Compression resistance of repaired structural concrete elements after core extraction

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Abstract: Core sampling for testing is considered a reliable method to provide information on structural materials and is one of the most implemented techniques in the evaluation of concrete elements. However, core drilling results in a decrease in cross section that can compromise structural mechanical strength even if the extracted section is repaired. Norm NBR 7680-1 recommends dry pack as a repair method but also allows the use of other techniques as long as its effectiveness is proven. This work evaluated the resistance of repaired structural prototypes after core drilling sampling. Concrete blocks with 20 MPa resistance were produced from which cores of 100 mm, 75 mm and 50 mm in diameter were extracted. The blocks were repaired with 20 MPa concrete, grout and dry pack techniques. The reconstitution with concrete showed poorest performance, while dry pack led to strengths even higher when compared to reference values.

Keywords: core sampling, dry pack, grout, compression strength.

INTRODUCTION

On-site evaluation methods are used to evaluate the compression resistance of reinforced concrete. This is necessary due to uncertainties in the properties of concrete or to better assess the loading capacity of the structural element [1]–[3]. Among in situ methods, core extraction is considered the most reliable since it replicates closely the real properties of the material [4]–[7].
Core sample extraction has the potential to create micro-fissures in concrete. This not only reduces the mechanical resistance of the material but also can induce lower resistance in samples with smaller diameters since they have a higher surface-to-volume ratio [36], [44]. The minimum sample diameter recommended by ASTM is of 100 mm [16] while British Standards EN 12504 allows compression testing on samples as small as 50 mm in diameter without the need for correction factors [45]. Norm ABNT NBR 7680:2015 recommends a minimum diameter of 100 mm for core samples but allows diameters of 75 mm and 50 mm in specific situations [17]. Another factor to be considered is the concrete class which causes further effects in compression tests of samples of varying diameter. The volume of the sample may or may not be important depending on the mechanical resistance of the concrete. Concretes with higher resistance are less likely to develop fissures during the extraction process when compared to concretes with lower resistance. Higher resistance concretes also present a more robust transition zone with higher adhesiveness surface with less flaking [44].

The objective of this study is to further contribute to the analysis of different repair methods in finished structures from which core samples have been extracted. In particular, structural grout and dry pack techniques were analyzed and compared. Also, since there were divergences with respect to the effect of sample diameters, comparative mechanical tests were conducted on blocks with different repair sizes.
2 METHODOLOGY

2.1 Materials
A total of 24 concrete blocks of class C20 were produced in a batch plant and divided into 3 groups, each containing 8 blocks. Group 1 contained clocks measuring 500 mm × 300 mm × 230 mm, group 2 contained clocks measuring 375 mm × 225 mm × 180 mm and group 3 contained clocks measuring 250 mm × 250 mm × 150 mm. Concrete dosing followed the methodologies of Tutikian and Helene [46] and Gil et al. [47]. This procedure was adopted so the extracted core samples had a constant volume ratio with respect to the original concrete blocks.

Following core extraction, three different recovery methods were used. The first method made use of concrete with the same characteristics as the original block. The concrete mixture was prepared in a vertical axis mixer. The second method utilized industrial-grade structural grout made from Portland cement, quartz sand and special additives. Grout was prepared with a water/solid material ratio of 0.12 and aging compression tests measured a resistance of 42 MPa after 7 days and 50 MPa after 28 days. The third method utilized dry pack made from a thixotropic and single component industrial plaster specific for structural repairs. Preparation used a water/solid material ratio of 0.13 and aging compression tests measured a resistance of 30 MPa after 7 days and 40 MPa after 28 days. Coarse basalt aggregate with a maximum granulometry of 9.5 mm was incorporated between layers as proposed by norm ABNT NBR 7680-1, Anex A [17].

2.2 Curing of concrete blocks
Concrete blocks were demolded and conditioned in a climate-controlled chamber kept at 23 ± 2 °C and relative air humidity of 97% for 28 days. Following this period, core samples were extracted.

2.2.1 Core sample extraction
Cylindrical core samples were extracted from the cured blocks. Procedures followed ABNT NBR 7680-1 [17] recommendations with a height/diameter ratio (h/d) of 2. Three distinct sample diameters were chosen: Ø100 mm, Ø75 mm e Ø50 mm with the last 2 reserved for concrete blocks with higher reinforcement.

Table 1 displays the characteristics of the concrete, source concrete block dimensions, sample dimensions, number of samples extracted, % volume of the sample relative to the block and the type of material used in the repair. From the blocks measuring 500 mm × 300 mm × 230 mm and 375 mm × 225 mm × 180 mm, 2 samples with diameters of 100 mm and 75 mm were extracted, respectively. From the blocks measuring 250 mm × 250 mm × 150 mm, 4 samples 50 mm in diameter were extracted. The position of each hole of extraction kept at distance of at least one sample-diameter from each other, and one sample-diameter with respect to the edges of the block as seen in Figure 1. Two blocks from each dimension were kept intact as reference. The drilled blocks had samples extracted horizontally in a direction perpendicular to the pouring of concrete. The drill was diamond-crowned and water-cooled.

![Figure 1 – Drilling hole placement according to block dimension](image-url)
2.2.2 Block repair

Block repair was conducted utilizing C20 concrete, grout and dry pack. Each block was prepared according to NBR 7680-1 [17], with the internal surface of each hole cleaned and saturated with moisture. This procedure was realized in order to ensure a better adhesiveness between the concrete block and the repair material [34], [48], [49]. Concrete repair was conducted by inserting fresh C20 material in molds and extruding it into the hole. After hardening, excess concrete was shaved off. Grout repair followed the same procedure as concrete as seen in Figure 2. Dry pack repair was conducted according to NBR 7680-1, Annex A [17]. The drilled hole was filled with alternating layers of mortar of thickness of less than 5 cm and coarse gravel of thickness between 9.5 mm and 25 mm. A cylindrical pestle 25 mm in diameter was used to push in and compact each layer as seen in Figure 3. Once filled, the external surface of the repair was smoothed out with a metallic trowel and curing allowed to happen. Figure 4 shows the finished repaired blocks with concrete, grout and dry pack.

![Figure 2 – Molds for concrete and grout repair](image-url)
2.2.3 Curing of repair material and testing

Repair material applied to the blocks was cured for 7 days with water spraying. After curing, the repaired block was allowed to age for a total of 28 days from the date of reconstitution. Compressions tests were performed in a universal press and neoprene slabs were used to distribute the load along the contact surface as seen in Figure 5.
3 RESULTS AND DISCUSSION

Results are presented in Table 2 and Table 3. Table 2 displays the compression resistance of cylinders measuring Ø 10 cm × 20 cm of C20 and grout after 28 days of aging. Table 3 displays the compression resistance of the concrete blocks with respect to each repair material and core sample size. The potential tension values are in accordance with norm ABNT NBR 12655:2015 [50]. Table 3 shows that, of the repaired concrete blocks, the ones with dry pack repair had the best performance. In particular, the repair with 100 mm diameter had a compression resistance 8.2% higher than the reference blocks.

Table 2 Repair material compression resistance

| Type of material | Load (kN)  | Tension (MPa) | Average Tension (MPa) |
|------------------|-----------|--------------|-----------------------|
| C20              | 303.41    | 38.6         | 39.1                  |
|                  | 310.31    | 39.5         |                       |
| Grout            | 540.64    | 68.9         | 62.0                  |
|                  | 432.09    | 55.0         |                       |

Table 3 Concrete Block Compression Resistances

| Material | Ø (mm) | Tension (MPa) | Potential Tension (MPa) | Ø (mm) | Tension (MPa) | Potential Tension (MPa) | Ø (mm) | Tension (MPa) | Potential Tension (MPa) |
|----------|--------|---------------|-------------------------|--------|---------------|-------------------------|--------|---------------|-------------------------|
| Reference|        | 11.0          | 8.3                     | -      | 10.1          | 13.5                    | -      | 9.5           | 12.1                    |
| C20      | 100    | 10.0          | 8.4                     | 75     | 7.2           | 8.1                     | 50     | 6.6           | 7.3                     |
| Grout    |        | 11.1          | 11.1                   |        | 12.9          | 12.9                   |        | 9.1           | 9.1                     |
| Dry pack |        | 9.6           | 8.6                     |        | 9.6           | 11.1                   |        | 9.1           | 11.9                    |

Comparisons of the performance of the repaired blocks and reference blocks are shown in Figure 6. Blocks with 100 mm diameter extractions repaired with grout and dry pack were able to resist compression levels higher than the reference blocks. As extraction size decreased, repaired blocks underperformed with respect to reference blocks. The worst performance was obtained with the 75 mm diameter extraction block repaired with grout: a 40% reduction with respect to the reference block.

Figure 6 – Compression resistance of repaired blocks compared to reference blocks
Figure 7 shows the effect of diameter of the extracted region on the compression resistance of each repair material. Overall, it can be stated that a 50 mm diameter extraction compromised the mechanical resistance of the repaired block the most regardless of the repair material. This was likely a result of damage to the concrete block in the extraction of this smallest sample. If the concrete itself was less resistant, core extraction could lead to the appearance of micro-fractures and flaking of aggregates. In this case, a core sample with a higher area/volume ratio became a relevant factor in the loss of mechanical properties.

Overall, dry pack presented the best efficiency in recovering the mechanical properties of the repaired blocks. This might be related to the water/cement ratio in this type of material. Smaller water content in the mixture leads to less shrinkage which is highly important in the structural repair of concrete. A shrinking repair material might leave gaps between the original material and filled volume so that the block would tend to fracture under compression before it can incorporate the resistance of the repair material. This phenomenon can be observed in the fracture characteristics of each block in Figure 8, with the fracture occurring in the interface between the repaired core and the block. While this may explain dry pack performance, comparison of the water/solid ratio between dry pack and grout showed minimal differences insufficient to cause such difference in performance (0.13 for dry pack and 0.12 for grout). In this case, compaction effects associated with the filling technique were likely to have influenced the results. In the case of grout, repair material was poured in with no special compaction executed. Dry pack, in the other hand, was filled in several packed layers and the energy of compaction could have induced greater adhesiveness and left fewer gaps in the interface with the block.
4 CONCLUSIONS

Results of this study demonstrated that dry pack was the most efficient filling material to repair core sample extraction volumes in concrete elements. Concrete itself was shown to be an inefficient repair material with the repaired block having a 38% reduction in compression resistance. Water content in the repair material might be considered an important factor in the performance of repaired blocks.

The diameter of core samples also influenced the results. Large core diameters resulted in repaired blocks that could exceed reference results. In the other hand small core diameters, which contain a higher surface/volume ratio, performed poorly probably due to damages to the concrete block structure caused during extraction.

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