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A reliable approach for determining concrete strength in structures by using cores

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Abstract. As known, concrete classes are described as strength of standard specimens produced and kept in ideal conditions, not including reinforcement and not subjected to any load effect before. Under the circumstances, transforming core strengths to the standard specimen strength is necessary and considering all parameters, affected on the core strength, is inevitable. In fact, effects of the reinforcement and the load history on concrete strength are generally neglected when these mentioned transforms are performing. The main purpose of this paper is investigating the effects of the reinforcement and the load history on the core strength. This investigation is experimentally performed on cores drilled from specimens having different keeping conditions, reinforced, unreinforced, subjected to bending and central pressure in various proportions of failure load during specified periods. Obtained results show that the importance of these effects cannot be neglected.

Keywords: concrete strength in structure; load history; effect of reinforcement; core

1. Introduction

It is known that determining the concrete strength, existing in reinforced concrete structures, is necessary for many cases especially repairing and retrofitting of structures, damaged by earthquakes or not damaged but not having earthquake safety. In this determination, because of being more reliable, the most common method is drilling concrete specimens in various diameter and slenderness, named as core, according to the current standards (Arıöz *et al.* 2006, Gözaçan 2002). After capping properly, foregoing cores are crushed under compression at laboratory and then acquired strengths are transformed to the standard specimen compressive strength. Potential strength of concrete used in structure, so the concrete class, is determined by evaluating these strengths with obtained findings from non-destructive methods, whose calibrations' are made according to the core strengths, together (Bloem 1968, Bungey *et al.* 2006) However, it is known that the concrete classes are determined as axial compressive strengths of the specimens produced and kept in ideal conditions, unreinforced and not subjected to any load effect before.

In this respect, as mentioned above transforming the core strengths to the standard specimen strengths is necessary. So, in these transformations considering all factors, affected on the core strengths, become unavoidable. However, the effects of the load history and the reinforcement on

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the concrete strength are neglected while the transformations are performed (Durmus 1976, Tam *et al.* 1978, Yip 1993). The main purpose of this paper is to consider the foregoing effects in these transformations.

2. The conditions required determining the concrete strength in the structure

It is known that the standard specimens taken from concrete produced at construction sites, for controlling the desired strengths in designs, sometimes does not represent this concrete sufficiently. Because producing, moving, placing and curing of the concrete at construction site are not ideal and the standard specimens are unreinforced and not subjected to any load effect before. So these cause the difference between the strengths of concrete produced at construction site and used in structures. This matter constitutes one of the basic reasons of determining the hardened concrete strength in the structure. The other basic reasons required this determining can be listed as following:

- that quality control is not made during the concrete casting,
- that the strengths of the standard specimens taken from fresh concrete is smaller than foreseen strength at design,
- that some damages occur in the structure,
- that the intended use of the structure is changed and/or additional floor is required,
- that repairing and retrofitting is determined as necessary against the vertical and/or horizontal loads due to the possibility of reduced concrete strength of the structure by fire, earthquake, etc.
- that determining the foreseen conditions in the current standards are ensured or not for the concrete structures is necessary (ACI Committee 437R. 2003, Dolce *et al.* 2006, EN 13791 2007, Sullivian 1991)

3. Methods for determining the concrete strength in the structure

It is possible to say methods used for determining the concrete strength in structures are assembled in three groups as non-destructive, semi-destructive and destructive (Malhotra 1979, Nevil 1977). Manual test hammer (Schmidt hammer) and ultrasonic testing methods are classified in the non-destructive, and drilling cores from hardened concrete is classified in the destructive methods group (BS 1881 1983).

As mentioned above in coring method, cylindrical concrete specimens, called as core, are drilled from the structure in specific diameter and slenderness with special tools, by giving minimum damage to its safety. Quality of the concrete used in the structure is determined by axial compression test performed on these cores. However, it is known that in practice the concrete strength is defined as type of the standard specimen strength (potential strength). In doing so, transforming the core strengths to the potential strength to determine the concrete strength existing in structures is necessary. Also considering all parameters affected on the core strength is inevitable for performing this transformation. The main factors affected on the core strength are accepted as (1) core diameter, (2) core slenderness, (3) coring direction, (4) coring location, (5) core cure, (6) core humidity, (7) core age, (8) reinforcement remained in core, (9) shear effect at drilling core, (10) strength level of concrete that cores drilled from, (11) cap quality and (12) loading speed (ACI Committee 214.4R. 2010, Arıöz *et al.* 2007, Bartlett and MacGregor 1994a,

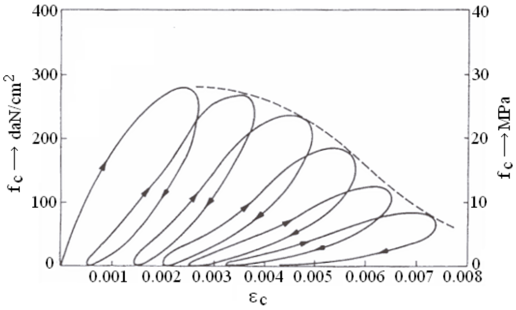

Fig. 1 Behavior of concrete under periodic loads (Sinha *et al.* 1964)

Table 1 Physical properties and visible sand equivalence (ESV) of the aggregate

Aggregate grain size mm	Loose unit weight kg/m^3	Specific weight		Water absorption %
		Dry	Saturated	
		kg/m^3	kg/m^3	
Coarse (>4 mm)	1400	2658	2670	0,42
Fine (<4 mm)	1450	2626	2640	0,52
ESV		95		

1994b, 1994c, Bungey 1979, Nikbin 2009, Tuncan *et al.* 2008).

However, it is known that elasticity module of the concrete is decreasing by loading and unloading (Fig. 1) and also creep and shrinkage are not free in the concrete. This case gives rise to thought that the effects of the load history and the reinforcement should be among the factors affected on the concrete strength.

4. Performed studies

Practically shrinkage and creep actions can freely happen in the standard concrete specimens because of not having reinforcement. However these actions cannot occur freely in the reinforced concrete structures, so some stresses occur between the concrete and the reinforcement. On the other hand, before testing, the standard specimens are not subjected to any load, whereas cores drilled from the structure are remolded by some loads. Under the circumstances it is thought that transforming the strengths of cores drilled from structure to the standard cylindrical specimen strength is essential. In this investigation firstly physical, petrographical, mechanical properties and graded combination of aggregates, cement and mixing water properties, concrete composition and production, properties of the reinforcement are given. Afterwards properties, production, keeping conditions, testing ages of the specimens, coring, experiments, results obtained from the experiments and by examining these results conclusions and recommendations are presented.

4.1 Physical and mechanical properties of the aggregates

Physical properties and visible sand equivalence (EN 933-8 1999, EN 1097-6/A1. 2005, ISO 6782 1982), mechanical properties and granulometric properties of the aggregates are presented in

Table 2 Mechanical properties of the aggregate

Core size mmxmm	Average compressive strength MPa	Standard deviation MPa	Elasticity module MPa	Poisson ratio
75 x 150	73,4	3,2	60000	0,17

Note: Compressive strength of the aggregate is determined by cores drilled from the rock that the aggregate is produced to make clear fracture mechanism of concrete.

Table 3 Graded combination of the aggregate

Grain classes (mm)	Percentage of total mass (%)
0,5-1,00	10
1,00-2,00	15
2,00-4,00	20
4,00-8,00	25
8,00-16,00	30

Table 4 Physical and mechanical properties of the cement

Physical properties			Mechanical properties		
Specific weight g/cm^3		3.05	Day	Bending strength MPa	Compressive strength MPa
Specific surface (Blaine), cm^2/g		3285	2	3,30	15,40
Setting time (vicat)	Starting	2,20 h	7	5,10	27,70
	Ending	3,20 h	28	6,50	35,90

Table 5 Chemical properties of the mixing water

Components	Quantity (mg/l)
Na^+	50,00
K^+	0,80
Ca^{+2}	100,80
Mg^{+2}	6,72
Fe^{+3}	3,00
Cl^-	125,00
SO_4^{-2}	45,00
HCO_3^-	210,00
NO_3^-	9,50

Tables 1-3 respectively. Petrographic texture of the aggregate called as limestone was determined as limestone with cement including partly old microfossils and less than %1 opaque mineral.

4.2 Properties of the cement and the mixing water

Physical and mechanical properties of the cement determined by factory, the mixing water properties, the concrete composition determined by absolute volume method are presented in Tables 4-6 respectively (ACI 318 2005, EN 12390-3 2009).

4.3 Properties of the reinforcement

Some of the standard cube and beam specimens produced as reinforced for determining the effects of the reinforcement on the concrete accordingly on the core strength. Some mechanical properties obtained from tensile tests (EN ISO 6982 2009) performed on the reinforcement are given in Table 7. Formwork and the reinforcement plan of the cube and beam specimens are given in Figs. 2 and 3 respectively.

Table 6 The concrete composition

Water/Cement ratio	Cement (kg/m^3)	Water (kg/m^3)	Total aggregate (kg/m^3)	Water saturation (kg/m^3)
0,50	350	175	1842	9,2

Table 7 Properties of the reinforcement

Reinforcement diameter	Average yield strength (MPa)	Average tensile strength (MPa)
Ø8	330	480
Ø14	406	605

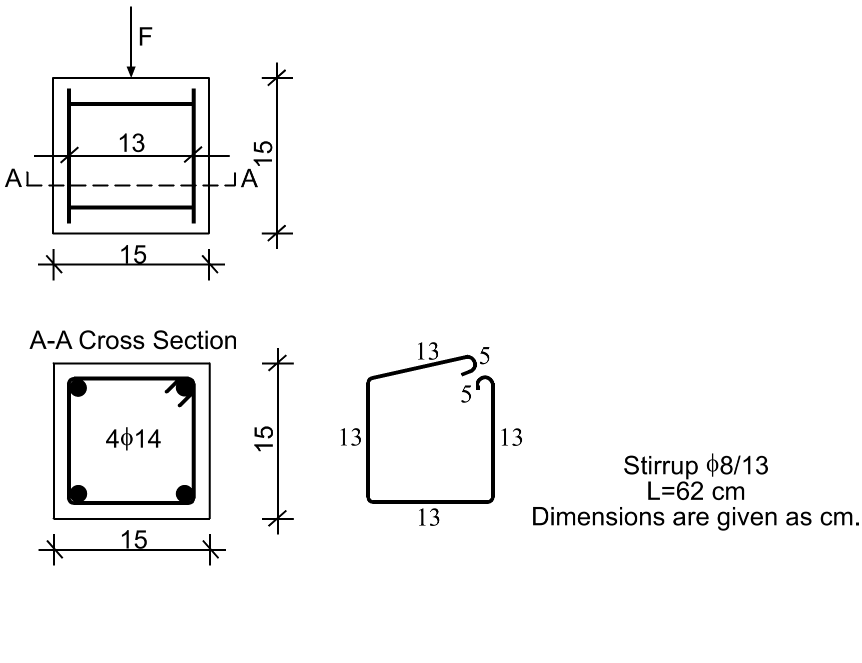

Fig. 2 The formwork and the reinforcement plan of the cube specimens

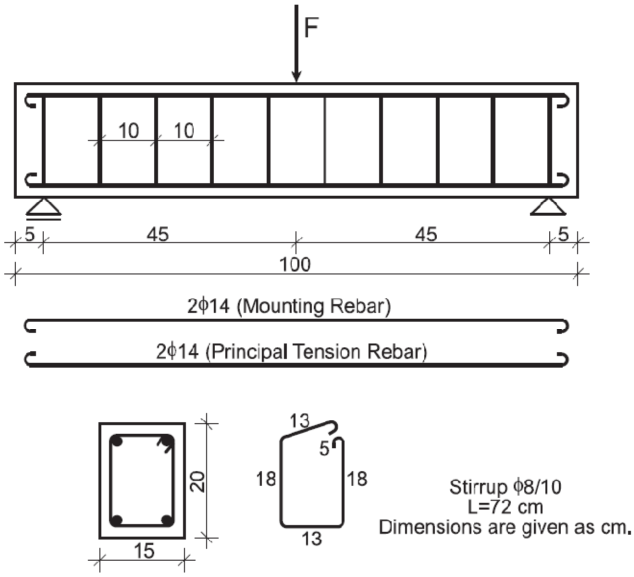

Fig. 3 The formwork and the reinforcement plan of the beam specimens

4.4 Properties, production, keeping conditions and testing ages of the specimens

It is thought to produce unreinforced and reinforced specimens, 75 mm x 150 mm, allows taking cores by not cutting reinforcements, for determining the effects of the load history and the reinforcement on the concrete strength accordingly on the core strength. And also it is planned to kept these specimens in three different conditions as in water, at laboratory and at out. The concrete was casting in three phases to the formworks placed on vibration table at a frequency of 2800 rpm. And in each phase the concrete was compressed by vibrating for 15 seconds. The specimens were removed from formworks one day after the casting. A part of the specimens was kept in water at $20^oC\pm2^oC$ for 27 days. Another part of the specimens was firstly kept in water at $20^oC\pm2^oC$ for 7 days and then in laboratory at $24^oC\pm2^oC$ and relative humidity of %75±5 for 20 days. And the other part of the specimens was kept at out of laboratory for 27 days in order to represent the concrete at construction site conditions.

The unreinforced and reinforced cube and the reinforced beam specimens were subjected to loading at specific proportions of the failure loads (F_r) during specified periods (72 hours) for determining the effect of the load history on the concrete strength. A part of the unreinforced cube specimens, at 28 days, was subjected to 30% and the other part of them was subjected to 25% of the failure loads, also a part of the reinforced cube specimens, at 28 days, was subjected to 20% and the other part of them was subjected to 25% of the failure loads for 72 hours. The failure loads at axial pressure of the unreinforced cube specimens kept in water, in laboratory and at out were determined as 640 kN, 600 kN and 480 kN respectively. The reinforced beam specimens, at 28 days, are divided four groups and these groups were subjected to 30%, 40%, 50% and 80% of the failure loads respectively, under the effect of point load in the midpoints of the beams, during 72 hours (Fig. 2). Average failure loads of these reinforced beam specimens were determined as 78 kN. Cores were drilled from the specimen as perpendicular to concrete casting direction (Fig. 4) (EN 13791 2007).

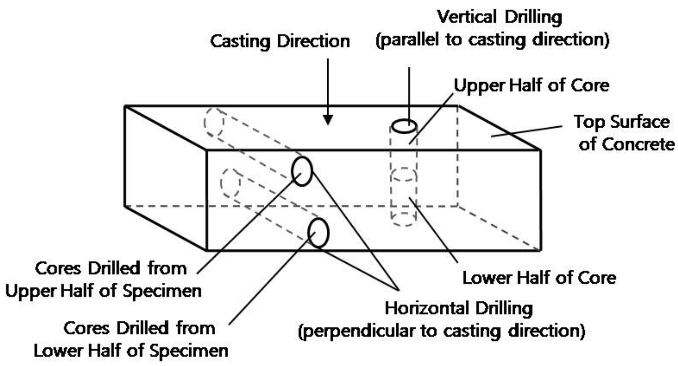

Fig. 4 Directions of coring from specimen

Table 8 The average compressive strengths of cores, 75 mm x 150 mm, drilled from the reinforced and unreinforced cube and beam specimens having different keeping conditions and load histories

Specimen name	Type of specimen from which core is drilled	Specimen dimensions mm x mm x mm	Keeping condition	Loading level *F*/*Fr*	fcm MPa
RBW	Reinforced beam	150x200x1000	water	unloaded	20
RBW_{30}	Reinforced beam	150x200x1000	water	0,30	21
RBW_{50}	Reinforced beam	150x200x1000	water	0,50	23
RBO	Reinforced beam	150x200x1000	out	unloaded	17
RBO_{40}	Reinforced beam	150x200x1000	out	0,40	20
RBL	Reinforced beam	150x200x1000	laboratory	unloaded	18
RBL_{30}	Reinforced beam	150x200x1000	laboratory	0,30	9
RBL_{50}	Reinforced beam	150x200x1000	laboratory	0,50	16
RBL_{80}	Reinforced beam	150x200x1000	laboratory	0,80	23
UBW	Unreinforced beam	150x200x1000	water	unloaded	23
UBO	Unreinforced beam	150x200x1000	out	unloaded	21
UBL	Unreinforced beam	150x200x1000	laboratory	unloaded	21
RCW	Reinforced cube	150x150x150	water	unloaded	27
RCW_{20}	Reinforced cube	150x150x150	water	0,20	20
RCO	Reinforced cube	150x150x150	out	unloaded	14
RCO_{20}	Reinforced cube	150x150x150	out	0,20	15
RCL	Reinforced cube	150x150x150	laboratory	unloaded	15
RCL_{20}	Reinforced cube	150x150x150	laboratory	0,20	16
RCL_{25}	Reinforced cube	150x150x150	laboratory	0,25	21
UCW	Unreinforced cube	150x150x150	water	unloaded	34
UCW_{30}	Unreinforced cube	150x150x150	water	0,30	27
UCO	Unreinforced cube	150x150x150	out	unloaded	20
UCO_{30}	Unreinforced cube	150x150x150	out	0,30	23
UCL	Unreinforced cube	150x150x150	laboratory	unloaded	20
UCL_{25}	Unreinforced cube	150x150x150	laboratory	0,25	22
UCL_{30}	Unreinforced cube	150x150x150	laboratory	0,30	23

5. Experiments and results

The results obtained from compression tests performed on the cores, 75 mm x 150 mm, drilled from the unreinforced and reinforced beam and the standard cube specimens keeping at different conditions, loading at varied levels are presented in Table 8.

5.1 The effect of reinforcement

As seen at Table 8, the ratio of average compressive strength of cores drilled from the reinforced cube specimens kept in water (RCW) to that of cores drilled from the unreinforced cube specimens kept in water (UCW) is about 0,79 and this ratio is about 0,70 for out keeping condition (RCO, UCO).

The ratio of the average compressive strength of cores drilled from the reinforced beam specimens kept in water (RBW) to that of cores drilled from the unreinforced beam specimens kept in water (UBW) is about 0,86 and this ratio is about 0,80 for out keeping condition (RBO, UBO).

It is seen that the strengths of the cores drilled from the reinforced specimens are less than those of cores drilled from the unreinforced specimens. It can be attributed to the creep and the shrinkage events not occurred in the reinforcement but occurred in the concrete. Because the creep and the shrinkage events are occurred more freely in the concrete specimens than the reinforced concrete specimens. Therefore, in these specimens, the damaging stresses caused by adherence between the concrete and the reinforcement do not occur.

This case provides to get high strengths for these specimens. Also the difference gets bigger when keeping conditions are getting away from ideal conditions.

5.2 The effect of load history

The average strengths of cores drilled from the UCW and UCW_{30} specimens are 34 MPa and 27 MPa respectively. Therefore a strength reduction about 20% is occurred due to the effect of the load history at this level. The average core strengths are 20 MPa and 23 MPa respectively (UCO and UCO_{30}) when keeping condition is out. And this corresponds to a strength increase about 15%.

These results indicate that the effect of the load history on cores depend on relative humidity of the cores. Therefore evaluating these two factors together is necessary for the determination of the concrete strength in the structures.

The average strengths of cores drilled from the RBW, RBW_{30} and RBW_{50} specimens are 20 MPa, 21 MPa and 23 MPa respectively. This case shows that while the loading level increases the core strength is also increase. It is clear that when concrete behavior is considered, the core strength is decreasing by the load history after a particular value of the loading level.

The average strengths of cores drilled from the RCW, RCW_{20} specimens are 27 MPa and 20 MPa respectively. 20% axial loading level for the cube specimens leads to a decrease about 26% in the core strength, contrary to bending.

These results indicate that it is not possible to obtain the concrete class used in designs from the strengths of cores drilled from hardened concrete of structures accurately, if the effects of load history and the reinforcement are not considered.

6. Conclusions

As mentioned above, the main purpose of this paper is considering the effects of the load history and the reinforcement on the core strengths. These two factors are not usually considered or can not be considered because of not having reliable results.

Main conclusions and recommendations of this study can be summarized in the following:

1. The reinforcement have always effect on the core strengths regardless of the shape, the size, the loading case and the keeping conditions of the specimen from which cores were drilled.
2. The average strengths of cores drilled from the reinforced and unreinforced cube specimens in unloaded case are different from each other. The core strengths decrease when the specimens are reinforced. This decreasing is about 20%, 25%, 30% in water, at laboratory and at out respectively.
3. The average strengths of cores drilled from the reinforced and unreinforced beam specimens in unloaded case are also different from each other. The core strengths also decrease in reinforced case. This decrease is about 14%, 15%, 20% in water, at laboratory and at out respectively.
4. The effect of load history varies by the relative humidity of the core, the loading level, the loading pattern, the shape and the size of the specimen, being reinforced or unreinforced and the keeping conditions but it always affect on the core strength.
5. The ratio of the average strength of cores drilled from the unreinforced cube specimens in unloaded case to those in loaded case varies according to keeping conditions. Such as for 30% loading level case the average strength of cores drilled from the unloaded cube specimens is about 20% greater than that of cores drilled from the loaded cube specimens when keeping condition is water. However, at the same loading level the average strength of cores drilled from the unloaded cube specimens is about 15% less than that of cores drilled from the loaded cube specimens for laboratory and out keeping conditions.
6. The average strength of cores drilled from the reinforced unloaded cube specimens is about 25% greater than that of cores drilled from the reinforced cube specimens subjected to 20% of the failure loads when keeping condition is water.
7. The average strength of cores drilled from the reinforced unloaded beam specimens are about %5 greater than that of cores drilled from the reinforced beam specimens subjected to 30% of the failure loads when keeping condition is water. This increase is 15% for 50% loading level case. However, when considering the concrete texture, it is normal that after a specified value, the loading level decreases the core strength and this decrease is varies according to the keeping conditions.

Briefly, evaluating the results obtained from this study shows that the load history and the reinforcement affect on the core strength. However, it is clear that these conclusions are valid for the specimens used in this study and the conditions of performed study. In this regard studies on this subject should be increased for generalizing the conclusions. Also performing these studies under different periodic loads will be beneficial. These subjects will provide the continuation of our research.

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