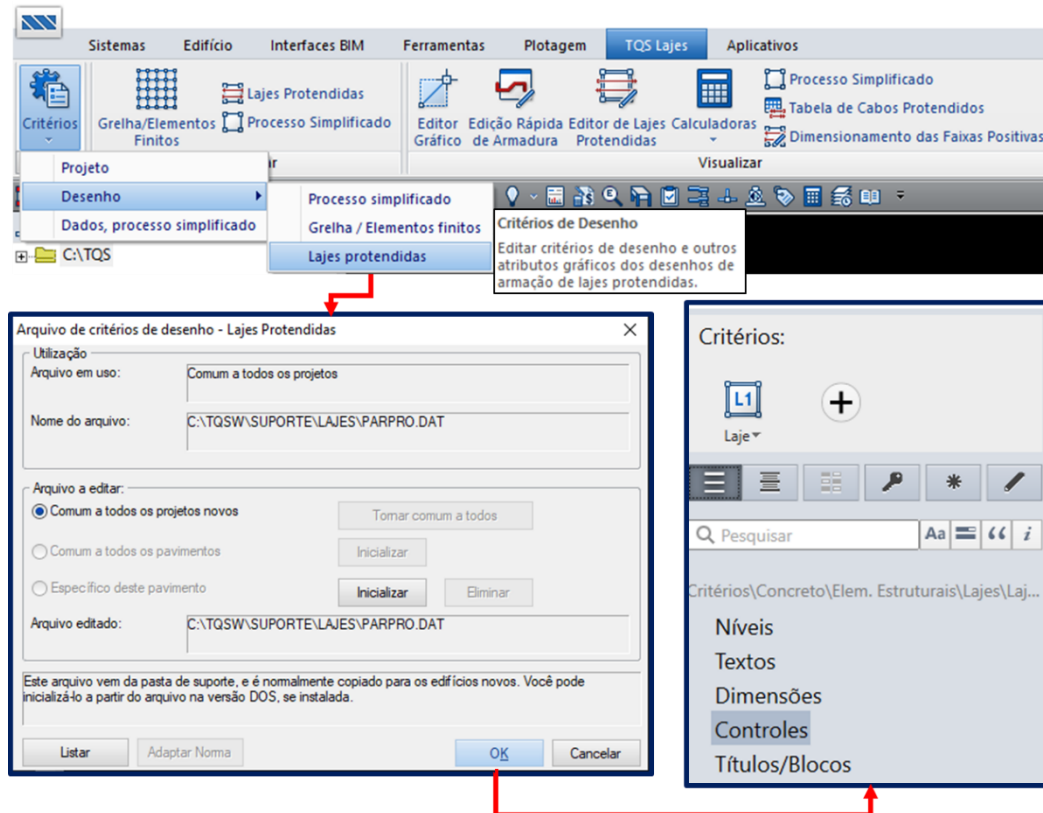
i. **Formwork design**

    a. **Draw axes**– Yes

ii. **Cotagem**

    a. **Horizontal elevation quotation** - Yes

    b. **Vertical elevation quotation** - Yes

    c. **Quote tendon bands** - No

    d. **Quote elevations –** With regular spacing (This option is indicated, so that a pattern is maintained)

    e. **Espaçamento regular –** 61 cm (This valueis a function of the dimensions of the waffle mold)

    f. **Quote tendo elevation –** In relation to its axis (usually the elevation of the cable from the lower face of the shape to the axis of the cable is reported)

iii. **Position**

    a. **Group positions –** Yes

iv. **Curvature of tendons in floors**

    a. **Number of points** - 5

    b. **Arc radius** - 500

4.3 Creating Building

During the creation of the building in TQS it should be noted some criteria to be adjusted so that the model is in accordance with standards of norm and good practice for the development of the model using the PavPlus system.

The structure in question resembles by analogy the process of developing a model of flat slabs, being a ribbed slab without beams supported on columns. One can opt for the development of the model in model IV and VI. The floors that are of this type of solution should be chosen by selecting the option of calculating this floor with post-tension.
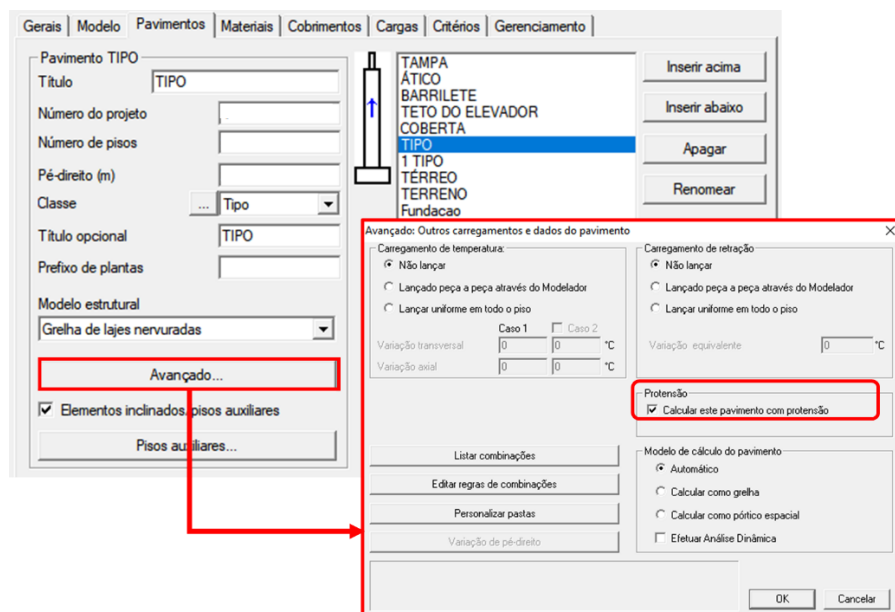
As for the materials, they must be defined by the engineer. Remembering that for post-tensioned slabs the Fck must be at least 30 MPa. And the class of aggressiveness also defined by the designer according to his need. The covers should follow the norm values, and in the secondary difference option for post-tensioned slabs should be set to 0 (zero) following some care during detailing.

PavPlus

The other editing points during the creation of the building in TQS must be in accordance with the normative specifications and standards used by the designer.

4.4 Modeling

The model must follow the limits of the architecture and conditions imposed by it. For the launch of the PavPlus slab in the TQS, after the launch of the columns with the limits defined by edge closures, most of the time, the slab must be inserted.

This slab is of the ribbed type T and in TQS, from version 21 are available the options of the manufacturer Impacto. If the version is earlier, you must fill in the data of the ribbed slab according to the patterns of the Pavplus shape. The loads to be inserted in the model must comply with standard 6120 and adapt to the type of use of the building.

PavPlus

i. Launch of the waffle molds

After defining the type of bucket, the waffle mold must be inserted and distributed on the slab.

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With the launch and distribution of the buckets, adjustments begin according to the conditions of limitations of the slab and choices of its massive regions that make up the concentrated cables.
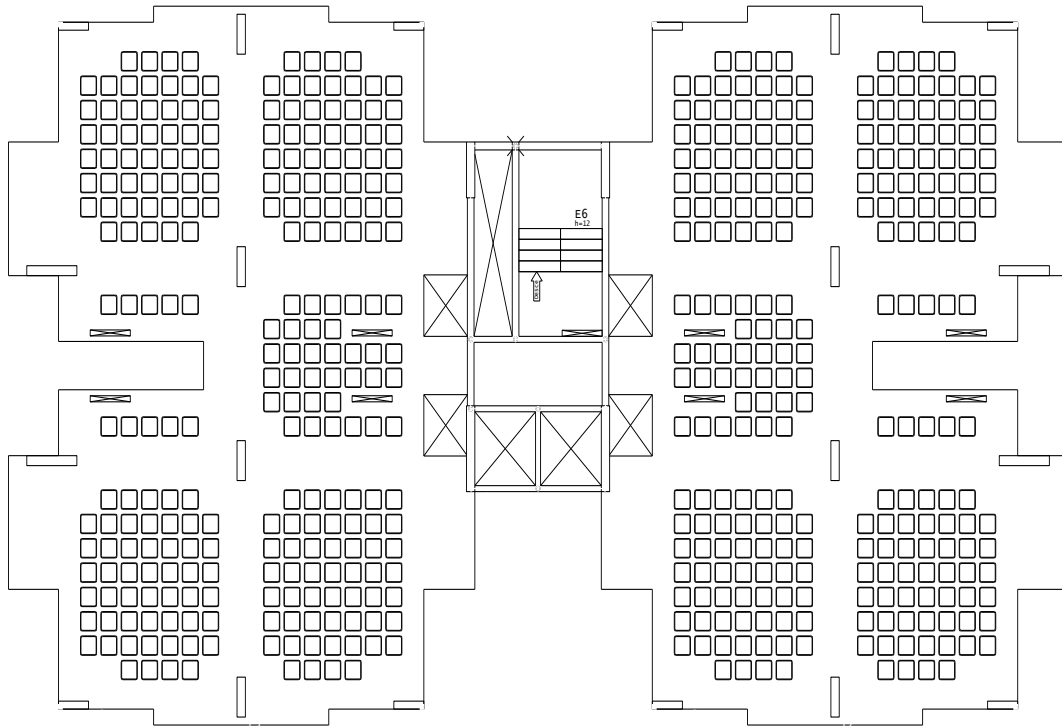
ii.   Indications

One should define the areas on nearby columns, eliminating the waffle slab, so that there is a massive region where the negative rebar on the column will be accommodated. This region also serves as a capital to absorb shear and punch efforts. These reinforcements respect the boundaries according to the NBR 6118 standard.

This elimination of the waffle molds represents a region of concentration of tensions, with the need to locate negative armor, which cannot be simply distributed in the covers of the ribbed regions. Another point to be noted is that during the detailing of the slab, it should be observed if the massive region meets the location of the negative and punch reinforcements.

PavPlus
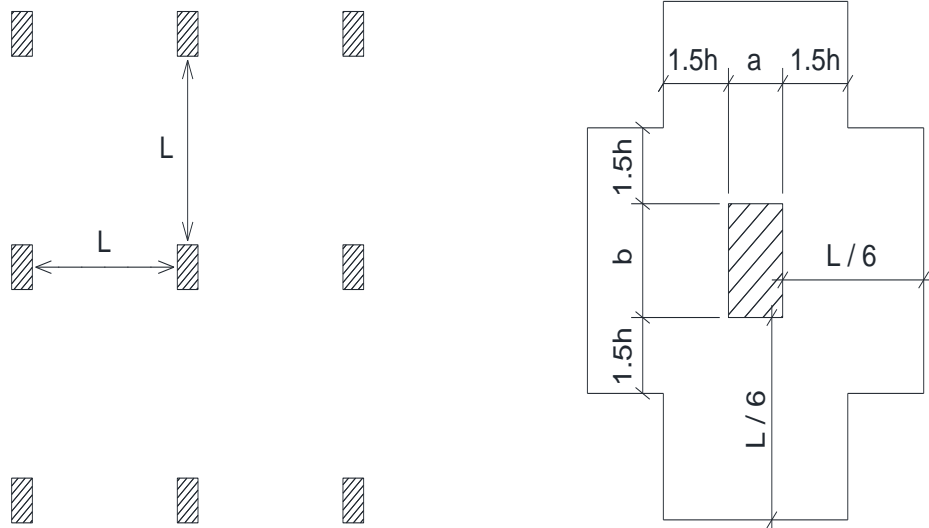
iii.   Processing

After all the launch and definition of the elements and distribution of the waffle mold, the model must be processed and the efforts acting on the structure must be verified. At this point, one can observe some strange behavior of the model, if it is not well adjusted and solved structurally.

iv.   Comments

The system intersperses massive and ribbed regions, which can generate possible doubts in the designers.

The system has the same considerations as post-tensioned flat slabs and works with tendons distributed in one direction and concentrated in the other. For this model, regarding the aspects of post-tension and distribution of the cables, the following points are taken into account:

1) The concentrated tendons must be contained in a band corresponding to the width of the column plus 3.5h (h=thickness of the slab) for each side of the pillar;

2) The maximum spacing of the distributed tendons should be a maximum of 120 cm or 6h (h=slab thickness);

3) The unbonded post-tensioned slabs monostrand can be arranged by a maximum of 4 (four) tendons per bundle;

4) Is possible to dispense rebar reinforcement against progressive collapse, if at least one tendon passes through the pillar in each orthogonal direction, (item 20.2.3.6 NBR 6118:2014).
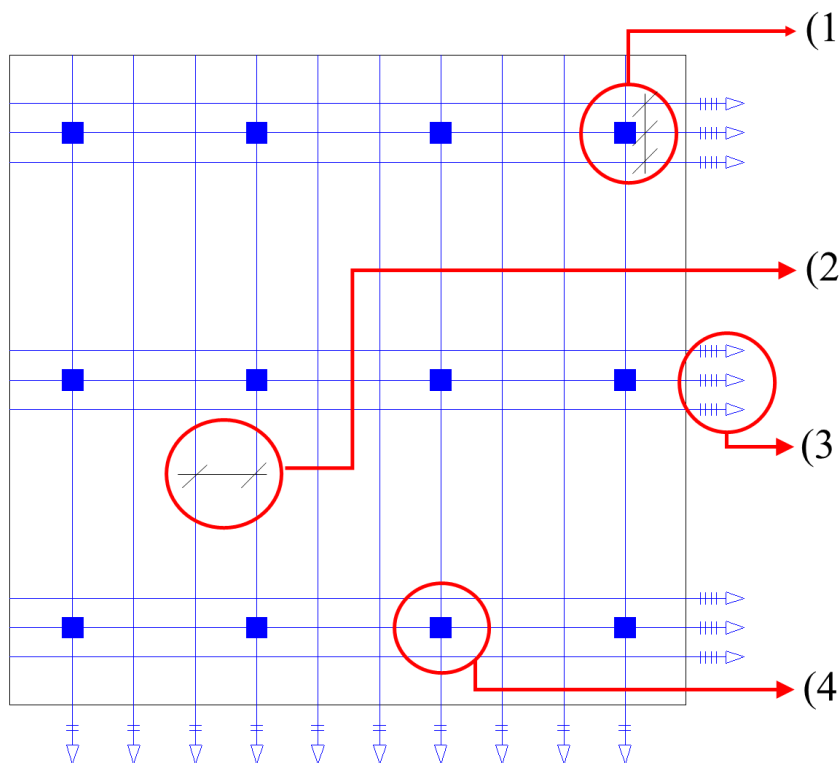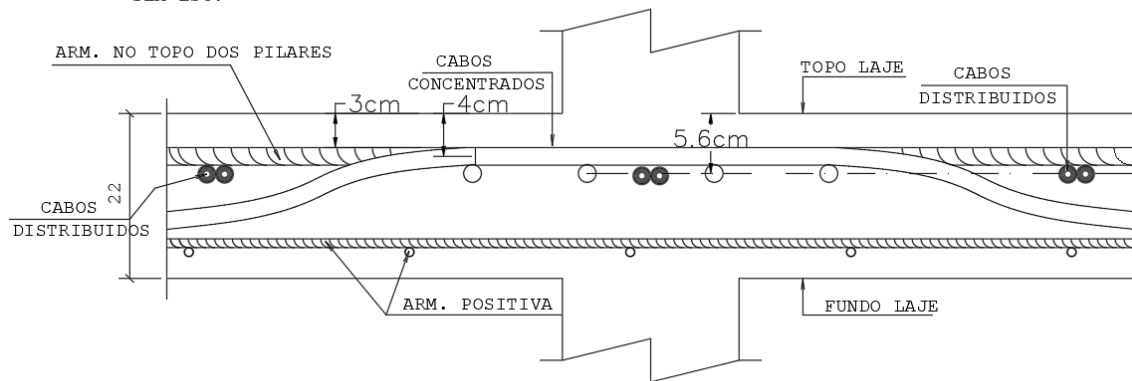

Depending on the details of the negative reinforcement, it follows the following patterns:

- Sobre o apoio das lajes lisas ou cogumelos protendidas, devem ser dispostas no mínimo quatro barras na face tracionada em uma faixa que não exceda a largura do apoio acrescida de 1,5 vez a altura da laje de cada lado.

1. The rebars shall be spaced no more than 30 cm apart and extended to a minimum distance of 1/6 of the free span in the direction of the reinforcement considered, from the face of the support. At least 4 (four) bars.

The detailing of the concentrated tendons follows the standard recommendations of post-tensioned flat slabs, where the tendon pass straight over the supports (columns or support elements) so that the post-tension passes together from the passive reinforcement. And in the distributed, the tendons are distributed between the ribs, and can be distributed every two ribs, and in the region of the supports must pass under the concentrated tendons.

DETALHE DO POSICIONAMENTO DAS ARMAÇÕES
NO TOPO DO PILAR.
SEM ESC.

ARM. NO TOPO DOS PILARES

CABOS
CONCENTRADOS

3cm 4cm

TOPO LAJE CABOS
DISTRIBUIDOS

5.6cm

22

CABOS
DISTRIBUIDOS

ARM. POSITIVA

FUNDO LAJE

*ATENÇÃO PARA COMPATIBILIDADE COM OS CABOS CONCENTRADOS.
*ATENÇÃO ARMADURA PASSIVA SUPERIOR ESTÁ NO SENTIDO DOS CABOS CONCENTRADOS.

It should also be paid to the compatibility of the tendons with the positive passive reinforcements inside the ribs, so that these two do not generate an interference in each other and make it impossible to run the system.

DETALHE DO POSICIONAMENTO DAS ARMAÇÕES
INFERIORES DA LAJE
SEM ESC.

CABOS
CONCENTRADOS/
DISTRIBUIDOS

TOPO LAJE CABOS

H

ARM. POSITIVA

FUNDO LAJE

*ATENÇÃO CABOS INFERIORES CONCENTRADOS / DISTRIBUIDOS POSICIONADOS ACIMA DA ARMAÇÃO INFERIOR.

4.5. Lauching RPU and RTE

The RPUs are the regions of uniform post-tension and the RTEs are the regions of transfer of effort. To define the RPUs and RTEs, the massive regions and distributed regions should be followed. It is important to always insert the RPU's following the orientations from left to right in the horizontal and from bottom to up in the vertical.

i.   Concentrated

For definitions of the widths of the RPU's in the direction of the concentrated tendons, one should have at most the width of the columns plus 3.5h for each side of the column. After defining the width and inserting the RPU representing the concentrated range, the RTEs are inserted. This RTE shall cover the entire RTU up to the midpoints between columns in the orthogonal direction to the RPU.

PavPlus

For example, it is presented in a schematic plan a release of RPU's of a floor type of a building, where the RPU's are represented by the blue elements and the RTE's by the red.
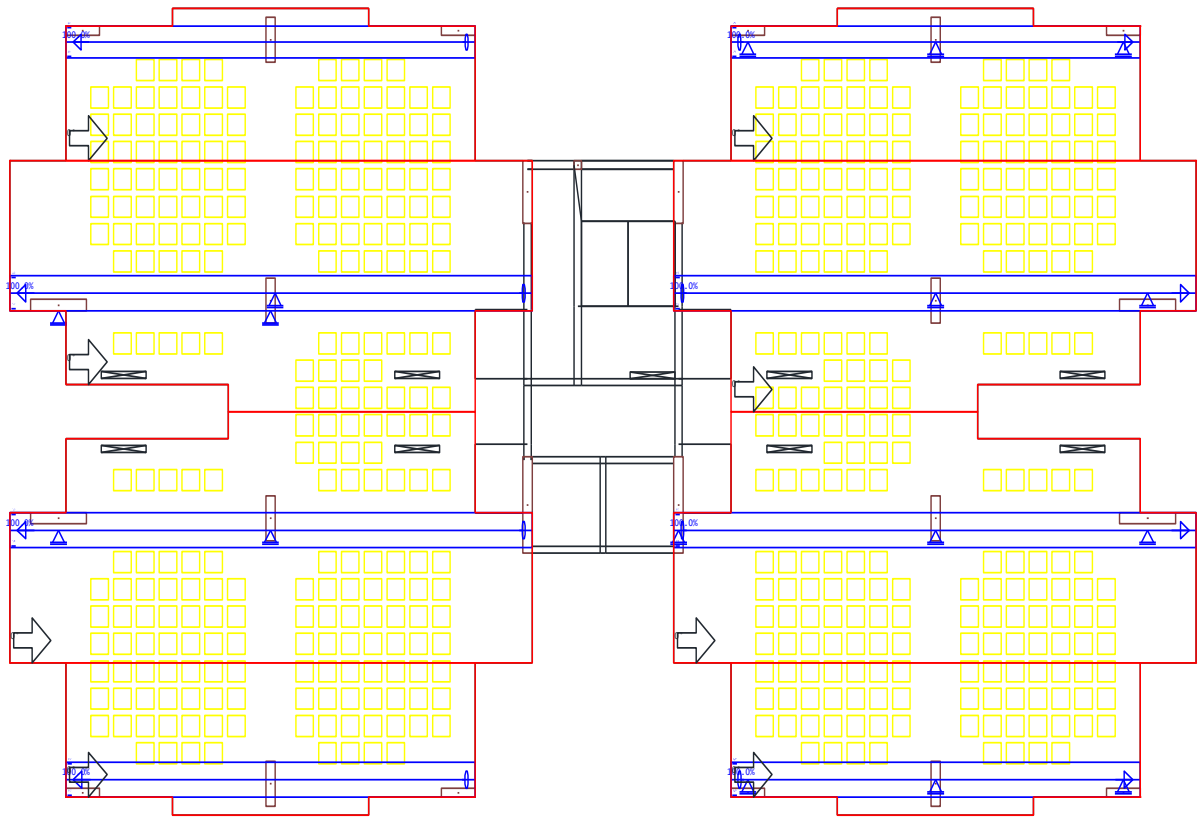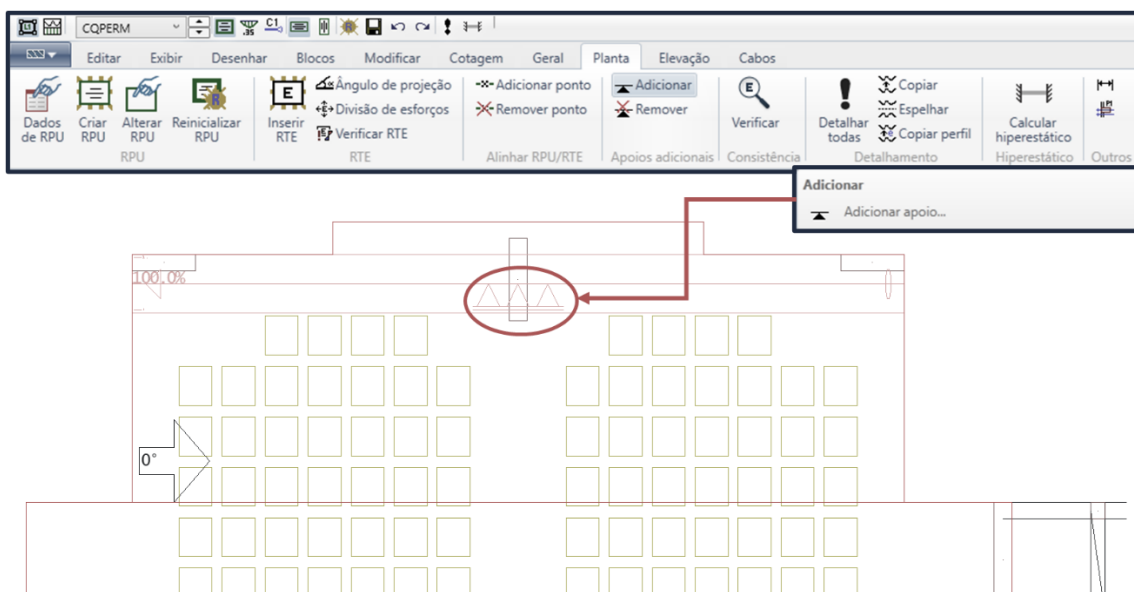

ii.   Distributed

The distributed RPUs are launched in the orthogonal direction to the concentrated ones and have widths between the midpoints of the supports, or delimited regions. In these RPU's (blue elements), the RTE's (red elements) are only necessary if there are regions where cables are not being distributed, and these regions start to take their efforts to the RPU bands launched.
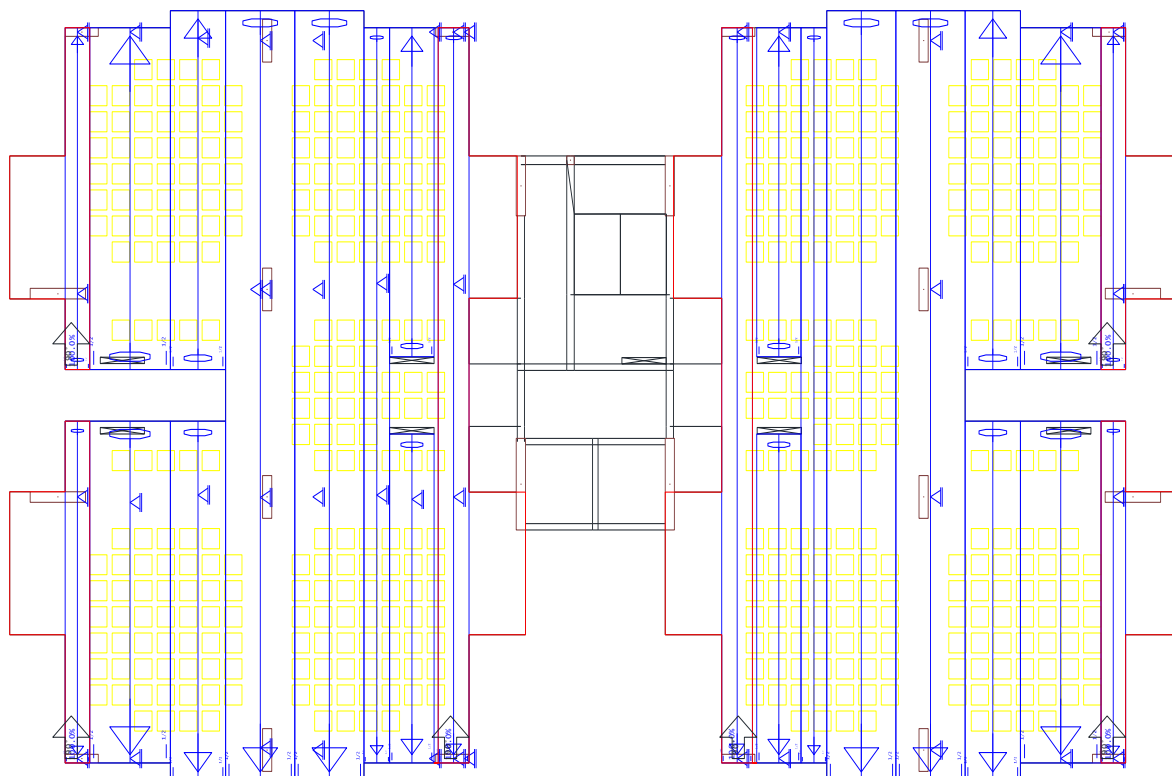
iii.   Considerations and Comments

     a.   Initially, one should analyze some points before processing the RPU's. One of them is that the concrete tendons pass straight in the supports, for this, additional supports are inserted for each side in the pillars, with a distance equal to 1.5h from the face of the pillars for all the elements that need the cables to pass straight over them.

     b.   Another point that should be taken into consideration are the coverings, where attention should be paid to the distribution of concentrated and distributed

reinforcement and the compatibility of passive and post-tensioned reinforcement, minimizing the points of conflicts between reinforcement. If they exist, let them be outside the main, maximal, and minimal points of the parables. For this, one must initially know the minimum negative and positive passive reinforcements.
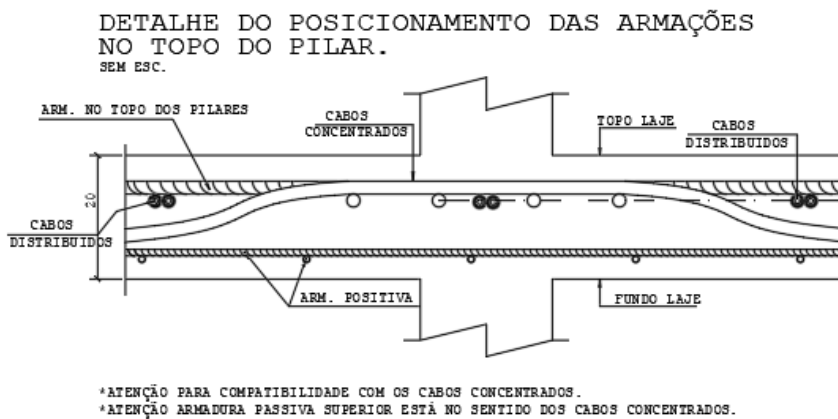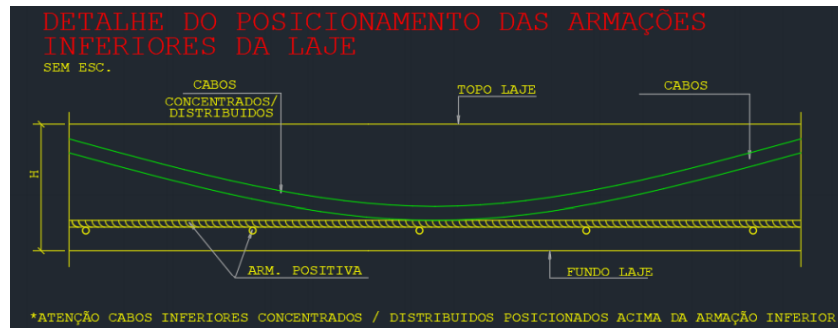
- **Positive reinforcement**

The standard has a table, **Erro! Autoreferência de indicador não válida.**calculation of positive minimum reinforcement for rectangular section elements as a function of the Fck of the element, however the PavPlus system is a section T. In the 6118:2014 standard is indicated in table 19.1, a criterion for determining the minimum armor for generic sections when post-tensioned.

Table 6 - Table of positive minimum armor for rectangular sections as a function of Fck.

SECTION SHAPE	VALUES OF ρ_{min} $(A_{s,min}/A_c)$ %														
	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
RECTANGULAR	0.150	0.150	0.150	0.164	0.179	0.194	0.208	0.211	0.219	0.226	0.233	0.239	0.245	0.251	0.256

PavPlus

REINFORCEMENT	Structural elements without active reinforcement	Structural elements with bonded post-tensioning	Structural elements with unbonded post-tensioning
Negative rebar	$\rho_s \geq \rho_{mín}$	$\rho_s \geq \rho_{mín} - \rho_p \geq 0,67 \cdot \rho_{mín}$	$\rho_s \geq \rho_{mín} - 0,5 \cdot \rho_p \geq 0,67 \cdot \rho_{mín}$
Negative edge rebar without continuity	$\rho_s \geq 0,67 \cdot \rho_{mín}$		
Positive reinforcement of slabs reinforced in both directions	$\rho_s \geq 0,67 \cdot \rho_{mín}$	$\rho_s \geq 0,67 \cdot \rho_{mín} - \rho_p \geq 0,5 \cdot \rho_{mín}$	$\rho_s \geq \rho_{mín} - 0,5 \cdot \rho_p \geq 0,5 \cdot \rho_{mín}$
Positive (main) reinforcement of slabs reinforced in one direction	$\rho_s \geq \rho_{mín}$	$\rho_s \geq \rho_{mín} - \rho_p \geq 0,5 \cdot \rho_{mín}$	$\rho_s \geq \rho_{mín} - 0,5 \cdot \rho_p \geq 0,5 \cdot \rho_{mín}$
Positive (secondary) reinforcement of slabs reinforced in one direction	$A_s/s \geq 20\%$ of main reinforcement $A_s/s \geq 0,9 \ cm^2/m$ $\rho_s \geq 0,5 \cdot \rho_{mín}$		-

Since the PavPlus system is formed by ribs, the minimum reinforcement can be calculated based on the minimum moment of cracking.

$$Md, mín = 0,8W_0 \ fctk, sup$$

W0 is the strength module of the raw cross section of concrete, relative to the most tractioned fiber;

fctk,sup is the superior characteristic tensile strength of concrete (see item 8.2.5 of standard 6118).

The dimensioning for Md,min can be considered met if the minimum rebar rates are respected.

The following is an example in which the procedures for calculating the ρ_{min} for determining the minimum reinforcement for a PavPlus slab of 10 + 10 with Fck of 30 Mpa are presented.

For a slab of h=20 (10+10) the section is as follows:

H(10+10) - 61x61x20
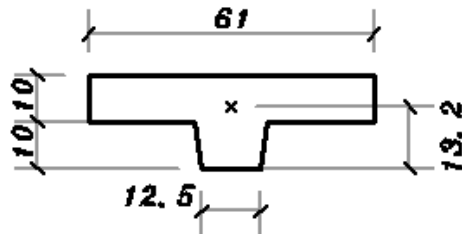
A=750 P=159. 2

Ix= 1. 722917e+004

$-W0 = 1305\ cm^3$

$-Fctk, sup = 37,65 kg/cm^2$

$-Md, mín = 39317\ kgf.cm (0,393\ tf.m)$

$-As, mín\ calculado = 0,52\ cm^2$

$-\rho mín, calculado = 0,069\% < 0,15\%$

Adotar 0,15%

$-\rho mín = 0,15\% * 750 = 1,13 cm^2/nerv$

Adopting 1 CP190 rope of 12.7mm per rib with a section of 1cm²

$-\rho mín - 0,5\rho_p = 1,13 - 0,5 * 1 = 0,63 cm^2/nerv$

Adopting 2Φ6.3 per rib

As the calculated is less than 0.15 $\rho mín$ %, 0.15% is adopted by indication of the norm.

The advantage of calculating by the minimum moment is that for Fck's greater than 30, one can use the $\rho mín$ 0.15%, but it must be verified that for the chosen section, the $\rho mín$ calculated is less than the absolute minimum. If so, there is no need to use the table with values of $\rho mín$ for the Fck's.

- **Negative reinforcement**

It follows the indications of item 20.3.2.6 of NBR 6118:2014 where only geometric parameters and relations between spans of the columns are considered.

$$\boxed{As = 0,00075 \cdot h \cdot l}\ \text{where:} \begin{cases} h = \text{slab thickness} \\ l = \text{medium span of columns} \end{cases}$$
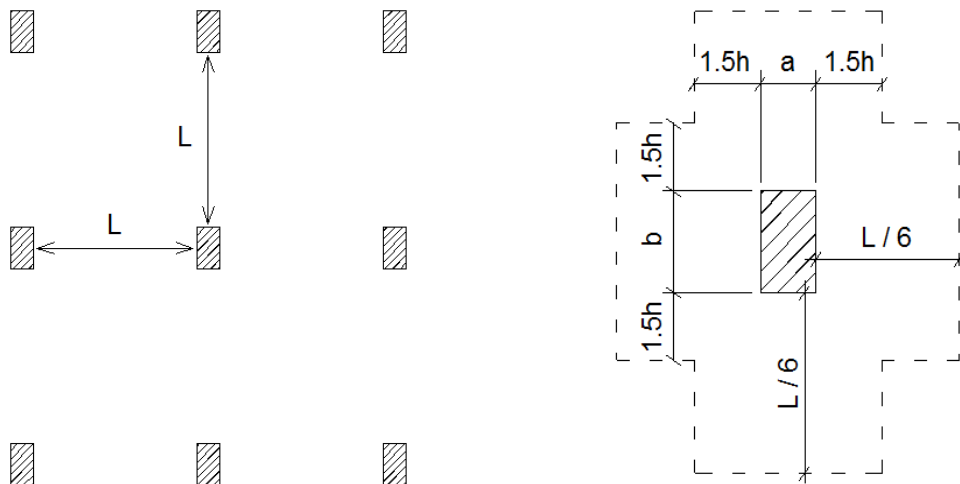
On the support of the flat slabs, at least **four rebars** shall be arranged on the drawn face in a band that does not exceed the width of the support plus 1.5 times the total height of the slab for each side.

The rebars shall be spaced no **more than 30 cm** apart and extended to a **minimum distance of 1/6 of the free span** in the direction of the reinforcement considered, from the face of the support.

- **Shear reinforcement**

Use shear reinforcement on slabs as indicated and verified in item 19. 4 of NBR 6118, when necessary.

- **Punch reinforcement**

Utilizar punch reinforcements according to indications and verifications of item 19.5 of NBR 6118 (NBR 6118:2014 – item 19.5.3.5).

iv.   **Edits to the post-tensioning template**

Depending on the dimensions determined for the minimum positive and negative reinforcements, the covers can be adjusted and the heights of the cables at the maximum inflection points can be determined. Being able to insert in an appropriate way the elevations of the tendons in the evaluation and adjustment of the tracing of the post-tensioned reinforcement.

This adjustment can be made directly in the criteria within the building edition or directly in the selected RPU. It is interesting to fit directly into the building to avoid errors due to the existence of different coverings on the same floor or building.

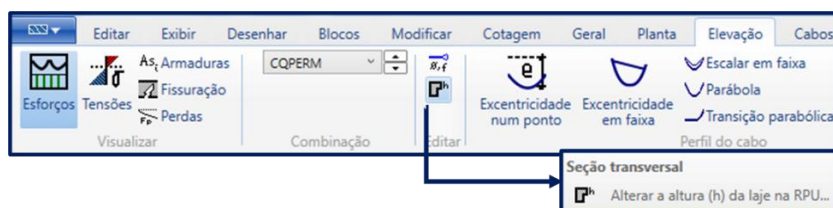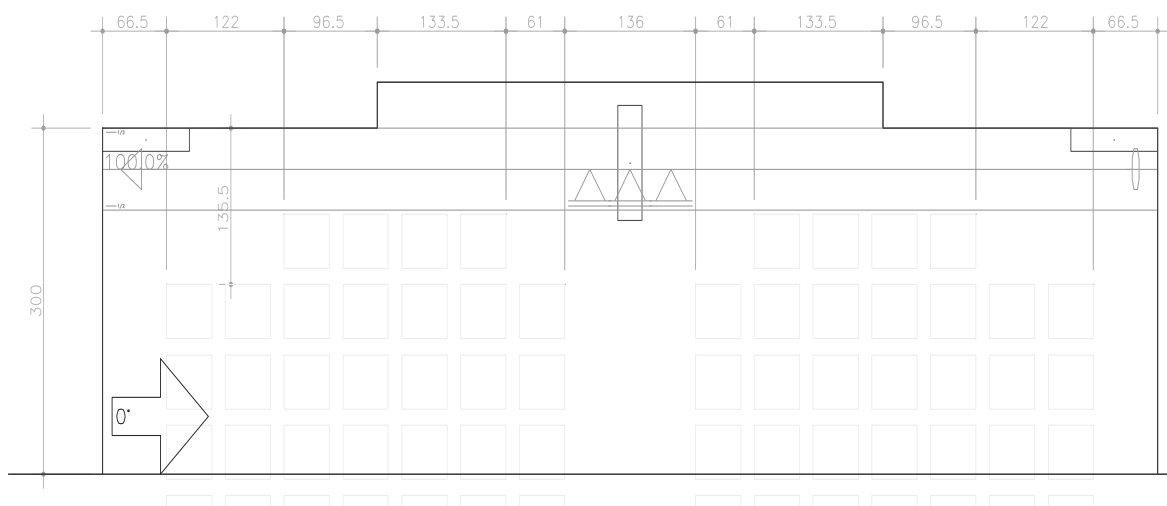**Option 1 – Straight into the Building Editor**

Option 2 – Inside the RPU

v.   RPU tuning
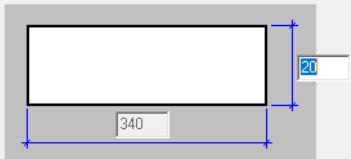
In addition to the adjustments of the tendons design, the sections of the RPUs should be checked and edited. That is, because there are several sections involved in this process, and in the same RPU there may be several stretches with different amounts of ribs and sizes of massive regions. This can be seen in the following example that in the same RPU there are 11 different sections.
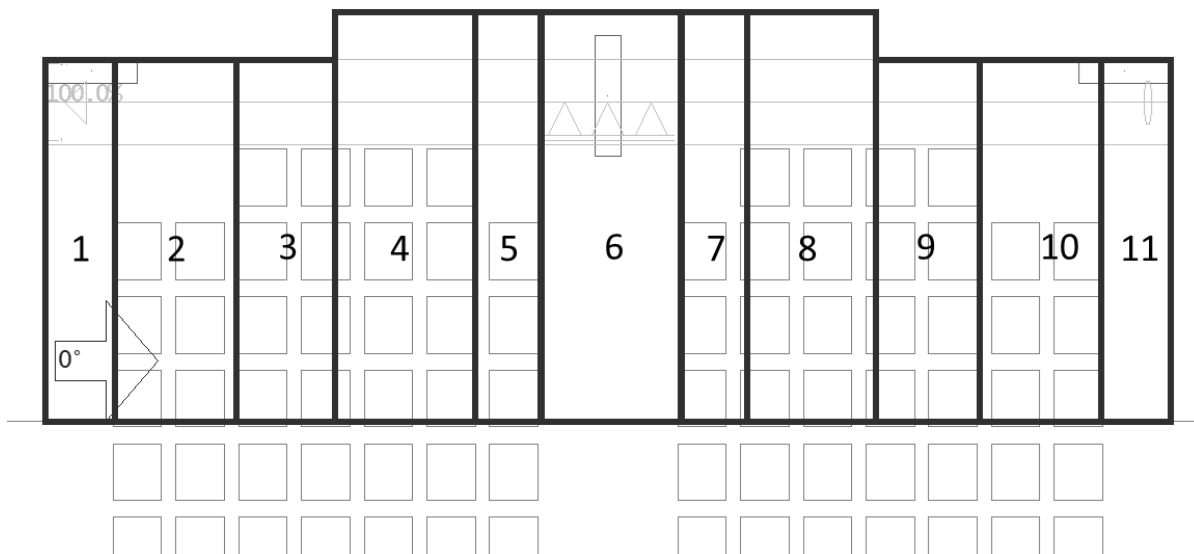
To edit the sections within the RPU, in the post-tensioned slab editor the cross-section command is selected and then, depending on its dimensions, you edit directly within the RPU section. For the exclusively massive sections, it is enough to know the size of this one, which in the case of section 1, would be from 300 cm up to 66.5 cm, a). And for the sections that have massive and ribbed regions should be added the width of the massive region with the number of ribs, multiplied by the average width of the rib, in the case of section 2 would be (135.5 + 2x14) cm from 66.5cm of the slab face up to 122cm, b).
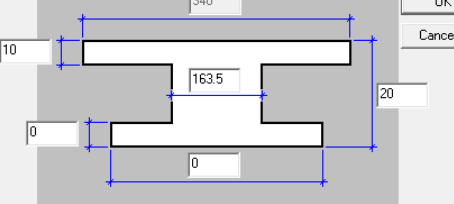
a) Rectangular section adjustment   **b) T-type section adjustment (ribbed)**

After adjusting the sections and cable strokes, the number of cables must be processed and adjusted so that there is no cracking and the section in which the RPU operates meets the standard limits. For this, the maximum eccentricities that the cable may have in its layout is defined. Paying attention so that there is no interference between the concentrated tendons and those distributed in the maximum and minimum points.

The minimum amount of cables must meet the average normal compression condition of 1 MPa (According to item 20.3.2.1 of NBR 6118:2014);

It is not advisable to adopt a number of cables that generate average normal compression greater than 4 MPa for slabs and 7 MPa for beams;

4.6 Detailing
   i.   Post-tension:

At least one rope must be passed inside the column in each direction to dispense with progressive collapse reinforcement detailing (NBR 6118:2014 recommendation). The ACI recommends two cables in each direction;

The concentrated cables shall be arranged in a band of width corresponding to the width of the column plus 3,5 times the thickness of the slab for each side of the pillar. Adopt bundles of no more than four tendons.

PavPlus

A characteristic of the post-tensioning in PavPlus is that the tendons distributed are between the waffle molds, and can be rented every two due to the economy of the Caderix and speed in assembly.

Both in live and dead-end anchorages, the tendons come out straight for 50 cm (according to NBR 6118) and join during a distance 12D, D being specified in the following drawing:
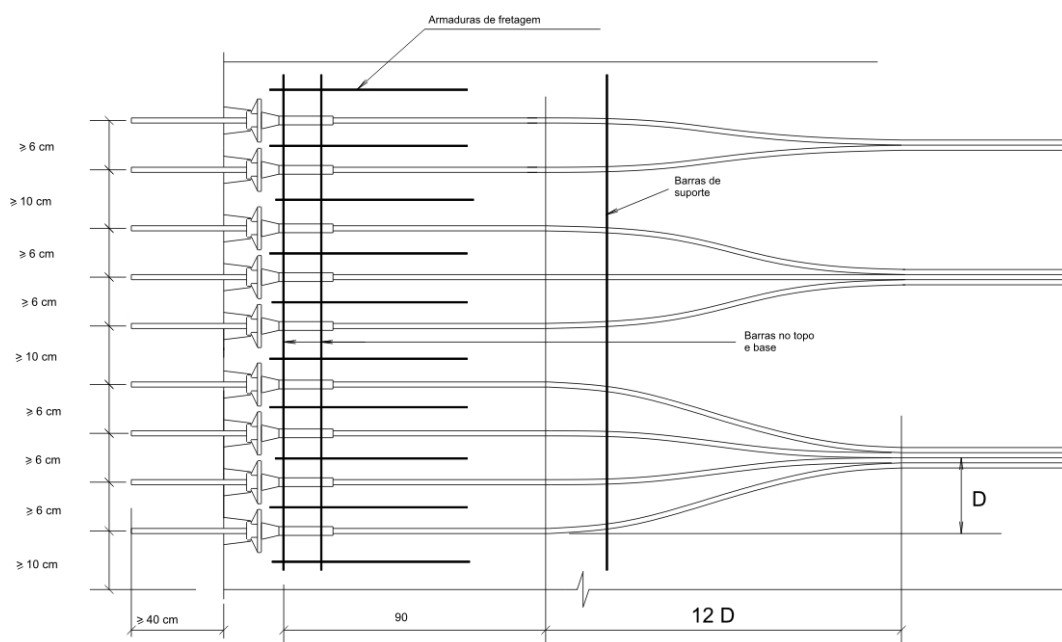

Deviation of tendons in design smaller than 1/10 does not require the use of clamps to contain the horizontal efforts from the post-tensioning (NBR 6118:2014 – item 20.3.2.5);

For marked deviations in design (greater than 1/10), use clamps that cannot be spaced more than 45 cm;
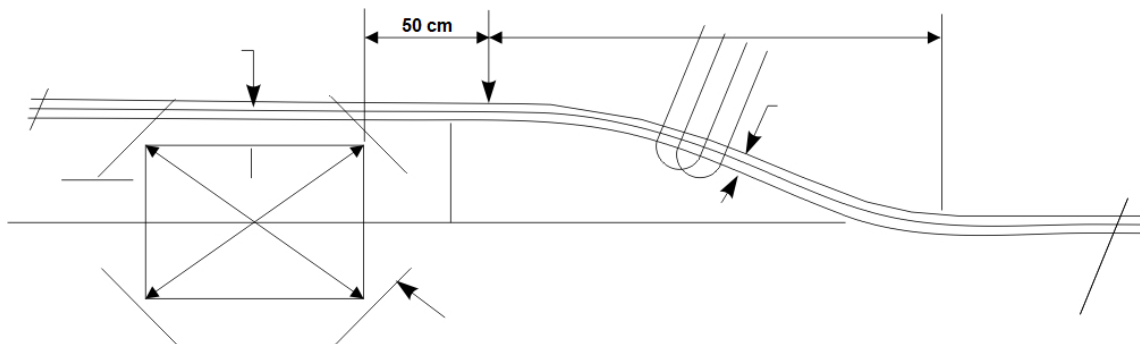

IMPACTO PROTENSÃO
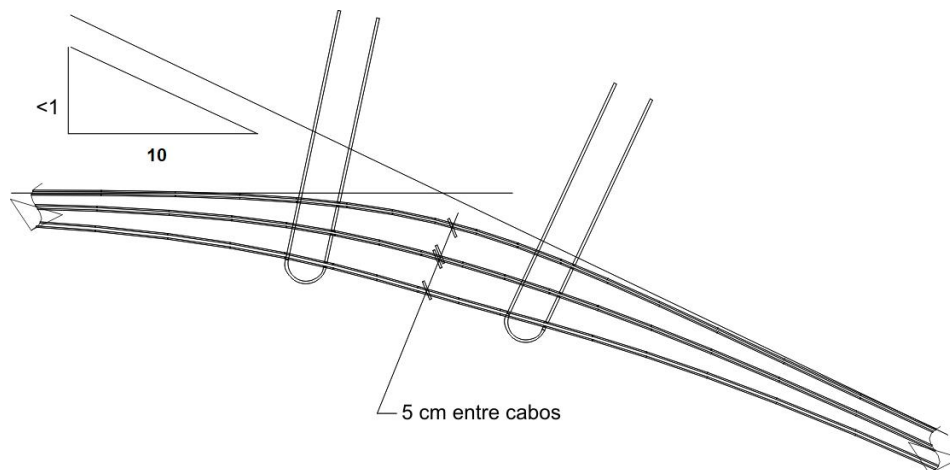
Deviations should have a parabolic development in design;

Along the deviation, the tendons must be arranged in such a way that in the center of the curve they are spaced at a minimum distance of 5 cm;
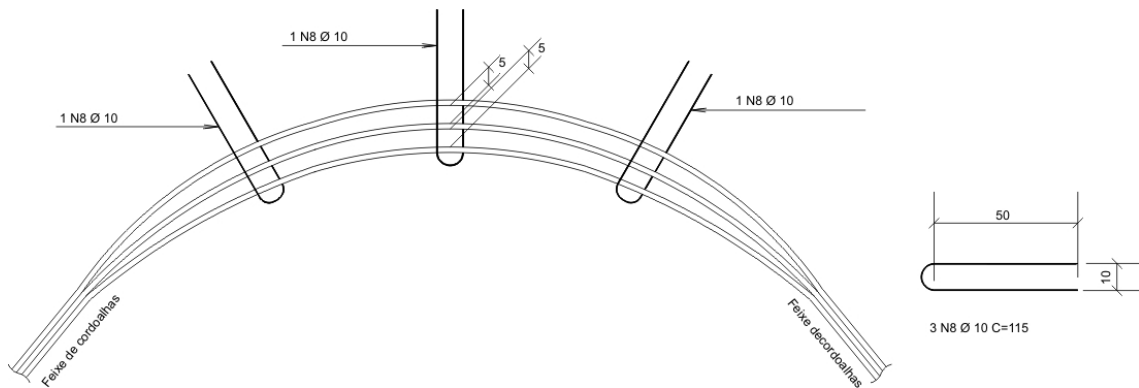
When deviating from cutouts of the slabs, the tendons must change their direction at least 50 cm away from the cutout;

The tendons cannot pass at a distance of less than 7.5 cm from the faces of the voids (NBR 6118:2014 – item 20.3.2.4);

Tendons distributed at a maximum distance of 6h or 120 cm.

ii. Passive reinforcement
a. Rebar – Positive Reinforcement

After the transfer of the rebar of the floor with post-tension, it is necessary to evaluate all the ranges of efforts, remembering that in the criterion of As,min must be marked the option

defined by the engineer, because if it is calculated directly by NBR 6118 will be adopted the values of the table for the indication of the necessary reinforcements. In this way, only the rebar will be defined by the ultimate limit state.

It is necessary to evaluate all the exploded bands, verifying which reinforcement is necessary and with this, the need to add more reinforcement than the minimum calculated by calculating the moment of cracking is evaluated. $\boldsymbol{\rho_{mín}}$

In addition to the calculation of the minimum rebar with the rib section, the minimum reinforcement should be evaluated when there is thickening of the section. That is, when there is a massive section that has more concrete, generating an increase in the size of the section. Developing the same calculation procedure performed for the rib.$\boldsymbol{\rho_{mín}}$

Preferably adopt welded steel mesh for positive frame (workability advantage).

b. Rebar – Negative reinforcement

It is necessary to compare the reinforcement found in the armor editor after the transmission of passive reinforcement of the processing of the post-tensioned slab, with the minimum reinforcement determined by the indications of NBR 6118 in function of the geometric conditions of the slab and its spans. With that, the negative rebar ends up in both directions.

For the detailing of negative rebar concentrated on the columns, some criteria must be followed such as:

- Number minimum of 4 bars for each direction;
- Maximum spacing of 30 cm;
- Spaced in a band of maximum width equal to the size of the column plus 1.5 times the height of the slab for each side;
- The reinforcements must cover a region that meets at least 1/6 of the internal span.

Quando houver apoios de lajes sem continuidade, deve-se prosseguir como detalhamento das armaduras mínimas negativas desses apoios conforme item 19.3.3.2 da NBR 6118:2014.

c. Punch

Following the indications of item 19.5.3.5, the punch is reinforcement by evaluating the requesting efforts on the columns in that region. Watching for interference between rebar and post-tensioning reinforcement.

PavPlus

One should preferably opt for the detailing of the punch reinforcements in conjunction with the detailing of the negative reinforcements.

d. Additional

The Detailing of the hairpin and additional rebar.
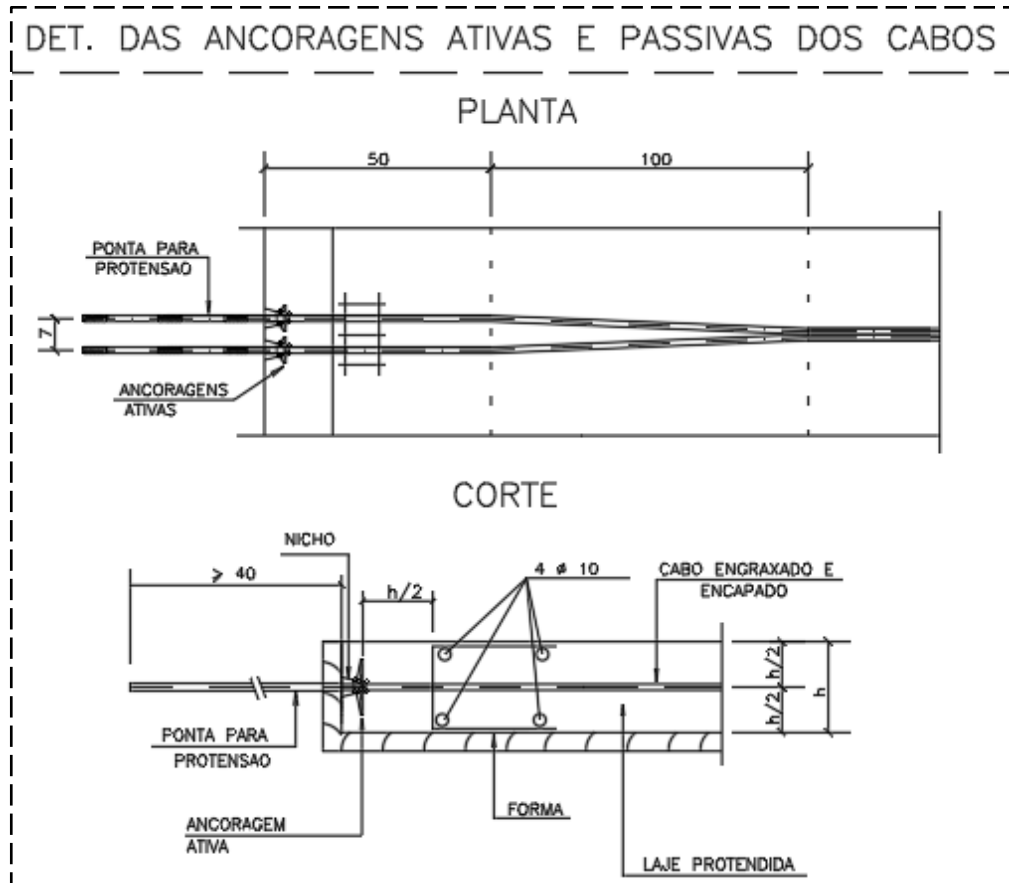
5. DESIGN MANUAL – ADAPT

In this section will be presented the necessary procedures for the development of a design with the PavPlus system using the *ADAPT-builder software*, which adopts the finite element method.

From CAD drawings imported into ADAPT, with the definition of the structural geometry, the launch of the structural elements begins. It is suggested that these CAD files be elaborated with the minimum of layers, containing only the geometric information of the floors.

The use of the program starts from the Edge and Floor-PRO options (Figure Figure 23). And the metric system used in this material will be MKS.
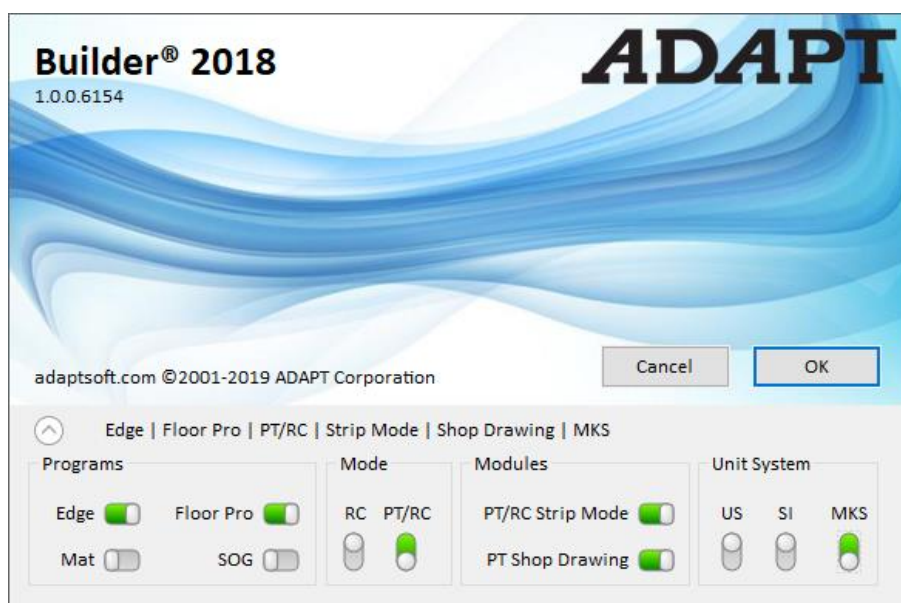

Figure 23 ADAPT-Builder Initial Program Selection Window

After the initialization of the program and with the base form ready, it proceeds with the launch of loads and other information of the floor. This allows the beginning of the steps for the adjustments and considerations necessary for the design of the PavPlus system.

5.1 Editing the Post-tensioned Slab Criteria – ADAPT

Before you start modeling and posting itself, you need to make the settings for:

- Materials: concrete, rebar and post-tensionig;

- Standard to be used for project boundaries and guidelines;

- Analysis and design options;

- Load combinations.

Material parameters and criteria, standard and design configurations can be changed using shortcuts (Figure 24). The configuration of the load parameters is done in the *Loading* tab, along with the *Load Case/Combo* group.

Figure 24 - Shortcuts for editing material criteria, standards, and analysis and design options.

5.1.1 Material Properties

The properties of the materials must be defined by the engineer, remembering that, for post-tensioned structures, the Fck must be at least 25 MPa for aggressiveness class I and 30 MPa for aggressiveness class II, according to NBR6188:2014, table 7.1.

5.1.1.1 Concrete

To change and configure the properties of the concrete, you must select the *concrete* icon. In this item, the properties of the concrete must be changed based on the initial conception of the project and the designer's choice (Figure 25).
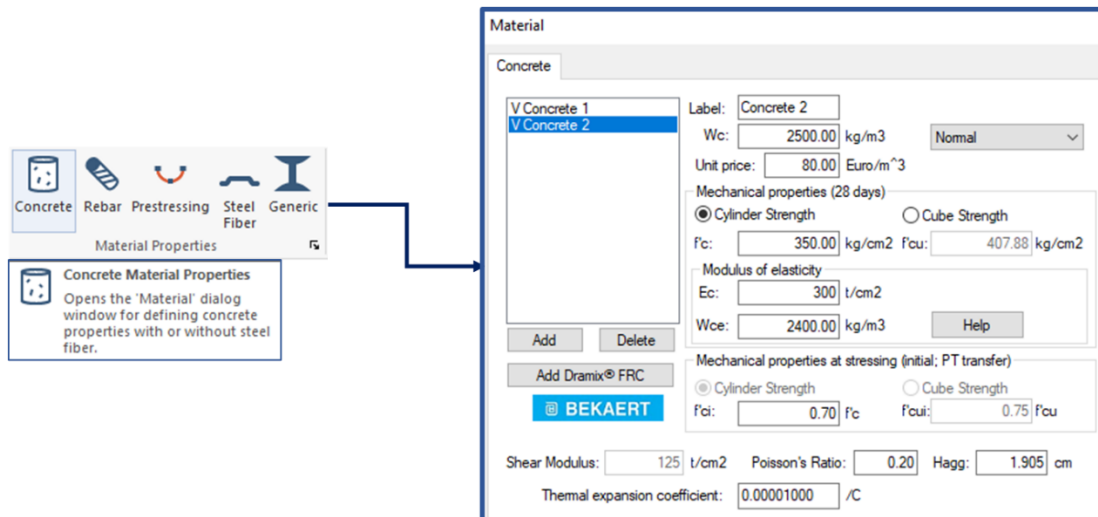
Figure 25 - Criteria and points for concrete configuration in ADAPT

5.1.1.2 Passive Rebar Reinforcement

To change the properties of passive reinforcement, you must select the *rebar* icon and change the steel properties to the CA 50 steel indications (Figure 26). If it is the designer's choice, you can also add more types of steel by clicking "add*".*

Figure 26 - Criteria and points for passive reinforcement configuration in ADAPT

5.1.1.3 Post-tensioning

To change the properties of the active reinforcement, one must select the *prestressing* icon and change the properties of the steel according to the indications of the CP (Figure 27). If it is the designer's choice, you can also add more types of steel by clicking add. In the case of Figure 27 the properties of CP 120 RB 12.7 manufactured by AcerlorMittal are presented:
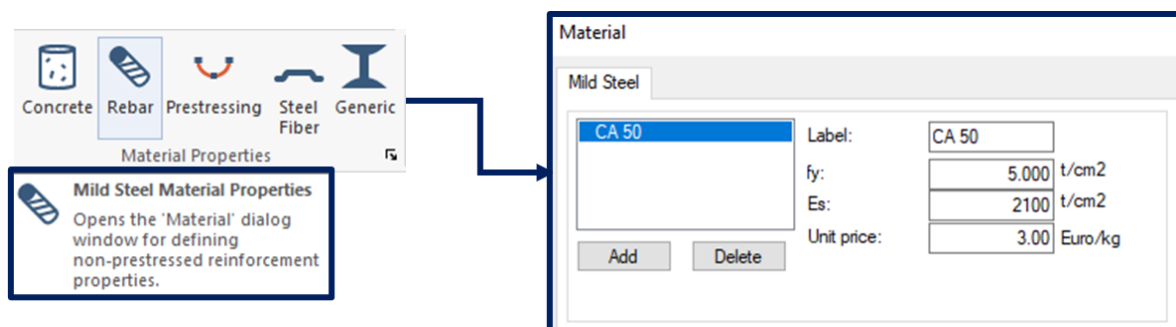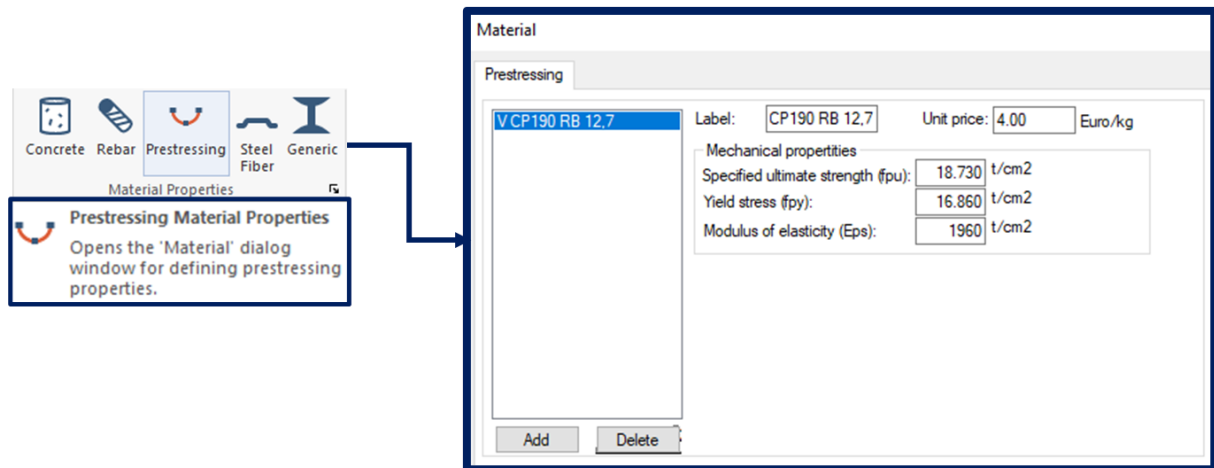
Figure 27 - Criteria and points for configuration of active armor in ADAPT

5.1.2 Standard Criteria and Analysis Options

For the adjustment of the standard criteria, in the case of the PavPlus system, only the (*two-way Slab Criteria)* will be configured. For this, the "*Design Code"* icon will be selected in the "*Design Criteria"* section. After selecting this icon will open a window containing several tabs with the types of structural elements. Following the selected "*Two-way Slab"* criterion, adjustments to the criteria for the PavPlus system can begin (Figure 28).

Figure 28 – Criteria and points for configuration of Standard criteria and analysis in ADAPT

5.1.2.1 Standard Selection

The standard used for the analyses will be the most up-to-date American code in the *software* version, in the case, the ACI 2014/IBC 2015. The selection of the design standard implies, between and others, in the determination of the stress and deformation limits of the parts. During the structural analysis, the indications of the American standard will be followed,

but the guidelines of NBR 6118:2014 will also be obeyed as appropriate. To select the desired standard just access the *Design Code* tab. Also, in this tab will be presented the *strength reduction factors*, which will not be changed and will be maintained the values of 0.90 and 0.75 respectively for maximum bending moment (*Bending mx value; Two-way shear*) and bidirectional shear force.

The choice for the ACI is due to the fact that, in some parameters, it is more restrictive than the NBR. Among these are stresses limits and combinations.

Figure 29 - Configuring Criteria in the Design Code Tab

5.1.2.2 Reinforcement Bar Length

In this section the lengths of the bars will be edited, in the items of minimum length of bars should be informed the relationship between the length of the bars of minimum reinforcement and the length of the span. The default values are 1/6 (approximately 0.17) of the span for the top bars and 1/3 (approximately 0.33) of the span for the bottom bars.

And for the anchorage lengths that are adopted 50 cm to the top and to the bottom. These values are not fixed, they must follow the indications of NBR 6118:2014, item 9.4.2.4. These lengths are adjusted and changed to standard standards after the checks and adoption of the detailing parameters.

Figure 30 - Minimum length criteria

5.1.2.3 Rebar Minimum Cover

In the "*Rebar Minimum Cover*" *tab,* the covers for the top and bottom of the slab reinforcement can be changed (Figure 31). This value should be chosen according to Table 7.2 of NBR 6118:2014, according to the class of environmental aggressiveness appropriate for the project.

Figure 31 - Criteria for editing minimum coverage

5.1.2.4 Preferied Reinforcement Size and Material

In this section can be edited which are the main bars for passive reinforcement to be used for detailing and sizing the pieces, however as the evaluations are made according to the "As" there is no need to initially pre-define these parameters. The other values will only serve to assist and guide this detailing.

Figure 32 - Criterion for defining diameter and preferred material for sizing

5.1.2.5 Shear Design Option

This flap deals with stirrups and studs for slabs, emphasize that by the shape geometries of the PavPlus System the criteria to be adopted for shear are the slab criteria and the punch must be analyzed, both following the indications of the NBR 6118:2014 standard. In this tab it will be indicated which type of armor should be used for the detailing of the shear and punch reinforcements on the slab. And the criteria for the calculation and sizing of the reinforcement for punch. It is at the discretion of the designer to define the type of armor of his preference (Figure 33).

Figure 33 - Criteria for shear and punch reinforcement

5.1.2.7 Rebar Round Up

In this section the *default* values provided by ADAPT will be maintained, in these points respectively the first and the second editable item refer to the rounding up of the length of the bar to multiples of the value informed (Bar *length round up)* and the spacing between multiple bars of the other value (Bar spacing *round down*), in the case of 5.0 cm and 2.5 cm. And the other parameter is related to the rounding up of stirrup *spacing*.

Figure 34 - Criteria for rounding armor

5.1.2.8 Analysis/Design Options

This tab presents some parameters that will be necessary for the development of the model. In this section the *(general analysis/design) option* should include the necessary options so that the model can be compatible with the actual physical model, so in the subgroup (*Both presstressed and conventionally reinforced)* should be marked the options for (*includes waffle/joist construction)* and the option to (Design all "beams" *using the respective building code requirements for "beams*"). These inclusions of the two options refer to the use of beams in the modeling, simulating the ribs in ribbed slabs, an essential point for the development of the PavPlus system in ADAPT.

In the subgroup of (*support conditions at the far ends of walls and columns)*, there are distinct configurations for the mode of an isolated floor and multiple floors. At this point, in addition to the option to (*retain user modification and create the rest as selected below)*, the designer must select *Single-level or Multi-Level* (one or multiple floors). In the isolated floor will be indicated the restrictions of position / displacement and rotation in the desired axes, in this case in only position in the Z axis. When multiple floors are selected, the default will directly mark the option of fixing rotation and deformation will be checked. The option to arm should also be marked when the resistance is greater than the moment of cracking.

Another option that should be checked is in the subgroup (*Minimum rebar option)*, to include the minimum non-post-tensioning reinforcement specified by the standard, adopting a minimum passive rebar for the elements.

Finally the last option to be edited in this tab is related to automation and type of finite element mesh generated, in (*general analysis options)*, at this point can be opted for two types of meshes, more uniform with elements in predominance and spaced meshes, which do not have a uniformization of the elements, varying between shapes and sizes within standards established in the *software*. These meshes can be chosen from the *(Generate uniform mesh)* and *(Generate sparse mesh)* options, respectively uniform and sparse. It is indicated for more regular elements and with a more uniform geometry a uniform mesh, however as in slab

projects the layouts are increasingly challenging and innovative, it is indicated to opt for a sparse mesh to suit the different types of *layouts.*
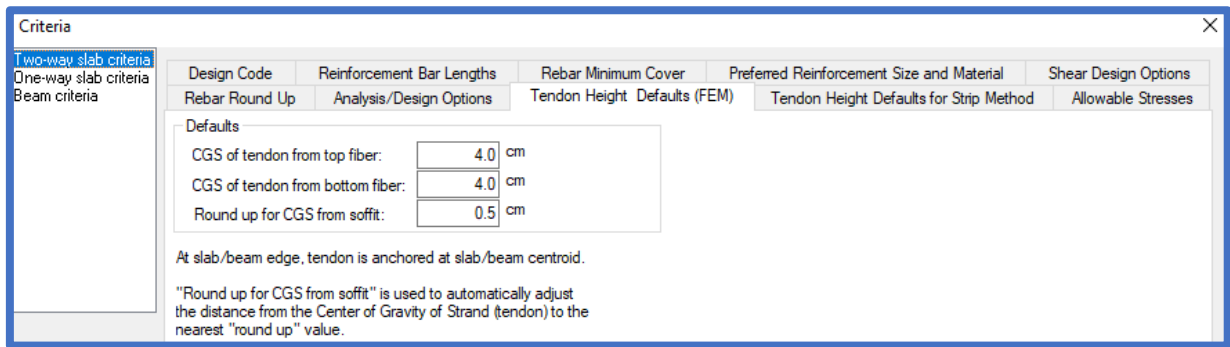
Figure 35 - Analysis and design criteria

5.1.2.9 Tendon Height Defaults (FEM-Finite Element Method)

This section refers to the maximum and minimum points of the tendons strokes that will be used by the *software* to perform finite element processing (FEM). These values can be configured in:

- *CGS of tendon from top fiber*: **4.0 cm**;
- *CGS of tendon from bottom fiber*: **4.0 cm**;
- *Round up for CGS from soffit*: **0.5 cm** (The last of these values means that the cable ordinate will be rounded up from 5 mm to 5 mm).

Figure 36 - Tendon Elevation Criteria

5.1.2.10 Allowable Stresses

In this session, the permissible values are usually treated for the stresses acting on the concrete according to the combination of loads. Traction limits are presented as multiples of fc'1/2 (fck1/2). The compression limits are presented as multiples of fc' (fck). Both with their value expressed in kgf/cm².

The predefined values based on ACI 318-14 (ACI, 2014) lead us to the limits of traction and compression as a function of the Fck and the metric system adopted, because the weighters varies according to the units, to verify the difference between the MKS, SI and American systems, see Appendice C of ACI 318-14.

The traction limit fctk,inf defined in NBR 6118:2014 (item 8.2.5), more restrictive than that defined by the American standard. However, we will see later that the load combination for verification of service limit states is more robust in ACI than in NBR, because NBR 6118:2014 uses the frequent or near-permanent combination, while ACI 318-14 uses the full load combination.

In the act of pretension, the limits for traction and compression presented in NBR 6118 (item 17.2.4.3.2 combined with item 8.2.5), is less restrictive than the ACI.

Seeing the differences of each code in relation to the permissible voltages, it is suggested to maintain the predefined values, that is, those recommended by the ACI 318-14. Table 7 presents the differences between the voltage limits in the ICA and NBR.Table 7

Table 7 Stress Limits NBR 6118/2014 and ACI 318-05

Maximum permissible stresses	In the act of post-tensioning (after initial losses)		In ELS-F (Cracking after all losses)	
	ACI 318-05	NBR 6118/2014	ACI 318-05	NBR 6118/2014
Compression (Mpa)	$0,6 \cdot fci'$	$0,7 \cdot fckj$	$0,45 \cdot fc'$ $0,60 \cdot fc'$	Does not indicate
Tension (Mpa)	$0,25\sqrt{fci'}$	$0,36\sqrt[3]{fck^2}$	$0,5\sqrt{fc'}$	$0,315\sqrt[3]{fck^2}$
Tension f/ Fck=30MPa Fckj=20MPa	1,12 MPa	2,65 MPa	2,74 MPa	3,04 MPa

> Due to post-tensioning plus permanent loads (sustained loads)
> Due to post-tensioning plus total loads

> Obs.: The lower allowable compressive stress for the quasi-permanent combination is justified by the ACI to prevent concrete failure due to repeated loads and to lessen the effects of slow concrete deformation.

As mentioned at the beginning of this chapter, the metric system used in the *software* was the MKS, because it presents the values of tensions in kgf/cm². So, to fill in the values in this section are indicated in Figure 37.

Figure 37 – Criterion of voltage limits using MKS.

5.1.3 Load Combinations

To define the load combinations, we must access the *Loading* tab and click on the *Load Combination* icon. A window containing a table opens. In the first column of the table (*Label*), you have the title of each combination. By default, according to the selected standard (ACI 318-14), there are five combinations already defined, which will be the only ones we will use. However, the value of some coefficients will be changed, as follows:

a. *Service (Total Load)*:
$$1,0 \times PP + 1,0 \times Perm + 1,0 \times Acid + 1,0 \times Prot$$
b. *Service (Sustained Load)*:
$$1,0 \times PP + 1,0 \times Perm + 0,4 \times Acid + 1,0 \times Prot$$
c. *Strength (Dead and Live)*:
$$1,4 \times PP + 1,4 \times Perm + 1,4 \times Acid + 1,0 \times Hiper$$
d. *Strength (Dead Load Only)*:
$$1,4 \times PP + 1,4 \times Perm + 1,0 \times Hiper$$

e. *Initial*:

$$1,0 \times PP + 1,2 \times Prot$$

The meanings of the abbreviations are as follows:

- PP – *selfweight*;

- Perm – *dead load*;

- Acid – *live load*;

- Prot – *prestressing*;

- Hiper – *hyperstatic*.

At the end of the changes, the table should look like the one shown in Figure 38.

Figure 38 - Table of configured load combinations.

In the service combinations (ELS), we decided to design in favor of safety, adopting the full load combination instead of the frequent load combination recommended by the Brazilian standard. In the second combination, we arbitrate that 40% of the accidental load will be of long duration, causing deformations by creep of the concrete.

In the last combinations (ELU), we changed to more the weighting coefficients of proper weight and permanent load (which are predominant in this project), and to less the

weighting coefficient of accidental loads. Thus, these combinations are in accordance with Table 11.1 of NBR 6118:2014.

Finally, the combination for the act of post-tension meets both the American and Brazilian norms. ACI 318-14 (ACI, 2014) requires an increase in the post-tension force by 15% (coefficient 1.15), while NBR 6118:2014 prescribes an increase of 10% (coefficient 1.10, item 17.2.4.3.1-a) for simplified verification of safety at this stage. Both standards require that the maximum compressive stress of concrete does not exceed 70% of the characteristic strength of the material relative to age at the time of pretension.

5.2 Model creation

During the creation of the model in ADAPT it should be paid attention to some criteria to be adjusted so that the model is in accordance with standards of norm and good practice for the development of the model using the PavPlus system, analogous to the processes in TQS. It must be defined whether the entire building will be modeled in ADAPT or only one floor will be solved in isolation. If the case is the complete building, the wind conditions must be adjusted to the parameters used in the Brazilian standards.

The purpose of the manual is not a comparison between standards or to present the necessary procedures for modeling a building using the ADAPT *software*. For these points and better understanding of the *Software* see material specific to the subject.

In this section will be presented some points necessary for the treatment of PavPlus type slabs in ADAPT. As mentioned in the TQS section, the system resembles a model of flat slabs, with ribbed regions in the regions of positive momentum, without beams and supported by columns.

5.3. Designing

The model must follow the limits of the architecture and conditions imposed by it. For the launch of the PavPlus slab in ADAPT, after the launch of the columns with the defined limits of the total slab, the launch of the ribs can begin. Figure 39 shows an example of a fully modeling pavement with ribs, beams, slabs and columns.
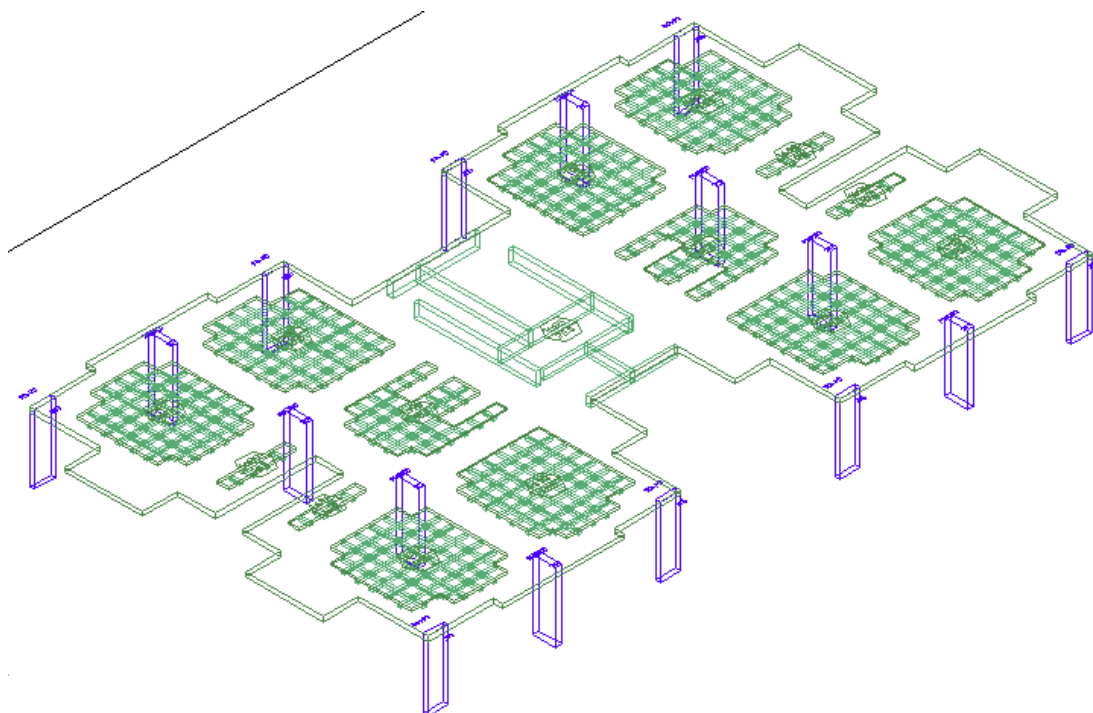
Figure 39 ADAPT modelled pavement

For the development of the model one must have the massive and ribbed regions of the slab well defined. With this it is possible to model the slab and the ribs. Initially, the slab element is launched with the appropriate thickness, after inserting itself into the contour of the region with ribs plus a slab that will serve to model the concrete layer on the ribs. And with this, the elements of beams that will represent the ribs are inserted (Figure 40).
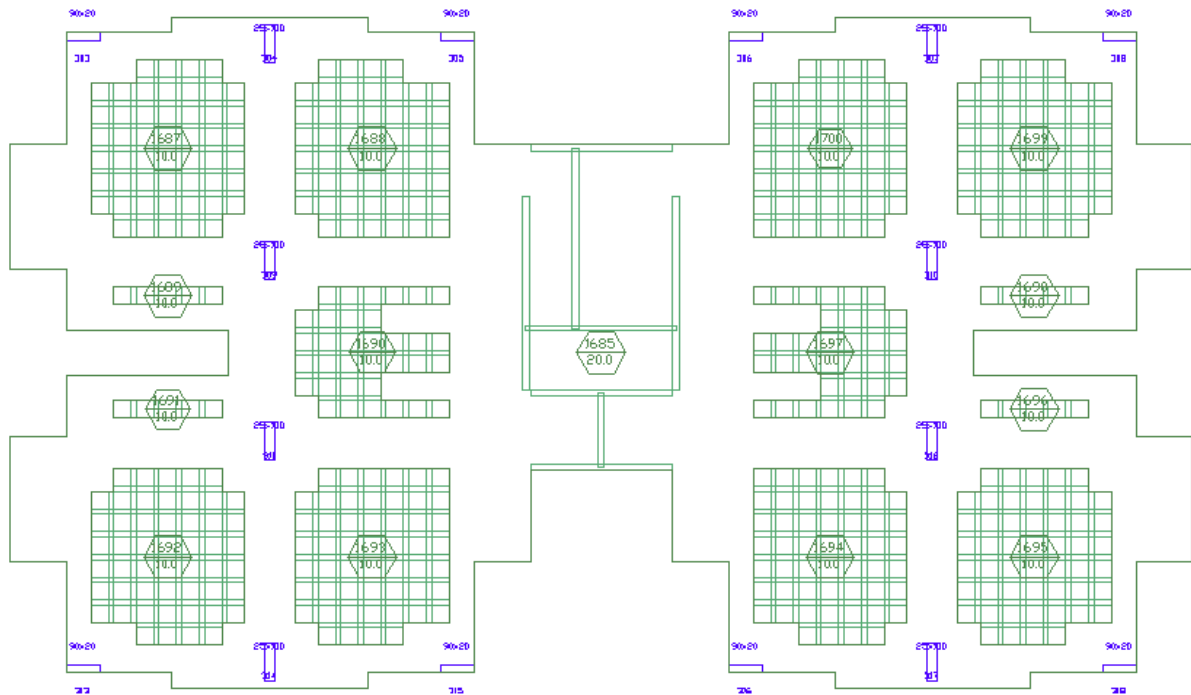
Figure 40 - Defined shape with the massive and ribbed regions of the slab.

i.   Launch of the Waffle Molds

Some care and procedures must be followed during this release. After defining the type of wallet mold and thickness of the concrete layer (above rib), the editing or launching of the ribbed slab can begin (Figure 41).
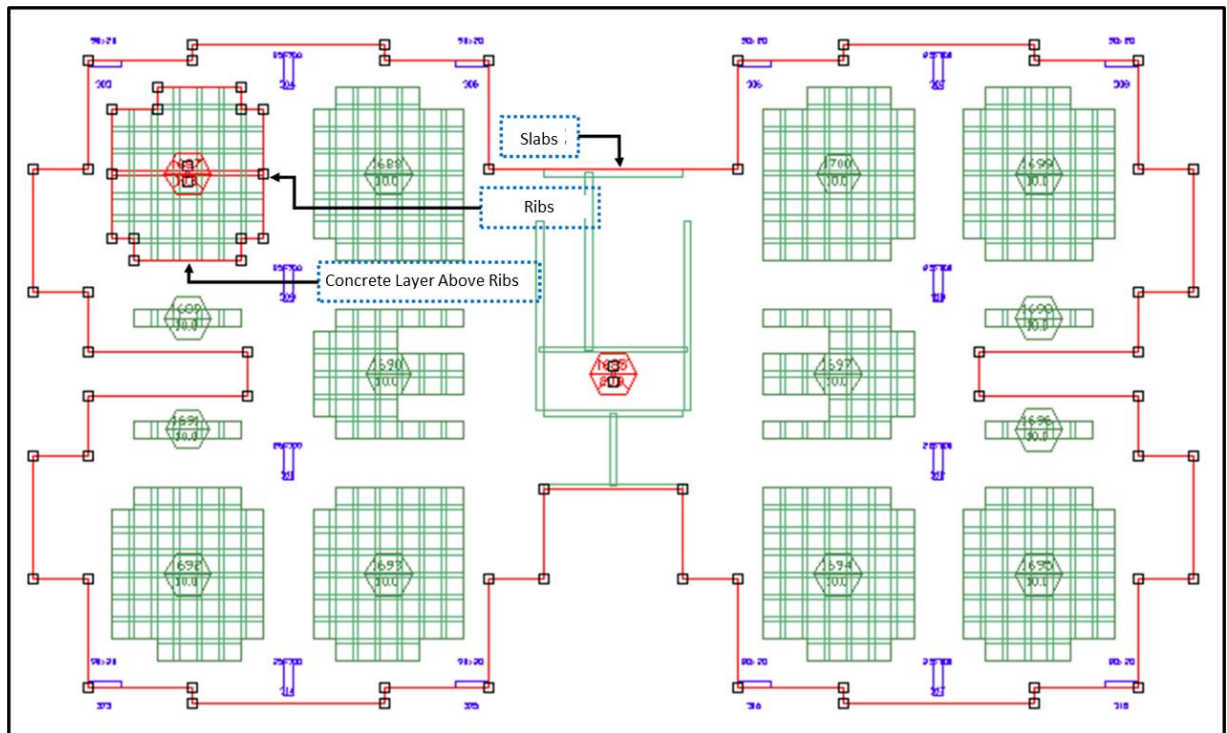
Figure 41 - Indications of each slab component in the model.

The concrete layer above ribs must have the desired layer thickness and is cast as a slab in the region with delimitation around the waffle mold, and the beams representing the ribs have the thickness of the midrib and height of the waffle mold, and must be inserted with a recess, (indicated in the program with *offset*), (Figure 42).
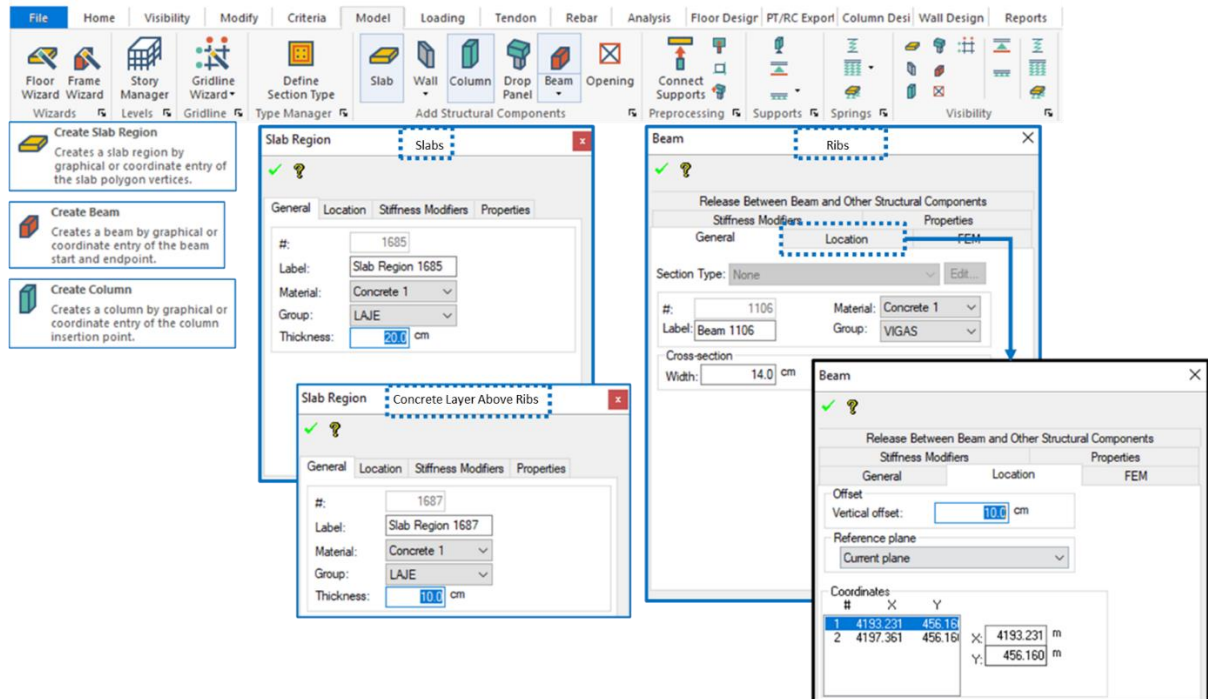
PavPlus

Figure 42 - Items and indications to insert slabs and beams that make up the PavPlus slab.

ii.   Indications and Comments

The same indications of distribution of massive and ribbed regions, see the items indications and comments in section 4.4 of this manual. For the comments and indications of good practices for the distributions of massive regions, ribs and tendons are commented on this point.

5.4 Post-tensioning tendons

Defining the amount of tendons is an iterative process, that is, an initial estimate must be made and, according to the results of the analysis, modify the *layout* of cables as many times as necessary. The initial estimate is based on the minimum average precompression required by the standard. NBR 6118 (ABNT, 2014) specifies, in item 20.3.2.1, that the maximum spacing between tendons should not exceed the value of six times the thickness of the slab, nor 120 cm. In addition, the same item requires that the average compression stress be equal to or greater than 1 MPa.

PavPlus

To achieve the minimum of 1 MPa (approximately 10 kgf/cm²) of precompression, we must imagine that each 12.7 mm string of CP-190 applies an average final force of 12 tf.

To add a cable bundle to the model, we must access the (*Tendon)* tab and click on the *add tendon* icon in the *Model* group, Figure 43. It is indicated to have a control point of the tendon 5 cm from the ends where the tendon will start and die, as well as points on the supports between the beginning and end of the tendon. At the end of the insertion, double-click on the tendon to open its properties window, Figure 44.
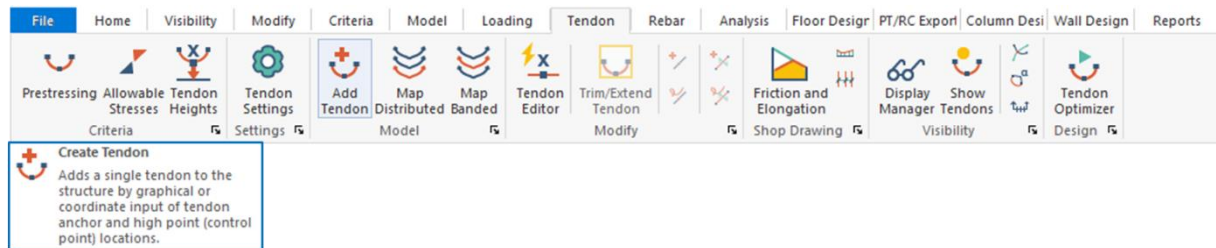
Figure 43 - Icon for Inserting Cables

In the properties window, in the General tab, you must make the following adjustments:

- *Group*: **Prot Hori**;
- *Material*): **CP-190**;
- *Area per strand*: **1.00 cm²**;
- *Tendon/duct height*: **1.6 cm**;
- *Number of strands*: **The number based on the pre-design for at least 1 MPa of compression**.
- *Mode*: ***Straight Line***.

Figure 44- Configuring the General tab of the cable properties

Before proceeding to the next tab, it is indicated to click on the green *check* icon to save your changes. Then, in the *Stressing* tab, you should change the following:

- In the group *Post-Tensioning Design Option*, check the option **Calculate Force**;
- *First end: **Dead Live** Last end*;
- In *Last End*:
  - *Seating loss:* **0.7 cm**;
  - Select **Jacking stress/f$_{pu}$**;
  - *Stress/f$_{pu}$*: **0.8**;
- *Long-term stress loss*: **1.0 tf/cm²**.

At the end, the *Stressing* tab should be configured as in Figure Figure 45. This configuration will serve both for all tendons of the model. This definition refers to the first inserted end of the tendon that will be the dead-end, while the second will be the live end. It was also defined that during the application of the wedges, there will be a loss of 7 mm of the applied elongation. The tension applied by the post-tension jack is equivalent to 80% of the last tension resisted by the strand ($0.8 \times 18.7 \approx 15$ tf/cm²). In addition, we agree that the long-term tension loss will be 1.0 tf/cm².

PavPlus
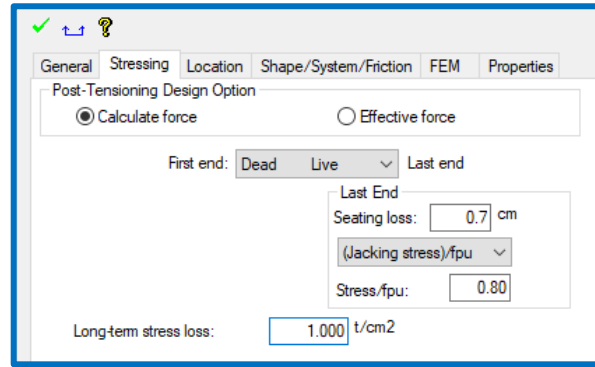
Figure 45 - Configuring the Stressing tab of Cable Properties.

By clicking on the green *check* icon to save, the last changes we will make will be in the *Shape/System/Friction* tab. In this tab, we can see a representative profile of the tendon generated in real time. It shows us what are the dead and live ends, the minimum and maximum points measured from the bottom and top of the slab, respectively, as well as the size of the span(s) and the value of the radius of curvature, when the tendon has height variation.

In the table below the automatic profile, each row represents a span. Our tendon has only one span (*Span 1*), so there is only one line beyond the *Typical* line. Changes made to the *Typical* line will be applied to all spans. We can make changes to it or to the *Span 1* line. The changes are as follows:

- *Shape*: **Straight**;
- *CGS Top First*: **6.7 cm**;
- *CGS Top Last*: **6.7 cm**;
- M_u (coefficient of friction cable-duct): **0.07**;
- *Wobble* (coefficient of angular friction): **0.0035 rad/m**;

The center of gravity (CG) of the tendons would coincide with the center of gravity of the slab, to prevent bending moment from being transmitted to the columns mainly at the start and end points of them. And in the regions of maximum and minimum tendons must be at a distance from the lower and upper face, respectively, of active armor coverage + 0.8, for covers of 3 cm the distance from the face is 4 cm. It should be noted that the tendons in both directions have profiles and elevations that can end up generating conflict at intersections.

PavPlus

Thus, the convention is adopted to increase the ordinates of the cables in the distributed regions of cables a distance from the face with 1.6 cm more than that considered for those of the other direction. This value is the outer diameter of the sheath. Thus, the cables in perpendicular directions are tangential to the maximum and minimum points. In ADAPT, these values are of the maximum and minimum points measured from the faces of the slab.

To adjust the tendon stroke, the values of the distance from the tendon axis to the faces and types of strokes must be entered in the *Shape/System/Friction* tab. The tendon should have a parabolic tracing to accompany the bending moment diagram. Thus, at the output of the tendon it presents a straight line and for the maximum and minimum points are suitable for the reverse parabola profile. In the region over the columns, it is indicated that the tendons pass straight over the columns and for this purpose points are inserted at a distance of 1.5h for each side of the column following the distribution of the negative reinforcement, Figure Figure 47.
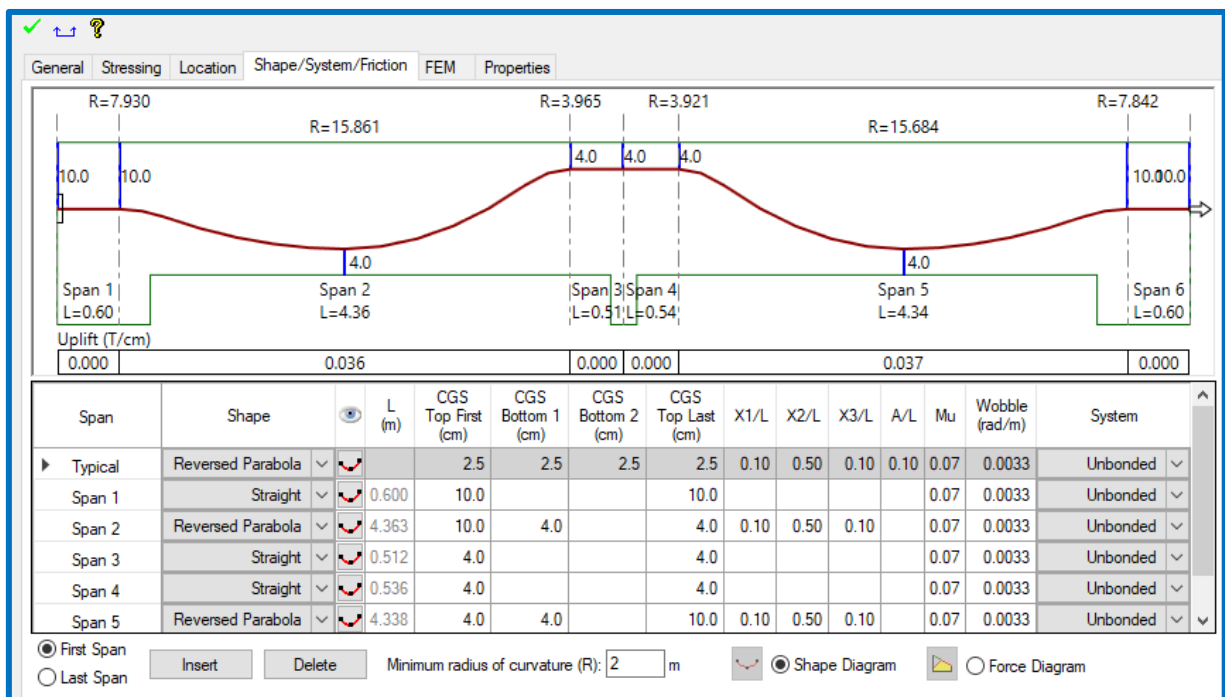
Figure 46 - Configuration of the *Shape/System/Friction* tab of the elevation and treaçado properties of the tendons.
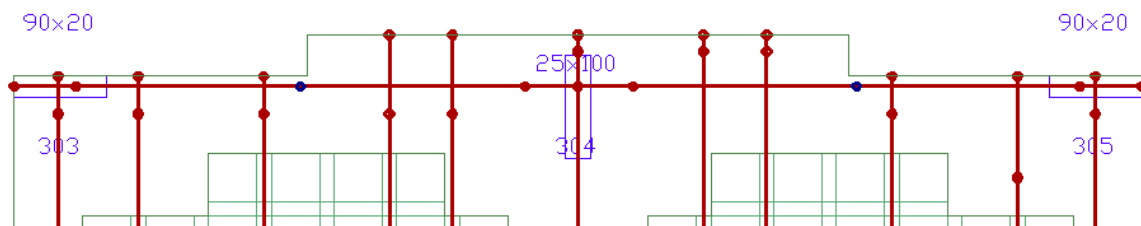
Figure 47 - Tendon Layout in Plan

i.   Concentrated and Distributed Tendons

For definitions in the direction of concentrated cables, a maximum of the width of the pillars plus 3.5h for each side of the pillar should be had. After defining the width and insertion of the cable represented by a concentrated cable bundle, Figure 48. It is indicated to separate the horizontal and vertical cables into groups.

The distributed tendons are launched in the orthogonal direction to the concentrates and pass through the midpoints of the rib and are distributed within them, being able to present themselves in all the ribs, or interspersing them in two and two, concentrating two or even 3 cables per rib. They can also be found in delimited regions, Figure 48.
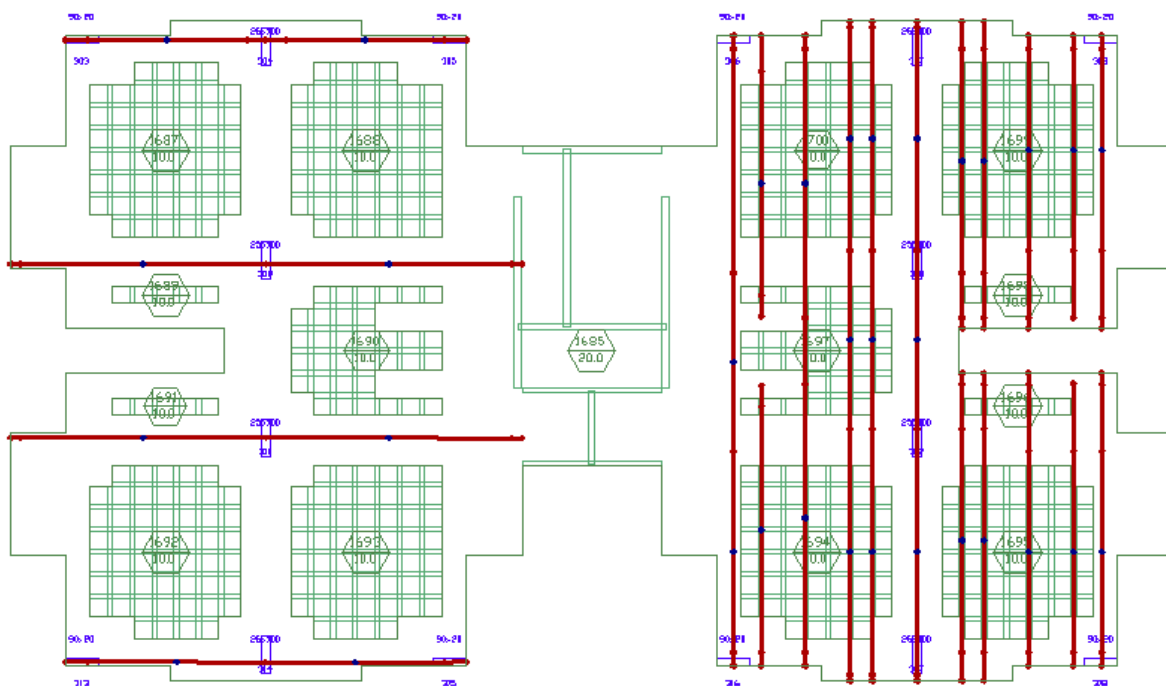
Figure 48 - Representation of the cables concentrated in plant

In section 4.4 of this manual are presented some parameters and criteria regarding the distribution of tendons for use in the TQS software, however as these parameters are for distribution and layout considerations applies to the launch of them in ADAPT as well. It is worth mentioning that, during the structural analysis, it is very common that it is necessary to make adjustments in the model: in the number and position of the tendons, in the thickness of the elements and even in the distribution of the waffle mold, if it is verified that the tension in the elements exceeds the limits of permissible stresses adopted.

5.5 Analysis

After launching all the structural elements in the floor and the tendons, it is suggested the generation of the mesh in finite elements to evaluate the consistency of the model and a quick check of the mesh distribution (Figure 49). For more information and specific materials on the subject of knitwear in ADAPT visit the technical notes section of the website, Builder Technical Notes | ADAPT Software Help (wordpress.com).
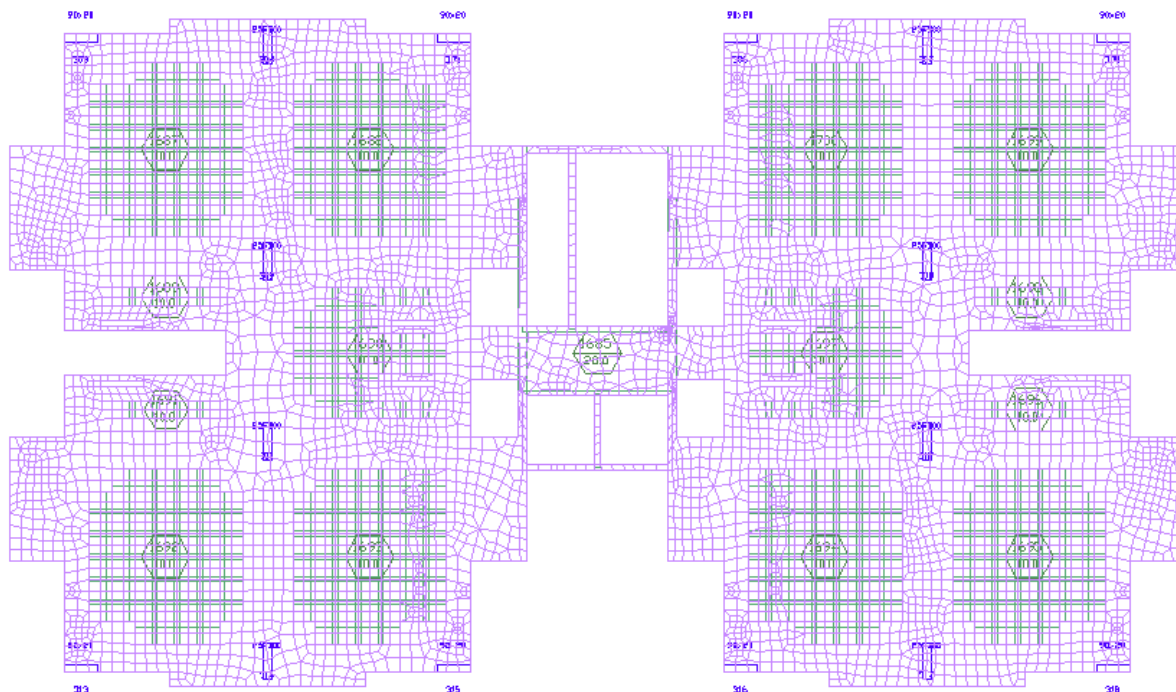
Figure 49 - Mesh Distribution

5.5.1 Support Lines e Design Sections

In the FEM, all the analysis is performed by means of the finite element mesh, without the need for arbitration of a load path, unlike what happens in the equivalent gantry method. It is for this reason that we do not need to define anything other than the size of the mesh elements to perform the analysis. However, to visualize some of the results, it is necessary that we trace the so-called *design sections*, which cut the elements of the mesh and show us an integration of the efforts acting there.

Design sections are transverse to an arbitrarily defined axis that connects the support points of the slab. For each alignment of supports, in *the x* and *y* directions, there must be one of these axes, it is no wonder that such axes are called support lines. Between two parallel support lines, lines are drawn at half distance from each, forming the tributary regions of each *support line*, which define the lateral boundaries of the *design sections*Figure 5050*).*
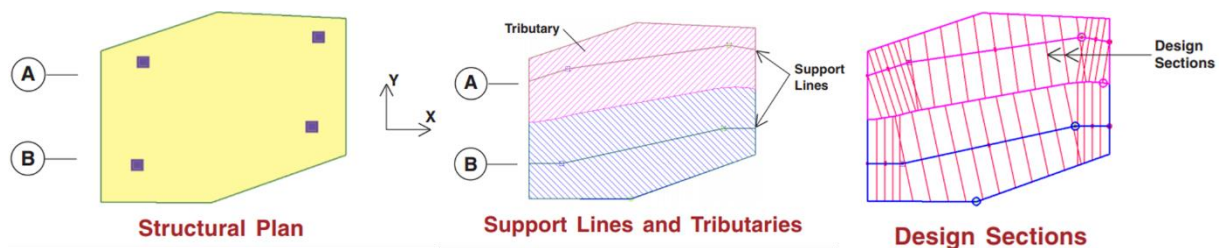
Figure 50 - *Support lines* and *Design Sections* schematic representation. Source: (AAlami, 2001).

The *support lines* are divided with reference to the axis, x and y, so one must launch separately on each of the axes. With the mesh off, to facilitate its insertion just go to the *Floor Design* tab and click on the *icon create X/Y Support line*, from the *Strip Modeling* group. As the slab has well-defined supports, columns, the support line should be inserted by clicking on the centroid of each aligned support, (Figure Figure 51). These lines define a region of influence of the efforts and how this distribution will be on the slab (Figure 52). In addition to the support *lines* when there are cutouts or other types of regions that delimit or depradronize the uniformity of the region generated by the delimitations of the *support* line, splitters should be inserted in the X and Y directions (Figure 53).

PavPlus
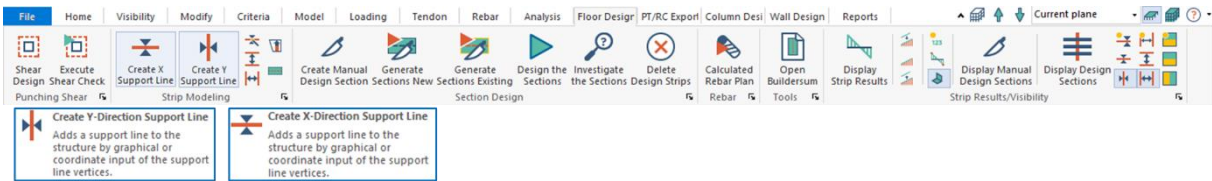
Figure 51 - Inserting *Support Lines*
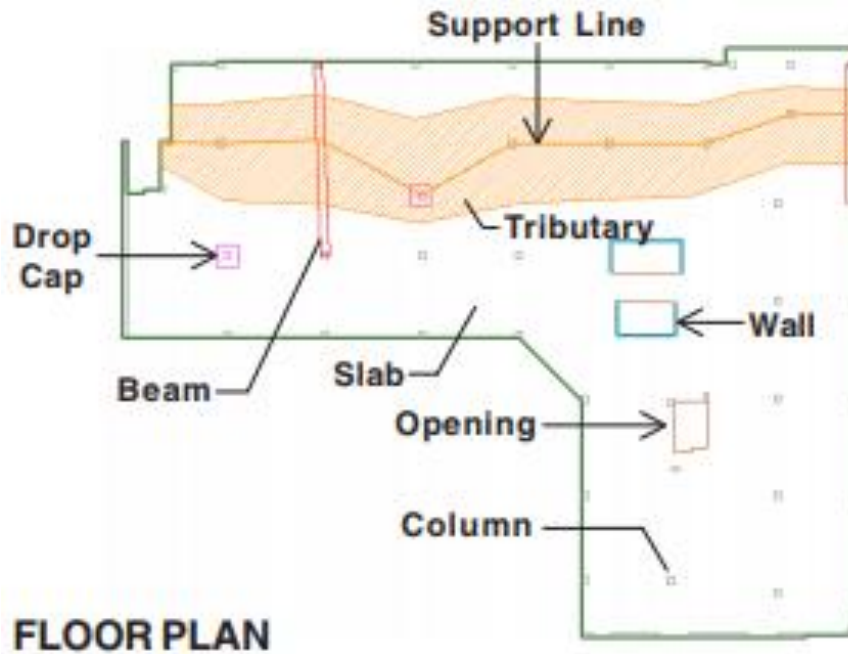
Figure 52 – *Support lines* on columns and representation of the tributary region on a floor. Source: (Aalami, 2001)
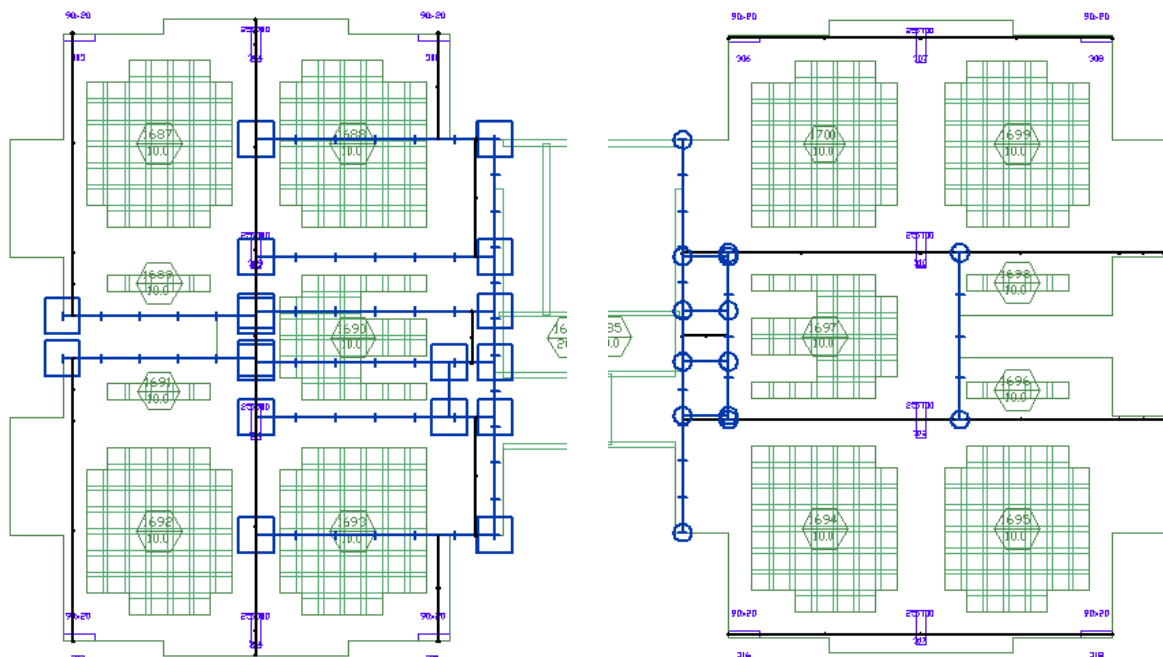
Figure 53 - *Support Lines* and *Splitters*, vertical and horizontal, respectively left and right side.

PavPlus

To automatically generate *design sections*, you must go to the *Floor* Design tab and click the *Create Sections New* button in the *Section Design* group (Figure Figura 54). After the generation of the *Design Sections* should appear several segmentations perpendicular to the *Support Lines* result should be as shown in Figure Figure 55. If it is of interest to the reader, it is indicated to see comments on the subject in the book *Post-Tensioned Buildings: Design and Construction*, (Aalami, 2014).
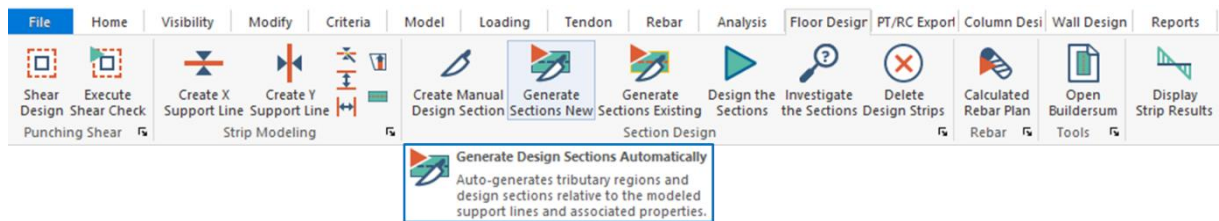
Figura 54 – Ícone de geração das *Design Sections*.
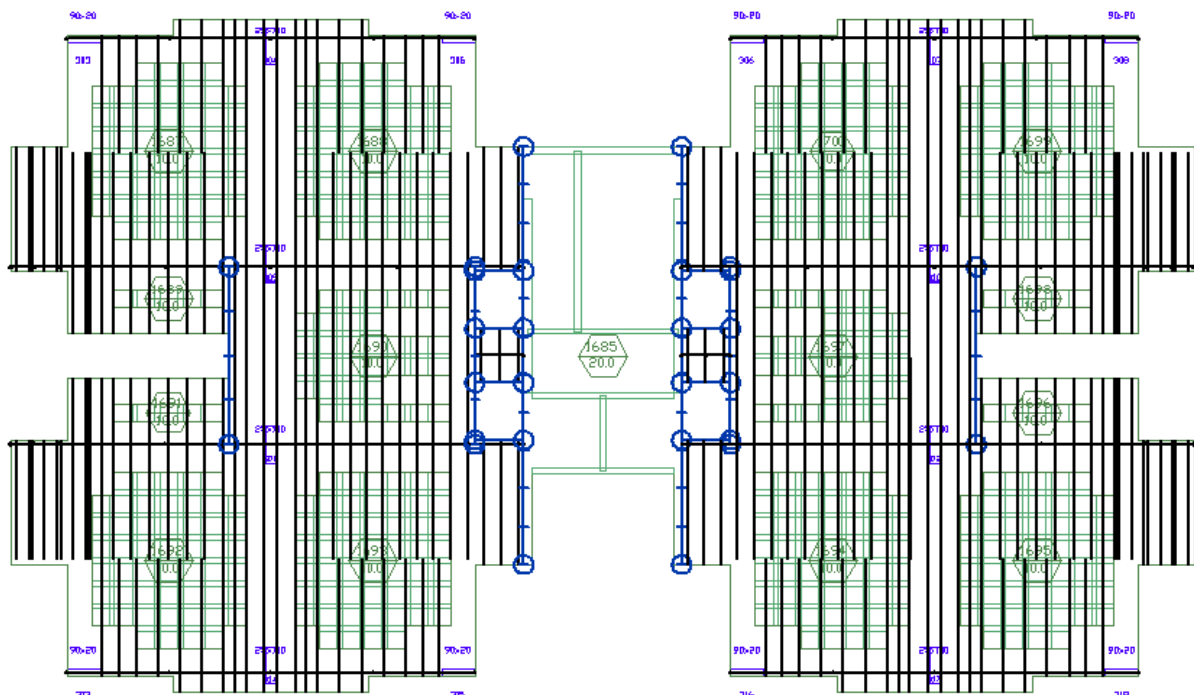
Figure 55 - Model with horizontal *support lines* with Splitter boundaries and *design sections*.

The next step is to transfer the results of the finite element mesh to the design sections, that is, to calculate them. This should be done right after all analysis, with the mesh generated. To calculate the design *sections*, click the *Design* the Design Sections button in the Section Design group of the *Floor Design* tab. When the program informs you that the sections have been drawn and asks if we want to save the template, just click yes. The results preview

window will open again. However, we will see that in the *Analysis* tab, a new group has been added: *Design Sections, (*Figure 56*).*

In the new group, there is a subgroup that interests us a lot, *Stresses*. Within it, we have four viewing options:

- *Top*: shows the stresses on the upper fibers of the section;

- *Bottom*: shows the stresses on the lower fibers of the section;

- *P/A (Precompression FEM)*: shows the pre-compression calculated by the FEM;

- *P/A (Precompression # of tendons)*: shows the precompression calculated by dividing the total force of the tendons by the section area.
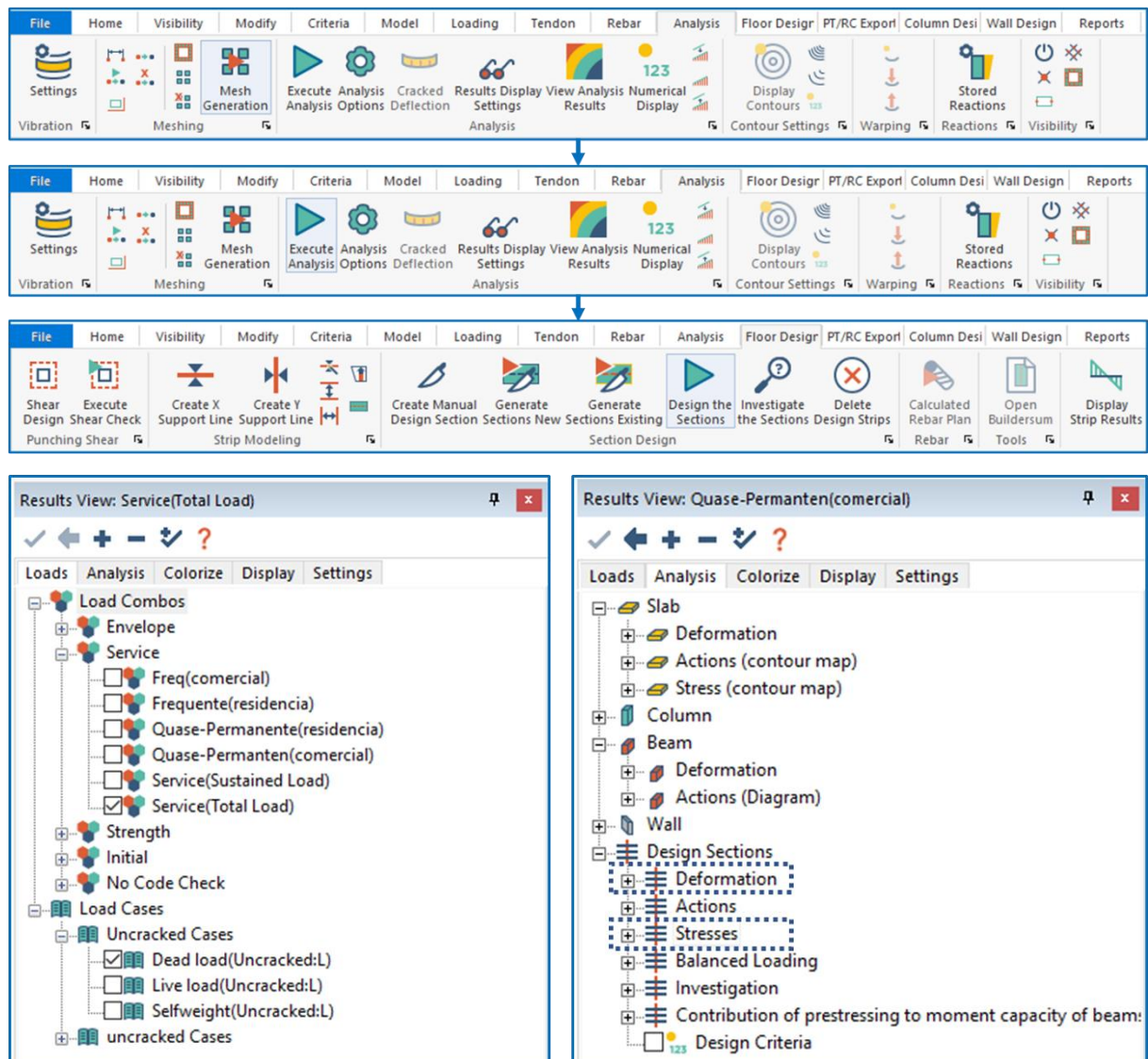
Figure 56 - Flow to perform floor processing

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These options are colored in green (*OK*) or red *(Not Good)* according to the fulfillment of the tension criteria that were established before the modeling. On each *support line*, a graph proportional to the pre-compression value will be drawn. In the upper left corner of the screen are the maximum and minimum pre-compression values (based on the two directions). All points should be checked, from pre-compression to tensions acting on the upper and lower fibers, respectively, the *Top* and *Bottom* options and checking both directions. In order for there to be no cracking of the concrete, we must keep the tensile stresses below the limit. The program automatically marks in magenta color the sections with exceeded limit. At this point, adjustments to the tendon paths should be developed for a better use of the post-tensioned system or, when necessary, increase the number of tendons in the region where the problem occurred.
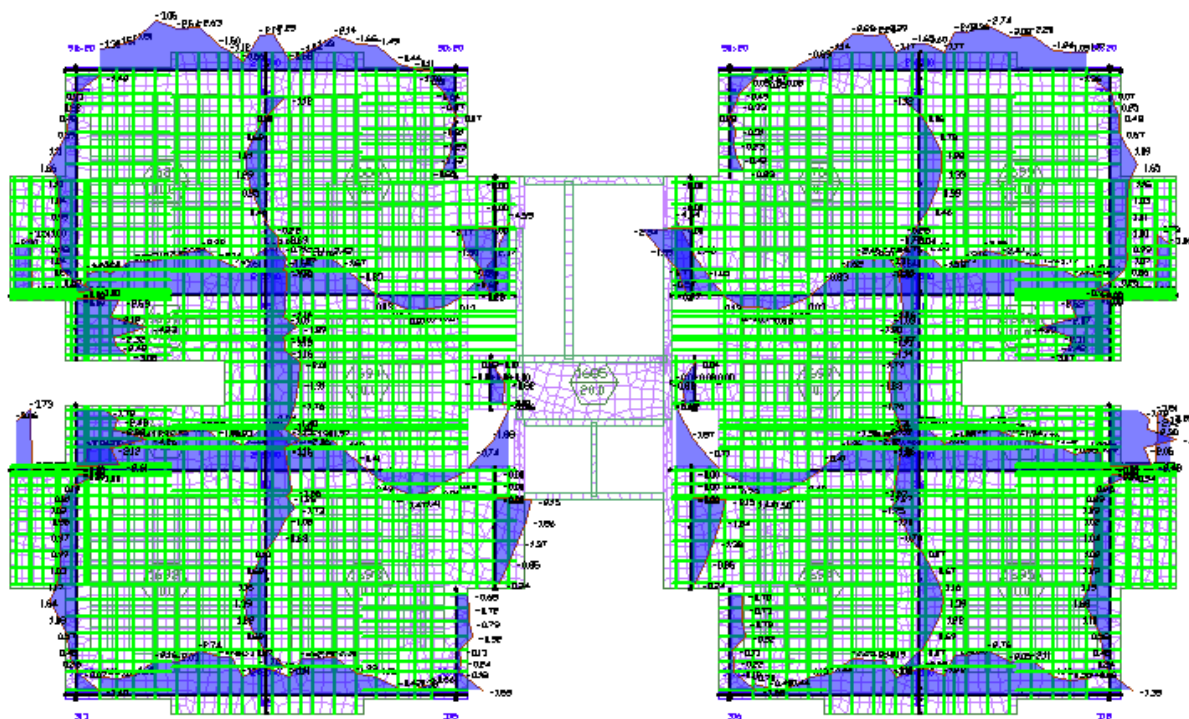
Figure 57 – Diagram of stresses on the lower fiber.

After the necessary adjustments, the model must be reprocessed and be able to meet the criteria of maximum tensile stresses and minimum pre-compression stresses, so that the window of visualization of the results presents the configuration shown in Figura 58.

PavPlus
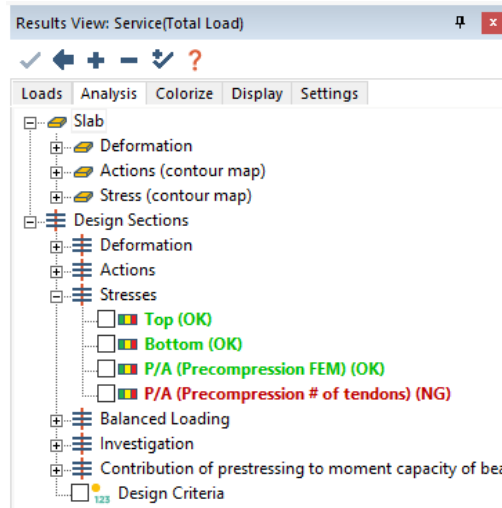
Figura 58 - Atendimento aos limites de tensão.

In some cases, the pre-compression option based on the number of tendons is marked in red, indicating non-compliance, one should analyze the option based on the MEF, as it is more accurate and check the maximum and minimum values.

5.5 Passive Rebar Reinforcement

After the evaluations of the tensions, the passive reinforcements generated are checked and, from there, the diameter of the welded steel mesh or rebar that will be used is defined. In the *Generate* group of the Rebar tab, the *Calculated Rebar Plan* icon to open the rebar calculation window. It is suggested to configure the program to show only rebar necessary to resist the requesting efforts, without taking into account the minimum rebar. Then, the setting in the opened window should be as follows:

- In group *Load Combination*:
  - Select the option ***Envelope Strength***;
- In group *Bar Length Selection*:
  - Select the option ***Calculated Lengths***;
- In group *Bar Orientation*:
  - Select the option ***Angle from global x-axis for bars along support lines in*)** **and keep the default values**.

This same configuration can be seen in Figure 59.

PavPlus
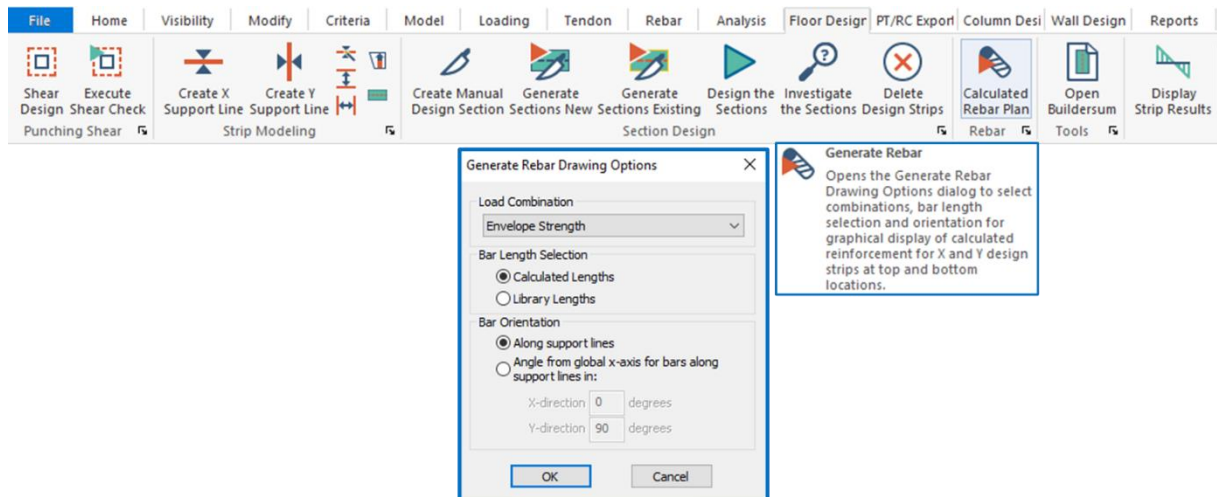
Figure 59 - Passive Armor Generation Window Configuration.

By default, the rebars in red are the background rebar (*Bottom* – B) or positive, the rebar in green is the top (*Top* – *T*) or negative. After the generation of the necessary rebar calculated in the program, it is possible to evaluate where there is a need for rebar addition, comparing with the minimum rebar for the slab, positive and negative rebar (Figure Figure 60).
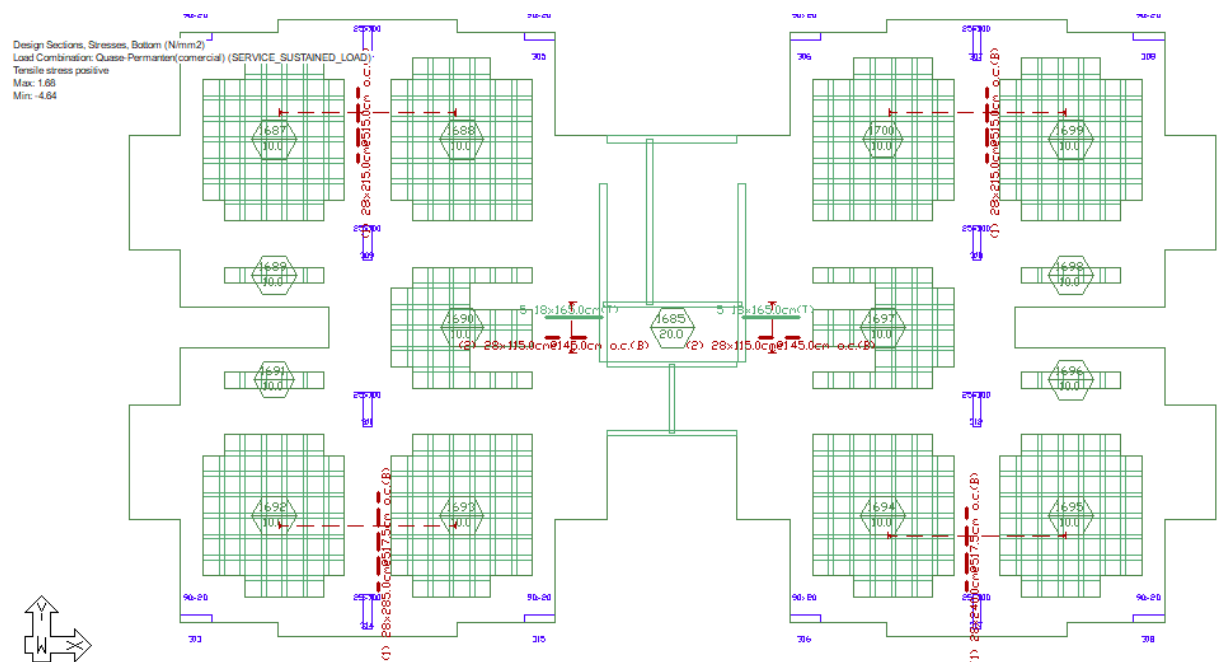
Figure 60 - Model with rebars for the ELU.

To calculate the minimum reinforcement and indications such as how it will be distributed on the slab, positive and negative, see sections 4.4 and 4.5 of this manual, one should also check punch and shear, (Figure 61).

IMPACTO PROTENSÃO

PavPlus
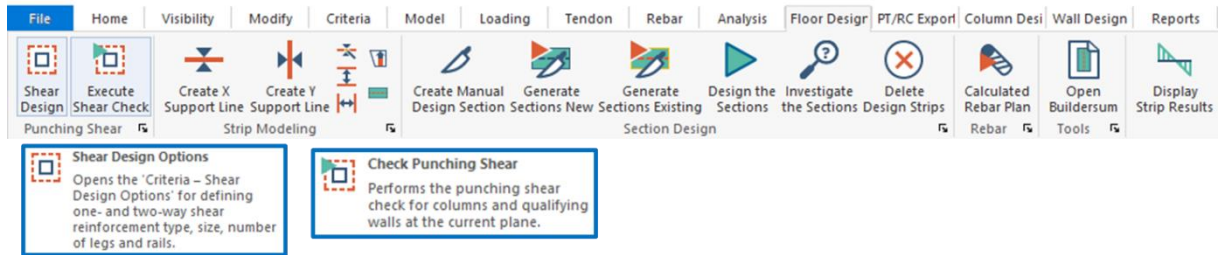
Figure 61 - Punch Check.

5.6 Reports

To aid in the detailing of the project and quantification of the materials, ADAPT has a tab called *Reports*. In it, there is the option to generate reports of the amount of each type of material used in the model (concrete, passive reinforcement steel, welded steel mesh, post-tensioning tendons, etc.), reports of applied loads, reports of reinforcements to combat punch (if it has been analyzed) among others.

Comments:

- In the table generated In the report, which contains the bundles, the length of each cendon does not include the tips that should be left for the act of post-tension. For each post-tension tip, at least 40 cm shall be added to the length of the strand;

- The weight of the tendons should be calculated using the specific weight of the cendons reported in this material, the table does not include the weight of the sheath, so the need to recalculate total weight.

For the detailing of the tendons, one must follow the flow presented in Figure 62(ordered) and define the spacing every 61 cm, see section 3 and 4 of this material, ask to view the spacing between tendons and display the elevations by clicking on any point outside the slab to appear the drawings of the elevations and elongation information.

PavPlus
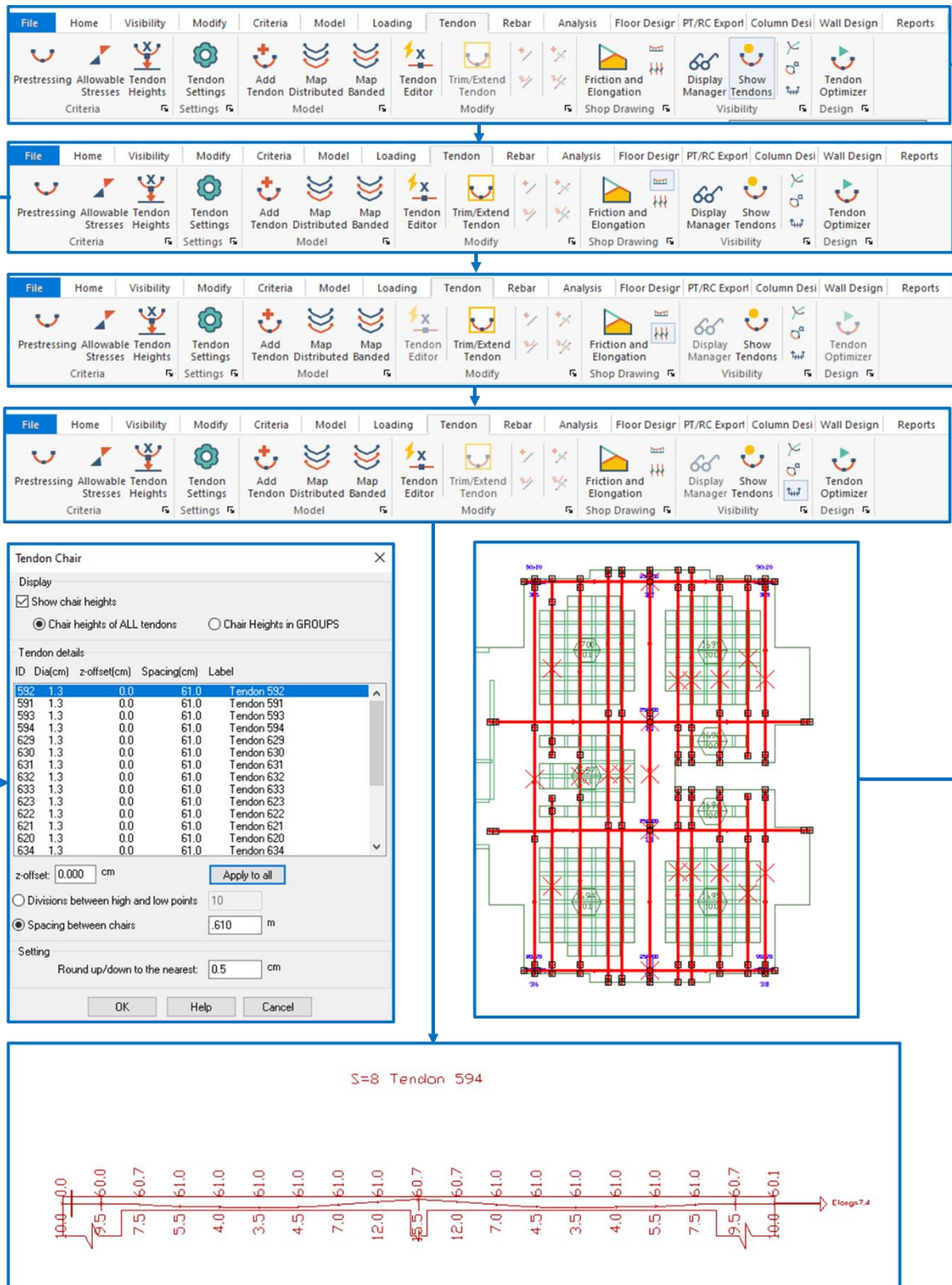
Figure 62 - Flowchart to view cable elevations and information.

The information presented may appear to indicate a pattern. Example text "S=2; L13,780; Elong=9.6". In this text, we have three pieces of information separated by semicolons:

- Number of *strands* in the bundle: 2 tendons (S=2);

- *Length* of the strand: 13,780 m (L13.780);

- *Elongation necessary*: 9,6 cm (Elong=9.6).

To detail, just export the plan that visualized with this information in a reference file of the CAD type and open it in some editing program.

6. PAVPLUS SYSTEM EXECUTIVE PROCESS
A) Formwork assembly and shoring:

As the PavPlus system consists of a complete solution for post-tensioning concrete structures, the metal horizontal shoring system used is also provided by Impacto. This system is composed of steel beams in rectangular tubular type profiles (Main Joist (LP) and Distribution Joist (LD)) that fit through a locking system called Head-Pin. The horizontal shoring is carried out by telescopic metal props, widely applied in the market. The elements that make up the system will be represented below.

The Main Joist (LP) is a rectangular piece of steel, of multiple modular size of 61cm on which the props are supported. They have on their lower face a slit intended to receive and fit the steel pins of the head and pin system that will be explained later.
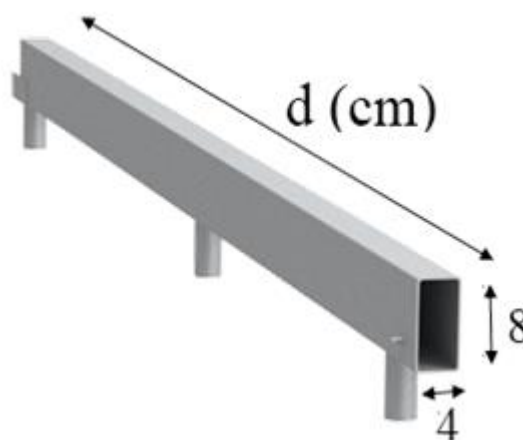
PavPlus

The Distribution Joist (LD) is a 117.5 cm steel piece that weighs 5.98 kg. It is positioned in a direction perpendicular to the LPs and rests on the Head-Pin set. On the LDs will be positioned the plastic molds (Waffle Mold or Flat Mold) that form the slab.
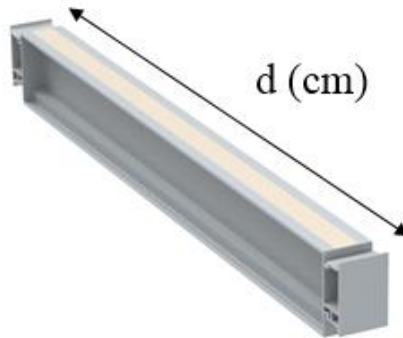
The head-pin fastening system performs the fitting and transverse locking between the Distribution Joist (LD) and the Main Joist (LP). The head is a piece of steel that weighs 480g, molded to receive the LDs laterally and support them along with the formworks. The pin is a cast iron accessory that vertically pierces the head and the LP, performing the locking between the two.
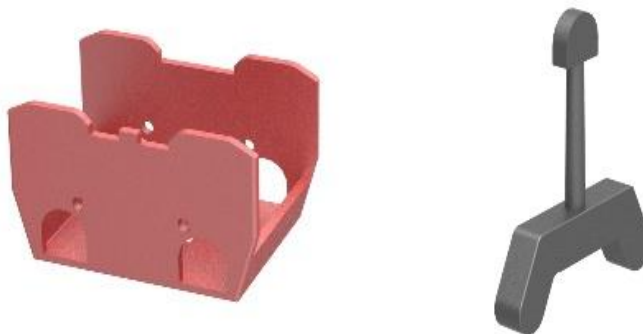
The assembly of the horizontal shoring follows a sequence of systemic steps foreseen in the project that must be obeyed in order to meet the desired degree of quality. The locking of the head-pin system in the LPs and the fixation of the LDs in it will be described in the diagram below.

PavPlus

Main Joist (LP)

HEAD

PIN

Step 01:
Attach the pin to the head and rotate it to lock

Step 02:
Attach the pin to the LP and rotate it to lock

Step 03:
Make sure the pin is securely secured to continue mounting

Step 04:
After attaching the head to the LP, it is necessary to suspend it by props. Always in pairs so that the structure does not unbalance

Step 05:
With the LPs locked and sustained, all that remains is to fit the LDs

Step 06:
The fitting of the LPs in the LDs, offers stability to the set that will receive the plastic formworks.

In this way, the loads provided by the slab on the molds are transmitted to the LDs, which in turn support and transmit the load to the head-pin system and this system, which is locked in the LPs, transmits the efforts to the LPs and these, finally, discharge through the props to the bottom slab.

Below are images of the horizontal shoring assembly process.

Figure 63: Suspension and stabilization of the Main Joists (LPs).

After fixing the LPs, it is possible to fit the LDs over the Heads. The fit between the two pieces is firm and tight, and can be performed using a conventional hammer to firm the LD over the Head.
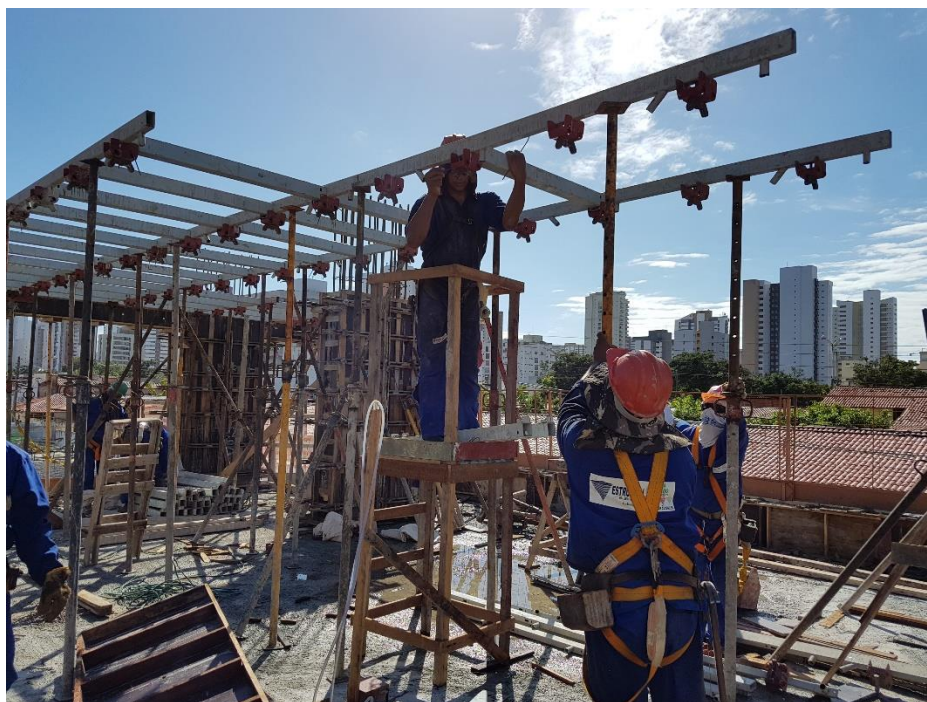
Figure 64: Fitting of the Distribution Stringers.

Figure 65: LPs being aligned.

The plastic formworks applied in the PavPlus system have two geometries: The Waffle Molds and the Flat Molds (Plasterits). Both pieces have as raw material the Granulated Recycled Polypropylene. Both the Plasterit and the Waffle Mold have flap dimensions of 61 x 61cm, in this way, it is possible to fit perfectly a pair of the two molds on the LD.

Figure 66: Unskilled labor positioning the waffle mold to the LDs.

The Plasterits are positioned in the flat regions of the slabs, places where there is a higher concentration of tendons. The waffle mold make up the ribbed portion of the slab.
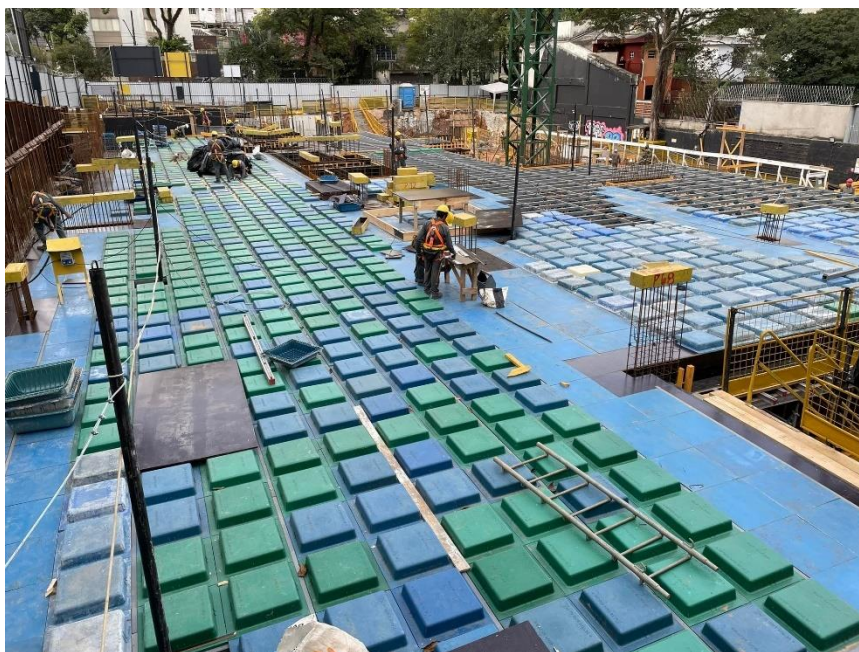
Figure 67: Distribution of waffle mold and plasterits on the slab.

The waffle molds have three flaps of approximately 7 cm and one flap of approximately 5 cm. This difference is due to the fact that in this shoring system, the top of the LPs is in contact with the concrete (being part of the formwork). Therefore, for all ribs to have the same width, the waffle mold must be positioned with the smaller flap in contact with the LP. The side that should be positioned next to the spar is indicated by an embossed arrow at the top of the waffle mold. The positioning of the waffle mold and plasterits, along with the direction of the arrows are already foreseen in the project.
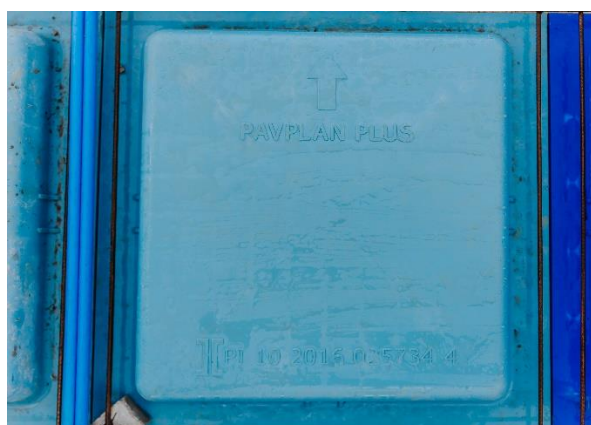
Figure 68: Smaller flap is in contact with the LP.

The complement and finishing of the formwork of the slab near the columns and the beams must be carried out with wood.

B) Placement of rebars; Installation of tendons and its acessories:

The assembly of the rebars and tendons, together with the accessories, is one of the biggest gains in productivity of the PavPlus system. The processes and solutions for the execution of the slab were elaborated always aiming to accentuate the speed and practicality of assembling the services involved. So that in the face of this, the times demanded by the workforce would decrease, along with the need for specialized professionals. Therefore, considerably reducing the cost of payroll.

To start the assembly of the reinforcement, first position according to the project (in the places where there will be elevations), the plastic elevation device (Caderix) that will both ensure the coverage of the rebar, as will sustain the orders of the tendons. This plastic part of the Caderix is titled as Barge by Impacto.

Figure 69: Barge stuck in the ribs of the waffle mold and receiving the rebars.

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The Barge has on its sides of shorter length two small rails on each side that were designed to be fixed on the friezes that are centered on the axes of the waffle mold. Once fixed to the friezes, the correct positioning of the elevations according to the post-tension design is guaranteed, in addition to the fact that it is impossible for it to move along the rib.

The Barges also have on their sides some extensions to ensure both the lateral covering of the rebar inside the ribs, as well as not to allow the Barge to run freely over the Plasterits, since this type of flat mold (plasterit) does not have fixing ribs.
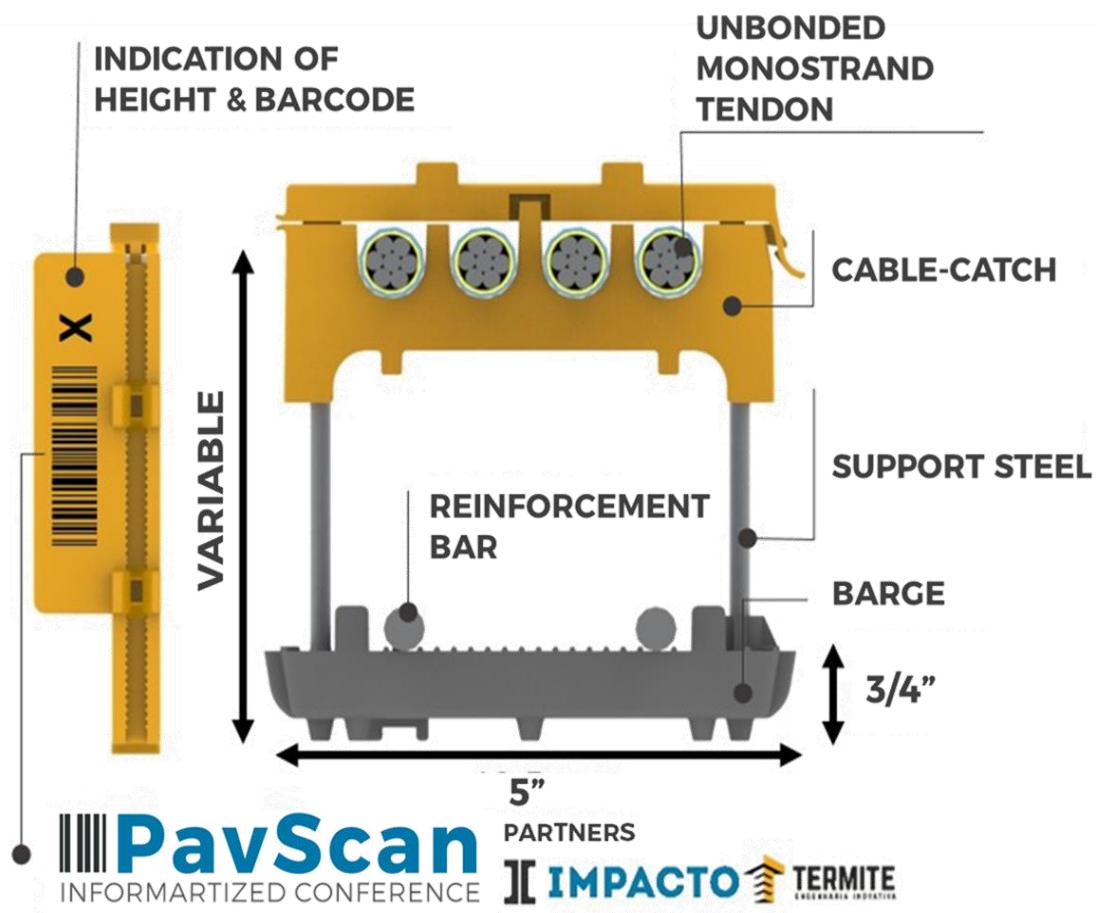
Figure 70: Schematic model of Caderix.

After the placement of the Barge, it is possible to position the rebar. The rebar in the PavPlus System consists of a set of welded steel mesh that are composed of two layers of rebar, one upper and one lower, with two parallel bars each, forming a " tic-tac-toe".

The steel mesh are divided into several specific sets that are numbered and described in design. These sets are made by the company Arcelormittal and sent ready for work, so that

it is only necessary to identify, through labels provided by the company, which set of canvas should be positioned in which area of the slab.

After positioning the steel mesh in their proper places and fitting them on the Barges, it is necessary to carry out the transfer between the sets and tie them, ensuring uniform work throughout the rebar.

It is very important that the predetermined assembly order in the design is obeyed, so that there is no overlapping of layers between the screens, aligning the bars of the upper layers.
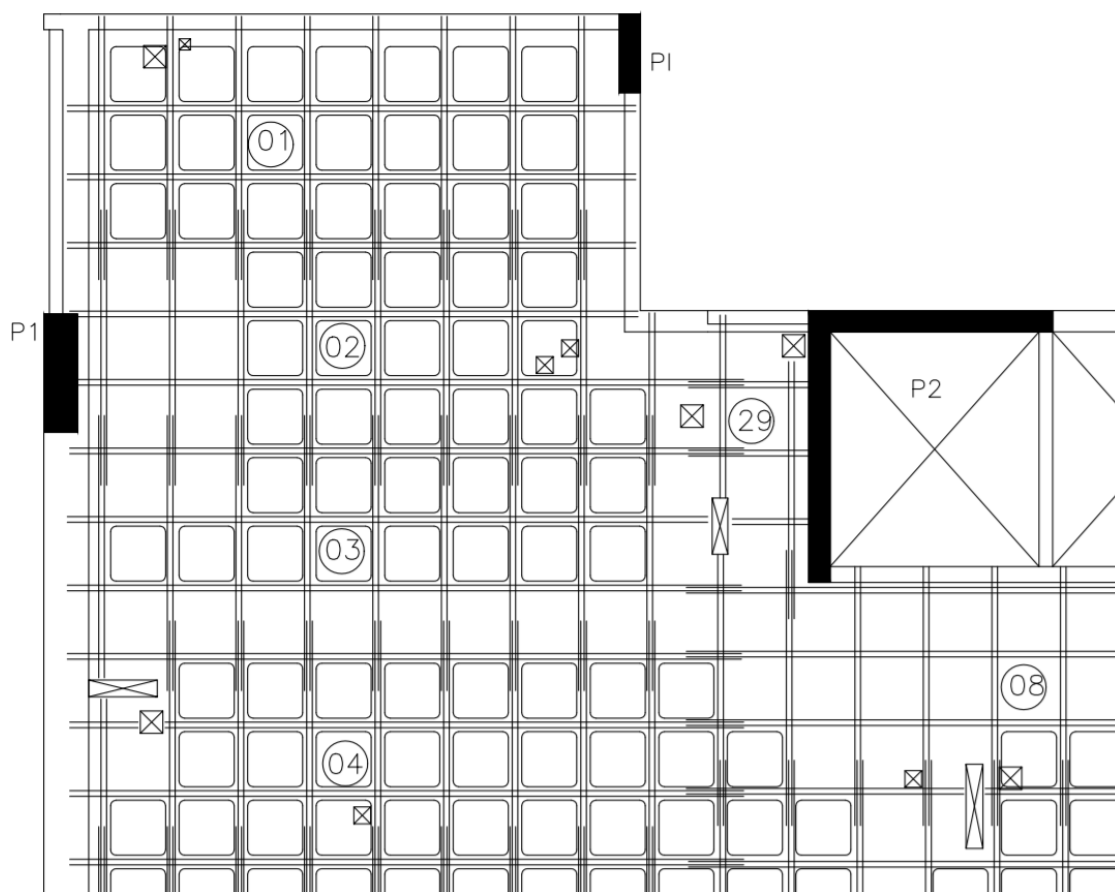
Figure 71: Design Plant indicating the assembly sequencing.
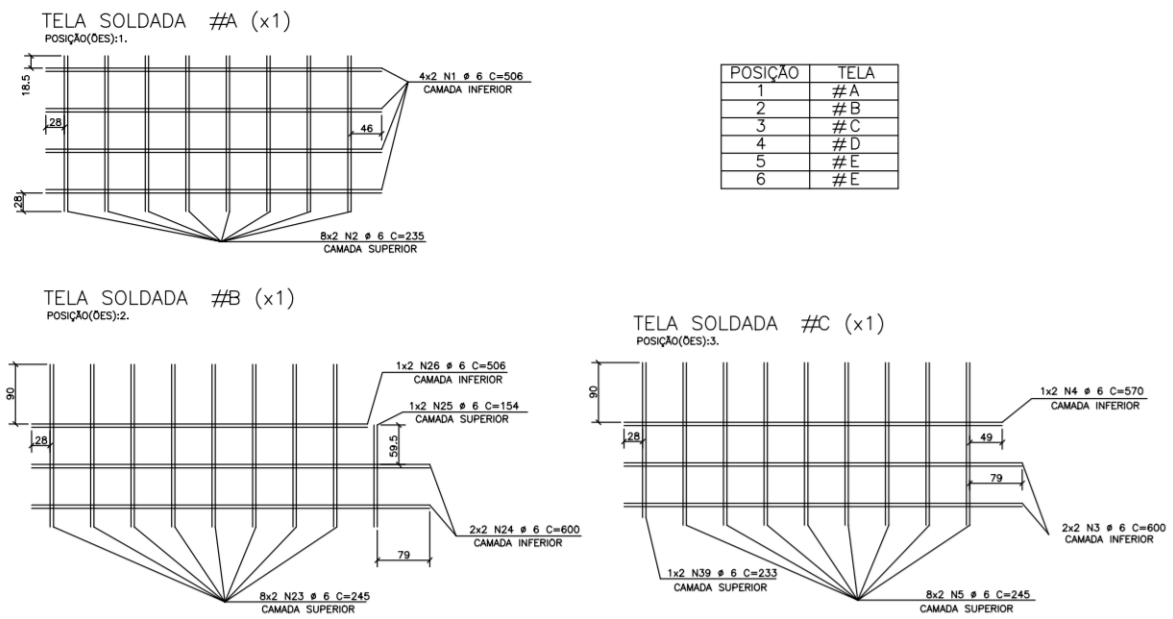
Figure 72: Detail of the steel meshs separated by models and positions.
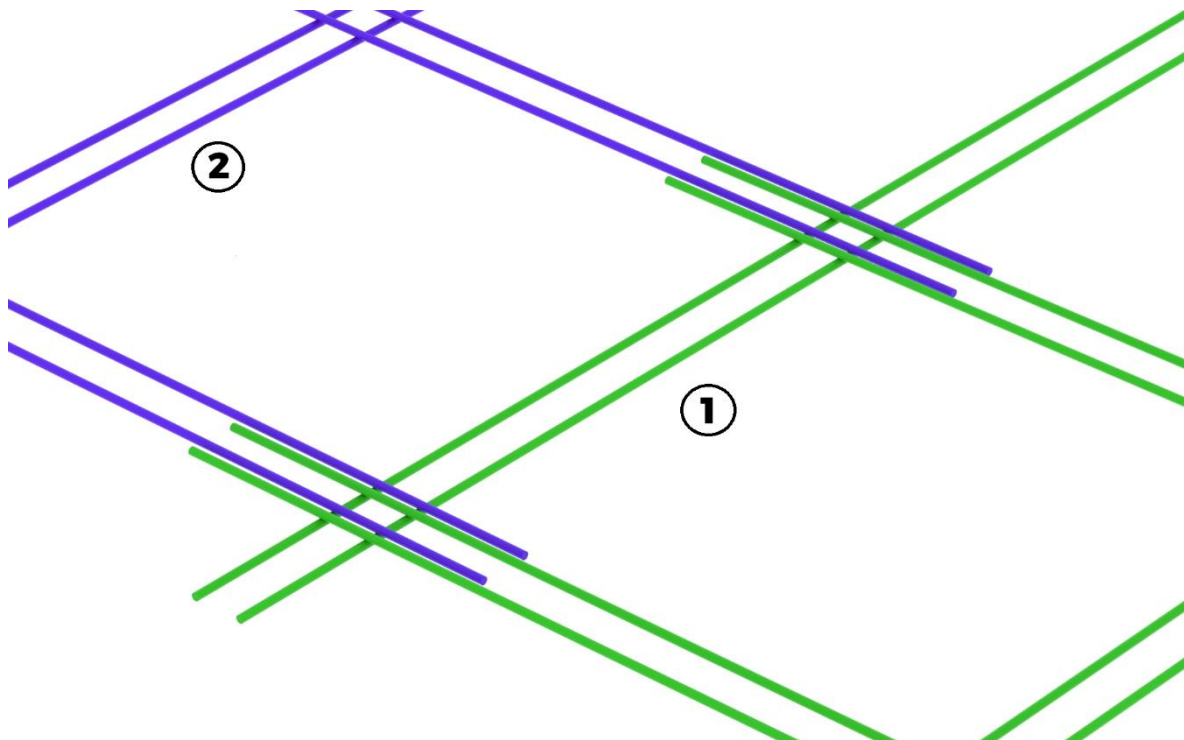
Figure 73: Following the sequence foreseen in the project, screen 1 is first positioned and then screen 2. In this way, ensuring that the stretches are correctly aligned. Otherwise, the rebar of 2 would be under screen 1.

Figure 74: Mesh Being Positioned.

Figure 75: Screens being tying.

Therefore, the assembly of the positive, negative and punch reinforcements existing in the slab is carried out. These reinforcements can be sent to work, assembled and welded, or if the site does not have a crane and "rocket" to hoist them, the rebars are sent conventionally so that the frame is made *in loco.*
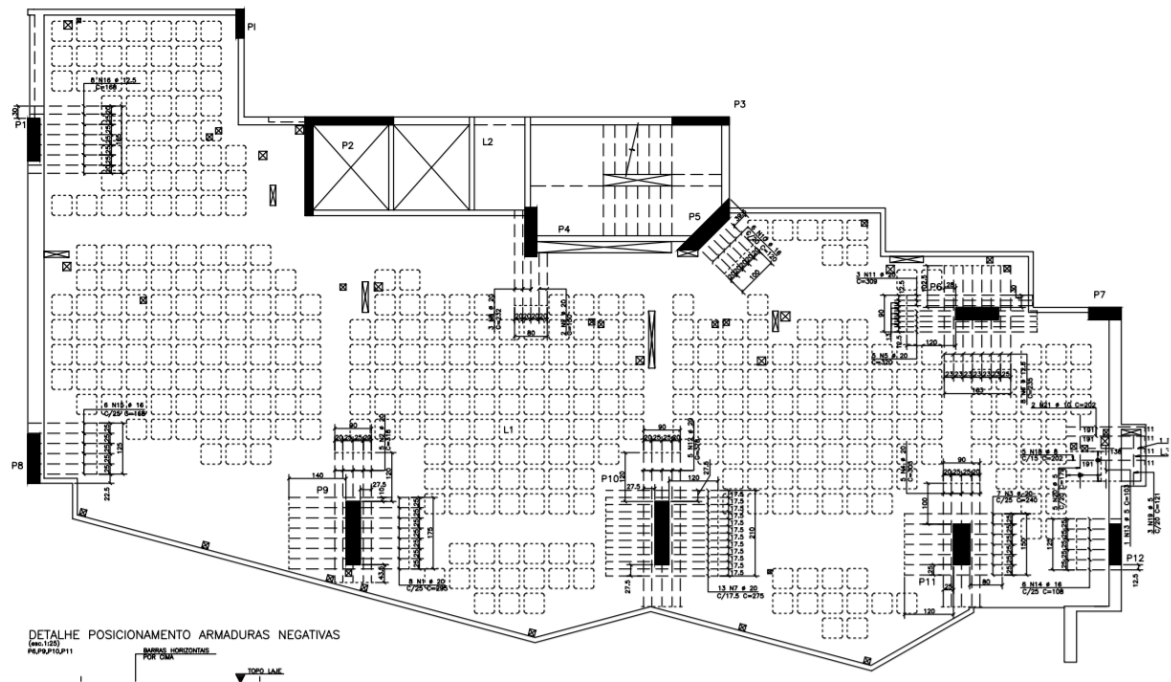
Figure 76: Negative rebar design.
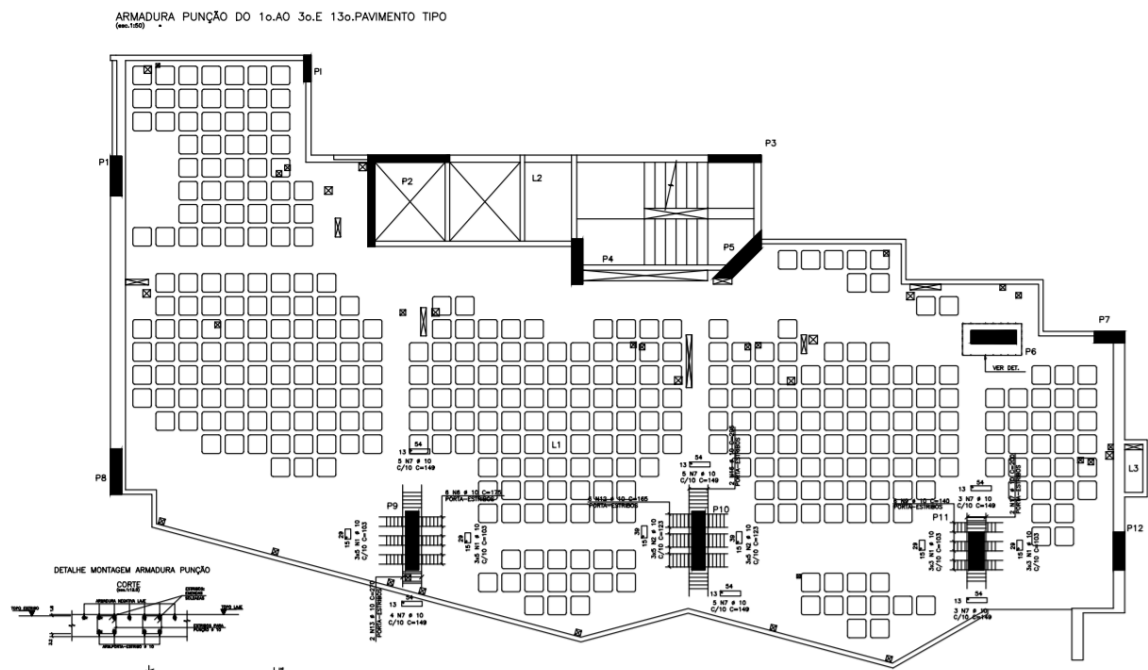
Figura 77: Punch reinforcement design.
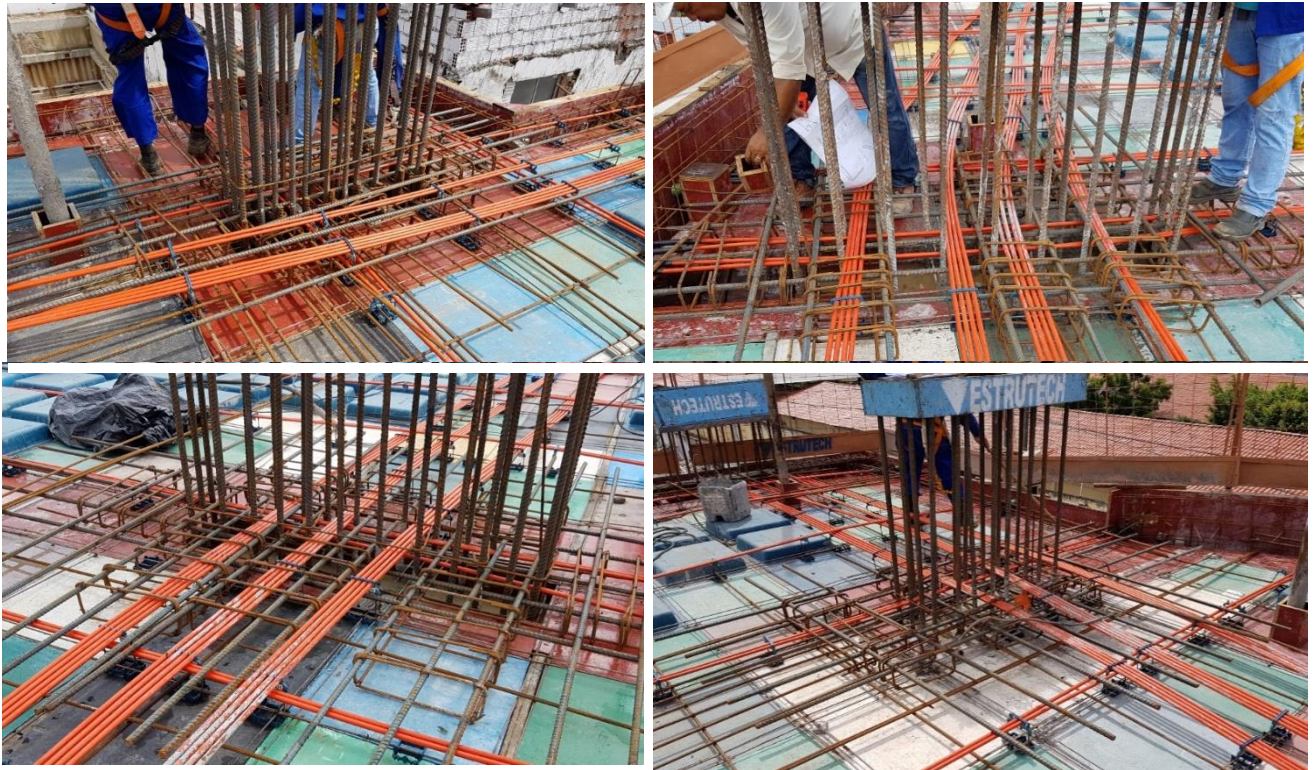
Figure 78: Photos of the negative reinforcements and punch near the columns P6 and P9 (Top) and P10 and P11 (Bottom).

Once the passive punch reinforcements, negative and positive, are assembled and armed, the passage and positioning of the tendons on the slab can begin.

The process of assembling the tendons begins with the marking and drilling in the wood formwork of the edge of the places that will receive live anchorage, spacing them according to the design. The holes must have a minimum lateral spacing of 7 cm between one and the other, the width necessary for the placement of the live anchorage. Then an employee of the company Impacto fits a plastic piece called a "pocket former" in the anchorage plate fixes the two by means of a wire of 60cm in length with two turns until they are well tied or can be fixed by nails. This live anchorage is fixed in the place determined in the design and is waiting for the tendons. This piece of plastic in the live anchorage has the function of preventing the concrete from enveloping the tendons, thus giving shape to the niches to fit the nozzle of the post-tensioning jack.
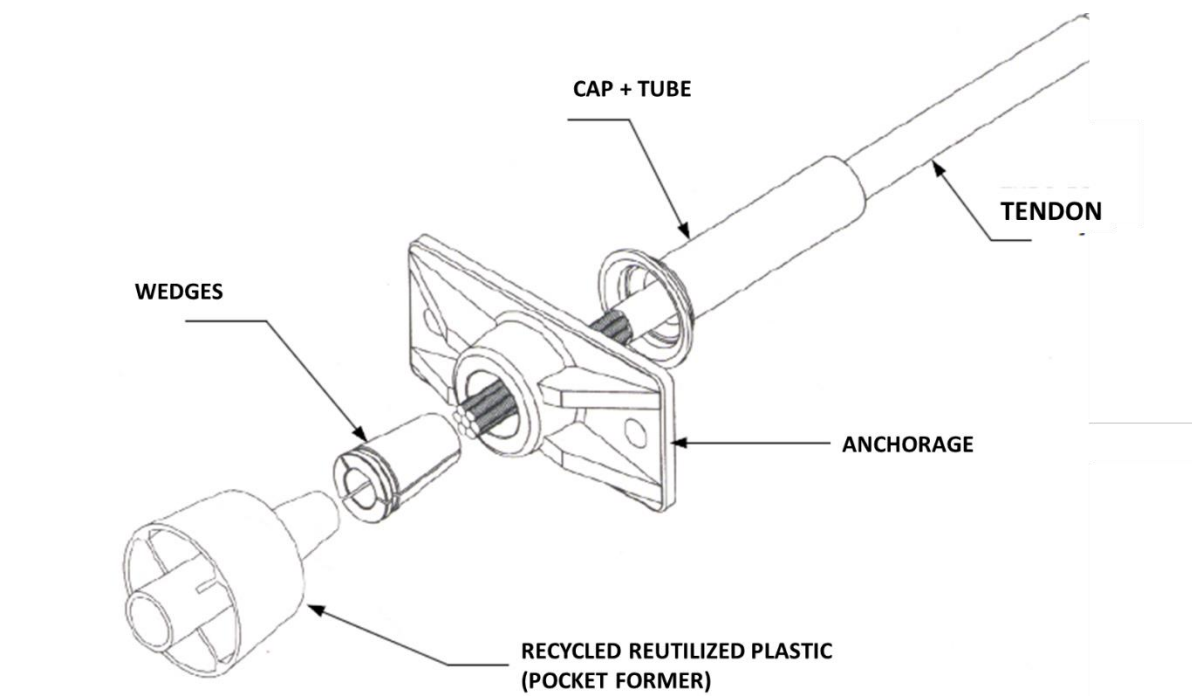
Figure 79: Ilus scheme locking pieces of live end.

The tendons are distributed on the slab according to the layout of the desing, each group of tendons will represent a bundle, and these bundle are separated during cutting and pre-blocking in the Impacto company. The distribution begins with the post-tensioning in the horizontal direction (massive), from the dead-end anchorage to the live one and then the post-tensioning in the vertical direction (distributed) in the same way. This ensures the necessary separation from the end of the tendon to the side shape, without the tendon needing to be moved away later.

For the fitting of the tendon in the live-end anchorage, the sheath is cut approximately 30 cm. Just long enough for the strand to pass through the live-end anchorage. Then, a 30 cm tube is placed with the cap open, and this tube must be tied to the strand, avoiding the flow of cement inside the anchors. When the strand is exposed, it should be covered with packing tape, if the apparent region is too large, it can be covered with a piece of the plastic sheath.

Figure 80: Tendons being cut to be positioned at the live-end anchorage.

The strands are gently shifted in the direction of the anchor plates. The perpendicular placement of the tendons within the anchor plates is checked vertically and horizontally. If this is not done correctly the result may be a break of the rope, a bursting of the concrete, a failure in the crimping of the wedges, low elongation, excessive loss in the crimping or other problems in the post-tensioning.

Figure 81: Tendons being positioned on live-end anchors.

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The dead-end anchors must be positioned and fixed at the heights indicated in the desing, and then the hairpins and additional reinforcements must be positioned in dead-end and live-end anchorages.

Figure 82: Dead-end anchors being fixed and aligned.

When the tendons are in the correct places, the ordinates (elevations) that will fix the tendons in the layout foreseen in the design are positioned. These elevations are composed of a plastic piece called Caderix that will sustain and fix the bundle of tendons. In this way, ensuring the ordered determined for the point in question. To verify that the ordinate meets the value indicated in the design, the height of the tendon is measured, from its axis, to the base of the formwork. The tolerance in the variation of these heights is determined by the designer.
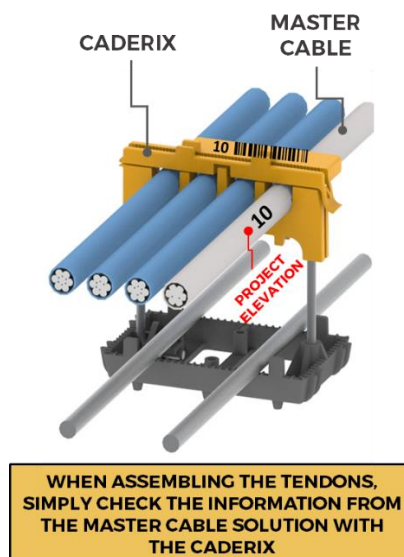
Figure 83: Set of CADERIX (Barge + Cabçe-Catch) and MasterCable.

Figure 84: Bundle fixed by the tendons grippers at the desired elevations.
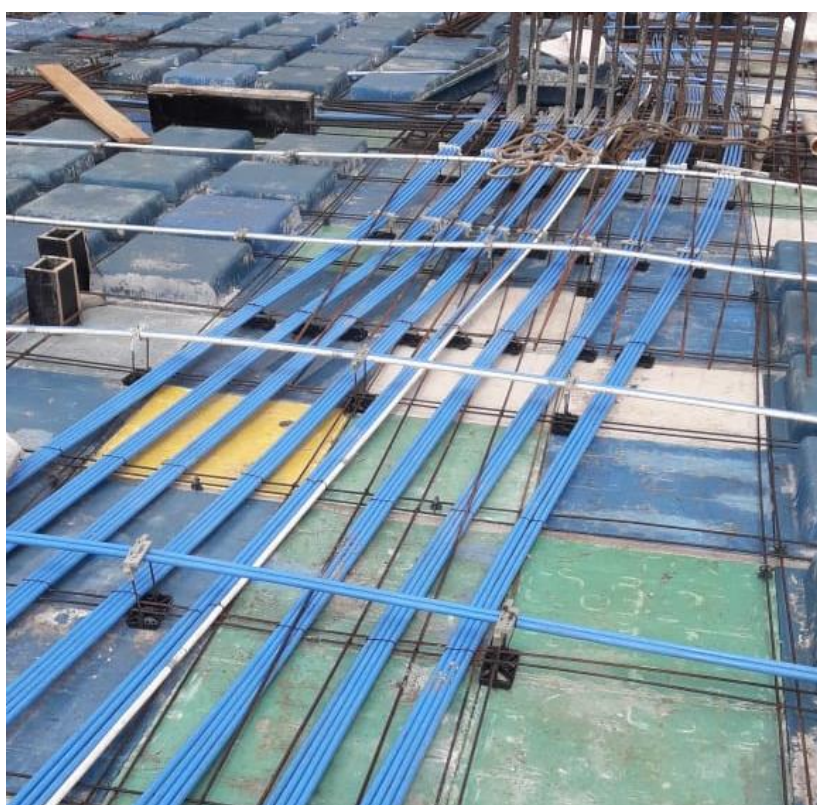
Figure 85: Completion of the post-tensioning assembly in the concentrated tendon region.

Figure 86: Completion of the assembly of the post-tensioning in the distributed regions.

At the end of the assembly, the heights are rigorously checked so that no pathologies occur.

The points that are checked are described below:

- *Number of tendons;*

- *If the extension of the tendon is between 30 cm and 50 cm – not so short, so the jack can pull it, and not so long, to avoid waste;*

- *If the tube are tied – to prevent concrete from entering;*

- *Distance from the strand of the dead-end anchorage to the formwork – must be greater than 2.5 cm;*

- *Sand next to the active anchors the cables are coming out horizontally;*

- *Whether the pocket forms are properly insulated;*

- *Elevation and spacing – if the Caderix elevation indications indicate the correct heights in the locations indicated by the design;*

- *Height and distribution of cables;*

- *Hairpins and additional rebars;*

- *If the tendons are touching the vertical passages of the slab.*

C) Post-tension Operation: Elogation Control

The structural designer specifies the minimum compressive strength of the concrete, and in how many days past the concreting should be made the post-tension. Usually the minimum fck is 21 MPa, with 05 days.

As the result is not immediate, it is requested that the specimens be broken on the day before the date of tensioning. The report must be delivered to the company responsible for the claim.

If for all specimens the resistance is greater than 21 MPa, the slab is ready to be tensioned. In the case of some specimens below 21 MPa, the calculating engineer must be consulted in order to make the release for tension or not. If the calculator does not release the tension, a new body of evidence must be broken. In the case of some beams, it may be necessary the design strength of the concrete at the time of pretension, which would cause the rupture of specimens only with 28 days and consequently the tensioning.

The CP210 tendons are tensioned with 16.5 Tf and the CP190 with 15 Tf, with changes if specified by the structural designer. The tensioning operation should be done under the control of a technician experienced with this type of work. He must make a strict control of all operations. Before the beginning of the tensioning, it is essential that the jack-pump set be verified, and the following items should be verified:

- *If the jaws of the jack are in a condition of use, not having smooth, broken or cracked teeth and being with the correct closure;*

- *If there are no cracks in the jaw plates, and if they are not warped;*

- *If the jack is clean, especially in the jaws and in the areas of the spike piston;*

- *Whether the pump oil level is adequate;*

- *If any screws are missing from the jack or pump, and if they are all tightly tightened;*

- *If the wires of the socket and the pump button are not peeled or loose;*

- *Whether the hoses are connected correctly to the pressure and return holes of the jack-pump;*

- *The size of the jack wedge beater (between 5mm and 8mm);*

- *Possible cracks or hydraulic leaks in the jack.*

- *This check should be done every time the Jack-Pump assembly is used, both in the tensioning and pre-blocking.*

After concreting the slab, the edge formwork must be stripped to begin the preparation of the slab for post-tensioning.

If the insulation and tying of the live-end anchorage and pocket form *have not been done well, it is possible that there is a thin layer of cement closing the niche. This layer must be broken. The* pocket forms *should be removed carefully so as not to break, and as they are being removed, they should be placed in a bag, because if they are well maintained they can be reused.*

Once the pocket forms *are removed, the cavity must be cleaned, checking and removing any cement cream that is there, to avoid damage to the monkey.*

Figure 87: Pocket Forms being removed to clean the niches.

The integrity of the concrete is verified in the niches and on all apparent surfaces. If any abnormality is detected, such as voids or abnormal porosity in the concrete, the responsible personnel should be notified before the post-tensioning operation.

The pair of wedges is placed manually inside the active anchor plate. The wedges should be evenly spaced, and inserted evenly into the cavity of the anchor plate.

Figure 88: Wedges being positioned.

With a jig at a fixed distance from the edge of the slab, a mark with quick-drying spray paint is made on each live end of the tendon to set a benchmark for stretch measurements. Before that, the grease of the strand must be removed with burlap, so that the paint remains there after post-tensioning. If the strand is not cleaned, it is possible that at the end of the post-tensioning the paint is no longer visible.

Figure 89: Markings for measuring elogations.

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The jack should be positioned unladen on the strand to be pulled, with the "beak" resting on the center of the anchor plate. If there is any failure in its positioning, the jack should be removed and replaced. Fit the jack's jaw evenly over the string, otherwise the jaws may be damaged, or even break the string. Avoid making any adjustments after loading is introduced.

The tendons are tensioned to the force requested in the project, usually 15tf or 16.5tf. If the elongation of the cable is greater than the stroke of the jack, additional tensionings should be performed.

Tendons that are tensioned at both ends can be tensioned simultaneously, but do not need to be tensioned simultaneously as long as it is verified that the wedges at the opposite end are pre-set and do not cause tendon to slip. These tendons should have greater elongation at one end than at the other. The stretching of the two ends should total the stretching shown requested by the designer.

The structural design should indicate whether the tendons will be tensioned at both ends, or only at one end. As well as it should indicate at which of the ends should be made the tensioning. If the conditions of the work allow and there is a need, the anchor site of the dead ends can be reversed with the anchor site of the live ends.

Figure 90: Fitting of the jack to the strand.

Figure 91: Pressure gauge marking 400 Bar.
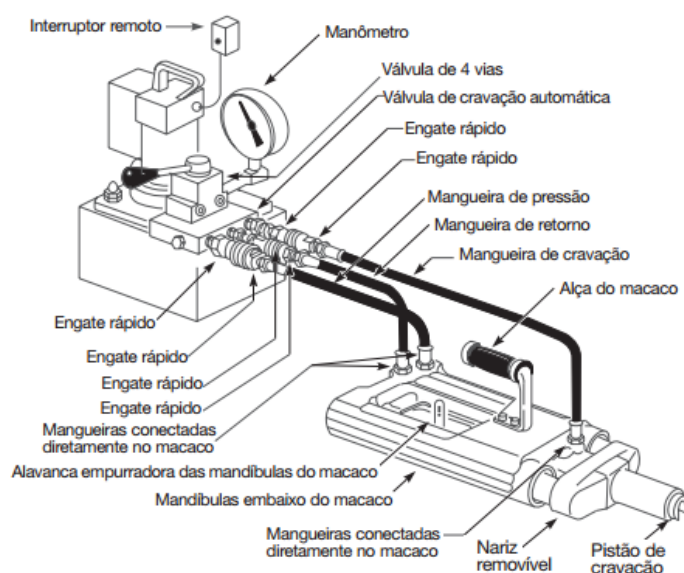
 After post-tensioing, the technician must fill out a report with the elongation of each tendon in centimeters. This report is sent to the specialized company to verify that the tendon had the required elongation in design. If it has not reached the theoretical elongation required by the structural designer, the tendons will have to be tensioned. A deviation of 10% in the elongation of the tendon is tolerated. The Table (Figure 32) shows the elogation worksheet of Impacto. Note that some tendons have the remark "REVIEW CABLE". These tendons must be tensioned because the stretching was below that requested by the designer. After the tendons are tensioned again, the new elogation should be checked.

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If the elongation is not indicated by the calculator, a theoretical elongation of 0.66% of the total length of the tendon is used.

The most likely causes of wrong elogation values are:

a) mark of the strand with faint paint, having faded;

b) wrong measurement. The measuring instrument shall be checked;

c) wrong reading of the pressure gauge due to error in the measurement tables;

d) wrong support of the jack;

e) excessive laying of the wedges due to error in the measurement tables;

f) wrong functioning of the jack;

g) excessive friction along the strand;

h) wrong placement of the tendon;

i) misplacement of the wedges;

j) variation in the properties of the material, particularly in the longitudinal modulus of elasticity of the steel;

k) slippage in the dead-end anchorage;

l) defective concreting in the anchoring region, causing crushing or excessive deformation;

m) voids in the concrete of the dead-end anchorage zone may present excessive elongations;

n) tendon exposed between the live-end anchor plate and the end of the sheath.

Cabo	Comp. Cabo (m)	Al. Teórico (cm)	Al. Real (cm)	Desvio(%)	Situação
FX1A-C1-1	20.05	13.4	13.0	-3.0	OK
FX1A-C1-2	20.05	13.4	13.2	-1.5	OK
FX1A-C1-3	20.05	13.4	14.0	4.5	OK
FX1A-C1-4	20.05	13.4	13	-3.0	OK
FX1A-C2-1	20.05	13.4	13.5	0.7	OK
FX2A-C1-1	20.05	13.4	11.0	-17.9	Rever Cabo
FX2A-C1-2	20.05	13.4	13.7	2.2	OK
FX2A-C1-3	20.05	13.4	14.0	4.5	OK
FX2A-C1-4	20.05	13.4	13.0	-3.0	OK
FX2A-C2-1	20.05	13.4	13.0	-3.0	OK
FX3A-C3-1	10.55	7.2	6.0	-16.7	Rever Cabo
FX3A-C3-2	10.55	7.2	6.7	-6.9	OK
FX3A-C3-3	10.55	7.2	7.1	-1.4	OK
FX3A-C3-4	10.55	7.2	7.0	-2.8	OK
FX3A-C3-5	10.55	7.2	7.2	0.0	OK
FX3A-C3-6	10.55	7.2	6.6	-8.3	OK
FX3A-C3-7	10.55	7.2	6.9	-4.2	OK
FX3A-C3-8	10.55	7.2	6.9	-4.2	OK
FX3A-C3-9	10.55	7.2	7.0	-2.8	OK
FX4A-C4-1	11.95	8.1	8.0	-1.2	OK
FX4A-C4-2	11.95	8.1	8.5	4.9	OK
FX4A-C4-3	11.95	8.1	8.6	6.2	OK
FX4A-C4-4	11.95	8.1	8.6	6.2	OK
FX4A-C4-5	11.95	8.1	8.4	3.7	OK
FX4A-C4-6	11.95	8.1	8.4	3.7	OK
FX4A-C4-7	11.95	8.1	8.9	9.9	OK
FX4A-C4-8	11.95	8.1	9.0	11.1	OK
FX4A-C4-9	11.95	8.1	7.0	-13.6	Rever Cabo
FX5A-C4-1	11.95	8.1	7.2	-11.1	Rever Cabo
FX5A-C4-2	11.95	8.1	7.5	-7.4	OK
FX5A-C4-3	11.95	8.1	8.0	-1.2	OK
FX5A-C4-4	11.95	8.1	8.9	9.9	OK
FX5A-C4-5	11.95	8.1	8.8	8.6	OK
FX5A-C4-6	11.95	8.1	8.0	-1.2	OK
FX5A-C4-7	11.95	8.1	8.9	9.9	OK

Figure 92: Tendon elogation report.

D) *Tendon Tip Cutting and Grout Filling*

After the end of the tensioning, elogations checked and reviewed by the engineer, the tendons should be cut 25 mm from the margin of the slab, ensuring the coverage of the tip of the strand. The cut can be made with oxyacetylene torch or another indicated by the engineer in charge, or cutting disc.

In the case of cutting with a blowtorch, care must be taken that the flame does not reach the wedges, and the cutting operation must be performed in time indicated by the engineer in charge. The strand should be cut by leaving a small tip of 13 to 20 mm after the wedge and allowing a covering of 25 mm in relation to the face of the concrete.

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Figure 93: Tendons being cut with the aid of the blowtorch.

Before sealing the niches, they must be carefully inspected so that they are completely clean and free of any material or impurity that jeopardizes the adhesion between the grout and the existing concrete.

After the ends of the strands are cut, the exposed part of the anchorage should be covered with grease and the cap closed, to prevent corrosion. It was later filled with grout.

In the case of post-tension of the intermediate anchors, the post-tensioning niches should also be filled with grout.

As soon as possible after the strands have been cut, the builder must seal the exposed anchorage plane. It is suggested that an epoxy mixture be used for this purpose, grout or an expansive mortar, without shrinkage and without components susceptible to corrosion. The grout mortar shall not contain, under any circumstances, any additive with chlorides, sulfates or nitrates, or other chemical element that damages the strands or anchors.

Special attention is drawn to the quality of the filling of the niches, taking into account the responsibility of the behavior of the anchors in the future behavior of the structure and its durability.

7. DESCRIPTION OF ENFORCEMENT PROCEDURES

The following are described briefly the steps for the execution of the post-tensioned concrete slab using the PavPlus system.

1) Adaptation of the executive design through the compatibility of the structural design for the use of the PavPlus system;

2) Proper rental of adjustable metal props (not marketed by Impacto);

3) Assembly of the head and pin in the LPs;

4) Lifting of LPs;

5) Fitting of the LPs in the metal props, forming a framing;

6) Leveling of the shoring frame by adjusting the metal prop and fixing the pin with head safely;

7) Fitting of the LDs between the LPs, forming a grid;

8) After assembling the shoring structure, the fittings are checked;

9) The placement of the plastic molds begins, which can be the Plasteritc(Flat Mold) or Waffle Mold,

10) Slab leveling

11) After the placement of the formwork is made a conference of the whole system;

12) Installation of the rebars, not provided by Impacto;

13) Installation of the unbonded tendons, with the help of the Caderix that will support the tendons and position them at the appropriate height, provided for in the design;

14) Concreting, the act of casting the still fluid concrete into the previously assembled formwork structures in order to compose the desired structure as well as the necessary strength;

15) Tensioning of the live ends of the unbonded tendons, that is, submission to tensile efforts, through the use of hydraulic jacks;

16) After 03 days, the stripping of the formwork system by the LDs and the formwork begins;

17) After the stripping of the LDs and the plastic formwork (Plasterit or Waffle mold), the LPs and some props still serve as re-shoring until the slab of the upper floor is cured;

18) Transport of the LDs to the next floor, as they are removed, to begin the new sequence of steps.

8. CONCLUSION

With this material we hope to provide the designer and builders with a source of consultation for the design and execution of the PavPlus System, since it is a recent system and has been gaining great acceptance in the market. Presenting a script with procedures for modeling, analysis and detailing in two of the largest commercial *software* aimed at post-tensioning used in Brazil. In addition to detailing the assembly system of post-tensioning execution, making the manual a complete material for those who want to understand a little more of the PavPlus system and how the execution of the post-tension is developed.

This material had the collaboration of several professionals focused on structural projects, in addition to the collaboration of the teams of Impacto, Termite and Post-tension Consulting Center (CCP).

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10. DESIGN TEMPLATE

      In this section are presented the designed floorplans of an enterprise using the PavPlus system. In these boards are presented the formworks of the floor, the detailing of the vertical and horizontal post-tensioning, as well as positive and negative rebars and punch reinforcement. The boards are presented in the A3 form (WITHOUT SCALE), however the original files. DWGs are available by accessing the QRCODE indicated at the end of the manual.

PAVPLUS - Drive

sketchfab.com

IMPACTO

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FORMA DO TIPO.
ESC. 1/50

Corte esquemático

Corte B-B

Corte A-A

Corte C-C

DETALHE LAJE PMPLUS H=20(10+10)
ESC:

ARMADURA POSITIVA PRINCIPAL DO PAV. TIPO.
ESC. 1/50

Tabela de aço

AÇO	POS	BIT (mm)	QUANT	COMPRIMENTO UNIT (cm)	COMPRIMENTO TOTAL (cm)
ARMADURA POSITIVA PRINCIPAL DO PAV. TIPO					
50A	1	6.3	12	806	9672
50A	2	6.3	56	1091	61096
50A	3	6.3	78	778	60684
50A	4	6.3	16	889	14224
50A	5	6.3	32	766	24512
50A	6	6.3	48	929	44592
50A	7	6.3	24	836	20064
50A	8	6.3	16	796	12736
50A	9	8	8	146	1168
50A	10	8	12	419	5028
50A	11	8	26	184	4784

RESUMO AÇO CA 50-60

AÇO	BIT (mm)	COMPR (m)	PESO (kg)
50A	6.3	2568	629
50A	8	110	43
50A =			672 kg

PESO Total   672 kg

ATENÇÃO!
A) - RECOMENDAÇÃO DO fck:
  1. fck > 30 MPa, APÓS 28 DIAS.
B) - COBRIMENTOS:
  - LAJES: 2,0cm
  - VIGAS: 2,5cm

OBSERVAÇÕES:
- RÍGIDO CONTROLE DE QUALIDADE NOS COBRIMENTOS.

L1 h=24
L2 h=24
L3 h=15

12 N10 ø 8 C/15 C=419
11 N11 ø 8 C/15 C=284

DETALHE GENÉRICO DO
REFORÇO DOS FUROS OU SHAFT
SEM ESC.

2 ø 12,5
4 ø 12,5
2 ø 12,5
FURO OU SHAFT
50
50

DETALHE DO POSICIONAMENTO DAS ARMAÇÕES
NO TOPO DO PILAR.
SEM ESC.

ARM. NO TOPO DOS PILARES
CABOS CONCENTRADOS
CABOS DISTRIBUIDOS
TOPO LAJE
FUNDO LAJE
ARM. POSITIVA
CABOS DISTRIBUIDOS

*ATENÇÃO PARA COMPATIBILIDADE COM OS CABOS CONCENTRADOS.
*ATENÇÃO, ARMADURA POSITIVA SUPERIOR ESTÁ NO SENTIDO DOS CABOS CONCENTRADOS.

ARMADURA POSITIVA COMPLEMENTAR DO PAV. TIPO.
ESC. 1/50

DETALHE DO POSICIONAMENTO DAS ARMAÇÕES
NO TOPO DO PILAR.
SEM ESC.

ARM. NO TOPO DOS PILARES

DETALHE GENÉRICO DO
REFORÇO DOS FUROS OU SHAFT
SEM ESC.

FURO OU SHAFT

*ATENÇÃO PARA COMPATIBILIDADE COM OS CABOS CONCENTRADOS.
*ATENÇÃO, ARMADURA PASSIVA SUPERIOR ESTÁ NO SENTIDO DOS CABOS CONCENTRADOS.

AÇO	POS	BIT (mm)	QUANT. COMPLEMENTAR DO PAV.	COMPRIMENTO UNIT. (cm)	TOTAL (cm)
ARMADURA POSITIVA COMPLEMENTAR TIPO					

ARMADURA NEGATIVA DO PAV. DO TIPO.
ESC. 1/50

ARMADURA NEGATIVA DO PAV. DO TIPO.

AÇO	POS	BIT (mm)	QUANT	COMPRIMENTO UNIT (cm)	COMPRIMENTO TOTAL (cm)
50A	1	12.5	32	175	5600
50A	2	12.5	40	130	5200
50A	3	12.5	48	200	9600
50A	4	12.5	20	300	6000
50A	5	12.5	28	250	7000
50A	6	12.5	32	265	8480
50A	7	8	8	135	1080
50A	8	12.5	14	135	1890
50A	9	12.5	20	155	3100
50A	10	8	12	295	3540
50A	11	12.5	20	331	6620
50A	12	12.5	24	240	5760
50A	13	8	20	224	4480
50A	14	12.5	11	260	2860
50A	15	8	2	78	156
50A	16	12.5	16	262	4192
50A	17	12.5	16	66	1056
50A	18	12.5	16	74	1184
50A	19	12.5	8	247	1976
50A	20	12.5	8	397	3176
50A	21	12.5	4	198	792
50A	22	12.5	8	254	2032
50A	23	12.5	4	201	804
50A	24	12.5	8	150	1200

RESUMO AÇO CA 50-60

AÇO	BIT (mm)	COMPR (m)	PESO (kg)
50A	8	107	42
50A	10	58	36
50A	12.5	753	725
50A =			

Peso Total = 802 Kg

P19 90x20 ARM.PUNÇÃO VER DET.1

P13 150x25 ARM.PUNÇÃO VER DET.3

P9 150x25 ARM.PUNÇÃO VER DET.3

P1 90x20 ARM.PUNÇÃO VER DET.1

P20 25x100 ARM.PUNÇÃO VER DET.4

PL4 25x100 ARM.PUNÇÃO VER DET.4

P10 25x100 ARM.PUNÇÃO VER DET.4

P2 25x100 ARM.PUNÇÃO VER DET.2

L2 h=20

P21 90x20 ARM.PUNÇÃO VER DET.1

P3 90x20 ARM.PUNÇÃO VER DET.1

P15 25x140 ARM.PUNÇÃO VER DET.4

PE1 20x20

L3 h=15

P7 25x215 ARM.PUNÇÃO VER DET.5

P8 25x215 ARM.PUNÇÃO VER DET.5

P22 90x20 ARM.PUNÇÃO VER DET.1

P4 90x20 ARM.PUNÇÃO VER DET.1

P16 25x140 ARM.PUNÇÃO VER DET.4

P23 90x20 ARM.PUNÇÃO VER DET.1

P17 25x100 ARM.PUNÇÃO VER DET.4

P11 25x100 ARM.PUNÇÃO VER DET.4

P5 25x100 ARM.PUNÇÃO VER DET.2

L1 h=20

P24 90x20 ARM.PUNÇÃO VER DET.1

P6 90x20 ARM.PUNÇÃO VER DET.1

P18 150x25 ARM.PUNÇÃO VER DET.3

P12 150x25 ARM.PUNÇÃO VER DET.3

DETALHE GENÉRICO DO REFORÇO DOS FUROS OU SHAFT
SEM ESC.

FURO OU SHAFT

DETALHE DO POSICIONAMENTO DAS ARMAÇÕES NO TOPO DO PILAR.
SEM ESC.

ARM. NO TOPO DOS PILARES
CABOS CONCENTRADOS
CABOS DISTRIBUIDOS
TOPO LAJE
FUNDO LAJE
ARM. POSITIVA
CABOS DISTRIBUIDOS

*ATENÇÃO PARA COMPATIBILIDADE COM OS CABOS CONCENTRADOS.
*ATENÇÃO, ARMADURA PASSIVA SUPERIOR ESTÁ NO SENTIDO DOS CABOS CONCENTRADOS.

DISTRIBUIÇÃO E ELEVAÇÃO DOS CABOS
HORIZONTAIS DO PAVIMENTO TIPO.

*CONFERIR MEDIDAS NO LOCAL

PROTENSÃO: AÇO CP190 RB EP - 12.7

RESUMO DE PROTENSÃO
Monocordoalhas não aderentes

VISTA 3C HORIZONTAL   X2

VISTA 4C HORIZONTAL   X2

L1
L2
L3

DETALHE DO POSICIONAMENTO
NO TOPO DO PILAR.

POSICIONAMENTO DAS ARMAÇÕES

NOTAS:

CONVENÇÃO DOS CABOS

ANCORAGEM
PASSIVA

ANCORAGEM
ATIVA

ATENÇÃO:
TODAS AS ANCORAGENS PASSIVAS

ATENÇÃO:

POSICIONAMENTO DAS CORDOALHAS
EM CURVAS HORIZONTAIS

DET. GENÉRICO DAS ANCORAGENS ATIVAS E PASSAGEM DOS CABOS

DET. DAS ANCORAGENS ATIVAS E PASSAGEM DOS CABOS

PLANTA

CORTE

05/07

RESIDENCIAL WEST VILLE.
PAVIMENTO TIPO

CONCEPTUS

DISTRIBUIÇÃO E ELEVAÇÃO DOS CABOS
VERTICAIS DO PAVIMENTO TIPO.

*CONFERIR MEDIDAS NO LOCAL

PROTENSÃO: AÇO CP190 RB EP - 12.7

RESUMO DE PROTENSÃO
Monocordoalhas não aderentes

VISTA 1C VERTICAL   x2
Esc. 1/25

VISTA 2C VERTICAL
Esc. 1/25   x2

VISTA 3C VERTICAL
Esc. 1/25   x2

L1

L2

L3

DETALHE DO POSICIONAMENTO DAS ARMAÇÕES
NO TOPO DO PILAR.

ATENÇÃO
TODAS AS ANCORAGENS PASSIVAS
DEVERÃO SER PRÉ-BLOCADAS.

CONVENÇÃO DOS CABOS

ANCORAGEM
PASSIVA

ANCORAGEM
ATIVA

NOTAS:

POSICIONAMENTO DAS CORDOALHAS
EM CURVAS HORIZONTAIS

PLANTA

CORTE

DET. GENÉRICO DAS ANCORAGENS ATIVAS E PASSIVAS DOS CABOS

DET. DAS ANCORAGENS ATIVAS E PASSIVAS DOS CABOS

CONCEPTUS

RESIDENCIAL WEST VILLE.

PAVIMENTO TIPO

06/07

AÇO	POS	BIT (mm)	QUANT	COMPRIMENTO UNIT (cm)	TOTAL (cm)
ARMADURA DE PUNÇÃO DET. 1			(X8)		
	1	50A 8	24	170	4080
	2	50A 8	24	145	3480
	3	50A 8	64	35	2240
ARMADURA DE PUNÇÃO DET. 2			(X4)		
	1	50A 8	16	228	3648
	2	50A 8	32	324	10368
	3	50A 8	88	50	4400
	4	50A 8	12	200	2400
ARMADURA DE PUNÇÃO DET. 3			(X4)		
	1	50A 8	32	241	7712
	2	50A 8	32	116	3712
	3	50A 8	80	95	7600
	4	50A 8	16	157	2512
	5	50A 8	16	50	800
	6	50A 8	16	148	2368
	7	50A 8	32	150	4800
ARMADURA DE PUNÇÃO DET. 4			(X4)		
	1	50A 8	24	146	3504
	2	50A 8	24	238	5712
	3	50A 8	64	40	2560
ARMADURA DE PUNÇÃO DET. 5			(X2)		
	1	50A 8	16	236	3776
	2	50A 8	16	178	2848
	3	50A 8	20	95	1900
	4	50A 8	6	182	1092
ARMADURA DE PUNÇÃO DET. 6			(X2)		
	1	50A 8	16	186	2976
	2	50A 8	8	95	760

RESUMO AÇO CA 50-60

AÇO	BIT (mm)	COMPR (m)	PESO (kg)
50A	8	991	392
50A =			

Peso Total .... 392 kg

ARMADURA DE PUNÇÃO DET. 1
P1/P3/P4/P6(90x20)
P19/P21/P22/P24
ESC.1/25
CORTE 1.1
CORTE 2.2
x8

ARMADURA DE PUNÇÃO DET. 2
P2/P5/P20/P23(25x100)
ESC.1/25
CORTE 1.1
CORTE 2.2
x4

ARMADURA DE PUNÇÃO DET. 3
P9/P12/P13/P18(150x25)
ESC.1/25
CORTE 2.2
CORTE 1.1
CORTE 4.4
CORTE 3.3
x4

ARMADURA DE PUNÇÃO DET. 4
P10/P11/P14/P17(25x100)
ESC.1/25
CORTE 1.1
CORTE 2.2
x4

ARMADURA DE PUNÇÃO DET. 5
P7/P8(25x215)
ESC.1/25
CORTE 1.1
CORTE 2.2
x2

ARMADURA DE PUNÇÃO DET. 6
P15/P16(25x140)
ESC.1/25
CORTE 1.1
x2

ARM.NEGATIVA NO PILAR