EFFECT OF SIZE OF SPECIMEN ON STRENGTH OF CONCRETE AND COMPARISON WITH NONDESTRUCTIVE TESTING METHOD: AN EXPERIMENTAL STUDY

Gopinandan Dey[1], Debasree Das[2]

1. National Institute of Technology Agartala, India
2. Indian Institute of Science Bangalore, Bengaluru, India

ABSTRACT. By far the most common test carried out on concrete is the compressive strength test, which is used as the most basic and important material property when concrete structures are designed. But it is not a unique material property rather depends upon sizes and shapes of the tested specimen. The dependency of strength of quasi-brittle material on size and shape of the specimen is called size effect. Standard specimen sizes and shapes used for evaluating strength are different from country to country. Moreover now-a-days many non-destructive testing (NDT) equipments are also commercially available. Therefore, a standard conversion factor is an utmost necessity for uniqueness of the strength parameter. In this experimental study two sizes of cube specimen and two sizes of cylindrical specimen are used for compressive strength and split tensile strength of concrete respectively. NDT is also conducted on the real structural member using rebound hammer and their relationship is reported.

Keywords: Size effect, Compressive strength, Non-destructive testing, Strength conversion factor

Gopinandan Dey is an Assistant Professor in Civil Engineering Department of National Institute of Technology, Agartala, India. His research interest includes concrete strength, durability and performance as well as non-destructive evaluation.

Debasree Das is a PhD Student, Indian Institute of Science Bangalore, Bengalueu, India.

INTRODUCTION

All materials have specific inherent material properties, which can be considered unique when they are independent of a specimen size and shape [1]. The basic property of concrete used for design purposes is its compressive strength. For evaluating compressive strength various shapes of samples are used at different countries; however, commonly used specimens are cylinders and cubes. Though cylinders of size Ø150 mm x 300 mm are used in the United States, South Korea, France, Canada, Australia and some other countries but many other countries including India, UK and Germany use 150 mm x 150 mm x150 mm cubes as standard specimens. The common notion that concrete compressive strength is a unique material property is an erroneous one [1] since the compressive strength of concrete changes based on specimen sizes and shapes due to its fracture characteristics.

Nominal strength of specimens made of quasi-brittle materials such as mortar, concrete, rock and composite materials are affected by the specimen size [2-3], more specifically, the nominal strength of laboratory size specimens differ from that of structural members used in construction sites of real structure. The difference in the nominal strength is a direct consequence of energy release into a finite-size fracture process zone (damaged localized zone). Well known as the size effect, the strength of a member tends to decrease when its size increases. The term size effect means concrete material strength dependency to specimen size variation.

Now a days, with the advent of high strength concrete, most often the crushing load of the standard size specimen exceeds the loading capacity of machine, which necessitates either to increase the loading capacity of the machine or as an alternative to use smaller size specimen [4]. For sustainable development it is always desirable not to waste any natural resource, hence NDT of concrete strength is preferable over destructive evaluation method. Therefore, establishment of proper correlation between destructive test method with various specimen shape and size and non-destructive methods will greatly help the civil engineering community to assess the structural strength and cross-check the same with another alternative method. A brief study in this context is presented in this paper.

EXPERIMENTAL INVESTIGATION

Materials details

All the materials are collected from various sources available in Tripura, a north-eastern state of India which are also widely used for various construction works in the state.

Cement

Ordinary Portland cement of 43 grade conforming to IS: 8112-1989 [5] is used in this study. The specific gravity of the cement is 3.17.

Fine aggregate

Fine aggregate conformed to grading zone IV as per IS: 383-1970 [6], the fineness modulus of the sand is 2.0 and specific gravity is 2.48.

Coarse aggregate

It is a general practice in India to use 20 mm nominal size coarse aggregate conforming to IS: 383-1970 [6] for most of reinforced concrete work, therefore same type of aggregate is used for this study. Specific gravity of the aggregate is 2.57 and water absorption 0.95%.

Admixture

A high range water reducing admixture (superplasticizer) of sodium naphthalene sulfonate formaldehyde (SNF) condensate category is used.

Water

Potable tap water is used for mixing the ingredients.

Sample details

For this study two different shapes of specimen viz. cube and cylinder are considered for compressive and split tensile of concrete respectively. Further two different sizes are considered for each of the shape. For variation of the materials three different mix proportions are considered as shown in table1.

Table1 Details of mix proportions

Sample No.	W/C	Cement (kg/m^3)	Water (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate(kg/m^3)	Superplasticizer (kg/m^3)	Slump (mm)
1	0.49	380.00	185.00	581.00	1168.00	4.00	115
2	0.44	420.00	185.00	553.00	1163.00	4.00	108
3	0.41	450.00	185.00	528.00	1164.00	4.00	100

For finding compressive strength of concrete twelve numbers cube of 150 x 150 x 150 mm are prepared for destructive and non-destructive tests and six numbers 100 x 100 x 100 mm cube samples are prepared for destructive test with each mix composition. Six cylindrical samples of each size and each mix proportion are also prepared. Therefore altogether 54 cubes and 36 cylinders are prepared for this study. Same materials are also used for construction of real structures. For ease of recognition of the samples they are assigned some designation as mentioned in table 2.

Table2 Designation of different spemen

Sample details	Designation for Mix1	Designation for Mix2	Designation for Mix3
Cube 150 x 150 x 150 mm	Cu150/1	Cu150/2	Cu150/3
Cube 100 x 100 x 100 mm	Cu100/1	Cu100/2	Cu100/3
Cylinder Ø 150 x 300 mm	Cy150/1	Cy150/2	Cy150/3
Cylinder Ø 100 x 200 mm	Cy100/1	Cy100/2	Cy100/3
Cu150 for NDT at laboratory	Rlab/1	Rlab/2	Rlab/3
Actual structural member	Rstr/1	Rstr/2	Rstr/3

Sample preparation

Ready mixed concrete prepared with the materials and proportions described above are collected from a construction site located close to the NIT Agartala concrete laboratory. Fresh concrete is poured in the mold and vibrated on a table vibrator for 10 sec for proper compaction. Molds are kept in the laboratory temperature at 20 to 270C. Demolding is done after 24 hours and the samples are kept submerged in curing tank until 28 days of age. Tests are carried after completion of curing on saturated and surface dry samples.Destructive test

Six samples are tested from each category. Tests for compressive strength are carried out on the cube specimen [7] in a compressive testing machine having maximum loading capacity 2000N and cylinders are tested for split tensile strengthin the same machine applying line load on two diametrically opposite side of the specimen. The compressive strength and tensile strength are calculated using equation 1 and 2.

$$f_c = \frac{P_u}{B^2} \tag{1}$$

$$f_{sp} = \frac{2P_u}{\pi d l} \tag{2}$$

Where,$f_c$and$f_{sp}$are compressive and split tensile strength in MPa respectively.

B, $d$and$l$are the length of side of cube specimen, diameter and length of the cylindrical specimen in mm respectively.

$P_u$is the ultimate load at failure in Newton for the corresponding test.

Non-destructive tests

Six cube samples of Cu150 type from each mix proportion are used for rebound hammer test [8] to assess the compressive strength of the material in non-destructive manner. The hammer is calibrated properly for horizontal direction of impact as per the guideline of the manufacturer. To perform the tests, samples are fixed between the platens of a universal testing machine and ten impacts on each face of the samples are given horizontally and a value of compressive strength is obtained for each face. Mean value of six faces and six samples are taken as the mean compressive strength of a particular type of sample.

Further rebound hammer tests are also performed on the actual structural members which are prepared with the same materials. Column members are chosen for tests to maintain the conformity of the direction of impact between the laboratory specimen and actual structural member. Columns are grinded by carborendum stone to make the surface smooth and ten impacts are given within an area of 300 mm x 300 mm. Six spots at random locations are tested to get a mean value of compressive strength of the structural members for each type of concrete.

RESULTS AND DISCUSSION

Compressive Strength

Variation of compressive strength obtained for various samples and across both the sizes are shown in Fig.1. From the figure it is seen that with increased water to cement ratio strength decreases for

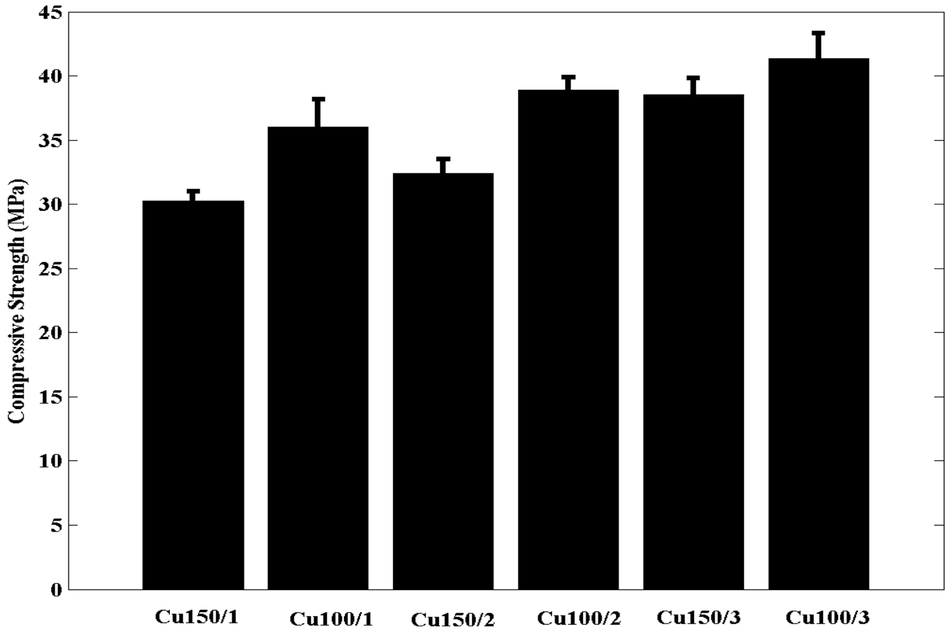

Figure 1 Compressive strength of sample with errorbar

both the sizes of the specimen. Cu100 of all the three samples show higher strength in comparison to its Cu150 counterpart. The compressive strength of Cu100 specimen found to be in the range of 7 to20% higher than Cu150. Errorbars which show one standard deviation from the mean value, are found to be higher in Cu100/1 and Cu100/3 in comparison to corresponding Cu150, on the other hand Cu150/2 and Cu100/2 show comparable value of standard deviation.

Split tensile strength

Split tensile strengths for all specimen are shown in figure 2. It is observed that this parameter also depends on water to cement ratio of the mix as well size of the specimen. The is similar to that of compressive strength. Here higher water to cement ratio and higher size of the specimen yield lower tensile strength of concrete. Data spread for all the samples are comparable as seen from the errorbars. The strength of Cy100 category are found to be 18 to 36% higher than their Cy150 counterpart.

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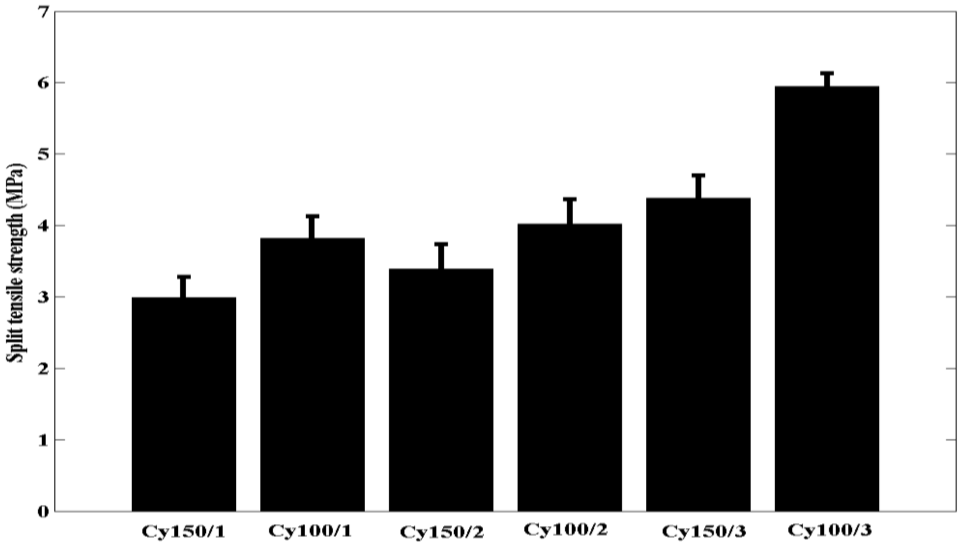

variation

Figure 2 Split tensile strength of samples with errorbar

Non-destructive evaluation of compressive strength

Rebound hammer tests are conducted on laboratory specimen as well on the real structure. Compressive strengths obtained from both types of rebound hammer tests are shown side by side in figure 3 alongwith the strengths found from destructive test using standard specimen size of 150 x 150 x 150 mm.

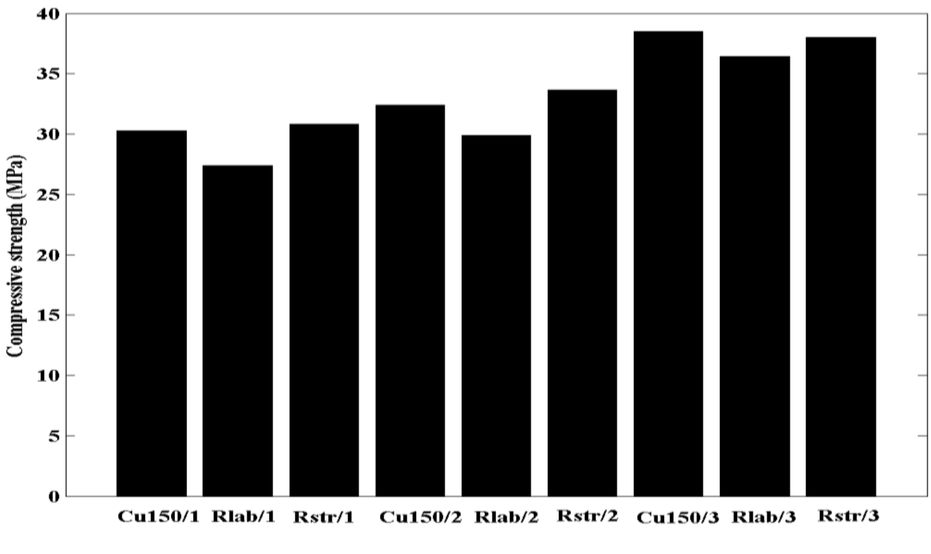

Figure 3 Compressive strength of specimen and structural member

Like the previous results of compressive and split tensile strengths, size effect also plays a role in evaluating compressive strength using rebound hammer method. Unlike the destructive tests this method shows lower strength in smaller size specimen i.e lower strength in the laboratory size sample in comparison to real structural member. Rebound hammer test on real structure yielded almost the similar compressive strength as found from standard specimen of 150 mm cube.

Size dependent strength conversion factor

Strength dependencies on size of specimen on destructive and non-destructive testing are observed in the previous discussion. The size dependent strength variation as obtained from the experimental study is presented in table 3.

Table 3 Size dependent strength factor

SPECIMEN TYPE	CONVERSION FACTOR
Compressive strength of standard specimen Cu150	1
Compressive strength of specimen Cu100	1.15
Compressive strength of Cu150 with rebound hammer	0.91
Compressive strength of real structure with rebound hammer	1
Split tensile strength of Cy150	0.10
Split tensile strength of Cy100	0.14

The values are normalized as the ratio of strength of standard 150 mm cube specimen and an average value of three types of specimen are considered to arrive at the conversion factor.

CONCLUSIONS

This experimental study shows an indication of dependency of concrete strength on size of the specimen in both destructive and non-destructive evaluation methods. Therefore, proper calibrations for various sizes are necessary for accurate estimation of strength with any sample size and testing method. From the experimental data it can be concluded that compressive strength of 100 mm cube specimen shows approximately 15% higher strength than that of standard specimen of 150 mm cube. A comparable result of compressive strength of real structure can be used when the experiment is carried out with properly calibrated rebound hammer. NDT can also be conducted to the laboratory samples for verification of the results. In case of split tensile strength 14% higher strength is achieved with 100 mm dia cylinder with respect to its 150 mm dia counterpart. However, further verification can be done with wide range of laboratory samples and different components of structural members.

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REFERENCES

1. Yi, S. T., Yang, E. I. and Choi, J. C.,Effect of specimen sizes, specimen shapes, and placement directions on compressive strength of concrete, *Nuclear Engineering and Design*, Vol. 236, 2006, pp. 115–127.

2. Bazant, Z.P., Size effect in blunt fracture; concrete, rock, metal. *Eng. Mech.*, Vol. 110 , 1984, pp. 518–535.

3. Bazant, Z.P., Xi, Y. and Reid, S.G., Statistical Size Effect in Quasi-brittle Structures: I. Is Weibull theory applicable?,*J. Eng Mech.,* Vol. 117, 1991, pp. 2609-2622.

4. Patnaik, A. K., and Patnaikuni, I., Correlation of strength of 75 mm diameter and 100 mm diameter cylinders for high strength concrete, *Cem Concr Res*, Vol. 32, 2002, pp. 607–613.

5. IS: 8112-1989, Ordinary Portland cement,43 grade - specification.

6. IS: 383-1970, Specification for coarse and fine aggregates from natural sources for concrete.

7. IS: 516-1959, Methods of tests for strength of concrete.

8. IS: 13311(Part 2)-1992, Non-destructive testing of concrete-methods of test.