Effect of core drilling and subsequent restoration on RC column strength

A. Masi, D. Nigro, M. Vona
Department of Structures, Geotechnics, Engineering Geology - University of Basilicata
Potenza, Italy

SUMMARY:
The study presented in this paper is focused on the estimation of in-situ concrete strength of existing Reinforced Concrete (RC) structures through core testing. A wide experimental program on RC members extracted from typical Italian existing buildings has been designed and carried out. RC structures to be demolished and designed only to gravity loads have been considered. A large number of tests has been carried out on column members and on cores extracted from them aimed at evaluating the effect of drilling on RC member capacity. To this purpose, after core drilling, monotonic loading-unloading compression tests have been carried out. Based on the results of these tests the effect of core drilling and of subsequent restoration on the strength of structural elements has been evaluated, by comparing performances of as-built columns, drilled columns and drilled-restored columns. Results show the effect of core drilling on the structural members, after being drilled and after a possible restoration. Further, some factors influencing the relationship between the local strength from core specimens and the in-situ strength of the structural member as a whole have been highlighted.

Keywords: RC existing buildings, In situ concrete strength, Core testing, Monotonic loading-unloading compression tests.

1. INTRODUCTION

The assessment of RC existing buildings is an important topic in earthquake engineering, particularly for buildings having poor seismic design. In the process of assessing and retrofitting RC existing buildings, investigation procedures have a crucial role to get an adequate knowledge of the structure to be evaluated. Among other factors, materials' properties and, particularly, concrete strength need to be estimated. According to several codes (e.g. NTC, 2008; CEN EC8-3, 2005; ACI 228, 1998), estimation of in-situ strength has to be based on both Non Destructive Tests (NDTs) and Destructive Tests (DTs), the latter being typically compressive tests carried out on cores drilled from the structure under examination. Core testing is considered the most reliable procedure to estimate in-situ concrete strength and many design codes provide some guidance on this procedure.
The present article is focused on the evaluation of effects of core extraction and subsequent restoration on RC column strength. To achieve this goal, the main results of an experimental program on RC structural elements have been reported and analysed. Specifically, a large number of tests have been carried out on RC column members extracted from existing old structures to be demolished. In some cases cores have been extracted from the column specimens aimed at evaluating the effect of drilling on RC member capacity. To this purpose, either directly after core drilling or after restoration works, monotonic loading-unloading compression tests have been carried out. Based on the results of these tests the effect of core drilling and of subsequent restoration on the strength of structural elements has been evaluated, by comparing performances of as-built columns, drilled columns and drilled-restored columns. The experimental program has been wholly carried out at the Laboratory of Testing Materials and Structures of the University of Basilicata – Potenza (Italy).

2. EXPERIMENTAL CAMPAIGN

The influence of core drilling on the capacity of RC structural elements has been not much addressed in the literature, although this problem frequently creates doubts and concerns in engineering practice.

A few indications can be found in some old works (Ramirez et al., 1974; Calavera et al., 1979) and in a more recent work (Campione et al., 2008) carried out on RC elements purposely prepared in laboratory. These works point out that the influence of core drilling can be negligible provided that the subsequent restoration is carefully carried out. To this purpose, some codes (e.g. CEB, 1997) give some recommendations on how restoration after drilling should be made.
In the present paper, some issues about destructive tests carried out on structural elements extracted from an existing structure have been investigated. The experiment campaign is based on structural elements already described in previous papers (e.g. Masi et al. 2007). Specifically, the experimental campaign is relevant to column members extracted from an existing RC school building, namely the Fantoni school located in Fivizzano (Italy). The structure of Fantoni school was originally designed only to gravity loads. As a consequence of the later seismic classification, the seismic capacity of the building was evaluated showing poor performances and, therefore, the building was partially demolished (Fig. 1).


Figure 1. Demolition and removal of some structural elements.

10 structural elements were extracted by the last story during the demolition works. As already described in other papers (e.g. Masi et al., 2007), concrete strength showed a significant inter- and intra-structural elements' variability. This condition is frequently findable in old buildings causing remarkable problems when the design concrete strength needs to be reliably estimated, e.g. in the capacity assessment of existing RC buildings.
Although in-situ concrete strength estimation can be based on a suite of destructive and non destructive tests, core testing is in any case necessary to achieve reliable estimates. However, core testing frequently produces some concerns with respect to its effects on the structural capacity during and, moreover, after drilling. To this end, the effect of drilling and subsequent restoration on the strength of some structural elements has been studied analyzing the results provided by a wide set of destructive and non destructive experimental tests on concrete and on purposely prepared structural member specimens.
The campaign of NDTs and DTs (in accordance of UNI EN 2001, 2002, 2005) has been designed and performed taking into consideration the main objectives of the experimental investigation. To this purpose, some preliminary ultrasonic tests have been performed on the structural members under study (columns) finalized at determining the variability of their mechanical properties along the height. The results show (Fig. 2) different trends of the ultrasonic velocity along the columns' height with a low variability in some columns (i.e. 2 and 3) and higher variations in the columns 1, 4 and 5.

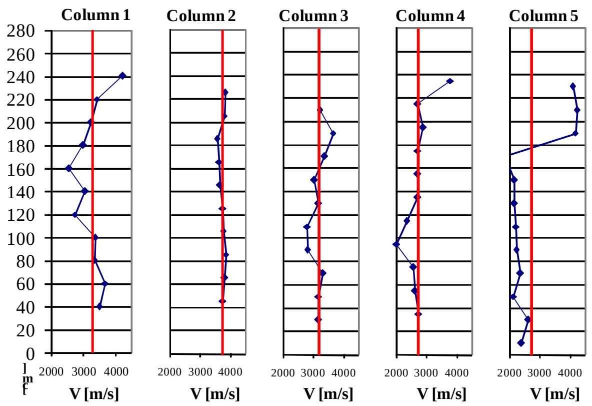


Figure 2. Structural members extracted from existing structures and prepared to tests.

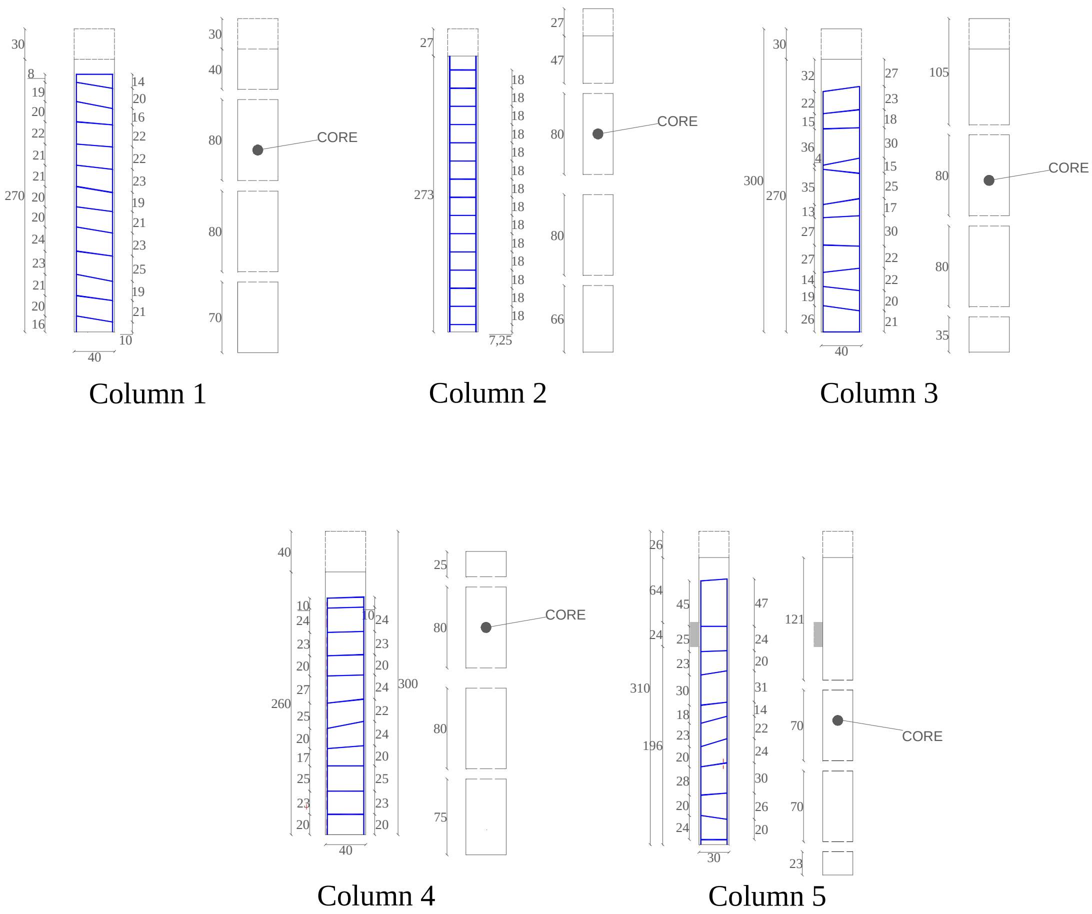


Figure 3. Specimens obtained from the column members.

After NDTs and core drilling, three cuts have been made on each column, as shown in Fig. 3, so that 10 specimens have been globally obtained, as follows:

- 3 drilled specimens;
- 2 drilled and subsequently restored specimens;
- 5 not drilled (as-built) specimens.

Table 1 reports dimensions (B and H cross section dimensions, c depth of concrete cover) and main characteristics of the 10 specimens, whose behaviour was investigated through monotonic loading-

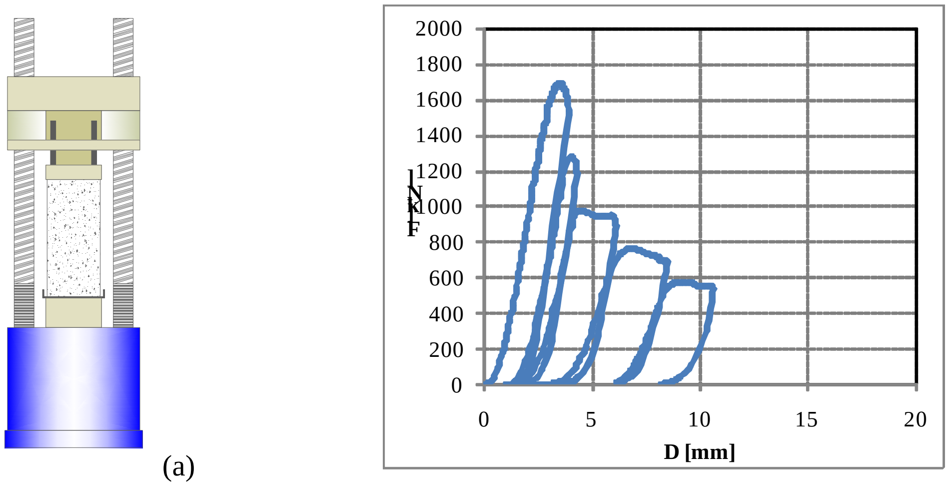
unloading compression tests (Fig. 4a). The compression test was performed in such a way the evolution of the column capacity related to the increase of the damage level could be examined. Unloading at each cycle was started at 95% of the maximum load reached at that cycle. The tests were stopped when the columns showed very heavy damage or when the maximum load reached at a cycle was less than 30% of the maximum force at the first cycle.
Fig. 4b shows a typical load-displacement diagram, where the curves relevant to the cyclic loading-unloading test on the specimen can be seen.
The following parameters have been used to describe the specimen performances:

- maximum strength,
- strength reduction (among the first and the following loading cycles),
- maximum number of cycles.

With regard to drilled specimens, they are representative of column conditions during and immediately after the core drilling; however, they could be considered as representative of the lower bound capacity in case of restoration interventions not adequately performed.

Table 1. Dimensions and characteristics of column specimens to be tested.

Specimen	Specimen condition	*L* (mm)	*H* (mm)	*B* (mm)	*c* (mm)	A_s (Longitudinal reinforcement) n°	mm
Column 1_1	Not Drilled	800	265	365	35	4	16
Column 1_2	Drilled and restored	800	265	365	35	4	16
Column 2_1	Drilled	800	280	280	20	4	16
Column 2_2	Not Drilled	800	280	280	20	4	16
Column 3_1	Drilled	800	380	390	30	4	12
Column 3_2	Not Drilled	800	380	390	30	4	12
Column 4_1	Drilled	800	270	370	30	4	16
Column 4_2	Not Drilled	800	270	370	30	4	16
Column 5_1	Not Drilled	800	285	285	15	4	10
Column 5_2	Drilled and restored	800	285	285	15	4	10



(a) (b)

Figure 4. (a) Test set up; (b) and monotonic loading-unloading compression behaviour.

3. RESULTS AND DISCUSSION

In this section, the main results of the experimental campaign are reported and analysed, with particular emphasis to the main goal of the paper, that is pointing out the effects of core drilling on column members' capacity.

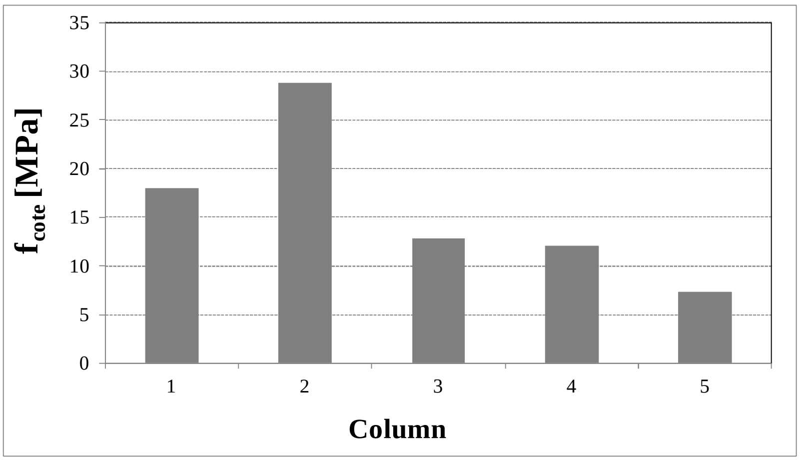


Figure 5. Compressive strength of cores.

Based on the strength of the extracted cores f_{core} (displayed in Fig. 5) and summing the contribution of longitudinal reinforcement ($A_s \cdot f_{y,s}$), the strength of the relevant columns has been estimated, as follows:

$$F_{col,Estimated} = F_{steel} + F_{concrete} \tag{3.1}$$

where:

$$F_{concrete} = A_c \cdot f_{core} \tag{3.2}$$

$$F_{steel} = A_s \cdot f_{ys} \tag{3.3}$$

with $A_c = B \, x \, H$ in both not drilled and drilled and restored specimens, $A_c = B \, x \, (H - D_{core})$ in drilled specimens, D_{core} is the diameter of the cores, f_{ys} = 470 MPa.

The values of $F_{col,Estimated}$ have been compared to the strength values ($F_{col,Test}$) provided by the compression tests on the specimens obtained from the columns where the cores were extracted (Fig. 6).

The comparison shows that the estimated strength ($F_{col,Estimated}$) is always higher than the experimental one with differences varying between 4% and 62%.

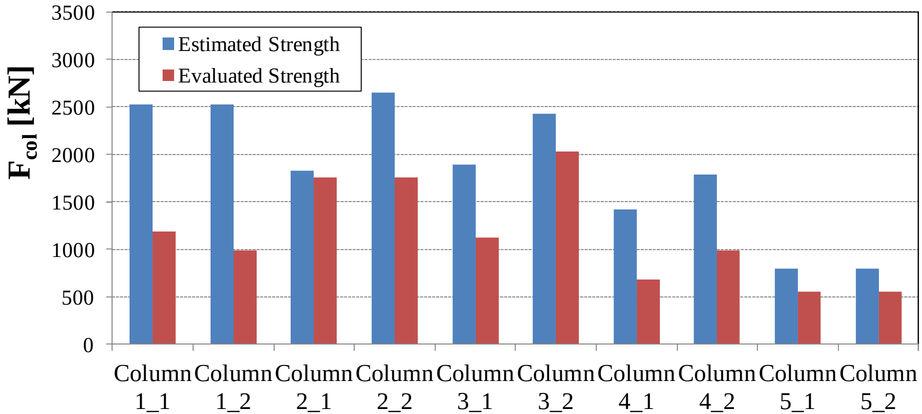


Figure 6. Experimental compressive strength ($F_{col,Test}$) *vs* Estimated compressive strength ($F_{col,Estimated}$) of column specimens.

In order to investigate on such significant differences, the post-test state of the columns has been analyzed. Generally, two different zones of concrete have been detected: an highly deteriorated external layer and an internal area with better quality. Therefore, the column specimens' strength has been estimated again considering an effective cross section, approximately considering only the internal concrete area:

$$F_{concrete,eff} = (B - 2 \cdot c) \cdot (H - 2 \cdot c) \cdot f_{core}) \tag{3.4}$$

$$F_{col,Corrected} = F_{steel} + F_{concrete,eff} \tag{3.5}$$

It is worth noting that different values of the concrete cover depth c were measured among the columns.
The recalculated strength of the columns is closer to the experimental values, as shown in Fig. 7, where differences between estimated and experimental strength values in the range 4-42% can be seen. It should be noted that the largest differences have been found in the drilled specimens, while the differences are almost negligible in the not drilled specimens.

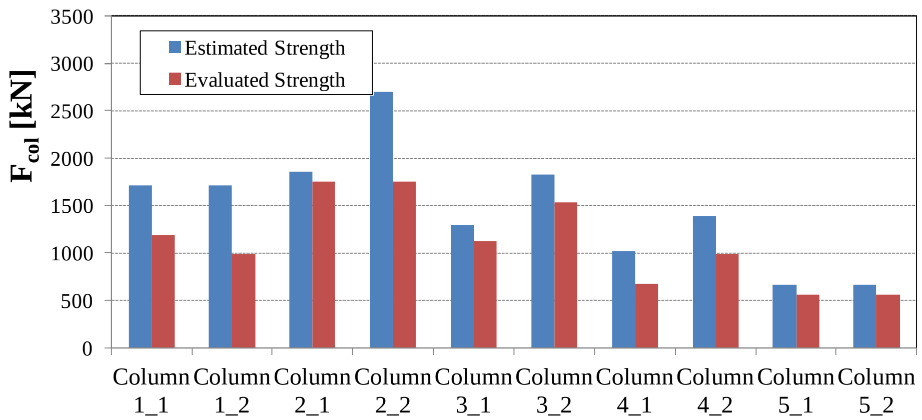


Figure 7. Experimental compressive strength ($F_{col,Test}$) *vs* Estimated corrected compressive strength ($F_{col,Corrected}$) of column specimens.

To evaluate the effects of drilling and possible restoration on the capacity of the specimens the results have been compared in terms of maximum strength, strength reduction (between the first and second loading cycle), maximum number of cycles.
Comparing maximum strength values highlights that the specimens subjected to core drilling without restoration show a significantly lower resistance. The strength reduction at the first cycle is more than proportionate to the reduction of the cross section due to the hole. These differences (ranging from 30% to 80%) could be due to the different collapse mode that is strongly influenced by the hole presence.
The same comparison performed among the specimens subjected to core drilling and those restored highlights the importance of correct procedures for restoration, provided that concrete quality is not very poor. In fact, dealing with the specimens obtained from column 1 (f_{core}=18 N/mm^2), a maximum strength value after restoration close to that of the not drilled specimen has been found. In this case the failure mode of the restored specimen does not appear to be affected by the previous drilling with a reduction of the maximum strength about 20% (Tab. 2). On the contrary, the results relevant to the specimens obtained from column 5 (f_{core}=7 N/mm^2), highlights that, even after an accurate restoration, the effects of core drilling can be dramatically high in structural elements with very low concrete strength.
With respect to the behaviour under repeated loading, it has been observed that generally a lower number of loading-unloading cycles could be applied on drilled specimens without restoration, compared to not drilled specimens. With respect to restored specimens, the same number of cycles has been carried out on the specimens 1_1 and 1_2, while a lower number has been found in the specimen

5_2 compared to 5_1 thus confirming the remarkable effects of previous drilling.

Table 2. Experimental results of loading-unloading compression tests on column specimens

Column specimen	Specimen condition	F_{max} at different test cycles [kN]								$\frac{F_{\max,\ II}}{F_{\max,\ I}}$	$\Delta F_{Dr\text{-}NoDr}$
		I	II	III	IV	V	VI	VII	VIII		
1_1	Not Drilled	1134	796	611	459	365				70,2%	19,6%
1_2	Drilled and restored	948	617	474	371	284				65,1%	
2_1	Drilled	1300	958	791	746					73,7%	30,0%
2_2	Not Drilled	1690	1274	977	764	563				75,4%	
3_1	Drilled	1105	850	790	601					76,9%	80,3%
3_2	Not Drilled	1992	1670	1291	1070					83,8%	
4_1	Drilled	663	514	445	355	309				77,5%	45,6%
4_2	Not Drilled	965	789	654	560	485	423	372	329	81,8%	
5_1	Not Drilled	548	469	401	351	306	266			85,6%	128,3%
5_2	Drilled and restored	240	194	156	129					80,8%	

These differences could also be due to the different construction quality, which appears to be poorer in some columns, as can be the case of column 5, e.g. by observing the hoops arrangement (Fig. 3).
Finally, a reduction of the maximum strength between the first and the second cycle has been generally found, with maximum values of $F_{max,II}$ in the range 65-85% $F_{max,I}$. Reduction values are slightly higher in case of drilled specimens but differences with not-drilled or restored specimens almost negligible. Therefore, the reduction of capacity due to core drilling can be effectively estimated through the parameters $\Delta F_{Dr\text{-}NoDr}$ and maximum number of cycles. The negative effects of drilling on the column capacity seem to be more significant for f_{core} < 15N/mm^2.

4. FINAL REMARKS

The study presented in this paper describes and analyses the main results of an experimental investigation on RC members extracted from typical Italian existing buildings designed only to gravity loads. Specifically, the effect of core drilling and of subsequent restoration on the strength of structural elements has been evaluated, by comparing performances of as-built columns, drilled columns and drilled-restored columns.
Analysis of results demonstrates that core drilling can remarkably reduce the strength of structural elements, moreover as a consequence of cross section reduction (temporary effect). However, not negligible differences can be found also after restoration interventions adequately performed (permanent effect). In fact, it must be emphasized that restoration can be difficult or even ineffective in low strength concrete thus leading to permanent reduction of cross section.
The experimental results emphasize the importance of carefully selecting the elements to be drilled, in particular when poor quality concrete is expected or found with preliminary tests. In such cases, while an accurate estimation of actual concrete properties is all the more needed, therefore core testing can be crucial, on the other hand core drilling could remarkably reduce the capacity of involved structural elements.
Making use of an appropriately planned campaign of non-destructive tests, the possibility of either avoiding or limiting core testing on members showing poor quality, should be considered.

REFERENCES

American Concrete Institute (ACI), 1998. Nondestructive Test Methods for Evaluation of Concrete in Structures, *ACI 228.2R-98*, Detroit, Michigan.

Calavera I., Aparicio G., Delibes A., Gonzales C., 1979. Effects of cores from coring test and bore filling on column behaviour, *Quality control of concrete structures*, Stoccolma.

Campione G., Fossetti M., Mangiavillano M.L., Priolo S., 2008. Influenza del carotaggio sullo stato tensionale e deformativo di elementi compressi. *Atti del Convegno Reluis Valutazione e riduzione della vulnerabilità sismica di edifici esistenti in c.a.*, Roma 29-30 maggio 2008, (in Italian).

CEB, 1997. Bulletin d'information N. 239, *Safety Evaluation and Monitoring*, May 1997.

CEN, 2005. Eurocode 8 – Design of structures for earthquake resistance – Part 3: Assessment and retrofitting of buildings (draft n. 6), EN 1998-3, Brussels.

Masi A., Dolce M., Vona M., Ferrini M., Pace G., 2007, Indagini sperimentali su elementi strutturali estratti da una scuola esistente in c.a.. *ANIDIS 2007 XII Convegno Nazionale l'Ingegneria Sismica in Italia*, Pisa, 10 – 14 giugno 2007 (in Italian).

NTC, 2008. Decreto del Ministro delle Infrastrutture del 14 gennaio 2008 "Nuove norme tecniche per le costruzioni" (in Italian).

Ramirez J.L., Barcena F.M., 1974. Relacion entre la resistencia de hormigon de las estructuras y la obtenida mediante ensayo de probetas testigo extraidas por corte, *Congreso de la A.E. para el C.Q.*, Barcellona.

RILEM, 1993. NDT 4 Recommendations for in situ concrete strength determination by combined non-destructive methods, *Compendium of RILEM Technical Recommendations*, E&FN Spon, London.

UNI EN 12504 – 2. Testing concrete in structures – Non-destructive testing – Determination of rebound number, December 2001 (in Italian).

UNI EN 12504 – 1. Testing concrete in structures – Cored specimens – Taking, examining and testing in compression, April 2002 (in Italian).

UNI EN 12504 – 4. Testing concrete – Part 4: Determination of ultrasonic pulse velocity, January 2005.