Concrete Compressive Strength Extracted from Existing Buildings

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ABSTRACT: The evaluation of seismic safety of existing buildings is an increasingly important topic in earthquake engineering, especially in the light of the provisions subscribed in recent national and international building codes. For reinforce concrete buildings that assessment is not possible without the definition of concrete mechanical properties and, in particular, the definition of its compressive strength. Since the '90s of previous century, the Tuscany Region has launched a campaign of diagnostic on-site tests as prescribed by the Tuscan Regional Program VSCA (Reinforced Concrete Buildings Seismic Vulnerability) for determining the quality of concrete in public reinforced concrete buildings. In this paper, two buildings - selected from those investigated by the Tuscany Region and now demolished after being declared unsafe are analyzed. In particular, some issues related to the concrete mechanical characterization both on-site and in laboratory are addressed considering the method of extraction of cylindrical specimens and the size of the sample obtained by grinding the core.

1 INTRODUCTION

In recent years, the new Italian codes, such as Ordinanza P.C.M. n. 3274 (OPCM 3274, 2003) and subsequent modifications and the Nuove Norme Tecniche per le Costruzioni (D.M., 2008), as well as the Eurocode 8 (CEN, 2004), have devoted particular attention to the evaluation of safety of reinforced concrete (rc) existing buildings. This interest arises from the various disasters that have occurred due both to seismic events and to poor design. Considering that in Italy more than half of the existing building consists of rc buildings characterized by age degradation and structural deterioration, it follows the need for defining the state of health of those buildings. The on-site determination of the mechanical properties of concrete and, particularly, of its compression strength is essential for a correct evaluation of seismic safety of existing buildings. Since the '90s of previous century, the Tuscany Region, in the context of national and regional programs of seismic prevention, has undertaken a series of tests on-site, both destructive (coring) and non-destructive (ultrasonic and sclerometric), aimed at assessing seismic risk of strategic and important rc buildings built between the years '50 and '80 and located in the most seismic areas of the region. In this manner, the knowledge on the materials quality has been widened in order to use it for evaluating the seismic vulnerability of rc existing buildings. The investigated buildings are about 360 for a total of over 2000 structural elements under examination. The large number of acquired data forms a reference database useful for local authorities, industry and Universities.
In this study, two issues connected to the definition of the concrete compressive strength by coring are addressed: 1) the influence of the core extraction direction, which can be orthogonal or parallel to the structural element axis; 2) size of the core diameter.

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These issues are discussed with reference to the database of on-site tests of Tuscany Region and, additionally, to some tests recently conducted by the Authors on concrete samples taken from structural elements (columns and beams) extracted from demolished buildings.
Compression testing in laboratory can be conducted on cubic or cylindrical samples, determining the corresponding values of the failure stress, respectively f_{cub} and f_{cyl}. The f_{cyl} can be taken equal to 83% of the correspondent f_{cub} due to many disturbing factors intrinsic to the methodology of test. In fact, in the technical literature different empiric formulations to convert the f_{cyl} to f_{cub} are present. These formulations take into account the value of f_{cyl}, the direction of the core extraction, horizontal or vertical to the axis of the structural element, and the slenderness of the specimen. In this paper, the results obtained from compressive tests conducted in the laboratory on cylindrical specimens, f_{cyl}, without applying any correction factors, are discussed.

2 INVESTIGATION AND DATA ANALYSIS

A sample of 860 structural elements (columns and beams), for which the results from destructive testing (coring) and non-destructive testing (ultrasonic testing and sclerometric) are available, has been considered as a sample (Cristofaro, 2009). These data belong to 277 existing rc buildings, built between the years '50 and '80 (Figure 1) and located in the most seismic areas of Tuscany: Amiata, Casentino, Garfagnana, Lunigiana Mugello and Valtiberina.

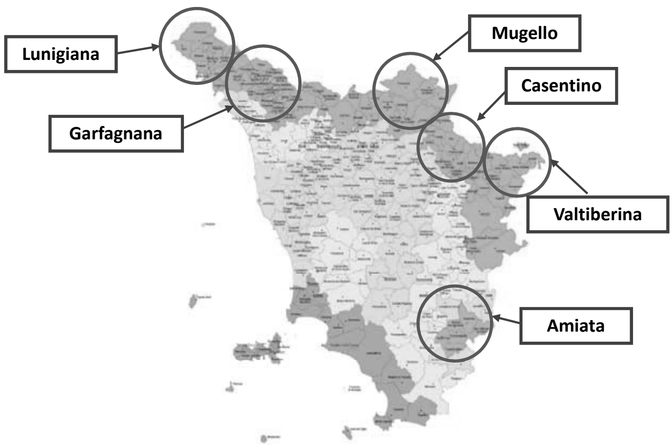
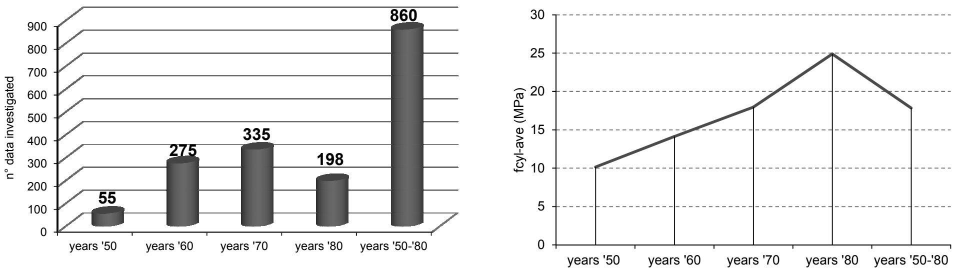


Figure 1 - Tuscany Region: location of investigated buildings.

Figure 2a shows, for each decade of building construction, the total number of available data (from destructive and non-destructive testing), and the respective average value of cylindrical specimens strength $f_{cyl-ave}$ (Figure 2b). From these data it emerges that the $f_{cyl-ave}$ tends to increase from about 10 MPa for buildings built in the '50s to over 25 MPa for those built in the '80s, while it is lower than 20 MPa for the entire sample of buildings.
Table 1 shows the main statistical parameters of f_{cyl} for each above mentioned decades. It shows that the value of coefficient of variation (C.V.) oscillates between 44% for data belonging to buildings built in the '50s and 48% for data related to buildings built in the '70s. In general, these high values reflect a wide dispersion of sample of data.
For all three decades considered the $f_{cyl-ave}$ is greater than the median. This difference between the mean and median shows that the distribution of f_{cyl} is asymmetric positive, meaning that there are high values that make the mean larger than the median. In fact, for all three decades, the distribution is skewed to the right (asymmetry positive), and in

particular data related to buildings built in the ‘50s have an index of asymmetry equal to 2.16, while those relating to the buildings built in the ‘60s and ‘70s have an index of asymmetry slightly larger than 1.



(a) (b)

Figure 2 - (a) Number of available data, (b) average value of f_{cyl}.

Table 1 - Principal statistical parameters of f_{cyl} for each decade.

Years ‘50			Years ‘60			Years ‘70		
Average	10.16	(MPa)	Average	10.13	(MPa)	Average	17.97	(MPa)
Median	9.29	(MPa)	Median	13.14	(MPa)	Median	16.38	(MPa)
Stand. Dev.	4.51	(MPa)	Stand. Dev.	6.43	(MPa)	Stand. Dev.	8.59	(MPa)
C.V.	44.38	%	C.V.	45.53	%	C.V.	48.00	%
Asymmetry	2.16		Asymmetry	1.25		Asymmetry	1.16	

3 TESTING AND RESULTS

Results from testing conducted by Tuscany Region have, in some cases, prompted the authorities to prescribe the demolition of the buildings under investigation. The present study refers to two buildings chosen among those investigated in the Regional program VSCA (Reinforced Concrete Buildings Seismic Vulnerability) and later demolished: the elementary and secondary school "Galileo Galilei" in Fivizzano’s town (MS) and the primary school gym in Castel San Niccolò’s town (AR).

Some structural elements taken during the demolition and cores taken from these elements have been subjected to further testing in the Laboratory of the Department of Constructions and Restoration, University of Florence.

3.1 Influence of core removal direction

The elementary and secondary school "Galileo Galilei" was built in 1959 in the Tuscany geographical district identified as Lunigiana. On-site investigation has been conducted on 14 columns and one beam for a total of 15 structural elements distributed on three levels.

Figure 3 shows the values of f_{cyl} for the 15 structural elements and the corresponding average value. From the graph of Figure 3 it can be seen that two columns at the ground floor present strength significantly greater than $f_{cyl\text{-}ave}$, which is equal to 9.6 MPa.

During the demolition five columns with a section 30x30 cm have been extracted. From three columns (columns 1, columns 2 and columns 3) a significant number of cores have been extracted in the Departmental Laboratory, to assess whether the f_{cyl} changes significantly along the length of the structural element. From each column at least one core has been extracted in a parallel direction to the axis of the column (vertical core), while all others have been extracted in the orthogonal direction (horizontal core).

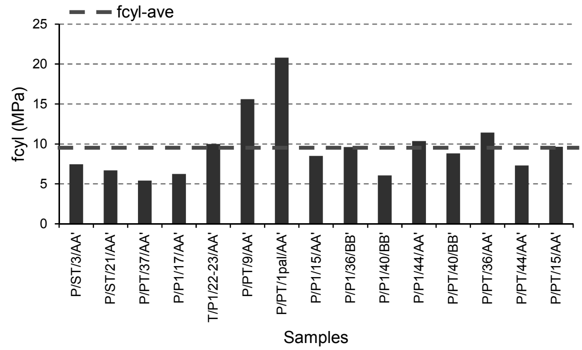
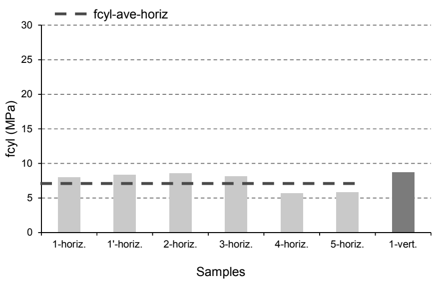
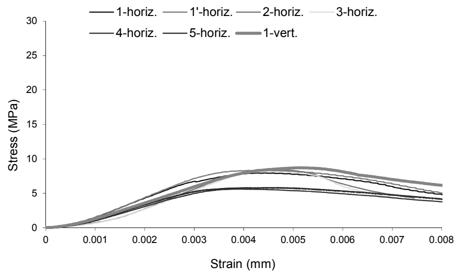


Figure 3 - f_{cyl} values of structural elements investigated on-site.

Figures 4a-6a show the f_{cyl} values obtained from the column 1, 2 and 3, while Figures 4b-6b show the corresponding constitutive stress-strain relationships. From column 1, six horizontal cores and one vertical core have been extracted. The f_{cyl} value from specimen 1-vert. is equal to 8.71 MPa and it does not differ significantly from the values of f_{cyl} obtained from the horizontal specimens, particularly it is only about 17% larger than the average strength of horizontal specimens $f_{cyl\text{-}ave\text{-}horiz}$, equal to 7.41 MPa (Figure 4a).

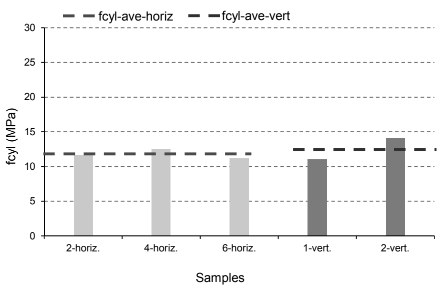


(a)

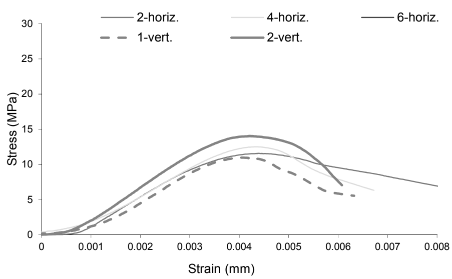


(b)

Figure 4 - Column 1: (a) f_{cyl} values from specimens, (b) stress-strain experimental relationships.



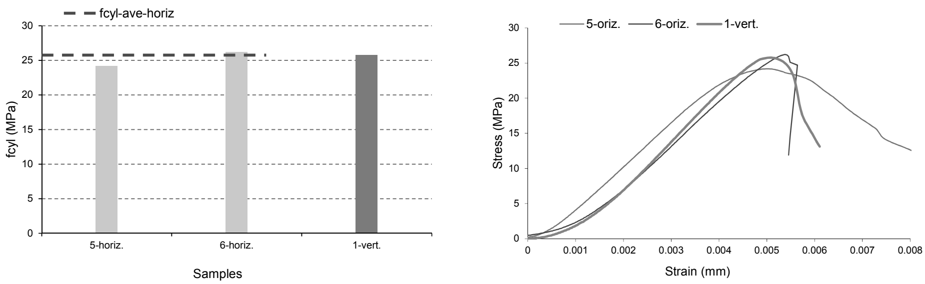
(a)



(b)

Figure 5 - Column 2: (a) f_{cyl} values from specimens, (b) stress-strain experimental relationships.

From column 2 two vertical cores and three horizontal cores have been extracted. The $f_{cyl\text{-}ave\text{-}vert.}$ obtained from the two vertical cores, approximately equal to 12 MPa, is larger than the $f_{cyl\text{-}ave\text{-}horiz.}$ by 6.5%, being equal to 11.74 MPa (Figure 5a).
From column 3 one vertical core and two horizontal cores have been extracted. The $f_{cyl\text{-}vert}$ value from the vertical core, approximately 25 MPa, is very close to the $f_{cyl\text{-}ave\text{-}horiz}$ value, equal to 25.2 MPa (Figure 6a).
The on-site data coefficient of variation is equal to 42%, while that of data from Laboratory tests is equal to 55%; both coefficients are high.



(a) (b)

Figure 6 - Column 3: (a) f_{cyl} values from specimens, (b) stress-strain experimental relationships.

3.2 Influence of core diameter

Castel San Niccolò' town (AR) is located in the Casentino district of Tuscany region. The primary school gym was built in 1975 without seismic code. In fact, Castel San Niccolò' town was classified as seismic town by a Royal Decree issued on 13 march 1927 n. 431, but it was de-classified in 1939. With the issue of Ordinanza P.C.M. 20 marzo 2003 n. 3274 (OPCM 3274, 2003) this town has been re-classified as seismic in zone 2. The structural elements investigated are two columns (1C and 2C) and one emergent beam (1B). The columns have a rectangular section about 75x30 cm (Figure 7a), while the beam presents a T-shaped section with base 30 cm and height 70 cm (Figure 7b). Both elements are reinforced with smooth longitudinal bars Ø 24, stirrups Ø 10 distanced by 15 cm.

(a) (b)

Figure 7 - Primary school gym of Castel San Niccolò town: (a) column, (b) beam.

The aggregate size in the columns is different from that found in the beam. This change has been verified both at the time of core extraction and with longitudinal cuts made on the elements using a cutting wall saw. In columns the aggregate present a blend of different sizes, from river and well washed. On the contrary, in the beam the aggregate size is small, with average size of 16 mm, containing sand (Figure 8).

Figure 8 - Characteristics of cores extracted from beam.

Cores with three different diameters: Ø 44 mm, Ø 84 mm and Ø 44 mm have been extracted to investigate the specimen ‘size effect’.
From on-site testing, it has been found good compressive strength of concrete with a $f_{cyl-ave}$ approximately 23 MPa (Table 2).

Table 2 - Data from on-site testing.

Sample	Ø core (mm)	f_{cyl} (MPa)
P/SI/32/B-B’	94.50	17.65
P/SI/13/A-A’	74.70	24.32
P/SI/5/A-A’	74.70	26.97

Below (Figures 9-11), the results of failure tests, f_{cyl} and average values $f_{cyl.ave}$, grouped according to the diameter, are shown. For cores extracted from column 1C (Figure 9) and column 2C (Figure 10), the variation in of $f_{cyl-ave}$ with the change in specimen diameter is limited or almost negligible, while the variation is more significant (about 3 times) for the beam 1B (Figure 11).

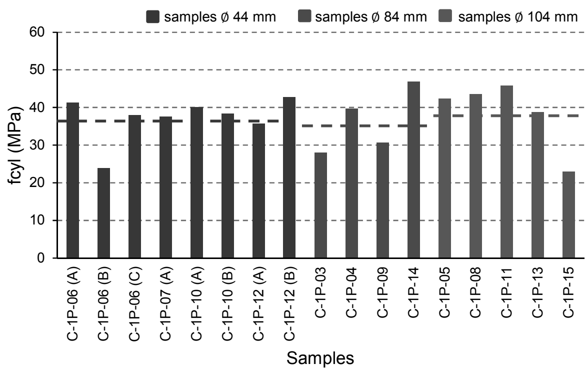


Figure 9 - Column 1C: strength values f_{cyl} and related average values $f_{cyl-ave}$.

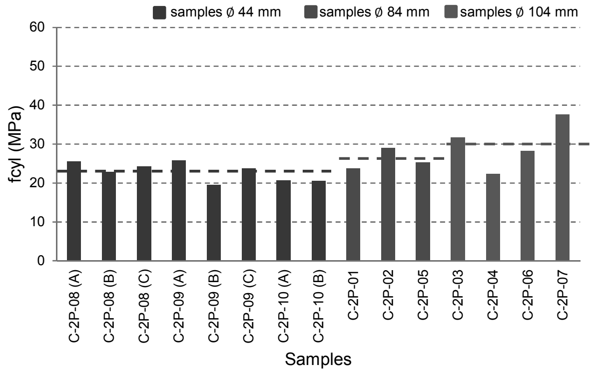


Figure 10 - Column 2C: strength values f_{cyl} and related average values $f_{cyl.ave}$.

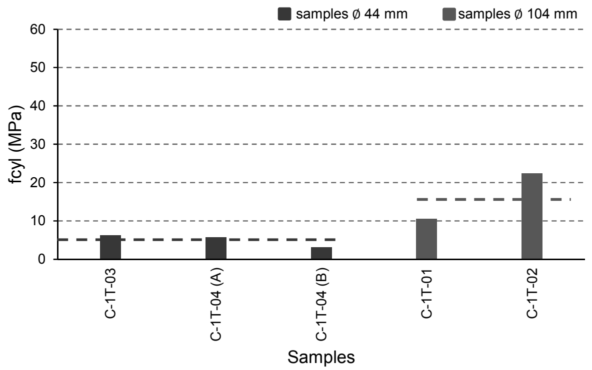


Figure 11 - Beam 1T: strength values f_{cyl} and related average values $f_{cyl.ave}$.

The above results show that for concrete with significant strength (about 35-40 MPa) the diameter of the specimen does not affect the results of $f_{cyl\text{-}ave}$, while for medium strength (20-30 MPa) this variation is significant (about 8 MPa); when the medium strength is low (10-20 MPa), the size effect appears to be of considerable impact. The f_{cyl} lowest values have been found in the beam 1B in which poor quality aggregate, with inclusion of sand, has been detected. The coefficient of variation (C.V.) of f_{cyl} related only to specimens with a diameter of 104 mm taken from columns is equal to about 28%.

4 CONCLUSIONS

The results obtained in this paper show that the compressive strength of cylindrical specimen does not vary significantly with changes in its direction of sampling, orthogonal or parallel to axis of the structural element. In particular, the strength obtained on specimens in the vertical direction are somehow larger than that obtained by taking the samples in orthogonal direction to the element. It would be appropriate to extend the study of the core extraction direction to understand how this aspect affects the results in terms of compressive strength.

In addition, the 'size effect', i.e. the variation of strength resistance caused by the variation of sample size has been found to be very low for concrete with high strength (35-40 MPa), while it is significant for poor quality concrete (10-20 MPa).

REFERENCES

Cristofaro, M.T. (2009). "*Metodi di valutazione della resistenza a compressione del calcestruzzo di strutture in c.a. esistenti*", PhD Thesis, University of Florence, Italy.

CEN, Eurocode 8 (2004). Design of structures for earthquake resistance – Part 3 Assessment and retrofitting of buildings.

D.M. 14/01/2008 (2008). "*Norme Tecniche per le Costruzioni*", Suppl. Ord. n. 30 G.U. n. 29 del 04/02/2008.

OPCM 3274 20/03/2003 (2003). Allegato 2: "*Norme tecniche per il progetto, la valutazione e l'adeguamento sismico degli edifici*".