A Comparative Study of Concrete Compressive Strength for High-Rise Building Columns

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Abstract. This article presents a comparative analysis between concretes with characteristic compressive strengths of 50 MPa and 90 MPa applied to the columns of a 130-meter-high building. The research evaluated the structural impacts of replacing conventional concrete with High Performance Concrete (HPC), while maintaining the original dimensions of the elements. The results indicated an 8.8% reduction in the maximum displacement of the top of the building, attributed to the increase in the concrete's deformation modulus. There was also a significant reduction in the rate of longitudinal reinforcement, especially on the lower floors, with the ground floor having the biggest reduction, 49%. The analyses were carried out using structural modeling in the TQS software, taking into account second-order effects (P-Delta) and the normative criteria in force. The conclusion is that the use of HPC represents an advantageous technical alternative for tall building projects, promoting greater structural stability and rationalization of resources.

Keywords: High-Performance Concrete, Compressive Strength, Reinforced Concrete Columns, Sustainable Construction

1 Introduction

Considering the growing urban density and the consequent appreciation of space in metropolitan centers, there is a tendency for construction companies to build high-rise buildings. This quest for verticalization, although promising, brings up complex challenges related to infrastructure and the environment. At the same time, the construction industry has made significant efforts to optimize processes and make efficient use of resources. Given the sector's growing demand for raw materials and energy, which results in considerable environmental impacts, it is essential to develop construction practices that prioritize speed, economy, safety and quality [1].

The evolution of resistance techniques is undeniable, and with the improvement of mathematical models, which are increasingly aligned with structural reality, it is possible to design column with smaller cross-sectional dimensions than in previous times, allowing slender elements to be obtained [2]. Advances in technological innovations in engineering and architecture have made it possible to create bolder buildings that challenge building traditions. However, these projects, when design with conventional materials, often become uneconomical and even unfeasible [3]. Thus, there is a pressing need to investigate new technologies, new materials and mathematical models that are even closer to the real conditions of use.

In this context, the use of High-Performance Concrete (HPC) is emerging as an innovative solution for engineering projects that require high mechanical strength and durability [4]. HPC not only makes it possible to build increasingly slender structures, but also contributes to the sustainability and energy efficiency of construction projects, in line with the contemporary needs of a sector facif f ng environmental and economic challenges.

Given this scenario, the aim of this study is to compare the structural performance with the use of concretes with different characteristic strengths - 50 MPa and 90 MPa - in high-rise building columns, assessing the technical and economic impacts of adopting HPC instead of conventional concrete.

2 Methodology

This study was based on a real project for a 40-storey residential building and analyzed two structural models, focusing on the tower columns. The analysis methodology was initially based on modeling a reference structure using concrete with a fck of 50 MPa. This model (figure 1) served as the basis for the comparative analysis. For both models, the original design dimensions were maintained, which enabled a direct assessment of the effects of changing the concrete strength.

After modeling the reference structure (50 MPa), the fck of the concrete was changed to 90 MPa. The changes to the technical and budgetary parameters were then observed. The analysis of both models generated comparative data on the global and local displacement of the building, allowing a detailed assessment of the stiffness gains and economic impacts of using high-strength concrete. TQS software [5], version 24, was used for this analysis.

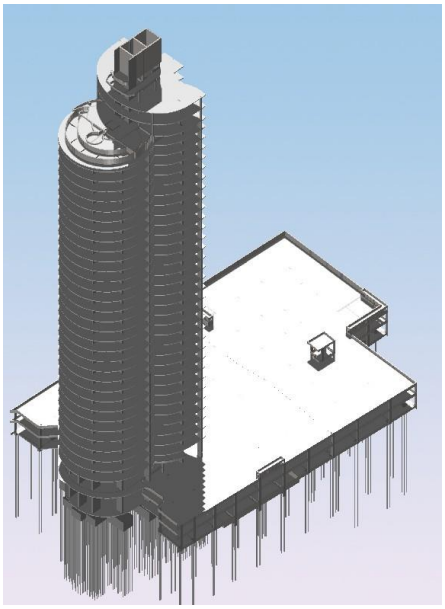


Figure 1. 3D model of the analyzed building

The structure was processed with a linear elastic analysis using TQS model VI. Using this model, the building is modeled as a spatial frame, made up of elements that simulate the beams, columns and slabs of the structure. The effects generated by the application of vertical and horizontal actions will be calculated using this model. In this way, in addition to the beams and columns, the slabs will be able to withstand some of the forces generated by the wind, a situation not seen in other models. In addition, the analysis of the P-Delta process was applied, an iterative process that takes into account second-order effects. This analysis is crucial for tall buildings, as it assesses how lateral deformations (displacements) influence the distribution of forces, ensuring structural safety under the interaction of vertical and horizontal loads. Also analyzed was the RM2M1 coefficient, which is a way of summarizing the results of this non-linear analysis in a single value. It indicates the intensity of the second- order effects, showing how amplified the stresses are compared to a linear (first-order) analysis. For the calculations, the software used the secant deformation modulus of the concrete (Ecs).

The slabs for the project were defined with a thickness of 12 cm for the core slabs and 20 cm for the other slabs, as can be seen in the formwork plan (figure 2).

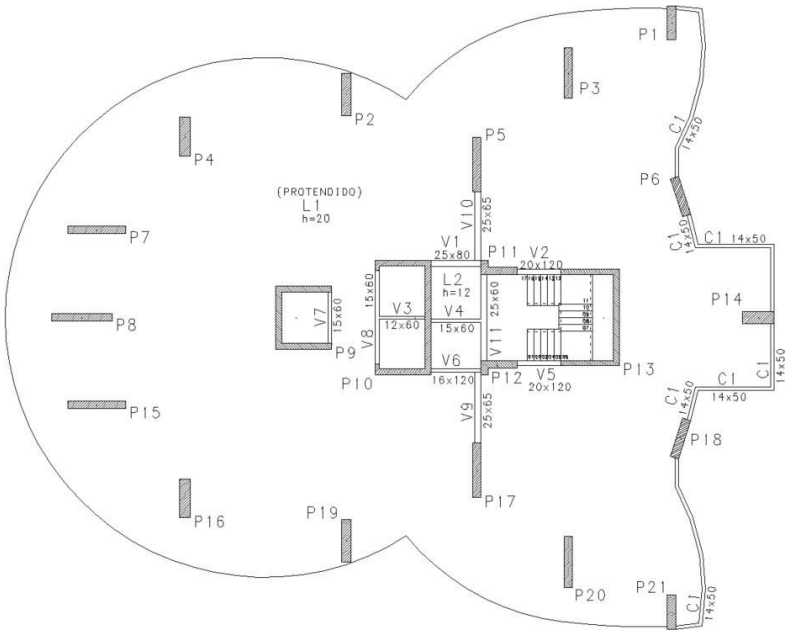


Figure 2. Formwork plan of the typical floor

During modeling, the structure's displacements were limited by normative criteria. The analyses and loads applied followed the guidelines of the main Brazilian standards: NBR 6118:2023 (Design of Concrete Structures) [6], NBR 6120:2019 (Loads for the Calculation of Building Structures) [7] and NBR 6123:2023 (Wind Forces in Buildings) [8].

3 Results and Discussion

Evaluation of the results obtained in the models with fck 50 and fck 90 reveals a direct correlation between the increase in concrete strength and structural rigidity, significantly impacting performance under load. Table 1 shows a reduction of 8.8% in the maximum top displacement for the fck 90 model, which fell from 7.58 cm to a value lower than that permitted by the standard. This improvement is justified by the increase in the modulus of deformation of the concrete, which, even without changes to the inertia of the columns, gave the structure greater rigidity. The susceptibility to displacements in the Y axis was more pronounced due to the lower inertia in this direction, a critical point to be considered in the design.

Table 1. Maximum roof displacement values of the analyzed models

fck (MPa)	X-axis displacement	Y-axis displacement
50	3.95	5.09
90	3.51	4.64

With regard to the displacements between floors, Table 2 shows that both models presented values within the normative limits, with no significant changes between fck 50 and fck 90. There was no change in the maximum inter-story drift values, but the values established by the standard were respected, which vary according to the right foot of the floor, where the lowest right foot is 2.52 cm and the highest is 7.09 cm, so the inter-story drifts were between 0.32 cm and 0.89 cm.

Table 2. Maximum inter-story drift values of the analyzed models

fck (MPa)	X-axis displacement	Y-axis displacement
50	0.12	0.21
90	0.12	0.21

The RM2M1 values were also not significantly reduced, with values of 1.28 and 1.25 for the fck 50 and fck 90 models respectively. Figures 3 and 4 show the displacement of the building's frame with fck 90.

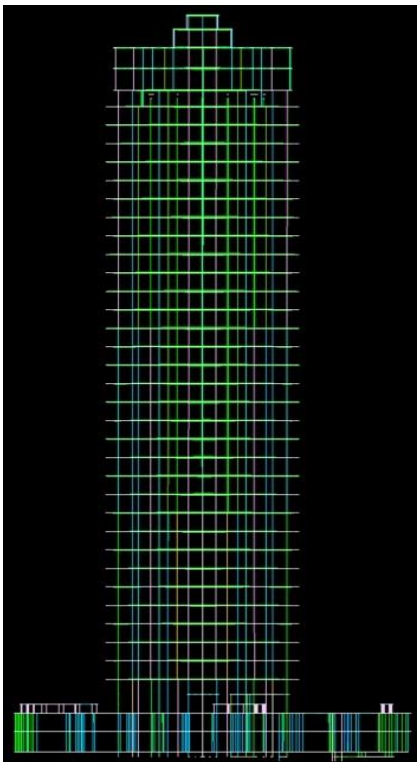


Figure 3. Side view of the frame displacement

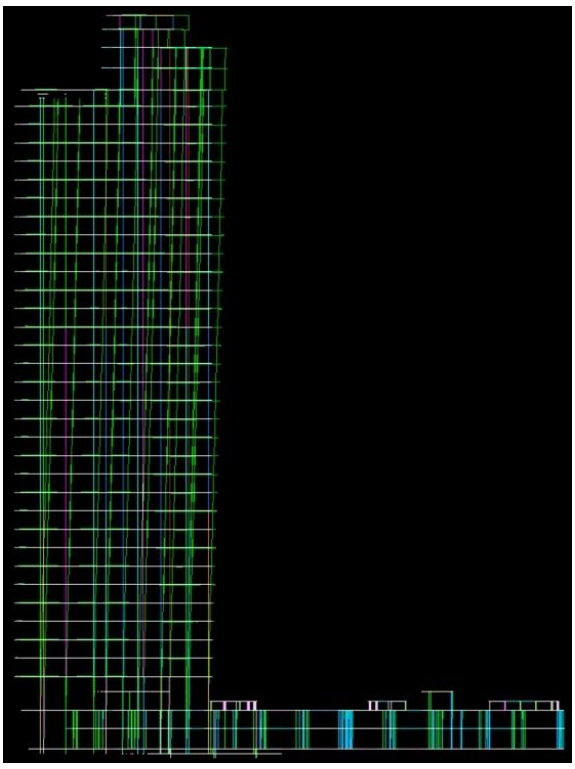


Figure 4. Front view of the frame displacement

The analysis of the steel ratio in the reinforcement of the columns highlighted one of the main benefits of using high-strength concrete. Replacing fck 50 with fck 90 resulted in a considerable reduction in the need for reinforcement, especially in the lower floors, where the axial loads are higher.

The most significant reduction occurred on the first floor, with a 49% reduction in the steel rate, as can be seen in figure 5. This saving extended up to the 8th floor, where the variation in the area of steel required was from 19.1 cm²/cm² to 0.5 cm²/cm². From this point on, the reduction was less significant, as the minimum reinforcement prescribed by the standard, depending on the column section, became the determining factor.

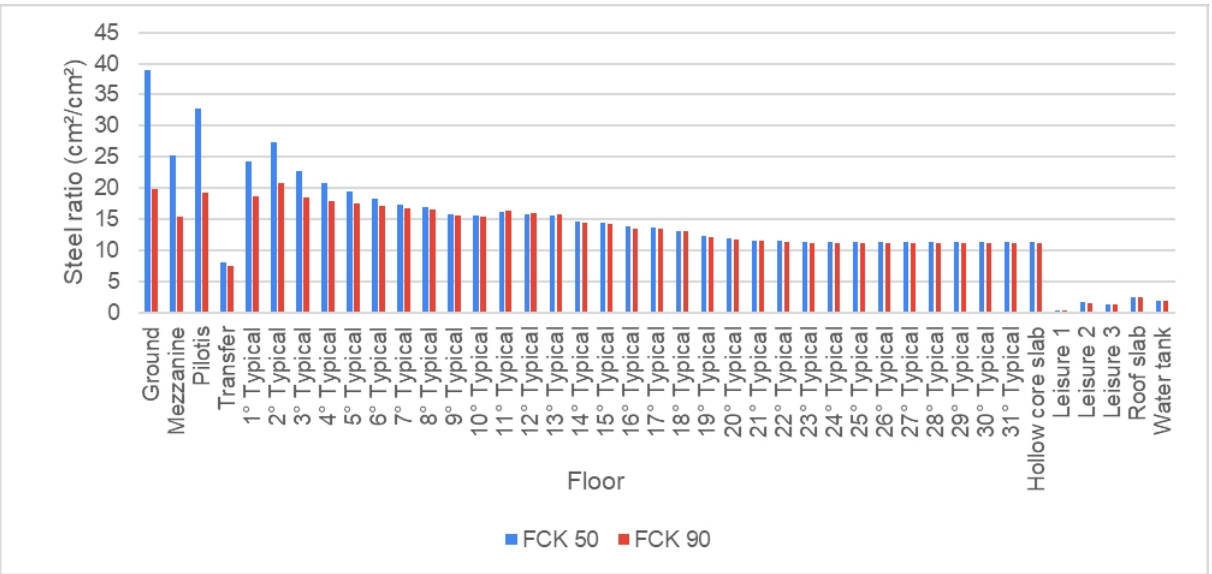


Figure 5. Steel ratio on each floor of the analyzed building.

In the P5 and P17 columns on the ground floor, the reduction reached 70%, demonstrating the efficiency of fck 90 in elements subject to high loads. On the other hand, column P9 for example, did not show the same reduction, indicating that other factors, such as the structural arrangement and geometry of the column, influence the optimization of reinforcement, as shown in figure 6.

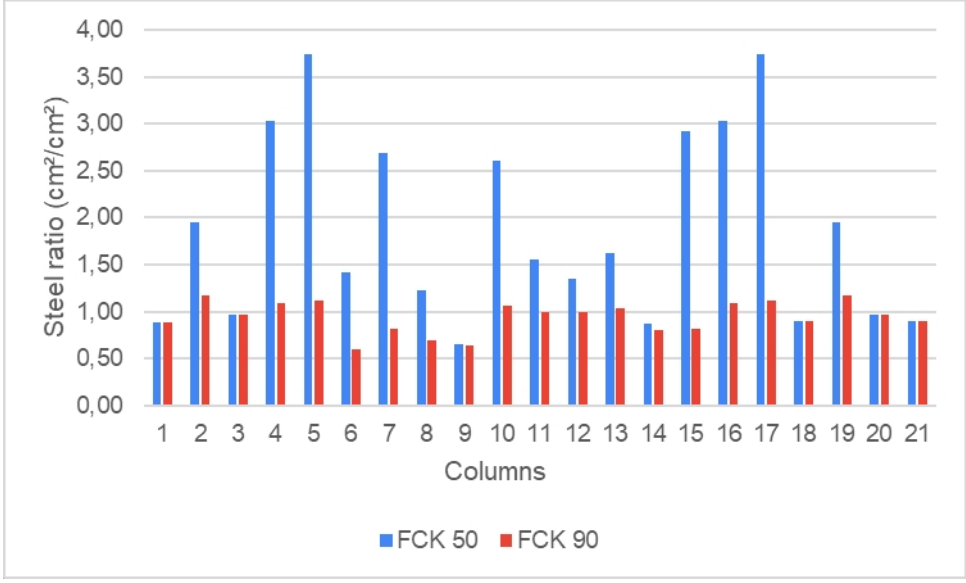


Figure 6. Steel ratio per column on the ground floor

The greatest reduction in the steel ratio between the type floors was observed on the 2nd floor (figure 7), a direct consequence of the variation in column section on the lower floor. This result reinforces the importance of considering the interaction between floors in order to optimize the structural design as a whole, maximizing material efficiency.

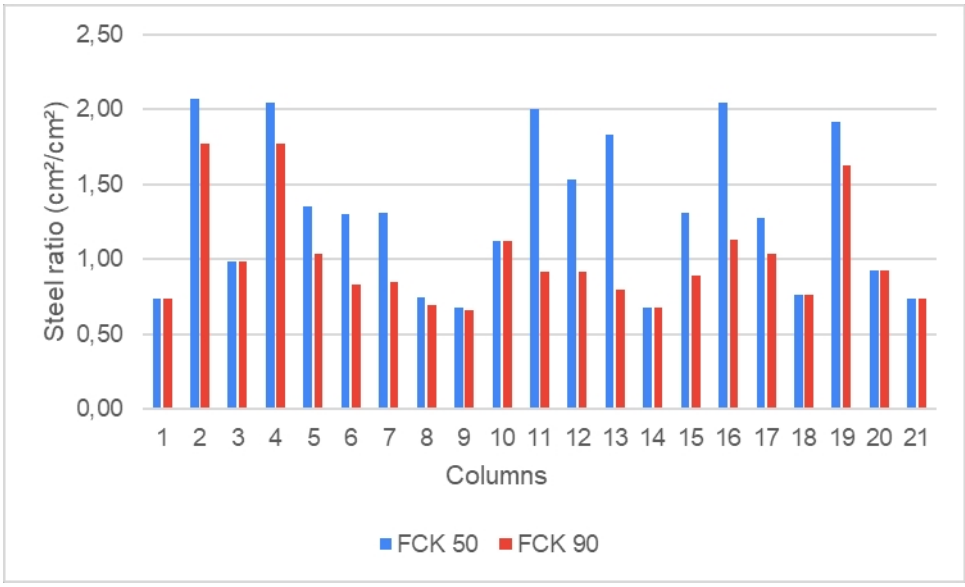


Figure 7. Steel ratio per column on the 2nd typical floor

4 Conclusions

The comparative analysis between concretes with characteristic strengths of 50 MPa and 90 MPa applied to the columns of a high-rise building showed that the use of High Performance Concrete (HPC) provides significant structural and economic gains. The adoption of fck 90 MPa resulted in an 8.8% reduction in the maximum displacement of the top, showing greater rigidity of the structure even without changing the dimensions of the elements.

In addition, there was a significant reduction in the rate of longitudinal reinforcement, especially in the lower floors, where axial stresses are higher. On the first floor, the reduction reached 49%, which represents substantial savings in material and labor.

Although the displacements between floors and the RM2M1 coefficient remained within the normative limits in both models, the results reinforce the efficiency of HPC in highly demanding structural situations. The improvement in the deformation modulus of the concrete and the consequent global stability of the building indicate that the use of high-strength concrete is an advantageous alternative for vertical projects, especially in basement floors.

It can therefore be concluded that HPC is a promising technical solution for high-rise buildings, contributing to the rationalization of resources, improved structural performance and progress towards more sustainable and efficient building practices.

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