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A NEW APPROACH FOR MEASUREMENT OF TENSILE STRENGTH OF CONCRETE

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Abstract: Tensile strength is one of the important strength parameters of concrete. Indirect methods have been used up till now for its measurement. These methods though widely accepted, do not furnish the true tensile strength of concrete. This paper presents a new approach for the experimental determination of true tensile strength of concrete. Results obtained by this test are quite encouraging and show 34% lower values than the splitting cylinder strength of concrete.

Keywords: Concrete, indirect method, splitting cylinder strength, tensile strength

INTRODUCTION

Tensile strength of concrete is of prime importance in case of water retaining structures, runway slabs, pre-stressed concrete members, bond and shear failure of reinforced concrete members and cracking of mass concrete works. So far much of the work is done upon the evaluation of tensile strength of concrete by indirect methods and comparatively fewer efforts have been made for its determination by direct methods. Yerlici [1965] describes that the behavior of concrete under tension has not been extensively investigated because of its limited tensile strength and extensibility. Although concrete is never made to carry tension, yet tensile cracking of concrete limits the usefulness as well as life of several structures. For such cases formulation of the behavior of concrete under tension is needed for the development of structural theory. Malhotra [1970] stresses upon the need of standard methods and size of specimen for the determination of tensile strength of concrete. Pandit [1970] confesses that none of the existing methods for determination of tensile strength of concrete compare favorably as regards reproducibility or reliability with compression test. Chen [1970] admits that the tensile strength of concrete is usually determined from indirect tests (splitting cylinder tests) rather than direct pull test on briquettes and bobbins or from flexural tests on beams.

ACI report {ACI Committee 224 [1986]} stated that methods used to determine tensile strength of plain concrete can be classified into one of the following categories, i.e. Direct Tension, Flexural Tension, Indirect Tension. Because of the difficulties associated with the application of a pure tensile force to plain concrete specimen, there are no standard tests for direct tension.

Winter and Nilson described the difficulties in determining the true tensile strength of concrete i.e. minor miss-alignment and stress concentration at the gripping devices. They further added that up till now tensile strength of concrete has been measured in terms of Modulus of Rupture which does not specify the true strength of concrete as it is based on the assumption that concrete is an elastic material and bending stress is localized at the outermost surface. Thus it gives larger value than that of uniform axial tensions. Naville claims that direct application of pure tensile force, free from eccentricity, is difficult and is further complicated by secondary stresses induced by the grippes or embedded studs.

Wang and Salmon state neither the splitting cylinder nor the modulus of rupture is the right measure of the tensile strength under uniform axial tension. However accurate measurement of uniform axial tension is difficult.

The conclusions of various authors especially Pandit [1970] and Malhotra [1970] stress upon the need of further research work to devise an ideal uni-axial test for determining the tensile strength of concrete as the Ring tension and Splitting tension tests are indirect methods.

The authors have established a new method for the measurement of true tensile strength of concrete. The details of technique and media of loading the specimen are presented as under.

DEVELOPMENT OF TECHNIQUE

This new technique for the measurement of tensile strength of concrete is developed to minimize the difficulties and drawbacks experienced by the previous authors during their investigation.

DESCRIPTION OF MOULD AND ITS PARTS

The shape of the mould resembles the dumb-bell or bobbin (Fig. 1). It consists of six separable parts joined together through nuts and bolts. For load application the mould further carries a system of hooks and strings joined with the upper and lower conical portions. The central part or the neck of the mould is made up of two semi cylinders fixed in place through nuts and bolts. The mould consists of following parts and accessories (Figs. 2 and 3):

1) Upper half cones with joining collars and brackets
2) Neck or central semi cylinders with joining collars and brackets
3) Lower half cones with joining collars and brackets
4) Wooden recess
5) U-Bars
6) Rings for U-Bars
7) Wire ropes or strings
8) Hooks
9) Bolts and Nuts

TESTING PROCEDURE

This is a unique technique where mould of the specimen serves double purpose. Firstly these moulds are used for casting of specimens and secondly during the testing of samples. For casting, all parts of the mould

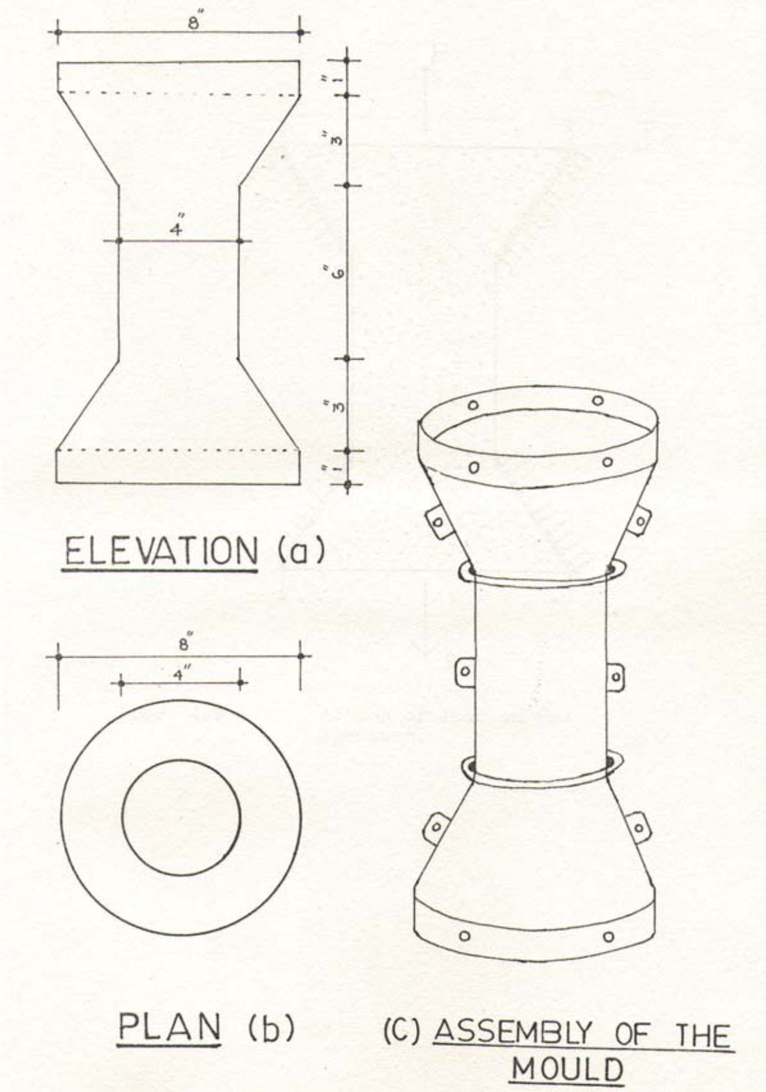

Fig: 1 Shape of the Mould indicating the inner di-mensions.

are joined with nuts and bolts placing rubber seal in the joints to make them watertight. A wooden recess is placed under the mould to keep the lower vertical portion free of concrete and thus allow the hooks to be inserted in the holes. The moulds are filled with concrete of desired mix. The upper vertical portion of the upper cone is also to be left blank as is done for the lower portion. The moulds after the required time limit are opened and samples are cured as specified by ASTM C-192. The sample is then removed from the curing tank and let it dry in open air (Fig. 4). The upper and lower cones are again fixed leaving the middle portion free to resist against the applied load as shown in Fig. 5. The hooks are inserted in the holes and U-bar is passed through the ring and held in the testing machine (Fig. 6). The failure load is noted and the tensile strength is calculated by the equation as under:

$$f_t = \frac{P}{A} \qquad \text{OR} \qquad f_t = \frac{4 \times P}{\pi \times d^2}$$

Where f_t = Direct tensile strength (psi)
P = Load of the web at failure point
A = Area of web at failure point
d = Diameter of web portion.

Fig. 2: Parts of mould showing inner view.

Fig. 3: Parts placed together.

Fig. 4: Concrete specimens.

Fig. 5: Specimen ready for tensile testing.

EXPERIMENTATION

Specimens for compression, splitting and flexural strengths are tested according to the relevant American and British standards. For direct tension test upper and lower cones were required to be re-fixed for load application. The samples for these moulds were removed and marked. The number and position of each part is carefully recorded so that during testing each part could be placed at the same position. Central portion of the mould was not attached to the samples to leave the web free to take tension under the applied load. To test the samples hooks were inserted in the holes of the mould and through U-Bars these were placed in the machine. The whole assembly along with strings was about 5 feet long and no testing machine except Buckton could pull such a long assembly. As such, this testing was done on 100 tons Buckton Universal Testing Machine. After holding both the upper and lower jaws in the machine, the specimen was ready for loading. The load was applied gradually and transfer of load could be visualized from the tightening of strings. When the stress in the specimen approached its maximum value, the sample failed in the web portion and the lower portion fell down. Loads were applied gradually so that the strings tightened slowly to avoid any jerk Fig.

6. After failure, the sample was removed and another sample was inserted in the hooks.

Fig. 6: During test load is being gradually applied.

DISCUSSION UPON RESULTS

The test samples for both direct and indirect tests were prepared from ordinary Portland cement, Lawrencepur sand and Margalla crushed stone. The results of the tests were compared and authors have tried to co-relate the values of direct test with that of indirect ones(splitting cylinder and modulus of rupture tests).

Six batches of samples were taken and tested after 7 and 28. Each batch carried three specimens for each age and test. Maximum values of load sustained by these samples before failure were observed. From these loads respective strengths are calculated for each sample by using usual formulae. Average strength is calculated and this value is considered as representative strength of that batch required to be used for further calculations. Similarly three samples from each batch for direct tension test were selected and tested. In each case failure occurred at the web level. The two parts of the broken specimen were placed again over each other and diameter at two perpendicular planes was measured at the breaking point with the vernier calipers having a least count of 0.001 inches. To attain the maximum accuracy, an average diameter was used in the calculations. Firstly individual strengths of each sample were calculated and then average of each batch was determined in order to obtain different co-relations between them. A comparison of different strengths calculated from direct and indirect methods is given in Table I.

Table 1: Comparison Of Direct Tensile Strength With Indirect Tensile Strength Tests

Batch No.	Direct Tension test "f_t" (psi)	Splitting Strength "f_{ct}"		Modulus of Rupture "f_r"		"f_{ct}" as %age of "f_r"
		(psi)	$(f_t / f_{ct})*100$	(psi)	$(f_t / f_r)*100$	
1 (1:2:4:0.6) *	214	312	68.59	685	31.24	45.55
2 (1:2:4:0.55) *	246	330	74.55	728	33.79	45.33
3 (1:1.5:3:0.6) *	183	251	72.91	560	32.68	44.82
4 (1:1.5:3:0.5) *	202	340	59.41	793	25.47	42.88
5 (1:1.75:3.5:0.55) *	186	302	61.59	588	31.63	51.36
6 (1:1.75:3.5:0.5) *	194	328	59.15	688	28.20	47.67
Average			66.03 Say 66 %		30.5 Say 30 %	46.27 Say 46 %

* mix proportions by weight i.e (Cement : Sand : Aggregate : w/c Ratio)

Following relations have been deduced from the above Table 1:

1) Relationship between direct tensile strength and split cylinder strength:

$$f_t = 0.66\ f_{ct}$$

2) Relationship between direct tensile strength and modulus of rupture:

$$f_t = 0.3\ f_r$$

3) Relationship between split cylinder strength and modulus of rupture:

$$f\,c_t = 0.46\ f_r$$

RELATIONSHIPS BETWEEN f_t, f_{ct} AND f_r

1) Comparison of f_t and f_{ct} is given in Table 1. From this table it is clear that f_t varies from 59 % to 74 % of $f_{ct,}$ with weighted average as 66%. The tensile strength determined by splitting cylinder test is 5 to 12% higher than that determined by direct tension test [Neville]. But in present test direct tensile strength is 66 % of Split Cylinder strength, or in other words Split Cylinder Strength is 50 % more than Direct Tensile Strength. This result does not agree with the result postulated by Neville. However, Neville based his conclusions on approximations as no direct method was available at that time. In the sample under split cylinder test, splitting was not produced by simple tension. In fact it started at points where concrete is under compression and this compression produced tension in the cylinder in lateral direction.
2) Comparison of Axial Tensile Strength and Modulus of rupture is available in Table 1. It is observed that f_t varies from 25 % to 34 % of f_r, with an average value of 30 %. ACI Committee 224 [1986] reported that tensile strength measured from flexural test is normally 40 %to 80

% higher than that measured from splitting test. Considering maximum value of 80 % being adequate, gives f_{ct} about 56% of $f_{r.}$ Referring to Table 1, f_t is 66 % of $f_{ct.}$ Combining these two relations f_t comes out to be 37 % of f_r. It indicates that the test results of present test i.e. f_t is 30 % of f_r closely agree to the recommendations of ACI Committee 224 [1986].

CONCLUSIONS

1) The present study basically is to introduce a new testing technique for measuring the True Tensile Strength of concrete, is aimed at reducing the uncertainty being observed in the measurement of tensile strength of concrete. Though the results do not agree with the Neville's expectations but still these are encouraging as Neville's observations were only based on judgment rather than experimentations. It needs extensive experimentations before this test is standardized and accepted for measurement of tensile strength of concrete.

   As the whole assembly has the potential to adjust itself in true vertical position, there still exists a very remote possibility that some minor workmanship defects may produce little misalignment and eccentricity. This can be avoided in two ways:

   a) To keep the assembly in true vertical position during the application of load, use of three hooks may be considered in place of four, used during the present experimentation.
   b) Use of turnbuckles along with hooks will help in eliminating eccentricity and misalignment (if any) of upper and lower part of the mould.

   The authors hope that these minor modifications will help in avoiding force/stress concentrations in the specimen.
2) The direct tensile strength of concrete is about 66 % of the Splitting strength i.e. approximately 34% lower, which is slightly different than the value given by Neville.
3) Splitting cylinder strength is about 46 % of the modulus of rupture.
4) The direct tensile strength of concrete is about 30 % of the modulus of rupture.

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