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Comparative Study of Steel Economy on fck-25 MPa and fck-50 MPa Reinforced Concrete Pillars in a 4-Story Building

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Abstract— *Reinforced concrete is the most widely used building typology in the world, with steel as its most expensive component. The use of high strength concrete tends to enable the making of slender pieces, its use directly implies the monetary cost of the work, thus generating savings or increasing the cost. The present work aims to show the steel consumption for a dimensioned building using 25 MPa and 50 MPa concrete, as well as to provide results regarding the utilization rates of concrete and steel sections and to draw conclusions about the mechanical tests performed to obtain the strengths. mentioned above. With the mechanical tests satisfactory results were obtained for the concrete consistency indexes measured by the slump test and by the axial compression and tensile compression tests it was possible to demonstrate the expected results. With the use of C50 concrete, a reduction in steel consumption was achieved mainly for the columns, when compared to the design made using C25 concrete.*
***Keywords* — Concrete, Software, Cost.**

I. INTRODUCTION

In the civil construction market, we have several types of construction and various materials that are used, such as steel and wood. But in the present scenario concrete is still the most used material in construction. Due to its low cost compared to steel, for example. In addition, it is a fluid material which is easily moldable, allowing the creation of pieces in irregular shapes geometrically. It has a good compressive strength and not so much considerable tensile strength, in this reasoning that reinforced concrete was invented. Previously we worked with casual strength concrete, 25, 30 and 40 MPa. ABNT NBR 6118 (2007) (1) itself did not include in its text the high strength concretes, from the update of the standard in 2014 that was inserted in its text the considerations regarding the high strength concretes (C50 to C90). High-strength concrete has become increasingly common, whether to build taller buildings, tunnels or to reach slender pieces.

Today we have several integrated calculation software for reinforced concrete structures, the best known are: TQS, EBERICK and CYPECAD. Software has come to increase the productivity of structural engineers. With them it is possible to model, analyze, dimension and detail the structures. For this work we chose to use Multiplus' CYPECAD software.

The software allows us to make fast simulations that would not be so agile manually, for this article we will establish cost analysis results for structures sized using 25 MPa and 50 MPa concrete, and demonstrate the strengths obtained through mechanical tests of axial compression and traction. by diametrical compression. With the purpose of showing the differences between the utilization rates of the concrete and steel sections, and exposing the real economy according to the SINAPI-BRA table of the state of Amazonas.

II. BIBLIOGRAPHIC REFERENCES

The use of high strength concrete makes it possible to produce increasingly slender parts and other economic advantages, depending on the use. This paper aims to demonstrate the consumption of steel for a dimensioned building using 25 MPa and 50 MPa concrete, and then the cost comparison according to the SINAPI-BRA table. Demonstrate the traces for the resistances mentioned above through mechanical tests, in addition to the utilization rates of the concrete and steel sections.

Sometimes the builder wonders if it is possible to reduce the steel consumption for the works, because it is one of the most expensive materials in construction.

2.1 Concrete

Concrete is a properly obtained mixture of cement, coarse fine aggregate and water. The various characteristics that it must present in order to be used depends fundamentally on the planning and care in its execution (2), (3).

It is a product or mass produced from the use of a cementing medium, which is the product of the reaction between a hydraulic cement and water, with aggregates fulfilling the cheapest filling paper. Its strength is influenced essentially by the components of this mixture and its degree of density, being considered the most important property especially for conventional concretes (4). It is noteworthy that they are very used concretes, since there are many applications in which the concrete with high water/binder ratio, but with a not so high compressive strength are still perfectly adequate and economical to the present times.

By definition Portland cement conventional concrete is a material composed of two distinct phases where the first and the cement paste, consisting of Portland cement and water, and the second the aggregates. The binder, which is cement, upon contact with water, develops binder properties as a result of hydration, which is the chemical reaction between cement minerals and water and, after some time, the combination hardens into a sturdy cluster (5), (6).

Table 1. Strength classes of structural concretes

Resistance class Group I	Characteristic compressive strength (MPa)	Resistance class Group II	Characteristic compressive strength (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: NBR 8953: 2015

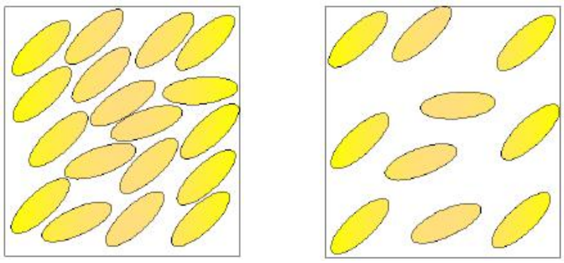
Conventional concrete is defined as that mixture that is produced using only cement, coarse aggregates and mints and water (3). In general, they are those produced on site, but can be manufactured in batching plants or concrete mixers. Their resistances are generally low, less than 30 MPa. In Brazil, most of the concretes used in construction are conventional or usual concretes.

ABNT NBR 8953 (2015) (7) classifies concrete in two groups, being group I conventional concrete, with resistances ranging from 20 MPa to 50 MPa, and group II categorized as high strength ranging from 55 MPa to 100 MPa, as shown. Table 1.

2.1.1 High Strength Concrete

What makes a concrete very high-strength is its very low water / cement ratio, always below 0.35 and often around 0.25, up to 0.20, and that due to low factor a / c the compressive strengths easily reach values above 50 MPa. High strength concretes present in their compositions common aggregates, although of good quality; Common Portland cement, although initial high strength cement may be used when initial strength is a requirement, in high consumptions, between 450 and 550 kg / m³, generally between 5% and 15% of the total mass of cementitious material; possibly other cementitious materials such as microsilica, ash or granular blast furnace slag, and always a superplasticizer additive. The dosage of superplasticizer is high, between 5 and 15 liters per cubic meter of concrete, depending on the solids content of the additive as well as its nature. This dosage enables reductions in the amount of water in the order of 45 to 75 liters per m³ of concrete. Other additions may also be used, epoxy polymers, artificial aggregates such as calcined bauxite sand and steel fibers. High strength concrete should be able to be cast into the structure by conventional methods and cured in a normal manner, although a well-performed wet cure is required (2), (8).

For Barros (2016) (9) superplasticizers are high-effect water reducers, when carefully matched to cement make it possible to reduce the water / cement ratio in high-strength concretes to approximately 0.23 and still achieve an excellent initial level of rebounding between 100 mm and 200 mm. Polycarboxylic ether polymers have long side chains that deposit on the surface of cement particles, causing dispersion by electrostatic repulsion. Figure 1 presents the phenomenon of cement grain deflocculating.



(a) (b)

Fig.1 - Effect of cement grain dispersion (a) flocculated (agglutinated) system (b) dispersed system
Source: AÏTICIN, JOLICOEUR and MACGREGOR (1994) (10)

High strength concrete has a high modulus of elasticity, as these two properties are related. The high modulus of elasticity is necessary to increase the stiffness of the building, reducing oscillation in the most intense winds. The construction of the Water Tower Place building in 1960 resulted in a shrinking of the lower floor pillar sections. It also significantly decreased the building's own weight by increasing its useful spaces. There was also a reduction in costs with prefabricated metal forms, as with the progressive reduction of the compressive strength of concrete on the upper floors, the forms could be used on all floors of buildings. Where the compressive strength of concrete has progressively decreased from 60 MPa at ground level to 30 MPa at the top of the building (11).

2.1.2 Computational Programs in the Aid of Structure Calculation

In the decades before the 1960s, structural designs were done manually, from conception to final detailing drawings. With the advancement of technology, several computational packages emerged, which streamlines and facilitates the elaboration of projects. Today in the market we have software capable of analyzing, dimensioning and detailing structures automatically. It is worth remembering that the software does not replace the engineer, the technology is here to add, increase production with regard to design. According to Kimura (2010) (12), there is no magic behind the computer screen, all output information is based on formulations drawn from consistent theoretical methods. There is several software for structural engineering in the market, in Brazil 3 integrated system software (calculates, scales and details) stand out from the others, they are: TQS, EBERICK and CYPECAD.

CYPECAD software is a Spanish program that is broadcast worldwide. Although not a Brazilian program, it has in its system the Brazilian standards (NBR 6118: 2014 - Design of concrete structures - procedures) (13), foundations (NBR 6122 - Design and execution of foundations) (14) , loading (NBR 6120 - Loads for calculating foundation structures) (15), bars (NBR 7480 - Steel for reinforcement for reinforced concrete structures - Specification) (16), winds (NBR 6123 - Forces due to wind in buildings) (17), actions and combinations (NBR 8681 - Actions and safety in structures - Procedure) (18), thus enabling its use.

The software uses to calculate the structure or the matrix method of stiffness, through a space hole consisting of pillars, beams and plates. Unlike TQS and EBERICK, or CYPECAD, it is used to determine the requirements of finite element methods (19), (20).

2.1.3 Structural Analysis

According to ABNT NBR 6118 (2014) (13) the principles of structural analysis are divided into determining the effects of actions based on the ultimate limit state (ULS) and the service limit state (SLS) and also establishing internal efforts and displacements. For Kimura (2010) (12), this is certainly the most important step in the elaboration of a structural project, because based on the results obtained by the structural analysis, the structural elements are dimensioned. ABNT NBR 6118 (2014) (13) lists five different types of structural analysis, which are: Linear Analysis, Linear Analysis with Redistribution, Plastic Analysis, Nonlinear Analysis and Analysis through Physical Models.

Structural analysis can be performed in separate elements, where we obtain stress and displacement values. When we talk about structural analysis of a building, it is necessary to adopt a certain structural model (numerical model). The structural model is nothing more than a prototype that simulates the real structure and important features such as boundary conditions, forces and connections between the structural elements. There are several types of structural models, among the best known are: continuous beam model, flat gantries, space gantries, grid model and finite element methods (FEM) (21), (22).

III. MATERIALS AND METHODS

The building under study was a four storey building with a specific multifamily residential use, consisting of a ground floor, 3 floors with a ceiling height of 3.00 m, a four-roof ridge with a 1.80 m ridge, totaling a useful height. of the 13.80 m building, the total area of each floor is 290.07 m² in each floor, making a total built area of 1160.28 m². The structure is of the conventional type with slabs, beams, pillars, and reinforced concrete foundations, adopted as closing elements ceramic bricks and light frames. The project follows a simple architectural conception, since the objective is analysis of the structural design. Figures 2 and 3 below show the details of floor plans of the type floor and structural design of the building.

In possession of the Architecture projects and structural design conception, the launch and sizing were made in the CYPECAD 2017 software, which is a program for reinforced concrete structure design, precast structures, prestressed and mixed concrete and steel structures that covers the project launch phases, structural analysis and calculation, sizing and final detailing of the elements. Resources for detailing and dimensioning are in accordance with Brazilian Reinforced Concrete Standards (NBR 6118: 2014 - Concrete Structures Design -

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Procedures) (13), Foundations (NBR 6122 - Foundations Design and Execution) (14), Loading (NBR 6120 - Loads to calculation of foundation structures) (15), bars (NBR 7480 - Reinforced steel for reinforced concrete structures - Specification) (16), winds (NBR 6123 - Wind forces in buildings) (17), actions and combinations (NBR 8681 - Structural actions and safety - Procedure) (18).

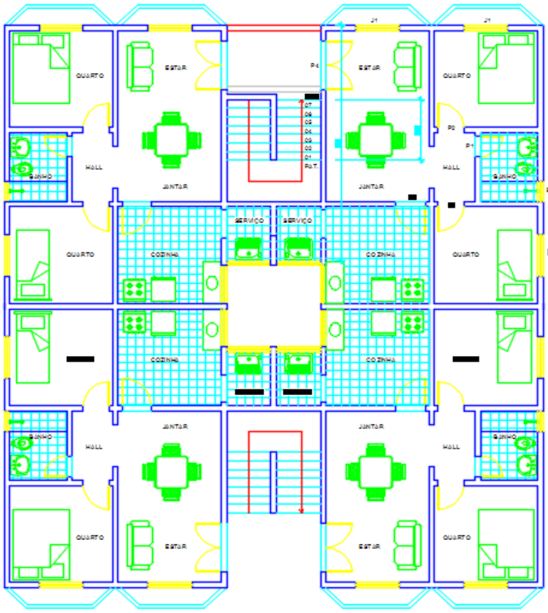

Fig.2 - Detail of the floor plan of the building under study
Source: Data produced by the authors (2019).

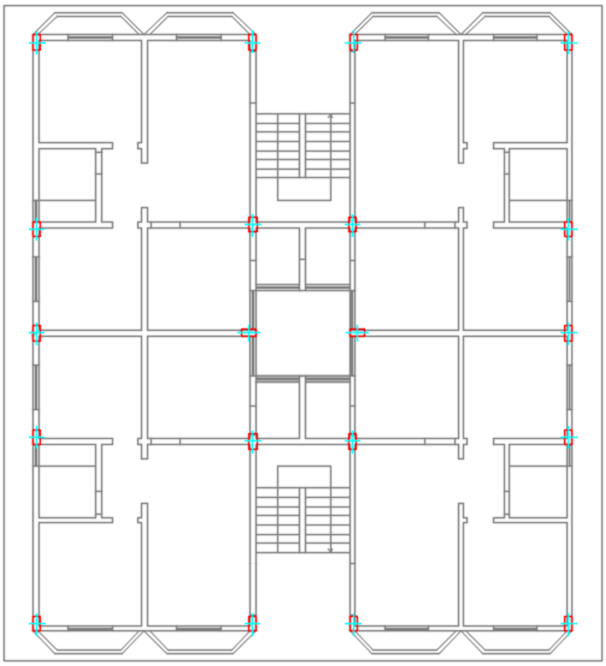

Fig.3 - Detail of the structural design of the building under study.
Source: Data produced by the author (2019).

The research methodology was divided into three phases:

Phase one: Mechanical tests of axial compression and traction by diametral compression were performed, which aimed the characterization of the materials, such as maximum diameter of coarse aggregate, compatibility of additives and additions involved in dosages of high strength concrete, greater than 50 MPa and strength. 25 MPa for later release in CYPECAD software.

The tests were performed according to ABNT NBR 5739 (2018) (23), and ABNT NBR 7222 (2011) (24) at the Construction Materials and Materials Resistance Laboratory of the Federal Institute of Education, Science and Technology of Amazonas - IFAM. Cylindrical specimens of 10x20 cm were molded, sulfur capped and tested on a universal electromechanical machine UMC 60T and 200T with the aid of global pavitest-UMC software, as shown in Figure 4.

(a) *(b)*

Fig.4: Mechanical tests: (a) axial compression, (b) diametral compression traction.
Source: Source: Data produced by the authors (2019)

Second phase: In this phase the launch and configurations of the commercial version CYPECAD 2017 program of fck 25 MPa were made for all the superstructure slabs, beams and pillars. Wind actions were considered in accordance with ABNT NBR 6123 of 2013 (17), where the characteristic wind speed adopted was 30 m / s, topographic factor for flat or slightly rough terrain of S1 = 1.0, factor S2 = 0,93 category IV and class A, while for S3 the factor considered was 1.00 for group 2. For the slabs was adopted thickness of 11cm (ABNT NBR 6118, 2014) (13), coating loads of 100kgf/m² and accidental 150kgf / m². The 16x50 cm section beams and 500 kff / m wall loads and disregard of the window and door spans had their dimensions compatible with the 20 x 40 cm pillars. The structural sizing scheme was calculated by the program considering the beams and columns as spatial frames using the finite element method. According to (ABNT NBR 6118, 2014) (13), 25 mm coverings were adopted for the slabs and 30mm for beams and columns, environmental aggressiveness class II. The CYPECAD software considers buildings as spatial frames, verifying their stability through the linkages of structural elements in their different considerations, as well as the analysis of second order effects is performed through the P-Delta process.

Third phase: In this phase the same launching considerations and program configurations as in the second phase of the research were maintained, changing to fck the concrete to 50 MPa, the 16x50cm beam sections compatible with the original Architecture and Design project. pillars in the dimensions of 20x40cm. With the results of concrete and steel obtained in the launches of the first and second phases, a cost survey was carried out comparing the two steps, through the unit costs table of the National Costs and Indexes Research System. of Civil Construction - SINAPI-BRA Amazonas 2019, issued by Caixa Econômica Federal in March.

IV. RESULTS AND DISCUSSIONS

4.1 Mechanical Tests

Figure 5 presents the results of the consistency tests, which is the property of freshly mixed concrete, which indicates the viability with which it can be properly worked and cast without separation, and is measured using the conventional drop test. The fall cone slump test was the instrument used for the test that presented 100 mm and 85 mm for the concrete with strengths of 25 MPa and 50MPa respectively shown in Figure 4. It can be observed that the values of the slump for the resistances of 25 MPa and 50 Mpa were different, but were within the acceptable range for the projected (100 ± 20) .mm The decrease in slump observed in high strength concrete is related to the lower hydration of the mixture, as they contain lower water / binder ratio, 0.32 for high strength concrete and 0.58 for conventional concrete. The abatement was adjusted with the fluidizing additive for concrete at a ratio of 0.80% by mass of binder, Portland CP IV-32 cement and microsilica, which resulted in lower flowability for the mixture.

The compressive strength of each mixture was evaluated as a function of cure time at ages 7, 14, 21, 28 and 90 days. The average compressive stress results are listed in Figure 6, which shows the variation of compressive stresses for the different ages of disruption.

Figure 6 shows a progressive increase in resistance with increasing age, as expected, and a significant difference between them. When comparing the resistances for the ages of 7 and 90 days, we had a percentage increase of 291% and 257% respectively, demonstrating that they remained practically constant throughout all rupture ages.

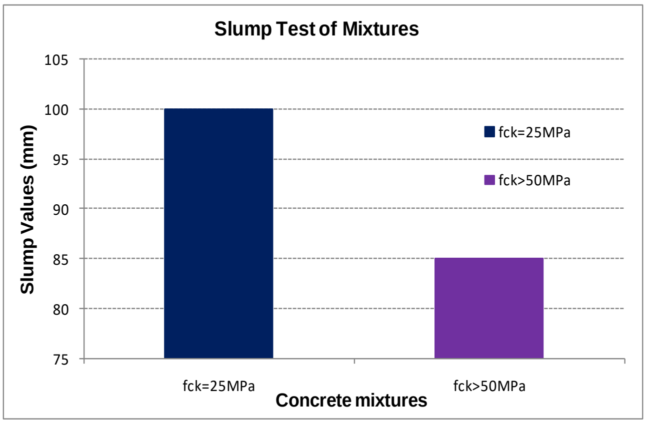

Fig.5 - Result of consistency tests: fck-25MPa and fck>50MPa respectively.
Source: Data produced by the authors (2019).

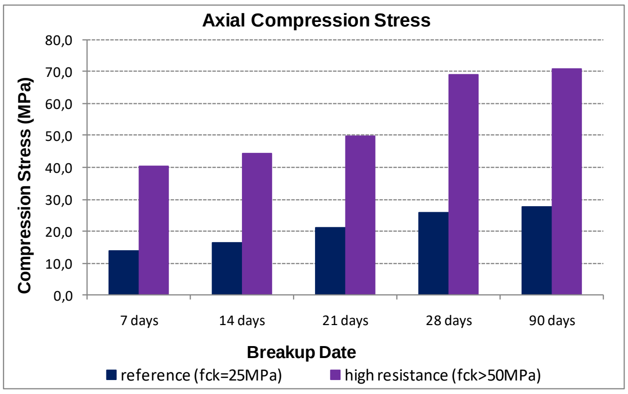

Fig.6. Comparison of axial rupture compressive stresses of conventional and high strength concrete.
Source: Data produced by the authors (2019).

4.2 Analysis of column performance

After the structural modeling of the building and the release of its permanent and accidental loads, we could reach the results of Table 2. It is worth mentioning that the structure was calculated using 25 Mpa and 50 Mpa Fck concrete for all structural elements except the foundations. in addition, we have narrowed the analysis of results of use only in columns, since they are structural elements that are mainly requested for compression, where they will have greater use with the use of a concrete with greater strength. Not least, the beams and slabs are structural elements that are subject to bending, among other efforts. Due to knowledge of Material Resistance and normative calculation procedures, these elements would not undergo significant changes with the increase of concrete strength, since they work mainly in traction regime.

The software calculates the elements and provides us with a utilization table (%), the closer to 100%, the greater the utilization of the section, that is, the element that has a low utilization rate is left with resistance. optimized for a

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smaller section of concrete and steel. For this research, the concrete sections of the structural elements were not optimized, so we could see the results from the utilization rates and the ratio of concrete area to steel area (Ac / As).

The following is a summary table showing the average of the abutment performance with the respective concrete classes, C25 and C50.

Table 2: Analysis of all pillars

PILLARS	DIMENSION (cm)	CONCRETE (Fck)	Ac/As (%)	EFFICIENCY		
				Q(%)	N,M(%)	ADVANTAGE (%)
All	20x40	25 Mpa	1,08	32,23	69,61	70,54
All	20x40	50 Mpa	0,77	19,56	48,3	48,8

Source: Data produced by the authors (2019.

According to Table 2, we can conclude that the pillars dimensioned with 50 MPa concrete resulted in a reduction of 21.74% regarding the utilization of the section, and consequently the Ac/As ratio fell from 1.08% to 0.77. % which translates to a certain steel economy.

4.2.1 Specific analysis of use of pillar P1

Table 3 shows the analysis of the 25 MPa and 50 MPa concrete verification rates for the P1 pillar, the results of shear stress analysis, normal stress and overall utilization, respectively. It has results in each element's bid, having different values for the top and bottom of the pillars.

As can be seen from Table 2, the overall utilization of the pillar at bid 2 was very close for both concrete classes. In this section the software dimensioned the abutment obtaining 8 steel bars of 12.5 mm for 25 MPa concrete, for 50 MPa concrete the software sized the abutment with a 25% reduction in reinforcement, i.e. 8 bars dropped to 6 12.5 mm bars. It can be stated that in the Type 2 pavement pillar throw the maximum utilization of the pillar was achieved for both the concrete section and the steel area. It is worth remembering that the P1 pillar is located in the corner of the building, being thus subjected to oblique compound flexion, where the utilization rate is not so significant, since the increase of resistance only presents considerable results in elements where its greatest demand is. the compression. Based on this information it is justifiable to approximate the utilization values.

Table 3: Efficiency check for P1 pillar

CHECKING THE EFFICIENCY FOR THE PILLAR - P1								
Concrete section								
Part	Dimension (cm)	Position	Verifications 25 MPa			Verifications 50 MPa		
			Q (%)	N, M (%)	Effec. (%)	Q (%)	N, M (%)	Effec. (%)
TYPE 3 (9 - 12 m)	20x40	Outer Superior	23.3	26.6	26.6	37.0	34.1	37.0
		Lower External	23.3	74.7	74.7	37.0	84.7	84.7
TYPE 2 (6 - 9 m)	20x40	Outer Superior	41.3	98.9	98.9	68.4	96.9	96.9
		Lower External	41.3	93.1	93.1	68.4	92.8	92.8
TYPE 1 (3 - 6 m)	20x40	6 m	6.5	93.1	93.1	12.1	92.8	92.8
		Outer Superior	36.0	66.3	66.3	59.8	83.4	83.4
		Lower External	34.7	62.3	62.3	57.8	79.7	79.7
PILOTIS (0 - 3 m)	20x40	3 m	5.8	62.3	62.3	10.8	79.7	79.7
		Outer Superior	19.0	44.5	44.5	30.5	67.5	67.5
		Lower External	19.0	34.6	34.6	30.5	55.5	55.5
LOWER BEAMS (-0.6 - 0 m)	20x40	0 m	3.6	34.6	34.6	6.7	55.5	55.5
		Outer Superior	6.8	22.7	22.7	11.6	38.4	38.4
		Lower External	6.8	22.7	22.7	11.6	38.4	38.4
Foundation	20x40	Foundation	2.1	22.7	22.7	4.1	38.4	38.4

Source: Data produced by the authors (2019).

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4.2.2 Analysis of the most requested and least requested pillar

Tables 4 and 5 show the utilization rates of the most requested and least requested pillars. This finding was obtained through the calculation memorial provided by the software. The most requested pillar was pillar P14, it is an intermediate pillar that is subjected to a normal force of 88.22 kN. The difference between the utilization rates for the two concrete classes was 30.59%.

Table 4: Most requested pillar analysis

REQUESTED PILLAR ANALYSIS			
PILLAR	DIMENSION (cm)	CONCRETE (Fck)	EFFICIENCY (%)
P14	20x40	25 Mpa	79,65
P14	20x40	50 Mpa	49,06
EFFICIENCY RATE DIFFERENCE			30,59

Source: Data produced by the authors (2019)

As shown in Table 5, the least requested abutment is P12 abutment; it is an end abutment subjected to a normal force of 38.95 kN. The difference between efficiency rates was 13.98%, we noticed that it was much smaller than the difference shown in Table 4.

Table 5: Most requested pillar analysis

REQUESTED PILLAR ANALYSIS			
PILLAR	DIMENSION (cm)	CONCRETE (Fck)	EFFICIENCY (%)
P12	20x40	25 MPa	53,26
P12	20x40	50 MPa	39,28
EFFICIENCY RATE DIFFERENCE			13,98

Source: Data produced by the authors (2019).

This difference is due to the location of the abutments in the plant, the most requested abutment (P14) is an intermediate abutment, therefore it is subjected to simple compression. much higher resistance to compression than to tensile strength. The least requested pillar (P12) is an end pillar, which is subjected to normal composite flexion due to eccentricity due to its location in the plant. It is subject to bending moment efforts which generates flexion. Thus, the use of the section proved to be much lower than that of the P12 pillar.

4.3 Cost Analysis (Steel)

Due to the increase of the concrete strength, a reduction in the amount of steel was obtained mainly for the columns, as we can see in tables 6 and 7.

Table 6: 25 MPa Concrete Steel Value

VALUE 25 MPa				
DESCRIPTION	UNITY	AMOUNT	UNIT PRICE (US$)	TOTAL PRICE (US$)
Slab Steel	Kg	5817,00	1.55	9016.35
Beams steel	Kg	3928,00	1.55	6088.40
Pillars steel	Kg	2818,00	1.55	4367.90
Stair steel	Kg	585,00	1.55	906.75
SUM OF ITEM				(US$) 20379.40

Source: Data produced by the authors (2019).

As shown in Tables 6 and 7, the columns had a reduction of 811 kg of steel due to the increase in section. To compare these costs, we use the values available in the table SINAPI-BRA (National System of Costs Survey and Indexes of Construction) for the state of Amazonas in May. Concrete consumption was not compared because we did not choose to optimize the concrete sections of the columns, only the comparison of steel reduction. Comparing the data in tables 6 and 7, we arrive at savings of around US$ 1432.20 for 50 MPa concrete.

Table 7: 50 MPa Concrete Steel Value

VALUE 50 MPa				
DESCRIPTION	UNITY	AMOUNT	UNIT PRICE (US$)	TOTAL PRICE (US$)
Slab Steel	Kg	5740,00	1.55	8897,00
Beams steel	Kg	3892,00	1.55	6032.60
Pillars steel	Kg	2007,00	1.55	3110.85
Stair steel	Kg	585,00	1.55	906.75
SUM OF ITEM				(US$) 18947.20

Source: Data produced by the authors (2019).

V. CONCLUSION

With the dosages adopted for the concrete we obtained satisfactory indexes for the concrete consistency and its characteristic resistances. A consistency value of (100 ± 20) mm was projected, and the slump test reached a value of 100 mm and 85 mm for the 25 MPa and 50 MPa concretes respectively, concluding that it is within of the acceptable range that was designed. Compressive strength showed a progressive increase concomitantly with increasing ages. The dosages for 25 MPa were satisfactory reaching the expected resistance, for the high strength concrete it exceeded 70 MPa at 90 days.

Regarding steel consumption, a reduction of 811 Kg was achieved when using 50 MPa concrete. Referring to the values with the SINAPI-BRA table, considerable savings were achieved. The results are significant when comparing values related to columns, elements subjected to flexion and traction do not undergo major changes. It is worth noting that the savings are even greater when choosing to optimize concrete sections.

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