https://dx.doi.org/10.22161/ijaers.611.36 ISSN: 2349-6495(P) | 2456-1908(O)

Comparative analysis between reinforced concrete sill plate and prestressed concrete sill plate, equating construction costs for a residential development

Yan Monteiro Gilonna, Nathali Carramanho de Azevedo, Sara dos Santos Santarém, David Barbosa de Alencar, Lívia da Silva Oliveira

Department Acadêmico, Centro Universitário FAMETRO, Manaus-AM, Brasil

Abstract— *The area of civil construction is responsible for developing new construction methods, with more efficient and economical technologies. The prestressed concrete sill plate is an example of engineering evolution when it comes to shallow foundation. The lack of planning in civil works can cause a number of problems and even overburden the work budget, especially in the case of sill plate execution service. For the accomplishment of this work, the case study methodology was used in a construction of a residential development located in the city of Manaus. Besides pointing out the economy consolidated by the project after adopting the new construction method based on economic feasibility studies, this quantitative work aims to compare two types of surface foundation: prestressed concrete and reinforced concrete sill plate. The prestressed sill plate, no matter how much it requires skilled labor to perform, allows for a significant reduction in one of the heaviest items in a budget spreadsheet: concrete. Thus, it can be observed through the analysis that the prestressed concrete sill plate method is the most viable for the construction company because it presents cost reduction and improvements in the ability to resist the loading of structures.*

Keywords*— *Sill plate; Foundation; Reinforced concrete; Prestressed concrete.

I. INTRODUCTION

Brazil undergoes several changes of government over the years, and with this, new construction methods are brought from several other countries. One such technique is the sill plate foundation. With Romanian origin, it was known to be used in the construction of aqueducts, however, in Brazil, this system was widely used to support only small structural loads. This method was used in larger works only in the 90s, with the arrival of prestressed concrete sill plate, in the construction of housing works in the city of Fortaleza - CE because it is considered a simple and economical foundation. Regarding the main materials that make up the sill plate, we find the concrete, passive reinforcement for reinforced concrete sill plate and active reinforcement for prestressed sill plate.

The objectives of this work are: to compare, in full, two construction methods of foundation, both executed in a real estate development with 42 residential blocks located in the west of the city of Manaus, to point out and prove, through budget data, the economy consolidated by the construction company after study.

II. THEORETICAL REFERENCE

2.1 Sill plate Basics

Sill plate is a structural element, a type of surface foundation in direct contact with the ground and is responsible for supporting and distributing building loads evenly to the ground. (11)

The expression sill plate should be used when the shallow foundation distributes the loads of all or part of the pillars of a structure (2). Its main purpose is to withstand the loads applied through the permissible ground capacity tension, thus reducing the stresses on the structures.

Ground strength and subgrade are as important as the sill plate itself as both are directly linked to the performance for which it was designed.

Given this, it is clear the importance of "requesting a geotechnical engineer, the classification of this soil, the tests for particle size, liquidity limit, plasticity limit and CBR in the natural conditions of humidity and compaction." (5).

The sill plate should be used when: the ground load capacity is low; if you want to make the repression proportional; the foundation area is larger than half of the

https://dx.doi.org/10.22161/ijaers.611.36 *ISSN: 2349-6495(P) | 2456-1908(O)*

construction area; the shoe areas are close to each other. (5).

2.2 Sill plate Basics

When it comes to structural systems, sill plates are designed according to four main types: plain sill plates; pedestal sill plates; ribbed sill plates, coffin sill plates. (5).

Smooth sill plate - easy to perform for its simplicity. It can be used as under floor and is widely used in popular housing because it is economical and safe;

Pedestal or Mushroom Sill plate - Increases the thickness at the base of the pillars, thereby improving resistance to shear forces. The pedestals can be either at the top or bottom of the sill plate, the advantage of choosing the bottom is to leave the floor surface flat.

Ribbed Sill plate - Runs with main and secondary ribs, which may be inferior or superior and placed under the structure. In the upper ribs, a fill for the floor leveling is required. In the case of the lower ribs, it is performed at the time of excavation.

Coffin Sill plate - Can be made with multiple floor levels to increase stiffness.

The types of sill plates mentioned above are of increasing order of stiffness and, depending on the type employed, their thickness ranges from 0.15m to 2.00m. (5).

2.3 Materials

2.3.1 Concrete

Concrete is based on the mixture of cement, water, sand and pebble. Mixing these ingredients with water creates adhesion between them, making them a tough paste and therefore a monolithic block. The proportion of these materials is known as trace or dosage.

Concrete is known to withstand high compressive loads and to have low tensile strength. This is due to the transition zone that forms around the coarse aggregate. The transition zone is formed in concrete making because water films are located around this aggregate, this increases the water x cement rate in that area making it more porous, i.e. less resistant.

As regards the strength class of concrete, class C15 is only used for temporary works or concrete which has no structural property (4). For passive reinforcement, concrete C20 is used and for active reinforcement C25 or higher. (1).

Table. 1: Strength classes of structural concretes

RESISTANCE CLASS GROUP I	CHARACTERISTIC RESISTANCE TO COMPRESSION (MPA)	RESISTANCE CLASS GROUP II	CHARACTERISTIC RESISTANCE TO COMPRESSION (MPA)
C20	20	C55	55
C25	25	C60	60
C30	30	C70	70
C35	35	C80	80
C40	40	C90	90
C45	45	C100	100
C50	50		

Source: ABNT NBR 8953 (2015).

2.1.1 Steel ropes

Considered as active reinforcement, steel strands are classified according to the number of wires that are manufactured: 3 and 7 wires. Its resistance is classified into two categories: CP-190 and CP-210. (3).

"The numbers 190 and 210 correspond to the minimum tensile strength limit in the unit force kilogram per square millimeter." (3).

The ropes are supplied greased and plasticized by the industries. Care must be taken that it does not compromise the efficiency of the ropes to the foundations. They must be free of corrosion and even before concreting, the plastic covers must be checked to ensure that there is no tear so that the frame does not come into direct contact with the concrete. coffin - Can be made with various floor levels to increase stiffness.

III. METHODOGY

For this work, the quantitative method was used. Quantitative research, using mathematical language, is based on studies that can be quantified and it seeks objectivity. (7).

Two construction methods will be addressed: conventional reinforced concrete sill plate and prestressed concrete sill plate. Both were executed in the same work, allowing for present budget data and consolidated economy after adoption of the new typology.

Planning in civil works is critical for any venture to achieve success. (10).

With a view to organizing for greater work efficiency, the service subthemes will be described in chronological order of execution.

3.1 Characteristics of the work.

Before describing the processes of execution of this study, it is important to highlight some information that characterize the enterprise in evidence in the present work: through geotechnical tests performed by an engineer specialized in the area, it was found that throughout the construction area presents the same characteristics. ground resistance, being possible the execution of superficial foundations in all the towers of the enterprise; direct cost

https://dx.doi.org/10.22161/ijaers.611.36 *ISSN: 2349-6495(P) | 2456-1908(O)*

of construction will be addressed in both construction methods; The development has 840 housing units, divided into 42 towers of 5 floors; Of 42 sill plates, 2 were made using the conventional reinforced concrete method and 40 on prestressed concrete; The venture is located in the neighborhood of Lily of the Valley, Manaus-AM and was divided into two stages: Phase 01 and Phase 02.

Fig. 1: Location of the project
Source: Own authorship, 2019

Fig. 2: Implementation of phase 01
Source: Builder's Internal File

Fig. 3: Implementation of phase 02
Source: Builder's Internal File.

3.1 Project Analysis

In order to bring innovations and viability to the work, an in-depth study of all the construction steps to be performed was made. Until then, for this typology, the conventional reinforced concrete sill plate was used in all the construction company's ventures.

After realizing the possibility of implementing a new construction method for the foundations of the towers, the designer was asked for a new design review, adopting the prestressed sill plate as the new foundation of the blocks.

Two designs were sent to the construction company, the first one contains the cable layout, the sill plate thickness and the amount of active reinforcement (CP190 RB 12.7mm strand) and in the second, the amount of shape and passive reinforcement is informed (screen welded Q 196), all according to ABNT NBR 6118 (2014) and NBR 7483 (2008). The software used is AutoCAD 2013 version.

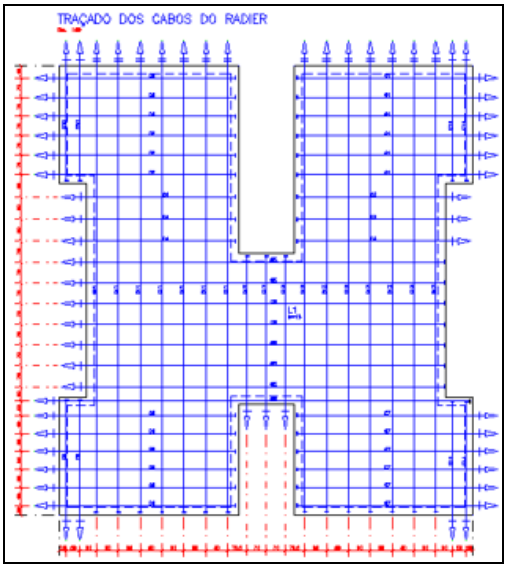


Fig. 4: Cable routing of prestressed sill plate
Source: Builder's Internal File

In figure 4, we can see the architectural design that shows the layout of the chordae and in table 2 below is the summary of them, where it is possible to obtain information such as: steel gauge, length and total weight.

Table 2: Cordoalha

Summary

PROTENSION SUMMARY Non-stick Mono-cables						
Ø	LENGTH	WEIGHT			ANCHORAGE	
		KG/M	KG	KG+4%	A	P
1 Ø 12,70MM	367,93	0,89	327,00	341,00	49,00	49,00
2 Ø 12,70MM	465,36	0,89	414,00	431,00	28,00	28,00
TOTAL WEIGHT = 741,0 KG						

Source: Builder's Internal File

3.1 Preparation of unit cost composition - CCU

The total cost of a work is based on the budgeted cost for each item in a budget spreadsheet. (8).

https://dx.doi.org/10.22161/ijaers.611.36 *ISSN: 2349-6495(P) | 2456-1908(O)*

Unit cost composition is all input required for a service to be performed. It contains the items of services (labor), materials and equipment.

To compose the reinforced and prestressed concrete sill plate, the quantities sent by the designer were used and the concrete volume was calculated through the product between the sill plate perimeters (calculated in design) by its thickness. The prestressed sill plate's thickness and concrete volume are 0.15m and 34.5m³, respectively. In the reinforced concrete sill plate, the thickness is 0.25m and 53.06m³ of concrete (including 4.0m³ of edge beam concrete and 5% loss coefficient for both cases).

Table 3: Armed sill plate unit cost breakdown

UNIT COST COMPOSITION - UCC				
SERVICE	UNITY		BASE: OWN	
Execution of Reinforced Concrete Radier, Esp. = 25cm, with edge beam - MAT. +	Sill Plate		PRICE (R$)	
	UNID	QUANT.	UNI PRICE	TOTAL
15MM COMPENSATED PLATE FORM - USEFUL. 3X - FOUNDATION	m²	30,17	30,88	931,65
AVERAGE SAND	m³	4,00	23,00	92,00
BRITA ESP = 5CM BALL	m³	11,00	110,00	1.210,00
EXTRA STRONG BLACK PLASTIC CANVAS MED. 4 X 100M 150 MICRAS 35KG (1 ROLL FOR 1.5 RADIER = 267M²)	m²	267,00	0,40	106,80
RECOZED WIRE No. 18 (1.24 MM)	kg	17,00	5,82	98,94
CA-50 STEEL MEDIUM	kg	36,00	4,16	149,76
WELDING SCREEN Q 196 MED. 2.45 X 6.00M 3.11 KG / M², PRESENTATION PANEL	m²	1.058,40	18,03	19.080,00
APCB 70 STEEL ARMOR SPACER	un	450,00	0,78	351,00
FCK 30 MPA CONCRETE SEBUM SLUMP 10 + -2 FOR FOUNDATION	m³	53,06	410,00	21.752,73
M.O. RADIER EXECUTION	m³	53,06	292,12	15.498,56
CUTTING AND FOLDING STEEL CA-50 - 10.0MM	kg	36,00	0,45	16,20
				R$ 59.287,64

Source: Own authorship, 2019

In table 3, it is possible to observe the description of each input, the units of measure, the coefficient and with the unit price it is possible to obtain the total construction value of a conventional reinforced concrete sill plate.

Table 4: Composition of prestressed sill plate unit costs

UNIT COST COMPOSITION - UCC				
SERVICE	UNITY		BASE: OWN	
Protected Radier Execution, Esp = 15, with edge beam, excluding metal shape - Torre	Sill Plate		PRICE (R$)	
	UNI	QUANT.	UNI PRICE	TOTAL
15MM COMPENSATED PLATE FORM - USEFUL. 3X - FOUNDATION	m²	12,93	30,88	399,28
AVERAGE SAND	m³	4,00	23,00	92,00
BRITA ESP = 5CM BALL	m³	11,00	110,00	1.210,00
EXTRA STRONG BLACK PLASTIC CANVAS MED. 4 X 100M 150 MICRAS 35KG (1 ROLL FOR 1.5 RADIER = 267M²)	m²	267,00	0,40	106,80
RECOZED WIRE No. 18 (1.24 MM)	kg	17,00	5,82	98,94
CP-190RB STREAM 7 WIRE 12.7MM	kg	937,00	9,75	9.135,75
CA-50 STEEL MEDIUM	kg	483,00	4,16	2.009,28
WELDING SCREEN Q 138 MED. 2.45 X 6.00M 2.20 KG / M², PANEL PRESENTATION	m²	264,60	10,82	2.862,97
APCB 70 STEEL ARMOR SPACER	un	450,00	0,78	351,00
FCK 30 MPA CONCRETE SEBUM SLUMP 10 + -2 FOR FOUNDATION	m³	34,50	410,00	14.145,00
M.O. SILL PLATE EXECUTION	m³	34,50	292,12	10.078,14
MO- STEEL STRIP PROTENSION	kg	937,00	6,50	6.090,50
CUTTING AND FOLDING STEEL CA-50 - 10.0MM	kg	483,00	0,45	217,35
				R$ 46.797,01

Source: Own authorship, 2019

Table 4 shows the inclusion of the 12.5mm CP-190 RB strand and the equivalent workforce in the composition, the coefficients of the other inputs changed along with the total value of the service.

The unit price of each input was collected from local suppliers. A competition framework was created, which contained at least 3 quotes per input, following the guidance of the Federal Court of Auditors booklet, p.59, TCU, which says: "Market research must contain a minimum of three quotes from different suppliers. If it is not possible to obtain this number of quotes, a detailed justification shall be provided. (Judgments 1,266 / 2011-Plenary, 837/2008-Plenary and 3,219 / 2010-Plenary). "

3.1 Execution

Although both methods seen above do not show much difference in their physical characteristics, execution varies according to the type of sill plate. Prior to execution, soil collection was performed to measure moisture content and compaction index as established by standard. The processes below describe how it was actually performed on site.

3.1.1 Prestressed concrete sill plate

In the execution of the prestressed sill plate, the first service to be done is the leveling and compaction of the soil (this is common for any type of sill plate) according to the topographic survey. In the next step are made the hydro sanitary installations and electrical passages. Before allocating the pipes in their proper place, it was necessary to make a layer of sand to accommodate the pipes. The next service is the execution of 7 cm gravel ballast and the placement of plastic tarp over the ballast. This ensures that the frame does not come into direct contact with the ground and ensures its leveling. After the base was completed, the sill plate final height wood forms were made in order to facilitate floor finishing. A layer of Q 196 welded mesh was laid throughout the sill plate area, respecting the cover distance of 3.0 cm. The ropes were allocated, respecting the distances according to the project. It was first checked if there was a tear in the roof so as not to risk the reinforcement coming into direct contact with the concrete. (6). So that the reinforcement does not have contact with the canvas, spacers were placed. Before concreting, check the installation levels, the height of the form and the locking of the form itself. C30 concrete is the one used, and its release has been carefully executed so that nothing goes out of place. The deformation was done the next day. The prestressing is done with hydraulic jack after the curing of concrete that varies from 7 to 9 days, or when it reaches the minimum safety limit equivalent to 21

https://dx.doi.org/10.22161/ijaers.611.36 *ISSN: 2349-6495(P) | 2456-1908(O)*

mpa. All prestressing service is performed by a specialized team, from the placement of the ropes to the cutting of the rope after its tensioning.

Fig. 5: Placement of chords
Source: Own authorship, 2019

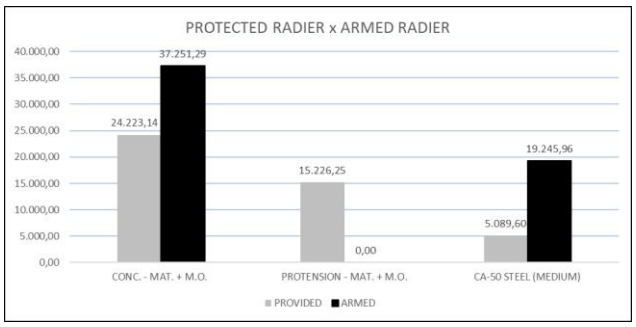
3.1.1 Reinforced Concrete Sill plate

For the reinforced concrete sill plate, the first steps (leveling and compacting the shape execution), mentioned above, are the same. Next, 4 layers with approximately 18 Q 198 welded screens per layer are placed over the entire sill plate area, respecting the distance between them and the cover, as informed in the project. After placing the screens, the concreting is done with the same caution and the concrete with the same strength (C30) mentioned above is used. At the time of cure, hydration is done carefully so that water does not damage the hardened concrete. The deforming is done 3 days after concreting.

Fig. 6: Execution of the armed sill plate
Source: Own authorship, 2019

IV. RESULTS ANALYSIS AND DISCUSSION

After composing the unit costs of reinforced concrete and prestressed sill plate, it was possible to analyze the real cost of construction in both methods. Even though it is necessary to hire another third party to make the prestressing, it pointed to a significant savings of approximately R $ 12.490,63 per sill plate, which is equivalent to R $ 499.625,20 in total savings. This is achieved by reducing the concrete rate by approximately 35% as illustrated in costs in the comparison below.



Graph 1: Comparison of costs between higher weight items of the armed and prestressed sill plate
Source: Own authorship, 2019

In addition to choosing this type of foundation, prestressed concrete sill plate has a very satisfactory track record in terms of performance. The use of this typology has benefits such as: reduction of cracks, minimizing or even extinguishing the control joints, its use in firmer soils is allowed, increasing durability and improving maintenance. (9)

The same institution mentioned above finds advantages after comparing the prestressed method with the conventional one: it is more impermeable due to its higher strength thus avoiding the cracking effect, the slab is less thick and consequently uses less concrete, the prestressing makes the stiffness foundation increases, thus resisting the loads from the structures.

V. CONCLUSION

In order to comply with what was proposed in the objectives, the present work addressed two types of foundation and through data and research, proved the innovation and improvement in this system that is widespread in Brazil: the conventional concrete sill plate. Being able to reduce costs, apply material and even increase the efficiency of a system is what engineering has been looking for over the years.

After the researches carried out for this work, it is understood that the foundation is one of the items that present great weight within the budget, because in its composition are inserted the concrete and steel. Therefore, it is one of the steps that needs special care at the moment it is lifted.

The planning performed played a major role in the success not only in bringing innovations to the work, but also in making the current venture economically viable.

Therefore, it is concluded that in the case of superficial foundations, prestressed concrete sill plate is one of the

https://dx.doi.org/10.22161/ijaers.611.36 *ISSN: 2349-6495(P) | 2456-1908(O)*

most viable methods to be performed and should be studied in more depth. It has been shown to be the most economical and most effective method for resisting higher structural loads compared to the conventional method.

ACKNOWLEDGMENT

To the engineering department of the FAMETRO University Center for their support in developing this work. To my family that is the basis of everything. To friends in particular: João Paulo Souza de Oliveira for their support and teachings.

REFERENCES

[1] ABNT, ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 6118: Projeto de estruturas de concreto —Procedimento. 2014.
[2] ABNT, ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 6122: Projeto e execução de fundações. 2010.
[3] ABNT, ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 7483: Cordoalhas de aço para estruturas de concreto protendido - Especificação. 2008.
[4] ABNT, ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 8953: Concreto para fins estruturais - Classificação pela massa específica, por grupos de resistência e consistência. 2015.
[5] DÓRIA, Luis Eduardo S.; Projeto de estrutura de fundação em concreto do tipo radier. Maceió/AL, 2007.
[6] EMERICK, Alexandre Anozé. Projeto e Execução de Lajes Protendidas. Ceará. 2002.
[7] FONSECA, J. J. S. Metodologia da pesquisa científica. Fortaleza: UEC, 2002.
[8] MATOS, Aldo Dórea. Como preparar orçamentos de obras: dicas para orçamentistas, estudos de caso, exemplos. São Paulo: PINI, 2006.
[9] POST TENSIONING INSTITUTE, Floor slab. Disponível em < https://www.post-tensioning.org/education/ptapplications/slab-on-ground.aspx > Acesso em: 06 de novembro. 2019.
[10] ROCHA, Ariane A. CASTRO, Nara L.B; A Importância do Planejamento na Construção Civil. 2013.
[11] SOBRAL, J.D.; Utilização do radier estaqueado como solução para obras de pequeno e médio portes em solo colapsível do Distrito Federal. 35p, bacharelado em Engenharia Civil na Universidade Católica de Brasília, 2015.