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On the Assessment of Actual Compressive Strength of Concrete in Reinforced Columns: Influence of Core Diameter and Slenderness Ratio

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Abstract

This paper studies the influence of core diameters and slenderness ratio on the assessment of the actual compressive strength of concrete on reinforced-concrete elements. The experiment consists of the preparation of three reinforced concrete columns and the extraction of cores to carry out both destructive (core diameter of 64 mm, 79 mm, and 103 mm) and non-destructive tests. The non-destructive test deals with the propagation of elastic and compressive waves by deriving the ultrasound pulse velocities. The results show that the assessment of the compressive strength of concrete depends strongly on the diameter of cores and the extraction zones. Furthermore, the derivation of the actual compressive strength by referring to the compressive strengths of the cores with a diameter of 64 mm shows a stringent appearance of a size effect. More interestingly, valuable details about the correlation between the concrete compressive strength assessment based on destructive and non-destructive tests are also presented.

Keywords: hardened concrete, compressive strength, ultrasound pulse velocity, core diameter, slenderness ratio

1 Introduction

The large integration of concrete in the civil engineering field has been strongly consolidated by its incisive qualities such as load-carrying capacity, sustainability, and cost. Despite the heterogeneity of the concrete, structures made as a combination of that material and reinforced elements are theorized and certified as a valuable solution to resist quasi-static and dynamic loadings [1 - 3]. However, with the impetus of improving the resiliency of cities, the monitoring of the degradation of reinforced concrete (RC) structures received much interest. Thus, structures made of concrete ceased to be consigned as maintenance-free [4]. Throughout the various indications about the degradation, the strength requirement and the seismic performance of the RC structures, the assessment of the compressive strengths of in-situ concrete is mainly advocated [5, 6]. Three main techniques are used to assess the compressive strength of concrete in-situ. These techniques are based on destructive, semi-destructive and non-destructive methods. The most common destructive method to evaluate the compressive strength of concrete is drilling and crushing cores [7]. One of the advantages of that method is

direct access to representative specimens of concrete. Furthermore, crushing cores with a universal testing machine (UTM) provides rapid indications about the quasi-static concrete compressive strengths. However, the non-exhaustive limitation of that time-consuming method is that it breaches the integrity of the structures. Additionally, the strength controlling procedure depends on the estimation of in-place concrete strength variation volume and its accessibility. The semi-destructive methods were developed to compensate for some of the destructive method limitations. The most popular physical and in-field method is the pulling-out testing (CAPO test) [8, 9]. The test consists of the measurement of the pulling-out strength of an insert previously cast into fresh concrete or installed in hardened concrete. Strength relationships between the pulling-out strengths and the compressive strength results could be derived. On one hand, this method limits the damage inflicted upon the structures. Furthermore, the method could be applied to a large surface compared to the potential prospecting area covered by the destructive methods. On the other hand, the influence of parameters such as bearing ring dimensions or depth embedment is considered as important. The non-destructive tests represent methods and techniques that do not undermine the structural safety and integrity of the structure in any way. To this end, transducers and/or sensors are generally used to collect information from the concrete. Subsequently, models are developed to derive an estimation of the concrete compressive strength. For instance, an estimation of the compressive strength of the concrete by using ultrasonic pulse velocity (UPV) measurement has been developed and adopted [10].

Among the presented methods of the assessment of the compressive strength of hardened concrete in-situ, the destructive method is deemed to be the most reliable [11, 12]. However, the application of a direct conversion between the compressive strengths of cores and standard dimension specimens made of concrete should rely on core diameters higher than 100 mm and a slenderness ratio (SR) of 1 or 2 [13]. The slenderness ratio is the quotient (ratio) between the height and the diameter (width) of the core. Otherwise, the estimation of the actual compressive strength of concrete is obtained after the introduction of coefficients, called strength correction factors [14, 15]. These strength correction factors are principally associated with the core diameter, the SR, the presence of reinforcement steel in cores, moisture and damage due to drilling [16]. Further parameters such as, aggregate sizes, core conditioning, number of cores, drilling locations contribute to complete a well-founded method for the concrete strength evaluation upon existing RC structures [17 - 19]. In addition to the latter's, hand mixing of concrete and pouring operation (compaction of concrete, etc.) could further complicate reaching a reliable estimation of the actual strength of concrete. In fact, in many countries, the urgent need to rehouse people or the uncontrolled willingness of the population to access the dwellings makes prosper the appearance of illegal constructions built without referring to building national recommendations. Consequently, casting vertical element with highly variable concrete strength using long and uncontrolled drop chute or with old fashion hand methods raises the risk to build structural element with dispersed concrete strengths [20].

This paper outlines the influence of core diameter and SR on the assessment of the actual compressive strength of concrete on vertical reinforced structural elements (columns). Both non-destructive and destructive tests are performed. The non-destructive test consists of the measurement of the UPV through the concrete in columns and drilled cores. The destructive test refers to extracting and crushing specimens with three different diameters 64, 79 and 103 mm and SR of 1 and 2. The results show that the concrete in columns is affected by a severe strength variation as old fashion hand methods are used. A concrete downgrading has been

confirmed by the analysis of core strengths with the largest diameter. The use of low core diameter and sample size pinpoints the importance of the scale effect on interpreting the strengths along the columns. More interestingly, a zone effect has been identified with non-destructive and destructive test methods.

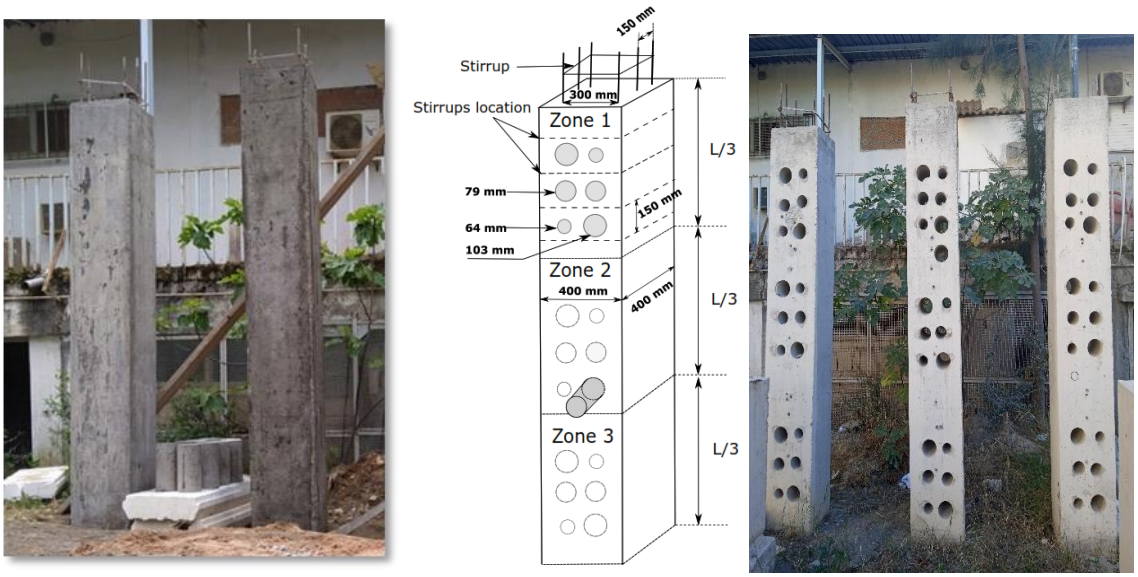
2 Materials and Methods

2.1 RC Elements

An ordinary C25/30 class concrete with a standard consistency has been prepared (hand-mixed concrete) for the experiment. The constitutive elements of the concrete mixture and the compressive strength after 28 days of curing according to [21] and [22] are listed in Table 1. The mean compressive strength of lab-cured molded specimens with a cylindrical shape of 150 mm in diameter and 300 mm in length is 25.37 MPa. The fresh concrete is used to fill three full-scale reinforced columns (labeled C1, C2 and C3) with old fashioned hand method (Figure 1). This method is still extensively used in the majority of regions in the country (Algeria). The dimensions of the columns are 300 cm in high (as a maximum height), and dimension of cross-section is 40 cm x 40 cm. The diameter of the longitudinal reinforcing steel bar was 12 mm and the distance between the extremities of each bar was 15 cm. Equidistant stirrups with a diameter of 8 mm provided the transverse reinforcement bar. Each stirrup was placed every 15 cm. Three zones labelled 1, 2 and 3 are delimited to perform both non-destructive and destructive tests on concrete. To control the concrete qualities on site and to assess the influence of curing conditions, four moulded standard-dimension cylindrical specimens (150 mm × 300 mm) are prepared for each poured column. After demoulding, the specimens were left outside and placed near the filled column to be exposed to the same curing conditions. These specimens are called field-cured specimens (FCS).

Table 1: Mixture proportions of the ordinary concrete (C25/30) and its lab-cured compressive strength

Constituents	**Units**	**Proportions**
Cement	kg/m^3	350
Natural Sand from rivers	kg/m^3	464
Natural sand from dunes	kg/m^3	271
Aggregates	kg/m^3	1058
Water	kg/m^3	210
Maximum aggregate size	mm	20
Consistency class		S2 (slump range between 50 to 90 mm)
Mean compressive strength, cylindrical specimen (D = 150 mm, L = 300 mm)	MPa	25.37



(a) (b) (c)

Figure 1: Reinforced columns (a) Columns after formwok removal (b) Drilling operation plan and delimitation of zones (c) Columns after drilling operation

2.2 Non-Destructive Testing

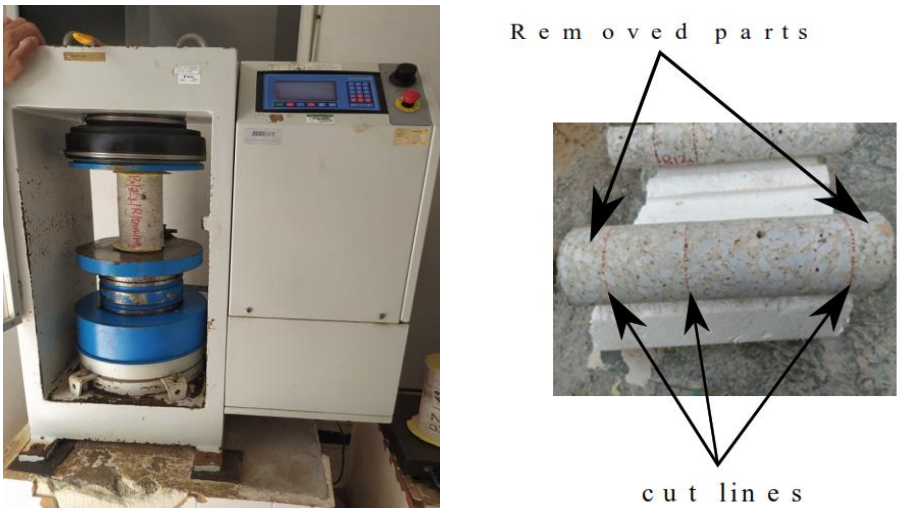
The measurement of the UPV has been used to perform non-destructive tests according to a standardized procedure [23]. The tests are carried out over the three delimited zones and on standard dimension specimens. The measurement spots on the columns have been pre-selected to be ulteriorly used to drill and extract cores. A portable pundit LAB ultrasonic pulse transmitter is used to generate longitudinal waves (Figure 2). The transmitter is connected to a transducer to emit waves with a nominal frequency of 54 kHz. The waves traveling along the specimens are captured after traversing the concrete by a second transducer (receiver). Direct transmissions are performed, and the wave velocities are automatically derived.



Figure 2: Ultrasound pulse velocity measurement (direct transmission performed on field-cured specimens)

2.3 Destructive Testing (DT)

The crushing tests were performed with a Universal Testing Machine (UTM) with a capacity of 2000 kN (Figure 3a). The applied loading rate in compression is 0.6 MPa/min, following standard recommendations [22]. The drilled cores are cut to study the unexposed volume of concrete in columns. From each extremity of a drilled core, a part of the concrete has been removed (Figure 3b). Before proceeding to the destructive test, the UPV is measured.



(a) (b)

Figure 3: Destructive test machine and sample preparation: (a) Universal Testing machine (b) Drilled core with a diameter of 103 mm

3 Results and Discussions

3.1 Influence of Core Diameter

Figure 4 shows the evolution of compressive strengths of cores with a SR of 2 as a function of core diameters. The compressive strengths of field-cured specimens with standard dimensions (150 mm in diameter, 300 mm in length) are also mentioned in that figure. The results from whole columns are presented. The columns and the core diameters are color-unified. At the first glance, the results of crushing specimens with a diameter of 150 mm and a length of 300 mm show important differences between the mean compressive strength of lab-cured specimens (given in Table 1) and field-cured specimens (FCS). The mean compressive strengths of the FCS referring to columns, 1, 2 and 3 are 17.69 MPa, 18.49 MPa and 18.41 MPa, respectively. Thus, a difference in the compressive strength up to 7.68 MPa has been observed between strengths of the lab-cured specimens and FCS.

From that figure, and independently from the core diameter, a large discrepancy on the compressive strengths of cores is observed. A marked discrepancy has been identified for a core diameter of 64 mm. For that diameter, the compressive strengths of cores range from 12.85 MPa to 27.91 MPa. For specimens with diameters of 79 mm and 103 mm, the compressive strengths of cores range from 8.33 MPa to 19.12 MPa and from 16.11 MPa to 25.67 MPa,

respectively. According to [13] and [25], the compressive strength of cores with diameters ranging from 100 mm to 150 mm and with a SR of 2 are equivalent to the compressive strengths of specimens with a diameter of 150 mm and a length of 300 mm. The application of that direct conversion concerns concretes prepared and conserved under the same conditions. By referring to the data plotted in Figure 4, the compressive strengths of cores with a diameter of 103 mm could be deemed as reliable and representative results. In fact, the strengths of these cores from each column are in majority higher than strengths of the field-cured specimens (83 % (5/6) for column 1, 83 % (5/6) for column 2 and 100 % (6/6) for column 3). This result could be considered as an indication that even though the columns were built with old-fashioned method, the direct conversion for strength assessment of concrete without using strength correction factor is reliable. However, the consistency of that direct conversion has been highlighted by analysing the strength of field cured specimens and large core diameter (103 mm).

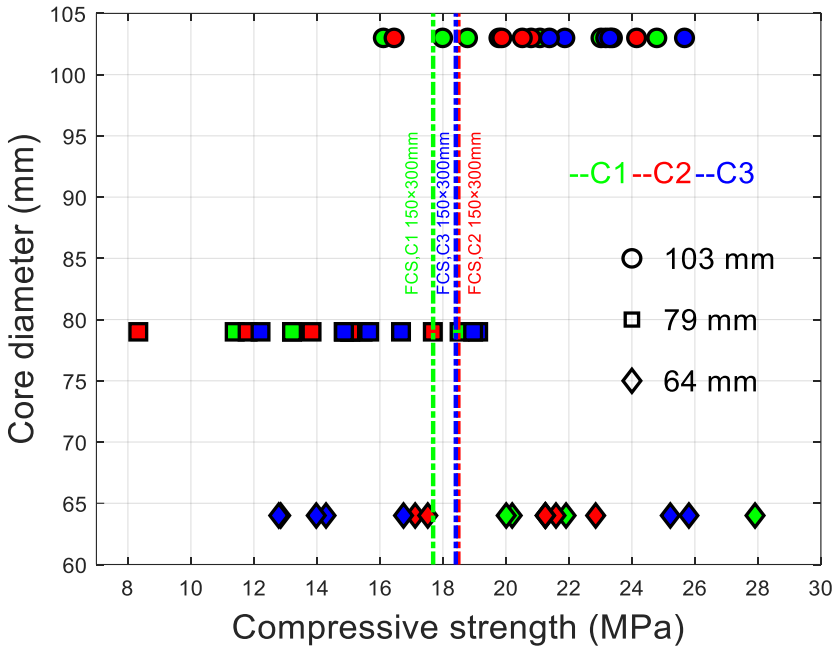


Figure 4: Compressive strengths of cores as function of core diameters

In practice, to estimate the class resistance of an in-place concrete, the estimated characteristic strength derived from core strengths ($f_{ck,core}$) should be compared with the onsite characteristic strength given in standards and code provisions [13, 24, 25]. For instance, according to [24] and [25], the onsite characteristic strengths of C20/25 and C25/30 concrete classes are 17 MPa and 21 MPa, respectively (see appendix). As the number of the cores for one diameter is six in each column, the estimated characteristic strengths of cores, $f_{ck,core}$, are calculated according to approach B cited in [24] and [25]. Thus, $f_{ck,core}$ is given as:

$$f_{ck,core} = minimum \begin{cases} f_{m(n),core} - k_n \\ f_{lowest,core} + 4 \end{cases} \quad (1)$$

where, $f_{m(n),core}$ is the mean strength of cores, n is the number of samples, called also the sample size ($n = 6$), k_n is a coefficient depending on n ($k_{n=6} = 7$) and $f_{lowest,core}$ is the lowest

compressive strength value of the cores. It is important to mention that the Grubbs test has been applied to detect outliers. The results of the calculation associated with core diameters of 103 mm, 79 mm and 64 mm and the standard deviation (std) of the core compressive strengths are given in Tables 2, 3 and 4 respectively.

Table 2: Estimated characteristic strength, $f_{ck,core(D)}$, for each column, core diameter D = 103 mm, SR = 2

Parameters (SR = 2)	**Column 1**	**Column 2**	**Column 3**
$f_{m(n),core\ (D=103mm)}$ (MPa)	20.29	20.26	23.13
Std	3.27	2.46	1.50
$f_{ck,core\ (D=103mm)}$ (MPa)	13.29	13.26	16.13

Table 3: Estimated characteristic strength, $f_{ck,core\ (D)}$, for each column, core diameter D = 79 mm, SR = 2

Parameters (SR = 2)	**Column 1**	**Column 2**	**Column 3**
$f_{m(n),core\ (D=79mm)}$(MPa)	14.47	13.59	16.25
Std	2.47	3.21	2.62
$f_{ck,core(D=79mm)}$(MPa)	7.47	6.59	9.25

Table 4: Estimated characteristic strength, $f_{ck,core\ (D)}$, for each column, core diameter D = 64 mm, SR = 2

Parameters (SR = 2)	**Column 1**	**Column 2**	**Column 3**
$f_{m(n),core\ (D=64mm)}$ (MPa)	20.69	20.27	18.14
Std	4.82	2.36	5.86
$f_{ck,core(D=64mm)}$ (MPa)	13.69	13.27	11.14

From Table 2, the estimated characteristic strengths derived from the core strengths with a diameter of 103 mm and for columns 1, 2 and 3 are 13.29 MPa, 13.26 MPa and 16.13 MPa, respectively. The difference between the limit of a valid classification of a C25/30 concrete class and the results of the estimated characteristic strengths is up to 7.74 MPa. Accordingly, a concrete downgrading should be applied over each column. In consequence, and according to standard provision [13, 24, 25], the concrete compressive strengths associated with columns 1, 2 and 3 should be ranked as C12/15, C12/15, and C16/20 class concrete, respectively. Thus, despite a valid concrete formulation of the concrete in the laboratory (targeted class of C25/30), the experiment illustrates the influence of parameters such as, curing conditions, drilling operation, pouring and preparation method in lowering the characteristic strengths of cores of in-place concrete.

By referring to Tables 3 and 4, the analysis of the mean and the characteristic compressive strengths of cores with diameters of D = 79 mm and D = 64 mm shows that cores with a diameter of D = 64 mm provide much more resistance compared to cores with a diameter of D = 79 mm. This result has been observed over the three columns. Furthermore, the calculation of the characteristic strengths of cores also shows scattering results as the core diameter is reduced. This observation could be deduced by analyzing the evolution of the standard deviation values. More interestingly, the evolution of the characteristic compressive strength of cores as the diameter is reduced could be considered as a stringent indication about the appearance of a size

effect. The size effect refers to the appearance of unexpected core strengths as the scale variation of cores is applied. For instance, the occurrence of that effect could be detected when the evolution of the compressive strengths of cores is not monotonic as the core diameter is progressively reduced for a constant SR [26]. In this perspective, half number of cores (50 %) with a diameter of 64 mm from 18 specimens provide compressive strengths higher than the on-site characteristic strengths of C25/30 class concrete (21 MPa). In comparison with the compressive strengths of cores with a diameter of 79 mm, the resistances of these specimens never exceed that value. The derivation of the actual strength and the class of the concrete by using core diameters less than 100 mm should be performed by introducing strength correction factors. This part will not be covered in this paper. The analysis of the characteristic compressive strength of cores as the core diameter is varied and the size sample (number of cores) is low shows clearly that, the approach B given in [24, 25] and expressed by (1) could be considered as severe. In fact, the calculation shows that the derived characteristic strengths are totally dependent on the coefficient k which implies a large deviation from the mean compressive strength of cores. Finally, to ascertain the appearance of a size effect, the influence of the drilling operation should be examined thoroughly as the drilling operations were performed at different locations along the vertical element. This parameter could probably have the influence on scattering the DT results. Thus, the influence of drilling locations will be discussed in the following section.

3.2 Influence of Drilling Location

Figure 5 shows the distribution of the core compressive strengths as a function of the drilling zones. The mean compressive strength and standard deviation (std) are given in Table 5. It could be observed that the zone least affected by the scatter of the compressive strength is the medium zone (zone 2). This observation is confirmed by the statistics. For instance, the value of the standard deviation of the core compressive strength with a diameter of 103 mm and drilled from the medium zone (zone 2) is 1.65. Comparatively, the values of the standard deviation derived from zone 1 (upper zone) and zone 3 (lower zone) are 2.83 and 3.02, respectively. Furthermore, this trend is confirmed and more marked as the core diameter is equal to 79 mm. For this diameter, the limitation of the lateral variation of the compressive strength of concrete has been achieved by selecting symmetrical emplacements for drilling (see Figure 1b). Additionally, the second important observation is the appearance of a zone effect, independently from the core diameter. It is worth noting that the mean compressive strength of the cores drilled from zone 1 (upper zone) is less than the mean compressive strength of the cores extracted from zone 2 and 3. This observation is confirmed whatever the core diameter. This phenomenon has been previously identified by authors and could be in relationship with critical factors in determining core strength such as method of compaction and the workability of concrete [12, 19]. More interestingly, the third important point to highlight is that the new representation of the mean compressive strength of cores as function of the drilling zone confirms the appearance of a size effect as a core diameter of 64 mm is used. The difference between the mean compressive strength of cores with diameters of 64 mm and 79 mm is quasi-constant and higher than 4 MPa. However, to confirm the consistency of these conclusions, the analysis of the compressive strength of cores with a SR of one might be performed. The next section will also treat the importance of the SR in the identification of a likely critical and/or recommended zone for drilling.

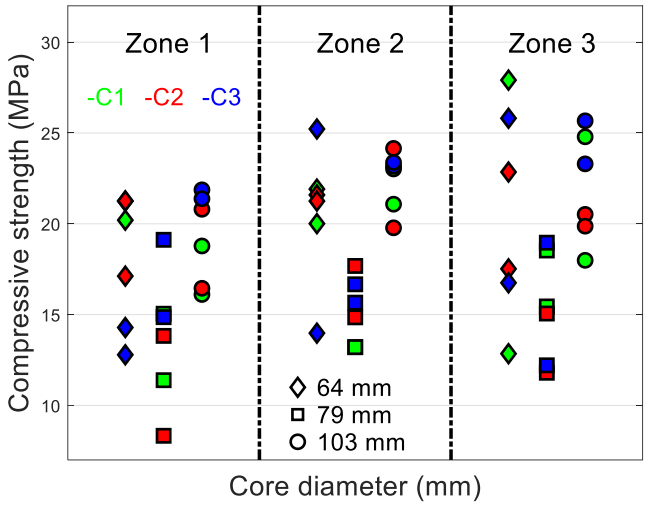


Figure 5: Distribution of the compressive strengths of cores as function of drilling zones, SR = 2

Table 5: Mean compressive strength of cores as function of drilling zones, SR = 2

	***D* = 103 mm**		***D* = 79 mm**		***D* = 64 mm**	
	$f_{m(n),core}$	Std	$f_{m(n),core}$	Std	$f_{m(n),core}$	Std
Zone 1 (upper)	19.45	2.83	13.76	3.65	17.82	3.60
Zone 2 (medium)	22.43	1.65	15.21	1.82	20.66	3.70
Zone 3 (lower)	22.02	3.02	15.34	3.02	20.61	5.83

3.3 Influence of the Slenderness Ratio

Tables 6, 7 and 8 show the calculation of the characteristic strengths of cores from the three columns with diameters of 103, 79 and 64 mm, respectively for a SR of 1. The straightforward way to assess the compressive strength of the in-place concrete is to deal with the characteristic strength of cores with a diameter of 103 mm. Thence, the estimated characteristic strength derived from DT applied on cores with that diameter are 13.95 MPa, 13.40 MPa, and 13.35 MPa for column 1, 2 and 3, respectively (see Table 6). To derive the concrete grade in columns, the obtained characteristic strengths should be compared with onsite characteristic strengths of molded cubic specimens with a lateral dimension of 150 mm. Thus, the strength of the in-place concrete in the three columns should be ranked according to [13, 25] provisions as a C12/15 (see appendix). In consequence, the DT results from cores with a diameter of 103 mm and with a SR of 1 and 2 (see part 3.1) confirm the severe downgrading of concrete by following the approach B in [24] and [25]. It is important to point out that this ascertainment has evolved as one drilling operation served to extract cores with a SR of 1 and 2. Furthermore, for a targeted concrete class of C25/30, the conventional assumption that the characteristic strengths of cores with a SR of 1 is higher than the characteristic strength of cores with a SR of 2 has not be confirmed.

For small diameter, the analysis of the characteristic strengths of cores over the three columns and for the cores with diameters of 64 and 79 mm confirms once more the appearance of a size effect as a core diameter of 64 is used. In fact, the characteristic strengths of cores with a

diameter of 64 mm are higher than those of cores with a diameter of 79 mm. The maximum difference in the strength assessment has been detected in column 1 and is up to 54 %. This concrete strength variation could be originated from various parameters such as the influence of drilling zone. To confirm the presence of a zone effect as observed for cores with a SR of 2, Figure 6 shows the distribution of the compressive strengths of cores as function of the drilling zone for cores with a SR of 1. The mean compressive strengths and the strength standard deviations of cores are given in Table 9. From that table and in accordance with the conclusion made for a SR of 2, the upper zone contributes to lowering the characteristic strength of concrete whatever the core diameter. In fact, the mean compressive strength of cores drilled from the upper zones are generally less than the mean compressive strength of cores in each column. For instance, the mean compressive strength of cores with a diameter of 103 mm are all higher than the mean compressive strength of cores in zone 1 (19.25 MPa). According to the data analysis made over the DT results of cores with a SR of 1 and 2 and extracted from columns, the selection and the use of drilling zone located in the top zone to assess the compressive strength of the element could not be a representative way to conduct a reliable estimation. However, in this study, the use of specimens with a SR of 1 could be a valuable way to confirm or infirm the appearance of a size effect.

Table 6 : Mean and characteristic compressive strength of cores, SR = 1, *D* = 103 mm

Parameters (SR = 1)	**Column 1**	**Column 2**	**Column 3**
$f_{m(n),core}$ (MPa)	20.96	20.40	20.35
Std	2.03	1.94	1.88
$f_{ck,core\ (D=103mm)}$ (MPa)	13.95	13.40	13.35

Table 7 : Mean and characteristic compressive strength of cores, SR = 1, *D* = 79 mm

Parameters (SR = 1)	**Column 1**	**Column 2**	**Column 3**
$f_{m(n),core}$ (MPa)	14.04	15.53	18.02
Std	1.33	2.51	2.15
$f_{ck,core\ (D=79mm)}$ (MPa)	7.04	8.53	11.02

Table 8 : Mean and characteristic compressive strength of cores, SR = 1, *D* = 64 mm

Parameters (SR = 1)	**Column 1**	**Column 2**	**Column 3**
$f_{m(n),core}$ (MPa)	17.82	17.71	20.06
Std	2.58	2.31	2.33
$f_{ck,core\ (D=64mm)}$ (MPa)	10.82	10.71	13.06

Table 9 : Mean compressive strength of cores as function of drilling zone (SR=1)

(SR =1)	***D* = 103 mm**		***D* = 79 mm**		***D* = 64 mm**	
	$f_{m(n),core}$	**Std**	$f_{m(n),core}$	**Std**	$f_{m(n),core}$	**Std**
Zone 1 (upper)	19.25	1.48	14.28	2.14	17.61	1.58
Zone 2 (medium)	20.99	2.07	15.73	2.24	18.21	3.37
Zone 3 (lower)	21.45	1.41	17.59	2.48	19.78	2.08

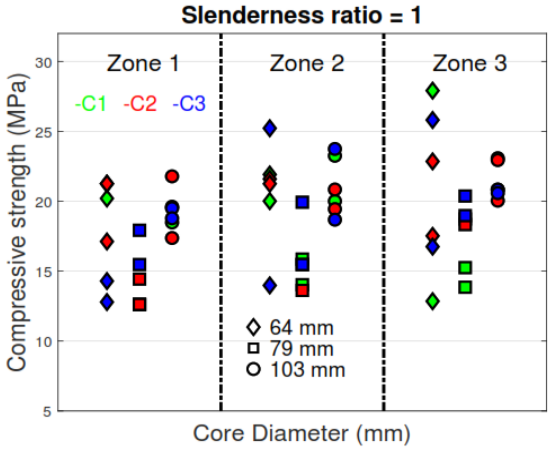


Figure 6: Distribution of the compressive strengths of cores as function of drilling zones, SR = 1

3.4 Ultrasonic Pulse Velocity (UPV) Testing

The UPV measurements are performed on columns (at core picking markers) using a longitudinal compression wave generated by a piezoelectric transmitter at a nominal frequency of 54 kHz and collected by a piezoelectric receiver (plane transducer). The European standard recommends to use grease to ensure perfect acoustic coupling between the column surface and the faces of the transducers [23]. The UPV measurements were made on all three areas (top, middle and bottom of each reinforced columns, as shown in Figure 1) at different curing ages of 7, 14, 21 and 28 days. The locations were chosen carefully, to avoid reinforcement bars, and to operate after that a valid core extraction from each measurement point.
Figure 7a shows the evolution of the UPV as function of curing age carried out on column 2 and on the location of picking marker corresponding to a pre-selected area to extract a core with a diameter of 103 mm. Figure 7b shows the evolution (characteristic trend) of the UPV measurements as function of curing age represented by drilling zones. In Figure 7b, each point on the curves represents an average of 18 UPV measurements collected from the three columns. From both figures, the ultrasonic pulse velocities increase with the curing time increase. The difference between the velocities of the ultrasonic waves at a curing age of 7 days and 28 days is almost constant, and it seems to be completely independent from the extraction zones. More interestingly, a stringent appearance of a zone effect has been observed. In fact, the ultrasound pulse velocities increase gradually from the top to the bottom of the reinforced column. This phenomenon can be explained by compactness of the concrete matrix at the bottom of reinforced columns due to the effect of gravity during the filling of the reinforced column using old fashioned hand method and the segregation of coarse aggregate that favor the increase of the ultrasound pulse velocity propagation [27, 28]. To analyze the difference between the UPV measurements performed on columns and cores, Figure 8a shows both measurements from the emplacement on columns and through the cores with a diameter of 103 mm and a SR of 2. It could be observed that the ultrasonic pulse velocity on RC columns before drilling are significantly lower than those on the cores. This result is in accordance with the conclusions of the European standard [23]. For completeness, Figure 8b represents the mean compressive strengths of cores as function of the mean UPV (clusters) through the different drilling emplacements and cores. The graphical representation of the points in Figure 8a has been

reduced to just six clusters in Figure 8b. The latter figure shows clearly that the UPV clusters on columns are concentrated in a narrow-banded range. Practically, it indicates that the elastic properties of the concrete along the columns are quite constant, and no significant impedance variation could be detected. However, after the extraction of the cores, the UPV clusters are confined in wide banded range. In addition, the clusters derived from the UPV measurements on cores with a diameter of 64 mm are higher than the clusters corresponding to other diameters. This observation is a clear indication about the reliability of the nondestructive testing on cores by using ultrasound to predict the appearance of a size effect.

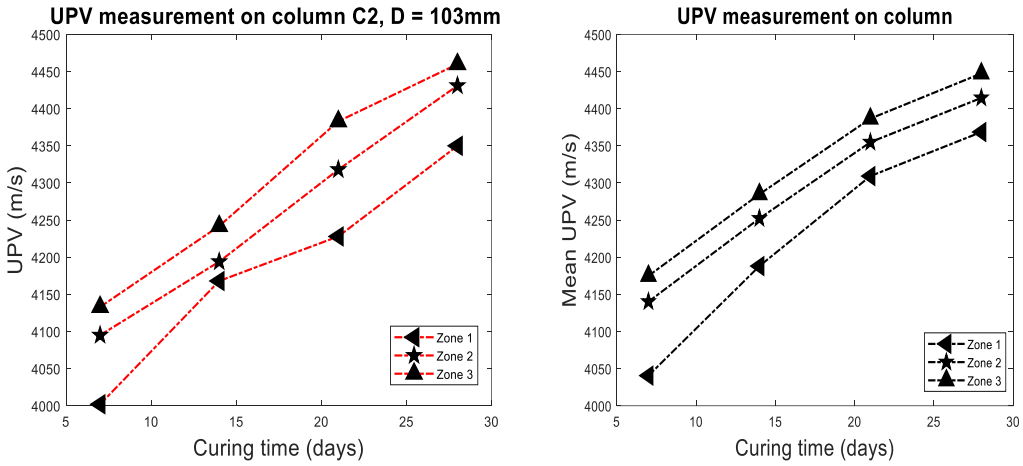


Figure 7: UPV measurement as function of curing time (a) UPV measurement on column 2 (b) a characteristic evolution of UPV as function of drilling zones

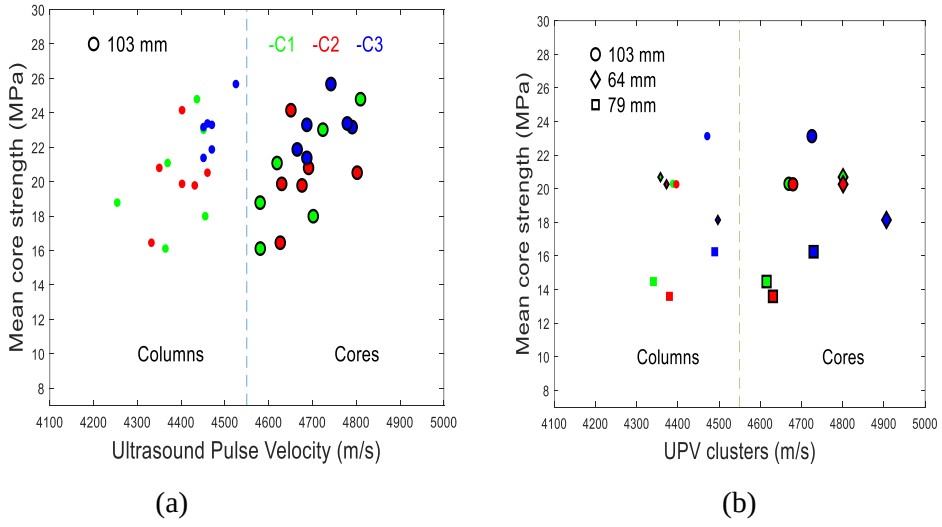


Figure 8: Mean core strength vs UPV measurement (a) on markers and cores with D = 103 mm (b) UPV clusters for the three diameters

4 Conclusion

This paper highlights the influence of core diameter and slenderness ratio on the assessment of the actual compressive strength of hardened concrete. Full-scale columns were prepared and subjected to infield destructive and non-destructive methods to evaluate strength variation of concrete. The non-destructive test relies on the measurement of the ultrasound pulse velocity over the columns and cores. The destructive method consists of drilling and crushing cores with different diameters. The drilling operation was conducted in three zones and three core diameters were used (103 mm, 79 mm, 64 mm). The results are discussed, and the main conclusions are the following:

- Severe concrete downgrading according to the procedure described on approach B in [24, 25] has been observed as an old-fashioned method is used in placing concrete.
- The appearance of a size effect as a core diameter of 64 mm has been detected. This observation has been made even with respecting the ratio between the core diameter and the maximum aggregate size higher than 3.
- Using a double UPV measurements with a nominal transducer frequency of 54 kHz on columns and cores is a reliable method to confirm the presence of a size effect.
- The appearance of zone effect on columns has been pinpointed as old-fashioned method is adopted. The highlighted zone effect contributes to lowering the characteristic strength of cores.
- The characteristic strengths of cores with a slenderness ratio of 1 are not necessarily higher than the characteristic strengths of cores with a slenderness ratio of 2 as prescribed by standards. This conclusion has been made as a severe concrete downgrading is observed.

Appendix

Table A1 shows the minimum characteristic in situ concrete compressive strength for different concrete classes as reported in [13, 24, 25].

Concrete class	**Minimum characteristic in situ concrete compressive strength (MPa)**	
	Cylinder	Cube
C8/10	7	9
C12/15	10	13
C16/20	14	17
C20/25	17	21
C25/30	21	26

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