Conceptual Elements for the Design of Concrete Shear Cores in High-Rise Buildings in Brazil. Implementation in Eberick Software

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Summary

The growth of large urban centers has created the need to build larger buildings to meet the population demand concentrated in small areas. Thus, taller and more slender buildings have been constructed, where dynamic actions become more important. Among the solutions used to ensure rigidity against horizontal and torsional actions is the use of rigid concrete cores. This structural element has a structural behaviour significantly different from conventional columns, generally modelled with bar elements, mainly due to the interaction with other elements of the structure and due to warping in the case of restricted torsion. This material presents fundamental aspects related to the modelling, analysis and dimensioning of rigid concrete cores and how these aspects are treated during implementation in the AltoQi Eberick software using the finite element method for the specific conditions of Brazil.

1 INTRODUCTION

High-rise buildings are complex engineering structures that meet the challenges of urban space optimization and population growth. One of the critical elements of these structures are shear cores, which form the backbone of their lateral load-resisting systems. In Brazil, the design of concrete shear cores must address specific challenges, including high wind loads prevalent in coastal regions and compliance with national codes, such as **ABNT NBR 6118 (2023)** [1] and **NBR 6123 (2023)** [2].

This article provides a comprehensive overview of shear core design principles for high-rise buildings, focusing on their modelling, analysis and design in **Eberick**, a popular structural engineering software developed in Santa Catarina, Brazil.

2 CONCEPTUAL ELEMENTS OF TALL BUILDINGS AND CONCRETE SHEAR CORES

2.1 Definition of a tall building and Concrete Shear Core

There is no exact definition of "tall building", this is subjective and can depend on several factors such as, the average height of the surrounding buildings, the relationship between the height and the dimensions in plan, the dynamic properties of the structure, or the technology used.

The Council on Tall Buildings and Urban Habitat (CTBUH) [3] developed the international standards for measuring and defining tall buildings. In general, if the height is greater than 50 m, and if the building can be considered subjectively relevant to one or more of the categories mentioned above, then it can be considered a tall building.

Concrete Shear Cores are an assembly of shear walls forming an open or partially enclosed polygonal section by the beams or floor slabs. These shear walls delimit spaces for elevators, stairs although sometimes they are used for the passage of the technological systems of tall buildings. Shear cores resist lateral forces through their stiffness and strength, reducing P-Delta effect**,** inter-story drifts and ensuring occupant comfort and structural safety, these elements integrate functionality and structural performance.

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2.2 The problem of height and the Slendernes

Let's consider a building with rigidity, mass, and uniform section in height, the wind pressures vary vertically according to the simplified continuous model of ABNT NBR 6123 [2]. Doubling the height the total weight of the P structure would result in 2P, but the moment and the total shear at the base would be 4.9 and 2.45 times greater respectively, if we triple the height, the weight would be 3P, But the moment and the total slash at the base would be 12.5 and 4.16 times higher respectively. The impact on horizontal displacements at the top is even greater, for height equal to "2h" the lateral displacements are 19.7 times greater, however, for height "3h" they are 112.7 times greater, Fig. 1.

The initial planning stage, it is advisable to consider the basic proportions of the structure, Height does not mean slenderness. The slenderness ratio (SR) can give a good initial indication of how hard the structural system will need to work. The SR can be obtained by dividing total building height by the smaller base width, SRs of around h/6 or less can usually be accommodated whereas for h/8 or above the structural system will be working harder and the dynamic behaviour is likely to be dominant in the structural solution.

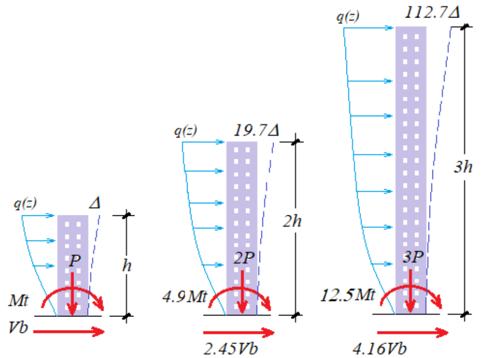

Fig. 1 Impact of the height on the forces at the base and horizontal displacements at the top

The SR should, however, only be used as a guide to the potential behaviour of tall buildings, the actual behaviour of the tall building is closely related to the ratio SR. This SR should not be confused with the slenderness of the concrete core or its components

2.3 F Geometry, Configuration and Position in Plant

Efficient shear cores are typically rectangular, L-shaped, or C-shaped. But, in general, the transverse sections can be very varied depending on the architectural solution for vertical circulation by means of elevators, stairs or for the technological systems of ventilation, electricity, hydraulics or waste evacuation. In some cases, a reduction of the section is carried out on the upper floors where the stresses are less, thus increasing the useful area of the floor. Engineers must balance functional requirements (e.g., elevator shafts) with structural efficiency to avoid torsional effects. Openings for doors and utilities must be carefully reinforced to maintain core integrity.

The position in the plant plays a fundamental role in the structural response. Based on this, the core can be classified in a general way into: Central, perimeter, mixed, and offset cores [7], Fig. 2.

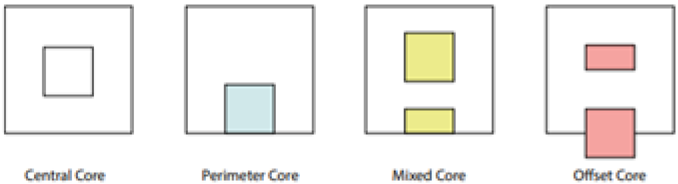

Fig. 2 Classification of central, perimeter, mixed and offset cores in tall buildings.

Was studied a 30-story building with two concrete shear cores, the action of the wind was calculated in accordance with the NBR 6123 [2], the following conditions were considered: basic speed 35 km/h, topographic factor S1=1.00, Category III terrain, S3=1.00 and critical damping ratio 0.015. Five models were studied varying the position of the concrete shear core in the X and Y directions, the concrete shear cores are linked by concrete beams of 60x25cm, Fig. 3. The results are shown in Fig. 4.

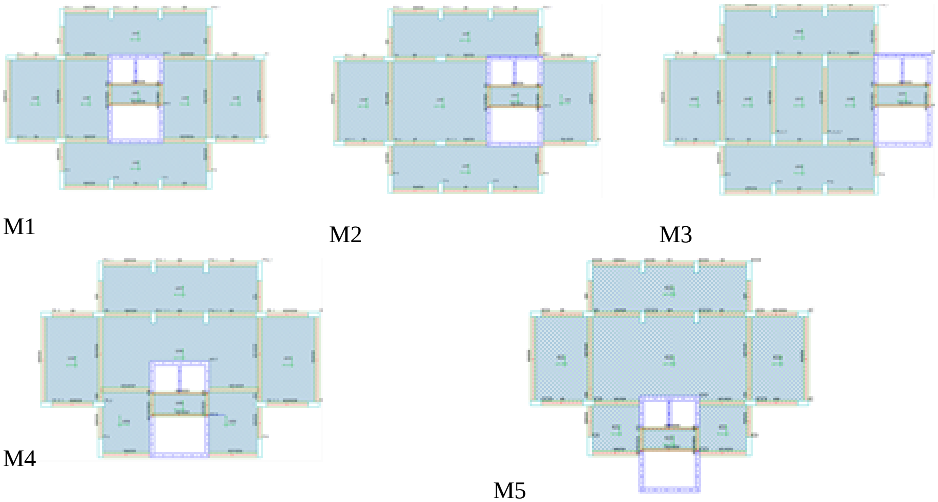

Fig. 3 Models studied by varying the position of the concrete core in the plant.

The analysis of Fig. 4 and 5 indicates that when the wind acts in the X direction, the horizontal displacements of the center of mass show little variation if the rigid concrete core is displaced in the X direction, while the maximum displacements are obtained when the core has the maximum offset in Y. The same behaviour is observed when the wind acts in the Y direction where there is little variation if the rigid concrete core is displaced in the Y direction while the maximum displacements are obtained when the core has the maximum offset in the X direction.

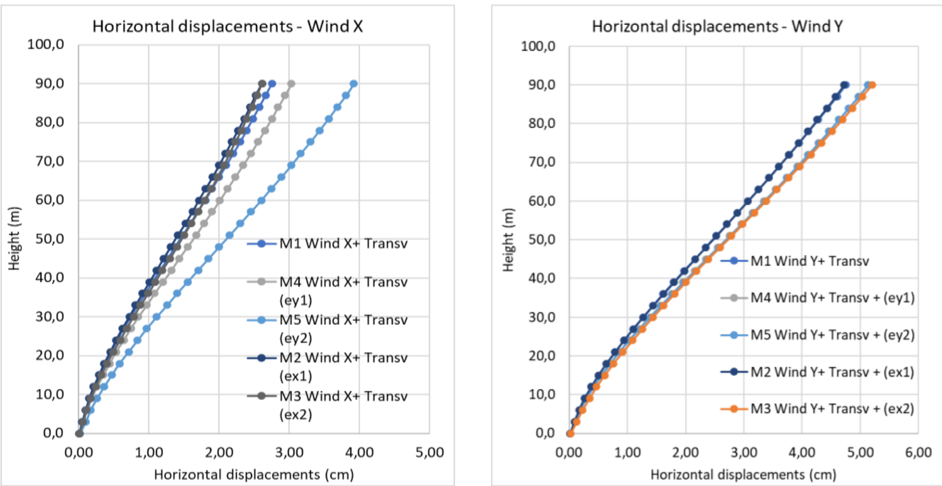

Fig. 4 Lateral absolute displacements of the center of mass of each floor

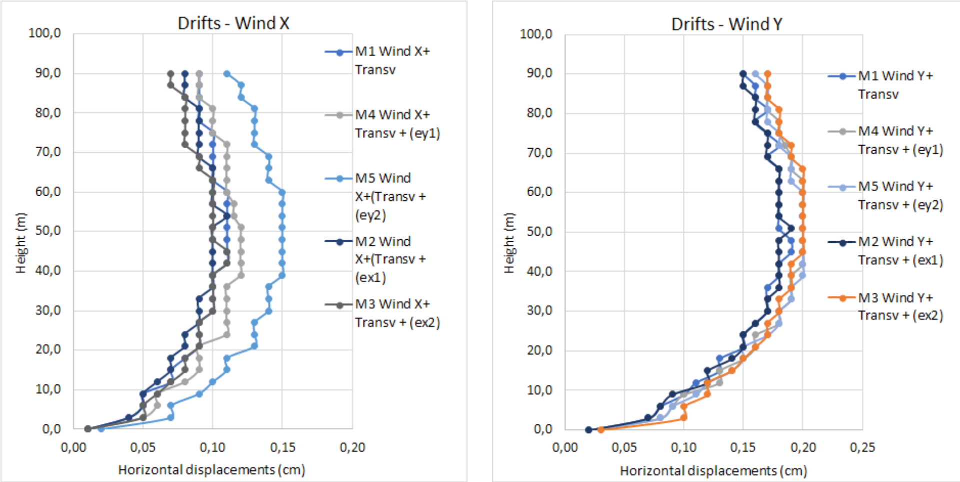

Fig. 5 Relative horizontal displacements (drifts) of the center of mass of each floor

2.4 Material Properties, Modelling, Design and Detailing

Material properties: Concrete strength and ductility are essential elements in the design of these elements. High-strength concrete is often preferred for its superior stiffness, reducing core dimensions and optimizing usable floor area.

Modelling: The bibliography on the subject [5], [7] presents several methods for the modelling of concrete cores based on bars and finite elements, internationally the Finite Element Method (FEM) is the most accepted by its versatility for the modelling of complex structural situations. Modelling by means of isolated member columns or connected by completely rigid members is not recommended, studies show that the behaviour under vertical loads is similar and acceptable, but under horizontal actions it presents significant differences in the case of important torsional effects on the structure, not capture the effects of warping of the core section or its correct interaction with the beams and floor slabs, problems that do not present themselves in modelling with grid analogy or with FEM.

Design and Detailing: To size the cross-section, the hypothesis of plane sections is accepted, although this may be far from reality, especially in cases of significant torsion in the building. On the other hand, most standards have different levels and specifications of detailing depending on the level of seismicity, with precise specifications for longitudinal and transverse reinforcements for the areas at the ends of shear walls and concrete cores. Reinforcement detailing must consider congestion at critical zones, especially around openings.

2.5 Material Properties, Modelling, Design and Detailing

In Brazil there is a long tradition in the use of the grid analogy method for the modelling of walls and slabs of different types, for the modelling of rigid cores and, although it is a method of easy understanding by the community of structural engineers, it is a method that has already been practically abandoned internationally for the analysis of structures of this type (especially for cases of horizontal loads acting axially to the plane of the plate), being preferred and more widely used the method of finite elements.

Wind Loads: Brazil's coastal cities face significant wind pressures. NBR 6123 [2] provides detailed guidelines for determining these forces, which often govern the design of high-rise buildings. In the case of tall buildings (H>100m) with SR>6 and frequency of the first mode <0.25 Hz, it is generally necessary to carry out a wind tunnel study to determine the wind horizonal forces, accelerations, pressures on the facades and other wind effects.

Seismic Activity: Brazil is not a country of high seismic activity, the Brazilian standard ABNT NBR 15421 [4] can be dispensed for structures located in about 80% of the national territory. Localized events require minimal provisions for dynamic forces, primarily in areas near geological fault lines, but even in these regions in the case of tall buildings the action of the wind is predominant.

3 DESIGN PROCESS USING EBERICK SOFTWARE

3.1 Overview of Eberick

AltoQi Eberick [6] is a software developed by company AltoQi for the modelling, analysis, design and detailing of structures in reinforced and prestressed concrete cast in-situ, precast, structural masonry and steel structures, is widely used in Brazil, offering a user-friendly interface tailored to local codes. It integrates wind and seismic load calculations, reinforcement detailing, and 3D visualization, integrated into the BIM methodology, making it a powerful tool for shear core design. The company AltoQi developed within the AltoQi Eberik software a resource to design structures of tall buildings with concrete cores modelled by the finite element method.

3.2 Modelling the Concrete Shear Core Eberick

The fundamental premise has been the simplicity of use, rapid learning curve and ease of understanding the results that have historically characterized the program. From the stresses calculated through a process of integration of the same, the resulting forces acting on each shear wall and on the complete section of the concrete core are calculated.

Geometry Definition: The program allows you to flexibly define concrete cores, consisting of any number of shear walls and angles between them at the joints. The walls are defined by locating the initial and final ends and can have different thicknesses, the thickness must be constant on each floor. The section can vary throughout the height of the building both in the thickness of the walls and in the number and length of these, it is also possible to configurate the dimension of the boundary ends of each shear wall, fig. 6. The section can be edited at any time.

The modelling of shear walls is carried out using flat finite SHELL type elements, in each element membrane and bending forces are calculated according to the theory of thin plates. The mesh discretization is configurable and the connection between the structural elements and the rigid core is made automatically, simplifying the process of building the structural model. The program has several tools for launching and editing concrete cores available in the Launch tab in the Concrete Core menu, fig. 6. These tools allow you to add or remove walls, move their ends, convert a conventional column in a concrete core, make a face of a wall fixed, edit vertically the section of the concrete core and copy data from a concrete core to others.

Materials: The program allows you to configure the properties of the concrete and the reinforcements, in the case of concrete these can vary, being, for example, of greater resistance on the lower floors and decreasing towards the upper floors.

Load Inputs: Wind and Earthquake loads are calculated automatically according to NBR 6123 [2] and NBR 15421 [4] respectively. Dead loads and loads due to temperature variation and shrinkage of the concrete can also be considered. Combinations of actions are performed automatically or manually defined by the user.

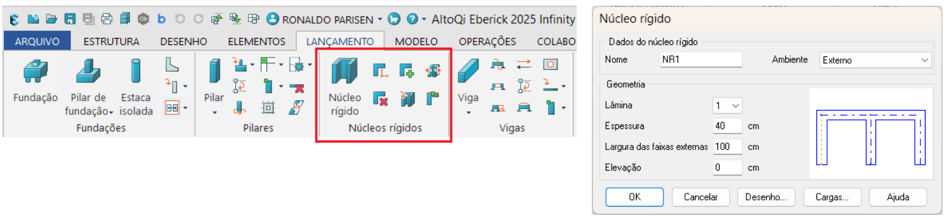

Fig. 6 Tools for creating and editing the section of concrete cores

Boundary Conditions: The program allows modelling isolated shallow foundations, mat foundations, and foundations on piles for concrete core. It is possible to configure the interactions of the concrete core with adjacent elements, such as slabs, stairs and ramps, beams and columns.

3.3 Structural design and detailing

The method of subdivision into strips presented in the ABNT NBR 6118 [1] for approximate consideration of localized effects of the Second Order has been adopted, with the difference that the stripes are not treated as isolated columns as indicated by the standard but consider the compatibility of deformations between stripes, this is to have an initial estimate of the necessary reinforcement areas in each strip, which can be subsequently edited and verified in the complete section of the concrete core. Each shear wall is analyzed in isolation considering the joint action of bending and torsional stresses to determine the longitudinal reinforcement and the shear and torsional stresses to determine the transverse reinforcement. Localized stresses are also verified, in these cases the corresponding reinforcements are added.

The program has a Window for the configuration of some parameters that influence in the design such as the type of connection of the concrete core walls at the top and base, the buckling length to be considered in each wall and the diameter and quantity of the longitudinal and transverse bars. It is also possible to group the reinforcements along the height of the concrete core, Fig. 8.

Analysis and human comfort verification: One of the main studies carried out in tall building projects are wind tunnel tests, the AltoQi Eberick program allows to perform a dynamic modal analysis and export the modal attributes and information necessary to perform this type of test. The software allows the import of the forces calculated in the wind tunnel test and, where this test is not necessary, it is possible calculate the wind forces by the simplified discrete model of the NBR 6123 [2], the program calculates the absolute and relative displacements between floors, horizontal accelerations and verifies the human comfort according to the criteria of this code.

Detailing and Documentation: Generate reinforcement detailing and schedules, including bar lengths, lap splices, anchorage and summary of materials. AltoQi Eberick exports detailed drawings and reports for construction, Fig. 9.

4 CASE STUDY: A HIGH-RISE BUILDING IN SANTA CATARINA, BRAZIL

To illustrate the capabilities and results of the program, a practical case of a tall building in coast of Santa Catarina is presented. The case study is a 60-storey residential tower (201.11m). According to the climate study, the wind speed in this region is 36 m/s. For the dynamic analysis, the first three modes of vibration of the structure were considered, Table 1 and Table 2 presents the frequencies and displacements at the top of the building calculated with AltoQi Eberick and the SAP2000 software.

Table 1 Frequency of the modes (Hz) AltoQi Eberick vs. SAP2000

Margin	AltoQi Eberick	SAP2000
Mode 1	0.126	0,1244
Mode 2	0.137	0,1357
Mode 3	0.323	0,3167

Table 2 Displacement at the top of the building AltoQi Eberick vs. SAP2000

	AltoQi Eberick	SAP2000
Horizontal displacement in X dir. (cm)	25	25,47
Horizontal displacement in Y dir. (cm)	32	32,98

Table 3 Total shear at base of the building (tf) AltoQi Eberick vs. SAP2000

Wind direction	AltoQi Eberick	SAP2000
V1(0°) in X dir.	267,23	265,14
V2(180°) in X dir.	-267,23	-265,138
V3(90°) in Y dir.	405,78	400,851
V4 (270°) in Y dir.	-405,78	-400,851

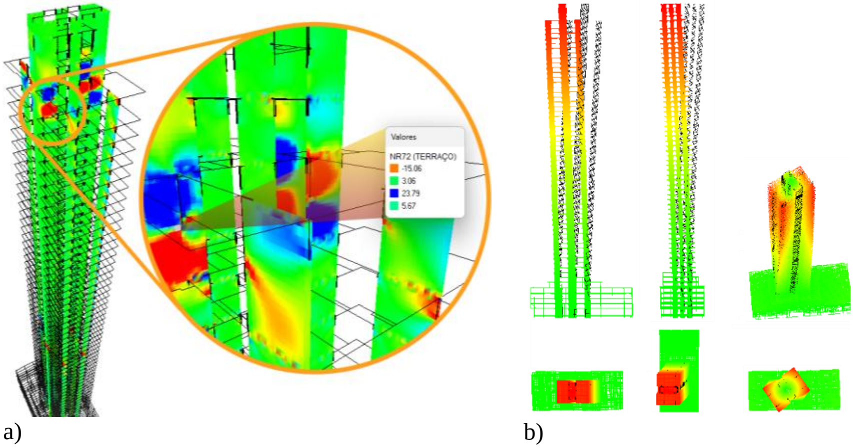

Fig. 7 a) Overview of stresses in the concrete core; b) Modal analysis - modes 1, 2 and 3

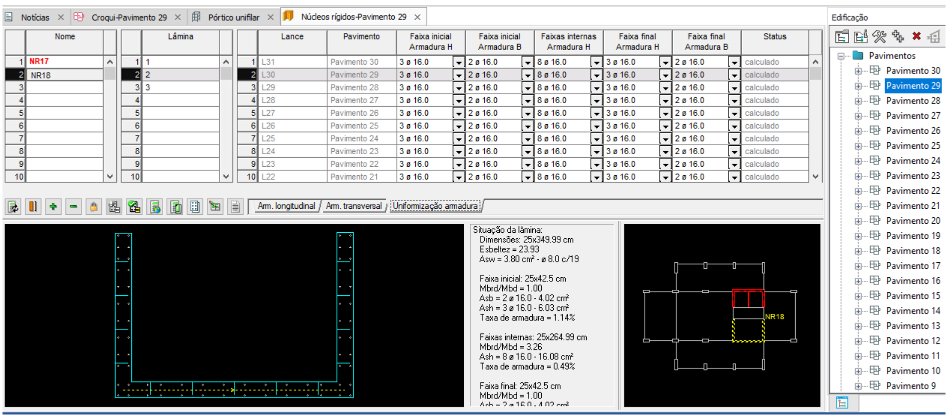

Fig. 8 Concrete core design window

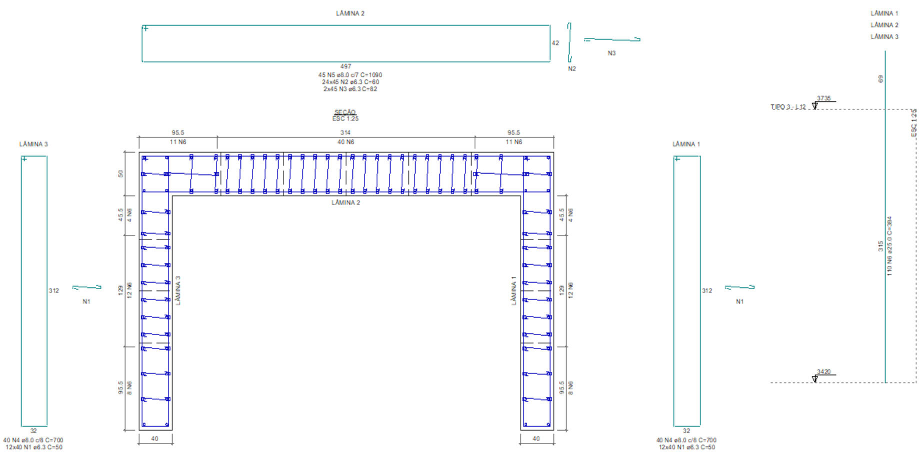

Fig. 9 Example avalaindo of concrete core detailing in AltoQi Eberick

5 CONCLUSIONS

To meet the demand for tal buildings construction projects, there is a need to improve design techniques, evaluating parameters which generally wouldn't be necessary for build-ings of lower height or less slenderness, such as, for example, evaluation of the building's vibration frequencies, avoiding the construction of buildings that generate discomfort for human use. As a solution for this type of construction, the use of concrete shear cores has become indispensable structural element for the strength and stability of high-rise buildings.

In view of this challenge, AltoQi Eberick software offers a robust platform for designing these elements, ensuring compliance with local codes and optimizing structural performance. The solution implemented in the software allows for the fast and efficient modeling of high-rise buildings with concrete cores, simplifying the work of preparing finite element meshes, the connection between structural elements and, above all, the interpretation and use of the results for structural design purposes.

With this, the structural engineer has a powerful tool in his hands to help in the study of different solutions, in order to find one that offers structural stability and human comfort, with the best cost-benefit, which would be difficult to achieve without an adequate tool.

References

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