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QUALITY CONTROL ACCORDING TO THE NEW BRAZILIAN STANDARD FOR STRUCTURAL MASONRY: ABNT NBR 16868-2

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ABSTRACT

Until recently, Brazil had several standards for structural masonry, one for each different type of masonry (concrete blocks, clay blocks, or clay brick). Recently, those standards were unified into a single text. The new text bundled together specifications for design, quality control and construction, and testing procedures. Published in August 2020, ABNT NBR 16868-2 Structural Masonry - Construction Execution and Quality Control, the topic of this article, provides the requirements for sampling and testing, and the conditions of acceptance of structural masonry components and elements in Brazil. Considering structural masonry local reality, especially its extensive use in the construction of buildings, from one-story to multiple story buildings, the Standard requirements are unique. This paper will show through example the requirements for the materials characterization prior to the beginning of construction and the quality control specifications during construction, considering a typical Brazilian building according to the new standard. Among the innovations in the new standard, it has been noticed that the requirements differ depending on the degree of complexity of the project. In addition, several less known aspects are presented, considering the great boldness of the current Brazilian structural masonry, especially when it comes to the construction of tall buildings.

KEYWORDS: *Brazilian masonry, buildings, building code, execution, quality control*

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INTRODUCTION

The unification of the Brazilian Association of Technical Standards (ABNT) for structural masonry, previously separated according to the type of material (concrete or clay bocks), has long been demanded by designers, builders, and industry. The new standard ABNT NBR 16868, under the general title "Structural Masonry", is expected to contain five different parts: 1. Design, 2. Execution and site control, 3. Test methods, 4. Structure in fire situation, and 5. Design for seismic actions. Parts 1 to 3 were published in August 2020. This text deals with issues related to site control, presented in Part 2 of the referred standard that unifies, improves, and replaces the standards ABNT NBR 15812-2: 2010 and ABNT NBR 15961-2: 2011.

In Brazil, the Structural Masonry sector is at an advanced stage of development [1], with the involvement of researchers, designers, associations, builders, and suppliers. The construction system is one of the most viable to meet the housing demand. Due to its versatility, ease of execution and economic viability, it is possible to be carried out with training of labor and without high investments in equipment, contributing to faster works and less waste generation.

In structural masonry, the walls must resist to several load types, in addition to performing as a partition. Thus, the construction job site control is extremely important, from the materials reception to the masonry completion, ensuring quality, durability, and safety to users.

It is common to find builders who are only concerned with verifying the quality of the material, forgetting the need for verifying the quality of the entire system. According to the guide for concrete mix [2], the organization and implementation of quality control in civil construction must involve a double control mechanism: production control and reception control. The first one is exercised by those who generate the product in one of the stages of the process; it is an internal control that is automatically exercised by those involved in production. On the other hand, the reception control is exercised by those who inspect and accept the products and services performed in the various stages of the process, that is, by the builder, owner, or their representatives. This means that the control process goes beyond just testing the materials.

The behavior of structural masonry assemblage depends on the performance of each of its elements (blocks or bricks, mortar, grout, and possibly reinforcement), individually and assembled. Therefore, in addition to controlling the materials individually, it is necessary to analyze them when assembled, checking their behavior for interface adhesion, deformation, and resistance.

Through the control tests, it is possible to verify that the minimum characteristics of quality and performance of each material and of the masonry, according to technical codes specifications. Prism testing results are often considered in many masonry analyses. The prism specimen is built by the superposition of blocks assembled by mortar, grouted or not, then tested in compression. From this test it is possible to evaluate the behavior of the materials together, offering basic information on masonry compressive strength which is the main parameter for design and job site control.

In addition to the laboratory tests, a jobsite visual inspection and measurement of dimensions of the units must also be carried out. The units must have sharp edges and must not show cracks or any other irregularities that could possibly compromise the masonry performance.

PRIOR TO CONSTRUCTION TESTING

In the new standard [3], it is maintained the idea that before the beginning of the work, the characterization of the compressive strength of all masonry materials in the construction, must be made. All possible block, mortar and grout assemblage must be tested in accordance with Section 5 of the mentioned standard.

Table 1 shows the minimum number of specimens to characterize the materials and elements, and the test methods. There was a reduction in the number of tests needed when compared to the previous standard revision.

Table 1: Minimum number of specimens per material or element

Material or element	Test	Number of samples	Test method (ABNT)
Block	dimensional	6[a] or 13[b]	NBR 12118[a]
	compressive		NBR 15270-2[b]
Mortar (40 mm cube)	compressive	6	NBR 16868-2, or NBR 13279
Grout (cylinder)	compressive	6	NBR 5739
Prism (2 course)	compressive	6	NBR 16868-3
Small wall	compressive	6 (optional)	NBR 16868-3
Wall	compressive	3 (optional)	NBR 16868-3
Prism (5 course) (Figure 1)	flexural tensile	6 (required when mortar other than cement, sand, and lime)	NBR 16868-3

*(a): concrete block

*(b): clay block

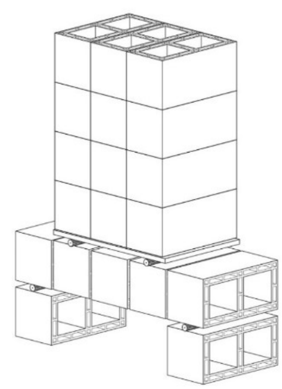


Figure 1: Flexural testing on a 5-course prism (weighing with blocks)

In the case the masonry characterization has already been carried out with the same materials in a similar construction within the 360 days prior to the beginning of the construction, there is no need to repeat those testing. This is another change in the code, since the last version stated this period as 180 days. Previous tests may have been carried out at another recent project by the same construction company, or by the material suppliers.

It is also worth mentioning the need to perform flexural tensile tests in a 5-course prism when using mortar additives, or even when there is any doubt as to its adhesion-to-block performance. This point is fundamental to choosing the mortar to be used. For example, when choosing a pre-mixed bagged mortar. Poor mortar-to-block adhesion will reflect low flexural tensile strength, and this mortar should not be used. In case the low adhesion is not identified in previous tests, several pathologies and even deficiency of prism resistance can occur.

The flowchart is presented in Figure 1, summarize the prior to construction demanded testing, specifying the prescribed tests, the minimum number of specimens and the standard that must be followed for each material and element of the masonry.

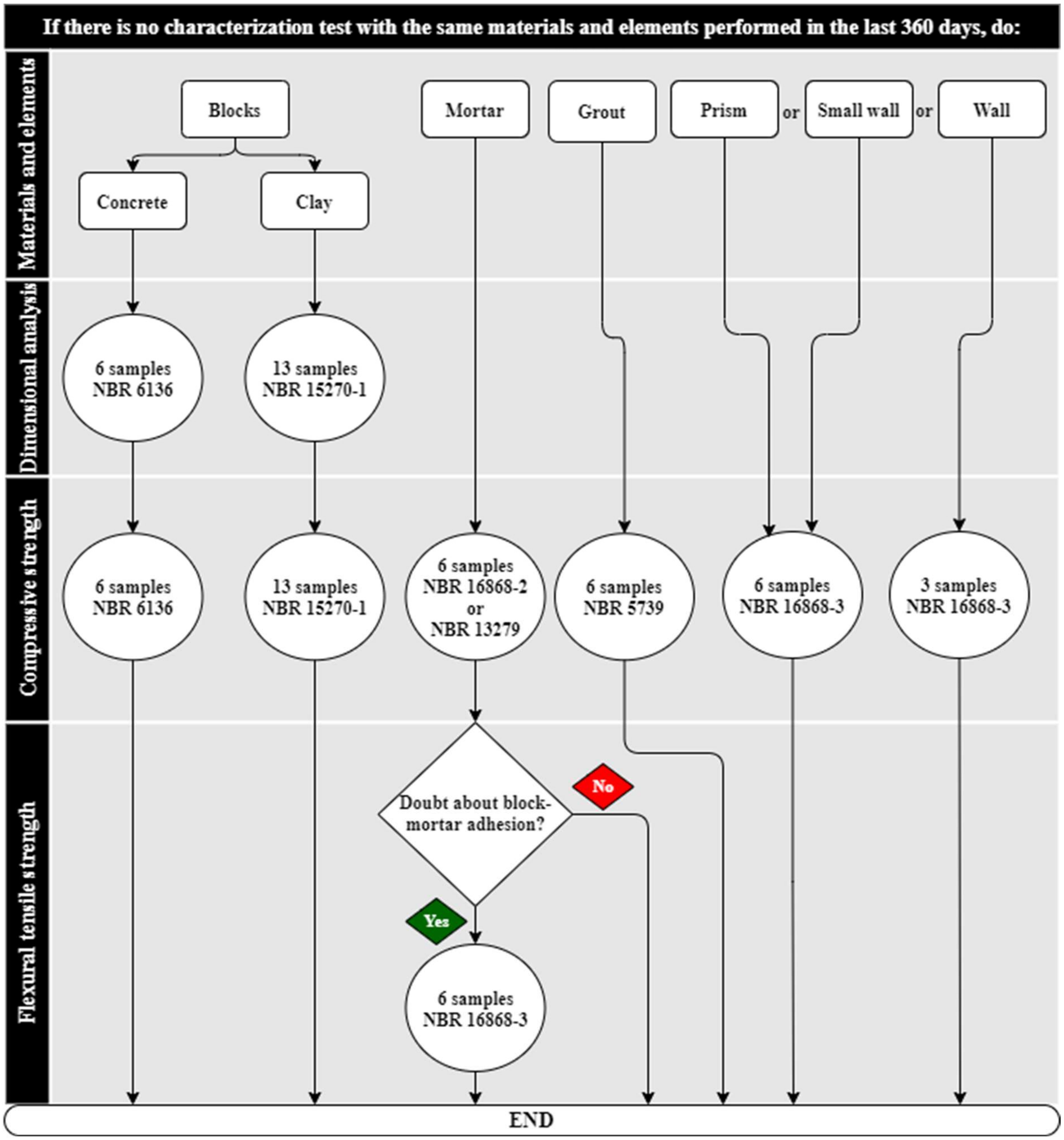


Figure 1: Flowchart of tests for previous characterization

ON-SITE CONTROL

Like the standards that were replaced, the new standard [3] also addresses issues regarding the delivery and storage of materials to detect non-conformities and guarantee the quality control of the entire system safely. Thus, it reaffirms the need for inspection of materials and masonry execution processes, in addition to carrying out technological tests on blocks or bricks, mortars, grouts and prisms during the execution of the project.

Bricks and Blocks

A major contribution that [3] brought to the industry was to clear a gap in Brazilian standardization, regarding the control of blocks or bricks in jobsites. The gap allowed the understanding that the existing "block" standards, specific to each type of block (concrete [4] or clay [5]), refers to requirements for production and acceptance in the block production plant, not suitable for jobsite control. The new standard [3] creates clear specifications in this regard.

The first point concerns the eventual exemption from testing on site. It establishes that: if the blocks or bricks supplied are certified for the quality of accredited conformity and have f_{bk} less than or equal to 14 MPa (gross area), and the jobsite control program includes prism control tests on all floors; there is no need to job-site block test control. If any of the previous criteria is not met, at least the dimensional control and compression strength of the blocks or bricks must be controlled on site. A novelty is that the absorption tests and average net area are optional, at the discretion of the person in charge of the work, and they may request this information from the supplier, through test reports.

Generally, in construction control, it is recommended to carry out a dimensional analysis test and visual inspection, ensuring that the dimensions of the block are within the tolerance specified in the corresponding standard, even in the case of certified blocks. The lack of dimensional accuracy of the block can cause variations in the wall as to its thickness, mortar joint, modulation and even impairing its strength.

Sites that need to carry out quality control of the block or brick on site, define the lot size through the most restrictive condition between the same f_{bk} or the limits described in Table 2, which establishes as criteria the number of floors above the one considered and the built area in plant. It should be noted that the standard committee was concerned with creating simple criteria. Thus, the reference for determining an inspection lot size is always the floor plan area. The specification also reflects the concern to be more rigorous in tall buildings.

Table 2: Lot size definition for block or brick control

Number of floors above that considered for control (up to the roof)	Built area in plan (m^2)
0 to 4	1800
5 to 9	1200
10 or more	600

Another clarified point refers to the definition of the supplier lot size (received on site) and the site lot size. Eventually, the site lot size may contain more than one supplier lot size, received in more than one delivery. The text raises the concern of the sampling to include a minimum number of specimens of each supplier lot size. The number of specimens in the sample lot size is established according to the following:

- Case 1: if the entire site lot size consists of blocks or bricks from a single supplier lot size, the minimum number of specimens must comply with concrete [4] or clay [5] unit standards;
- Case 2: if the work lot consists of more than one supplier lot size, the minimum number of specimens must comply with the concrete [4] or clay [5] unit standards, and the minimum number of five copies per supplier batch must be included in the sample.

The block or brick lot is accepted if the dimensional analysis is within the tolerances allowed by the respective concrete [4] or clay [5] unit standards, and if the characteristic compression strength is greater than or equal to that specified in design.

Mortar and grout production

At least the grout characteristic compressive strength (f_{gk}) and the mortar average compressive strength (f_a) must be checked on site, both at 28 days. Sampling in accordance with the new standard [3] determines six specimens for proof and an additional six specimens for eventual counterproof, for each lot.

The lot size for mortar and grout is defined by the most restrictive condition of the following limits:

- 600 m² of floor built area;
- two floors for buildings with blocks or bricks of $f_{bk} \leq 6$ MPa (gross area);
- one floor for buildings with blocks or bricks of $f_{bk} > 6$ MPa (gross area);
- two weeks of production;
- mortar or grout made from raw materials of the same origin, the same mix design, and the same mixing process.

It is important to remember that a new lot must be defined in jobsite control program when there are variations in the mortar or grout production procedure on different days. Another issue concern works that receive the premixed grout with systematic and more rigorous control. In this case, the control can be performed according to the specifications of specifications of the Portland cement concrete standard [6].

The mortar is accepted if the coefficient of variation of the sample is less than 20% and the average value is greater than or equal to that specified in the design. In the case of a mortar compression resistance result with an average value one and a half times higher than that specified in the design, the procedure for receiving and mixing it must be reviewed and the masonry monitored for the appearance of cracks. This concern was included in the new text, as a “yellow light sign”, as very rigid mortars may not be able to accommodate deformations.

For the grout, the lot is accepted if the characteristic value of the sample is greater than or equal to that specified in the project. Grouts with compressive strength of 15 MPa and higher are considered structural and applicable to structural masonry. It is important to perform the slump test to verify the workability of the grout, measuring its consistency in a fresh state to guarantee the complete filling of the holes without segregation and that it does not show retraction that causes the displacement of the grout in the blocks.

Masonry strength by prism test

The jobsite prism testing on site may be dispensed when the characteristic resistance of the prism obtained in the previous characterization tests is greater than or equal to twice the resistance specified for the prism in the project. This is generally more applicable to small buildings, such as one and two stories' houses.

For other situations, the recommended number for testing is six hollow prisms per lot. In the case of a project in which there is grouting to increase the compressive strength of the masonry in the floor referring to the lot, the same number of fully grouted prisms must be tested. Usually, the grouting to increase the compressive strength is distributed along the wall, and not always reinforced (Figure 2). It is recommended the additional construction of an equal number of specimens for eventual counterproof. The standard also allows a minimum number of three specimens, but in this case the formulation to calculate the sample characteristic strength is more restricted, resulting in a 95% - value more distant to the average - value when compared to the formulation to analysed six-specimens result [7].

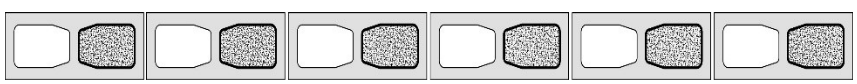


Figure 2: Example of typical grouting to increase the compressive strength of the wall, which leads to the mandatory fully grouted prism test

Another topic addressed by the standard directly affects jobs with several repetitions of houses or buildings. The idea of reducing the number of prism tests in sets with several buildings already existed in the previous standardization, but the requirements were difficult to apply. The new standard [3] brings simpler requirements, maintaining the idea of reducing the number of tests, meeting certain criteria. After testing at least four different lots with a coefficient of variation less than 15% in all lots, it is possible to dispense the prisms testing, provided that the blocks or bricks are from the same manufacturer, strength, and dimension. Prism testing must be restarted if the construction takes more than one year or if the are any changes in the masonry materials and execution procedures. Thus, any change in materials or procedures, or when there is a delay in completing the project, leads to the need to re-test.

The prisms must be molded on site and transported to the laboratory when the block resistance is greater than or equal to 14 MPa (gross area). When the resistance of the block is less than 14 MPa, it is also possible to test prisms molded in the laboratory, if the following conditions are met:

- the blocks and materials used in the mortar and grout must be taken from the job;
- two samples of six grout specimens must be formed for testing, one sample molded on the construction site and another in the laboratory; the same procedures are also required for the mortar testing;
- the (f_{gk}) and (f_a) of the work must be at least equal to 90% of the (f_{gk}) and (f_a) of the laboratory; and the coefficients of variation of the mortar tests cannot be higher than 20%.

The lot size for hollow prisms and for grouted prims (if required) is defined by the lower of the following limits:

- 600m² of area built in a plant;
- two floors, if the project carries out the quality control of the block or brick; or one floor, if the project was exempted from carrying out the quality control of blocks or bricks;
- blocks or bricks from the same manufacturer, strength class and dimensions;
- one year of production;
- masonry assembled using the same materials and procedures.

The floor masonry is accepted if the estimated characteristic resistance of the prism is greater than or equal to the resistance specified in the design. The masonry must also meet the geometric requirements for location, elevation and backing. In case of noncompliance, one of the following actions must be taken:

a) review the design to determine whether the structure, in whole or in part, can be considered acceptable, observing the values obtained in the tests;
b) check the masonry's compressive strength by means of on-site tests (new possibility pointed out by the standard) or the extraction of cores [7];
c) provide reinforcement of the structure;
d) determine the restrictions on the use of the structure;
e) decide for partial or total demolition.

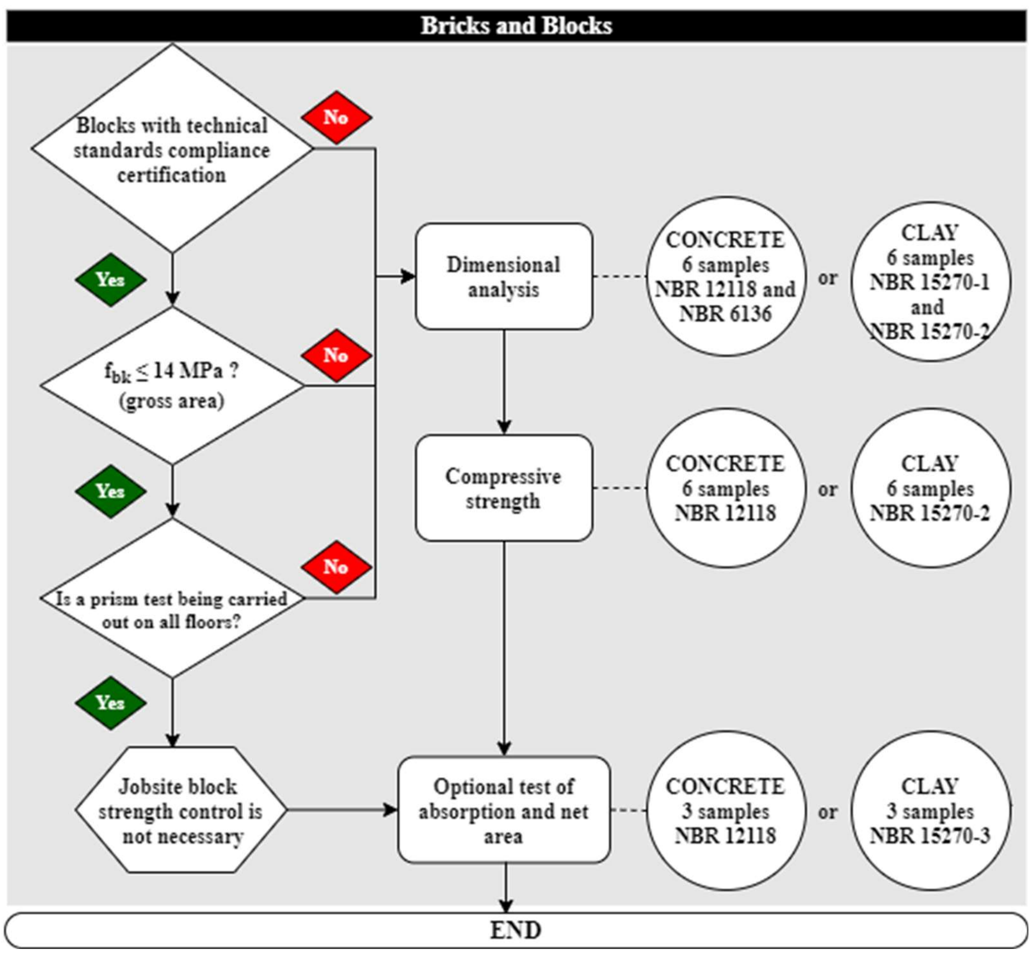
The reference date for testing is 28 days but testing at a younger age may be accepted. In this case, resistance at 28 days is deemed as the results of the tests performed at a younger age. For a hollow block prism, the test date at 14 days is recommended, as there shall not be a sensitive difference in results.

The masonry of the storey is accepted if it is $f_{gk,\ est} \geq f_{gk,\ design}$ and meets the requirements of Table 3.

Table 3: Variables of geometric control in the production of masonry

Requirements		Tolerance limit
Bed joint	thickness	± 3 mm
	level	2 mm/m
		≤ 10 mm
Head joint	thickness	± 3 mm
	vertical alignment	2 mm/m
		≤ 10 mm
Wall alignment and location	vertical	± 2 mm/m
		± 10 mm / floor
		± 25 mm in the total height of the building
	horizontal	± 2 mm/m
		≤ 10 mm
Upper level of the walls	leveling	± 10 mm

In Figure 3 a flowchart is presented summarizing the necessary procedures.



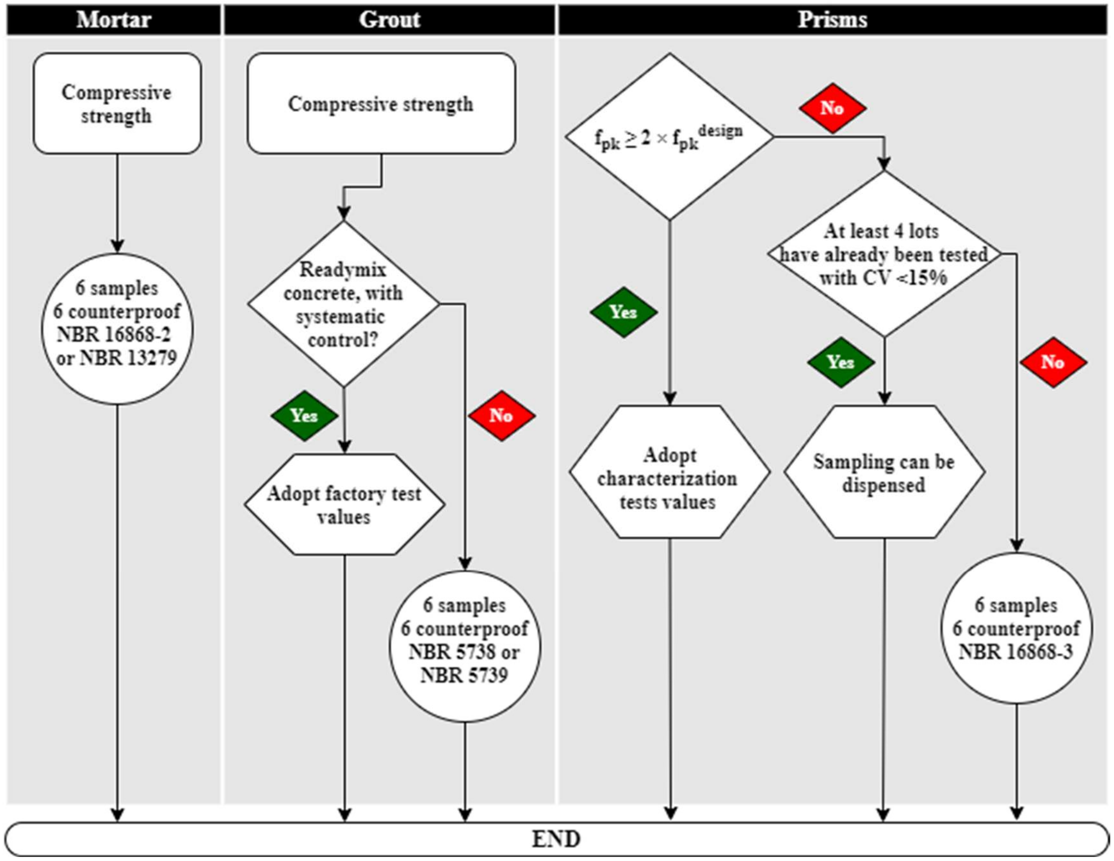
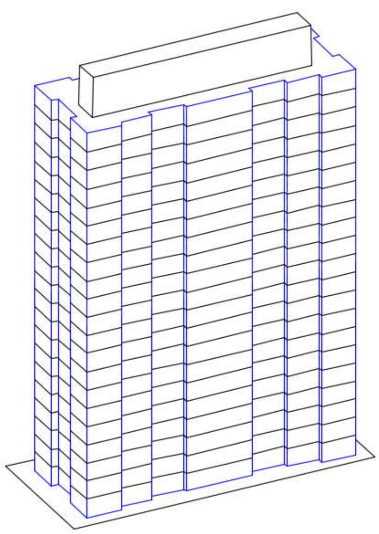


Figure 3: Flowchart of tests to be carried out per batch on site

EXAMPLES OF ON-SITE CONTROL

The following is practical example of the control of construction works in structural masonry commonly found in Brazil.



- Construction of 20 floors, resistance as shown in Table 4;
- Built area of 600 m² per floor;
- Certified 140×190×390 mm concrete blocks;
- Number of blocks per floor = 15,000;
- Premixed bagged mortar;
- Grout mixed in batch plant;
- Supplier lot size of 15,000 blocks;
- Grouted prism testing from the 1st to the 10th floor (grouted walls to increase the resistance to compression on these floors).

Table 4: Variables of geometric control in the production of masonry

Floor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
f_{bk}	20		18		16		14		12		10		8		6		4			
f_a	14				12				8				6							
f_{gk}	35		30				25				20				15					
f_{pk}	12.0		11.7		10.4		9.8		8.4		7.0		6.0		4.5		3.2			
f_{pk*}	19.2		18.7		16.6		15.7		13.4		ngv									

Where:

- f_{bk} : is the block characteristic compression strength;
- f_a : is the minimum average of the mortar compression strength (40-mm cube);
- f_{gk} : is the grout characteristic compression strength (cylinder);
- f_{pk} : is the two-course hollow prism characteristic compression strength;
- f_{pk*} : is the two-course fully grouted prism characteristic compression strength.

The characteristic strength is 95% confidence value. In the case of the mortar average strength, a tested sample is acceptable if also the coefficient of variation does not exceed 20%.

Previous Characterization (before the beginning of construction)

In his example the blocks are certified, and the supplier tests results are acceptable. The grout is also mixed at a concrete batch plant and no prior-to-construction test result is needed.

For the mortar it is necessary to perform compression tests, six specimens each of the required resistance value: 6, 8, 10 and 14 MPa. As the mortar is premixed, it is necessary to perform a flexural tensile test in 5-course prisms for each block / mortar combination: f_{bk} / f_a of 20/14, 18/14, 16/12, 14/12, 12/8, 10/8, 8/6, 6/6, 4/6 (six samples of each).

The same combinations of block and mortar must be considered for the hollow prism test (f_{pk}). In the case of the grouted prism (f_{pk*}), testing is required up to the 10th floor, f_{bk} / f_a / f_{gk} combinations: 20/14/35, 18/14/30, 16/12/30, 12/14/25, 12/8/25, 10/8/20. Six prisms are tested for each combination.

Control during the execution of the work

Block

Only perform visual inspection on each delivery reception (certified blocks).

Mortar

On delivery, reception, the expiry date of the material and the integrity of the bags are checked. According to the condition indicated in item "***Mortar and grout production***", each floor is a control lot. The sampling will be 12 specimens per floor, 6 for proof and 6 for eventual counterproof.

Grout
The job site receives grout premixed in a concrete plant. One concrete cylinder is tested from each delivering truck as specified in the Portland cement concrete standard [6].

Prism
According to item "***Masonry strength by prism test***" for the definition of the prism lot size, each floor is one lot. The sampling of prism will be 12 specimens per lot, 6 for proof and 6 for eventual counterproof. Hollow prism must be tested in all floors. Because walls are grouted to increase their axial compression only up to the 10^{th} floor, grouted prisms will be tested up to the 10th floor only.

Summary
Table 5 provides a summary of the tests, not counting counterproofs.

Table 5: Variables of geometric control in the production of masonry

	Material or Element	Test	Specimens quantity numbers
Characterization	Block	Compressive strength and dimensional analysis	10 specimen
	Mortar	Average compressive strength	10 specimen
	Grout	Characteristic compressive strength	10 specimen
	Hollow prism (2 blocks)	Compressive strength	10 specimen
	Grouted prism (2 courses)	Compressive strength	10 specimen
	Prism (5 courses)	Flexural tensile strength	6 specimen
Construction control	Block	Compressive strength and dimensional analysis	10×20 = 200 specimen
	Mortar	Average compressive strength	6×20 = 120 specimen
	Grout	Characteristic compressive strength	6×20 = 120 specimen
	Hollow prism (2 courses)	Compressive strength	6×20 = 120 specimen
	Grouted prism (2 courses)	Compressive strength	6×10 = 60 specimen
	Prism (5 courses)	Flexural tensile strength	6×20 = 120 specimen

FINAL COMMENTS

The new standard [3] establishes a procedure to provide quality, safety, and efficiency in structural masonry construction. The updating of structural masonry standards in Brazil followed the evolution of industry, research, and construction companies. The participation of competent professionals in these areas was of great importance for the development of a quality text, specific and exclusive to the Brazilian reality.

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