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EXPERIMENTAL AND STATISTICAL INVESTIGATION OF THE COMPRESSIVE STRENGTH ANISOTROPY IN STRUCTURAL CONCRETE

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Abstract: Assessment of the load - carrying capacity of in-service concrete structures is often based on the concrete compressive strength obtained from drilled cores. These cores are typically drilled perpendicular to the concrete surface, under the assumption that the mechanical properties of the concrete are isotropic. Recent studies however showed that concrete may in fact be subject to anisotropic behaviour. These studies are limited to newly cast concrete only, and little is known about the anisotropic behaviour of in-service structures in service. This study presents the first results of a large experimental programme where the anisotropy of the compressive strength in service concrete structures is investigated. For this, 12 cores, drilled from a large concrete slab, beam located in pune, are tested. two drilling directions are considered. The results are analysed using statistical techniques. The results showed that there is a statistically significant difference between the compressive strength in longitudinal and transverse/vertical direction. In countries under constant earthquake risk, it is compulsory to determine seismic performances of existing structures and consequently strength of concrete used in construction should be known to make a decision for repairing-strengthening. Sometimes it is needed to know in place concrete in reinforced concrete structures. Under the circumstances, concrete specimens called core are taken in different diameters from various place of structures and compressive strength is determined by test carried out on these core specimens. In technical literature, there are many equations used for converting core strength to standard cylindrical strength. In this study, it is determined that there is a valid relation between compressive strength of core specimens taken from concrete specimens which are cured in different conditions and those of standard cylindrical specimens

Keywords: In-service concrete, Core strength, Compressive strength, anisotropy etc.

I. INTRODUCTION

Strength assessment of existing concrete structures is often based on calculation models developed for design of new structures. In this context, the strength parameters adopted in the calculations are usually determined by test of samples taken from the structure. The concrete compressive strength is mostly determined from test of drilled cores, whose compressive strength is subsequently converted to standard cylinder compressive strength. Due to practical reasons, the cores are always drilled perpendicular to the surface of the structure. However, it is known that the core compressive strength is dependent on the drilling direction, for example, found as much as 50% strength difference between cores drilled parallel and perpendicular to the casting direction. If this directional dependency (i.e. strength anisotropy) is as dramatic as suggested by Hughes and Ash, then the current practice as described above - to estimate the residual capacity of an existing structure may potentially be misleading Despite the relevance and the potential impact on current practices for strength assessment of existing structures, the subject of compressive strength anisotropy has received very little attention in the literature,. The few previous studies disagree strongly on the magnitude of the anisotropy; absolute as well as relative. Furthermore, it is difficult to draw any general conclusions from the previous studies,

mostly due to three shortcomings. These are:

(1) the sample sizes were small,

(2) the conclusions were drawn without a sound statistical analysis of the results,

(3) the geometry and origins of the test specimens were not directly comparable to the cores drilled from actual structural members.

B. Objectives of the Present Study

1.To take a closer look into the strength anisotropy of concrete

2.To present advanced statistical analysis of the results.

3.To study the influence of important design parameters and conditions on the anisotropy

4.To study the parameters such as influence of reinforcement, w/c ratio, curing time, load history and structural geometry

5 To study the anisotropy that cannot be attributed to damages or cracking due to previous loading

C.Anisotropy

The existence of strength anisotropy in concrete (without a previous load history) is often explained by segregation or water migration in the fresh concrete, which causes weak interfaces or initial micro cracks between the cement paste and the undersurface of the large aggregate particles. The most commonly used measure for anisotropy is the ratio between the concrete core compressive strength parallel to the casting direction (fc, $core_1$) and the core compressive strength perpendicular to the casting direction (fc, $core_2$), see also Fig. 1 In this project, the anisotropy will mainly be discussed on the basis of the difference between the core compressive strength parallel and perpendicular to the casting direction, i.e

$$\Delta f_{c\ Core} = fc,\ core_1 - fc,\ core_2$$

The reason for measuring the anisotropy as an absolute strength difference rather than a strength ratio is that the statistical analyses to be presented below show, that the concrete strength class (i.e. $f_{c,\ cylin}$) has no significant influence on $\Delta f_{c,\ core}$.

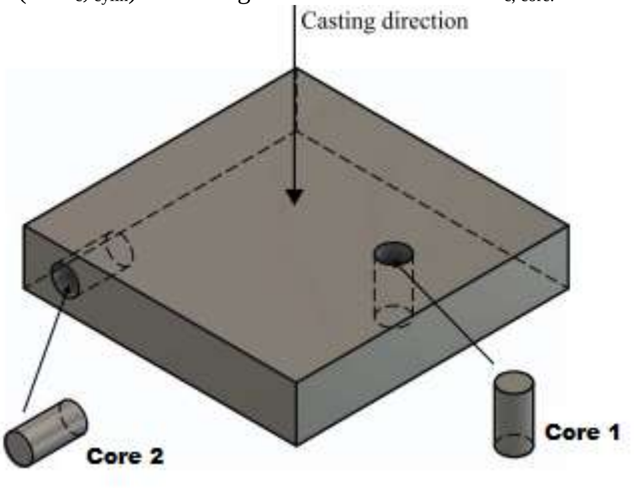


Fig. 1 Illustration of a slab with notation of casting and drilling direction.

II. METHODOLOGY OF WORK

2.1 Problem statement

The experimental programme to investigate the anisotropy in structural members with and without load history comprises three test series. Each test series consists of a large number of cores drilled from beam- or slab members produced at a local manufacturer of precast concrete elements. In the following, details of each of the test series are provided. Furthermore, all compression tests were carried out in an electro-mechanical compression machine with a capacity of 1200 kN. provides details on the performed compression tests.

2.2 Test series 1

The goal of Test series 1 is to investigate the anisotropy in concrete slabs without load history, i.e. to study anisotropy that cannot be attributed to damages or cracking due to previous loading. The parameters varied in this series are the reference cylinder strength, $fc_{,cylin}$, (i.e. basically the w/c-ratio) and the presence of reinforcement. The influence of the reinforcement is interesting to investigate because the reinforcement mesh in flat slabs (without shear links) may induce unidirectional micro cracks due to anisotropic shrinkage conditions. These micro cracks may influence the strength anisotropy

The drilled cores in this series were obtained from four slabs with the dimensions 1500 × 1500 × 200 mm. To study the influence of $fc_{,\ cylin}$, two slabs were cast with a relatively low $fc_{,cylin}$ (Mix A) and two slabs were conducted with a relatively high $fc_{,cylin}$ (Mix B). Details on Mix A and Mix B can be seen in Table 1 To study the influence of the presence of reinforcement for both Mix A and Mix B, one slab contained top and bottom mesh reinforcement and one slab contained no reinforcement. The reinforcement meshes consisted of T8mm rebars per 150 mm in both directions.

Each pair of slabs (Mix A and Mix B) was cast from the same batch of concrete. After casting, the slabs cured for 24 hr covered in plastic before they were demoulded, wrapped in plastic and stored indoor until core drilling.

Cores with a diameter of 100 mm were drilled with a water-cooled diamond drill according to the drilling plan displayed in Fig. 2 The drilling plan ensures that all cores were taken from positions not intersected by rebars. 6 drilled cores were used for compressive tests and 6 were used for split tests. The cores, used for compressive tests, were grinded in both ends to ensure plane loading surfaces. The height of the cores after grinding is shown in 200mm. The cores were tested after 28 (Mix A) and 28 (Mix B) days, respectively.

Simultaneously with the production of the slabs, Ø100 × 200 mm cylinders were cast from the same concrete batch in order to determine the reference cylinder strength of each concrete mix. The cylinders were cured under the same conditions as the slabs.

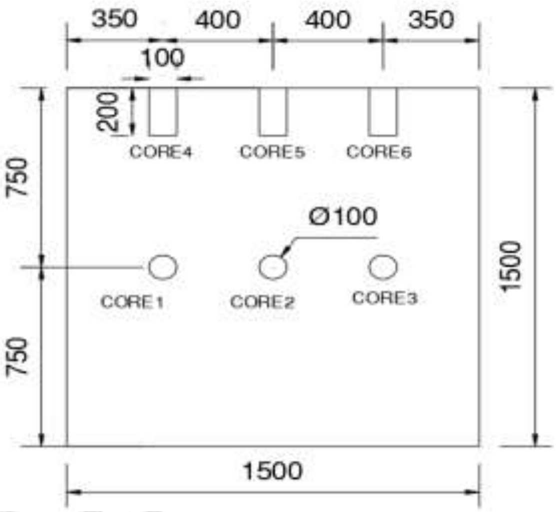


Fig 2 Drilling plan for Test series 1 of slab

Table No. 2 Concrete mix composition for the slab test series.

	Reinforced slab	Unreinforced slab
Test series	Mix A	Mix B
Slab thickness	200mm	200mm
Max. aggregate size [mm]	8mm	8mm
Aggregate type	Round	Round
Cement	Ordinary Portland cement of 53 grade	Ordinary Portland cement of 53 grade
w/c	0.6	0.6
Air-entraining admixture	Yes	Yes
Super-plasticizer	Yes	Yes
Materials	Concrete 20 and Reinforcement Fe 500	Concrete 20
No. of core in parallel direction	3	3

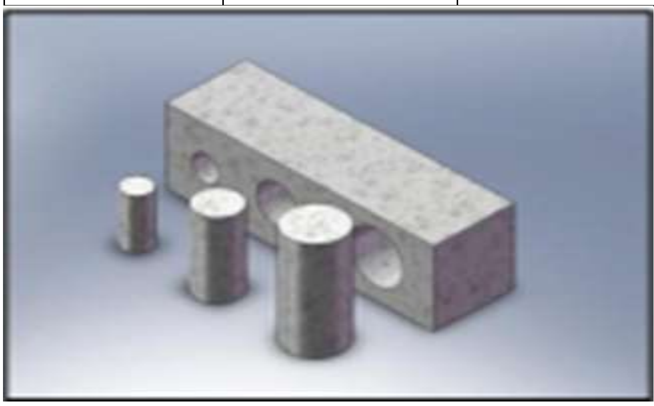
No. of core in perpendicular direction	3	3

2.2 Test series 2

The goal of Test series 2 is to investigate the influence of curing time on the strength anisotropy. For this purpose, cores drilled from beams without load history were tested. The primary motivation to focus on the curing time in this test series is that the large variation in the strength anisotropy published in the literature is also based on test specimens with very different curing times. Hence, it is relevant to investigate the correlation and possibly provide a partial explanation for the published results. The drilled cores were obtained from four unreinforced beams with dimensions 200 × 200 × 1500 mm. Details on the concrete mix composition may be found in Table 2. The beams were cast from the same batch of concrete and cured for 24 hr covered in plastic before they were demoulded. The beams were subsequently wrapped in plastic and stored indoor for further curing until it was time for core drilling. Drilling of the Ø100 mm cores took place according to the plane displayed in Fig. 3. The curing time until core drilling and testing was different for beams 28 days. When necessary, the cores were grinded before testing to ensure a plane loading surface. The height of the cores after grinding was 200 ± 1 mm. Simultaneously with the production of the beams, a number of cylinders (Ø100 × 200 mm) was cast in order to determine the reference cylinder strength for the four curing times 28 days. The cylinders were produced and cured under the same conditions as the beams.

Table No. 2 Concrete mix composition for the beam test series.

	Reinforced slab	**Unreinforced slab**
Test series	Mix A	Mix B
Beam size	200x200x1500	200x200x1500
Max. aggregate size [mm]	8mm	8mm
Aggregate type	Round	Round
Cement	Ordinary Portland cement of 53 grade	Ordinary Portland cement of 53 grade
w/c	0.6	0.6
Air-entraining admixture	Yes	Yes
Super-plasticizer	Yes	Yes
Materials	Concrete 20 and Reinforcement Fe 500	Concrete 20
No. of core in parallel direction	3	3
No. of core in perpendicular direction	3	3



a. Cores drilled perpendicular to the direction of casting

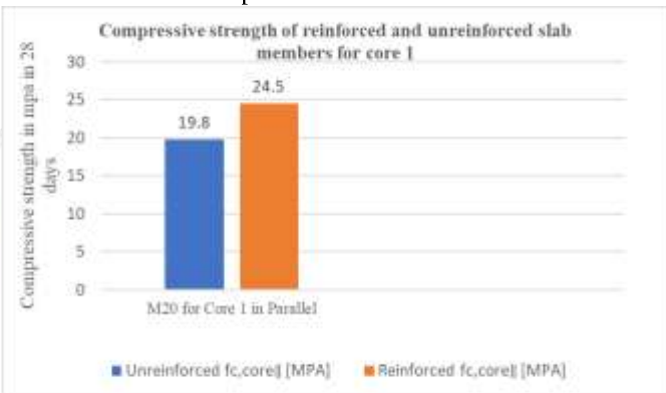
b. Cores drilled parallel to the direction of casting

Fig. 3. Drilling plan for Test series 2 of beam

III. RESULTS AND DISCUSSION

3.1 Compressive strength of reinforced and unreinforced slab members for core 1 in parallel direction after 28 days

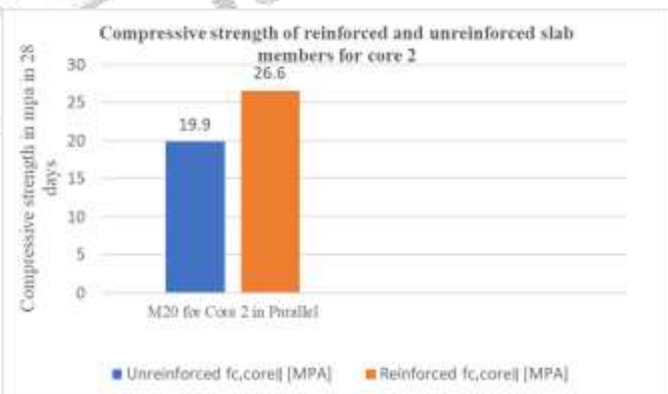
Compressive strength of reinforced and unreinforced slab members for core 1 in parallel direction



Graph 1 Compressive strength of reinforced and unreinforced slab members for core 1 in parallel direction after 28 days

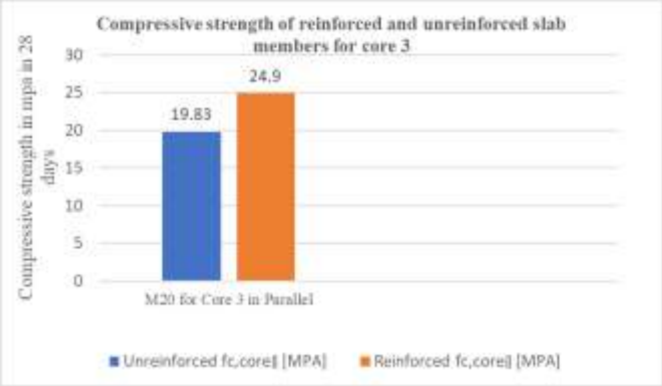
3.2 Compressive strength of reinforced and unreinforced slab members for core 2 in parallel direction after 28 days

Compressive strength of reinforced and unreinforced slab members for core 2 in parallel direction



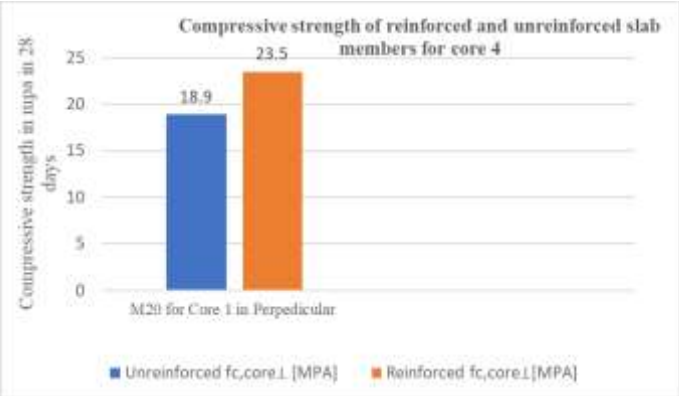
Graph 2 Compressive strength of reinforced and unreinforced slab members for core 2 in parallel direction after 28 days

3.3 Compressive strength of reinforced and unreinforced slab members for core 3 in parallel direction after 28 days



Graph 3 Compressive strength of reinforced and unreinforced slab members for core 3 in parallel direction after 28 days

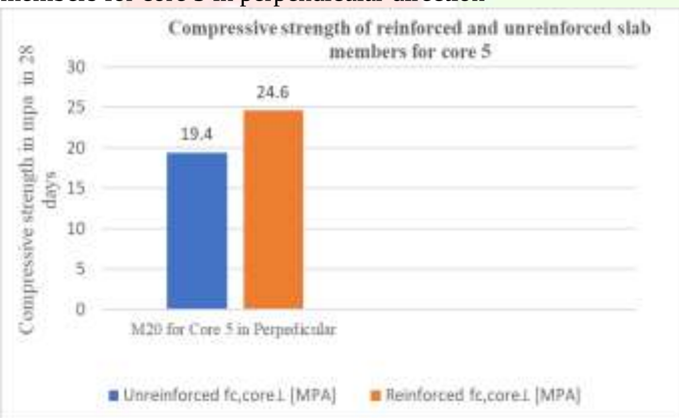
3.4 Compressive strength of reinforced and unreinforced slab members for core 4 in perpendicular direction after 28 days



Graph 4 Compressive strength of reinforced and unreinforced slab members for core 4 in perpendicular direction after 28 days

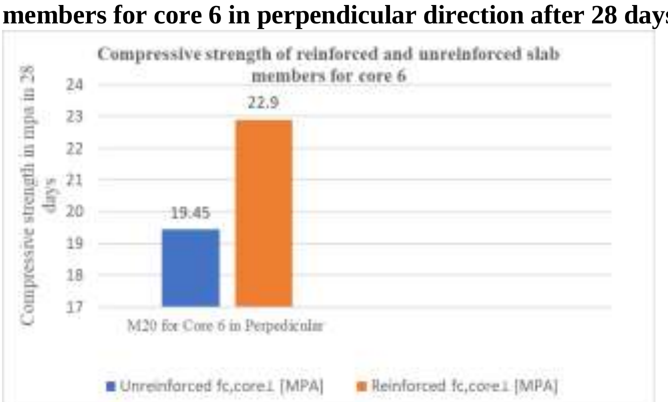
3.5 Compressive strength of reinforced and unreinforced slab members for core 5 in perpendicular direction after 28 days

Compressive strength of reinforced and unreinforced slab members for core 5 in perpendicular direction



Graph 5 Compressive strength of reinforced and unreinforced slab members for core 5 in perpendicular direction after 28 days

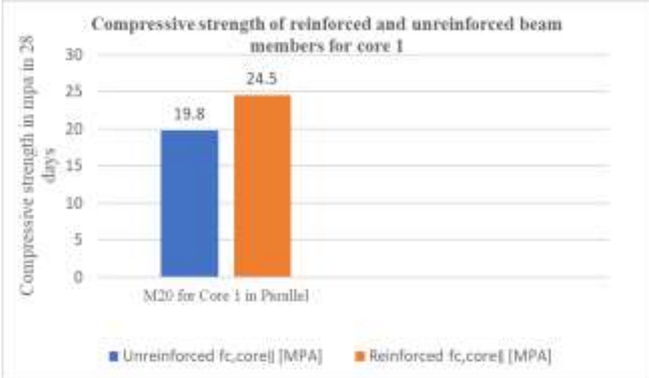
3.6 Compressive strength of reinforced and unreinforced slab members for core 6 in perpendicular direction after 28 days



Graph 6 Compressive strength of reinforced and unreinforced slab members for core 6 in perpendicular direction after 28 days

3.7 Compressive strength of reinforced and unreinforced beam members for core 1 in parallel direction after 28 days

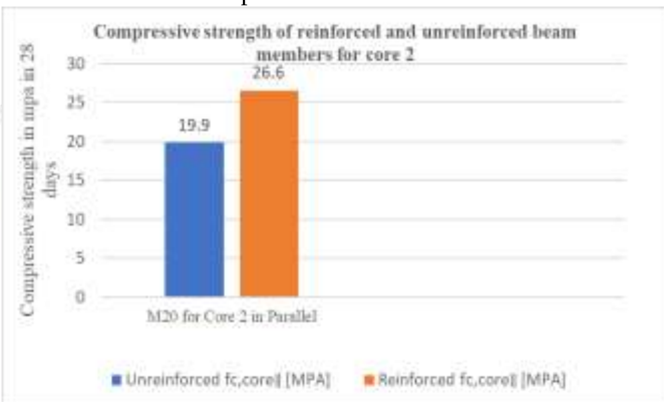
Compressive strength of reinforced and unreinforced beam members for core 1 in parallel direction



Graph 7 Compressive strength of reinforced and unreinforced beam members for core 1 in parallel direction after 28 days

3.8 Compressive strength of reinforced and unreinforced beam members for core 2 in parallel direction after 28 days

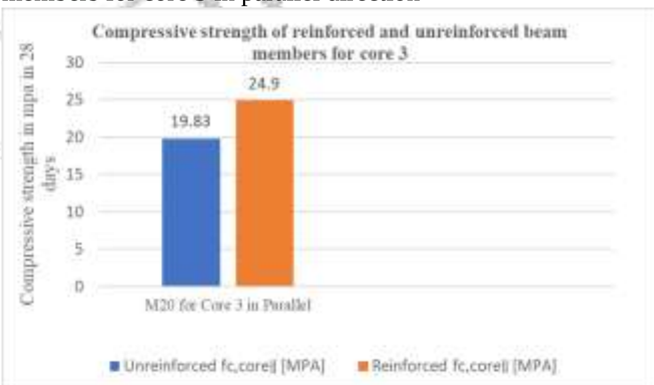
Compressive strength of reinforced and unreinforced beam members for core 2 in parallel direction



Graph 8 Compressive strength of reinforced and unreinforced beam members for core 2 in parallel direction after 28 days

3.9 Compressive strength of reinforced and unreinforced beam members for core 3 in parallel direction after 28 days

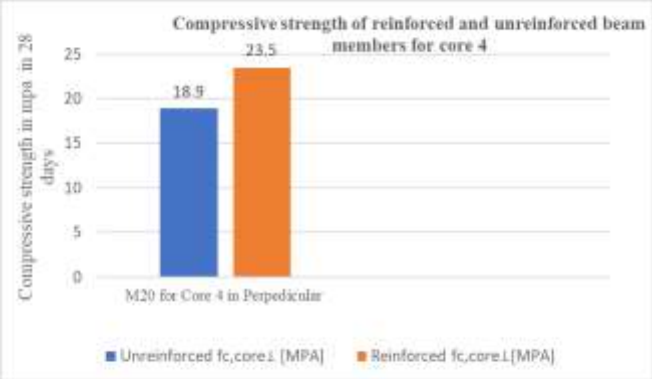
Compressive strength of reinforced and unreinforced beam members for core 3 in parallel direction



Graph 9 Compressive strength of reinforced and unreinforced beam members for core 3 in parallel direction after 28 days

3.10 Compressive strength of reinforced and unreinforced beam members for core 4 in perpendicular direction after 28 days

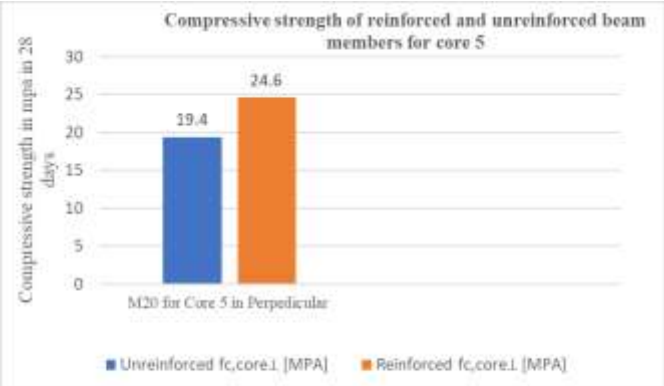
Compressive strength of reinforced and unreinforced beam members for core 4 in perpendicular direction



Graph 10 Compressive strength of reinforced and unreinforced beam members for core 4 in perpendicular direction after 28 days

3.11 Compressive strength of reinforced and unreinforced beam members for core 5 in perpendicular direction after 28 days

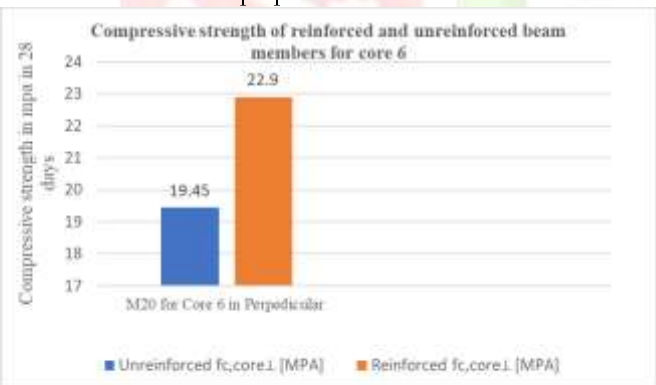
Compressive strength of reinforced and unreinforced beam members for core 5 in perpendicular direction



Graph 11 Compressive strength of reinforced and unreinforced beam members for core 5 in perpendicular direction after 28 days

3.12 Compressive strength of reinforced and unreinforced beam members for core 6 in perpendicular direction after 28 days

Compressive strength of reinforced and unreinforced beam members for core 6 in perpendicular direction



Graph 12 Compressive strength of reinforced and unreinforced beam members for core 6 in perpendicular direction after 28 days

IV. CONCLUSIONS

This project presents a study on the anisotropy of the concrete core compressive strength by combining experimental investigation and statistical analysis. The main conclusions of the study are presented in this section. The following conclusions may be drawn from the test results:

Based on the broad investigations and comparisons following conclusions were drawn

1. The statistical analysis of the experimental results from Test series 1 shows that the reference cylinder strength, fc,cylin, has no significant influence on the anisotropy in slabs without load history if the anisotropy is measured as a strength difference, Δfc,core.
2. The statistical analysis of the experimental results from Test series 2 shows that the curing time has no significant influence on the anisotropy in beams without load history.
3. According to the proposed explanation, the geometry of the structural member has a significant influence on the strength anisotropy for structural members without load history. In slabs and wide beams, it is expected that fc,core∥ is larger than fc,core⊥ (positive anisotropy) due to the vertical weak interfaces from the dynamic segregation. In beams with a small width, it is expected that the horizontal weak interfaces due to static segregation will be dominating. Consequently, fc,core⊥ is expected to be larger than fc,core∥ (negative anisotropy). It was assumed that the 'static segregation' does only have a governing effect if the dynamic segregation does not lead to anisotropy. Thus, the anisotropy might be smaller when static segregation is governing (narrow beams) then when dynamic segregation is governing (slabs and wide beams)
4. Unreinforced Compressive strength of slab members is 19.18 % less than reinforced Compressive strength of slab members for core 1 in parallel direction after 28 days
5. Unreinforced Compressive strength of slab members is 25.19 % less than reinforced Compressive strength of slab members for core 2 in parallel direction after 28 days
6. Unreinforced Compressive strength of slab members is 20.36 % less than reinforced Compressive strength of slab members for core 3 in parallel direction after 28 days
7. Unreinforced Compressive strength of slab members is 19.57 % less than reinforced Compressive strength of slab members for core 4 in perpendicular direction after 28 days
8. Unreinforced Compressive strength of slab members is 21.13 % less than reinforced Compressive strength of slab members for core 5 in perpendicular direction after 28 days
9. Unreinforced Compressive strength of slab members is 15.06 % less than reinforced Compressive strength of slab members for core 6 in perpendicular direction after 28 days
10. Unreinforced Compressive strength of beam members is 19.18 % less than reinforced Compressive strength of beam members for core 1 in parallel direction after 28 days Unreinforced Compressive strength of beam members is 25.19 % less than reinforced Compressive strength of beam members for core 2 in parallel direction after 28 days
11. Unreinforced Compressive strength of beam members is 20.36 % less than reinforced Compressive strength of beam members for core 3 in parallel direction after 28 days
12. Unreinforced Compressive strength of beam members is 19.57 % less than reinforced Compressive strength of beam members for core 4 in perpendicular direction after 28 days
13. Unreinforced Compressive strength of beam members is 21.13 % less than reinforced Compressive strength of beam members for core 5 in perpendicular direction after 28 days
14. Unreinforced Compressive strength of beam members is 15.06 % less than reinforced Compressive strength of beam members for core 6 in perpendicular direction after 28 days

V. ACKNOWLEDGMENT

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