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CONCRETE RINGS FOR DETERMINING TENSILE STRENGTH OF CONCRETE

V. M. MALHOTRA

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EFFECT OF SPECIMEN SIZE ON TENSILE STRENGTH OF CONCRETE

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TITLE NO. 67-20

AN ACI DIGEST PAPER

Concrete Rings for Determining Tensile Strength of Concrete

By V. M. MALHOTRA

Presents results of an investigation to determine the tensile strength of concrete made with ¾ in. maximum size aggregate using 12 in. ring test specimens. Twenty-nine concrete mixes were prepared and test specimens were cast and tested. Relationships between the 12 in. diameter ring tensile strength and 4 x 8 in. cylinder compressive strength are presented; the line of best fit together with 95 percent confidence limits have been established. The regression analysis shows that there is a high degree of correlation between the ring tensile strength and compressive strength of concrete.

The effects of ring size on the tensile strength of concrete, and data on the reproducibility of test results are also presented.

It is concluded that ring specimens of 12 in. inside diameter can be satisfactorily cast and tested and that this specimen size should be standardized for determining the tensile strength of concrete made with aggregate of ¾ in. maximum size.

Keywords: compressive strength; concretes; regression analysis; research; specimens; splitting tensile strength; tensile strength; tests.

■ IN 1965 THE CANADIAN MINES BRANCH reported the ring test for the determination of tensile strength of concrete. Subsequently, correlations were reported between the ring tensile strength of concrete and the compressive, flexural, and splitting tensile strengths. All the reported work had been carried out using ring specimens which were of 6 in. (15 cm) inside diameter, 1½ in. (3.8 cm) high, and 1½ in. (3.8 cm) wide. This specimen size naturally limited the maximum size of coarse aggregates to ⅜ in. (9.5 mm). Discussions which followed the publication of the original papers suggested the desirability of larger size ring specimens so that aggregate of ¾ in. (19 mm) maximum size could be used. Practical considerations indicated that the largest test specimen that could be used without jeopardizing portability of the test equipment was a 12 in. (30 cm) inside diameter ring, 3 in. (7.5 cm) high x 3 in. (7.5 cm) wide. This would allow concrete specimens to be cast with aggregate of ¾ in. (19 mm) maximum size. Furthermore, a specimen of this size would require only 0.24 cu ft (0.0068 cu m) of concrete which is little more than the 0.20 cu ft (0.0056 cu m) required for a 6 x 12 in. (15 x 30 cm) cylinder. The inside radius to thickness ratio of this size of specimen would be 2:1, the same as reported in the earlier work, thus requiring no change in the use of equations for the calculation of tensile stresses.

ACI member **V. M. Malhotra** is materials engineer, Construction Materials Section, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Ontario, Canada, where he is engaged in applied research in the field of concrete and concrete aggregates. Mr. Malhotra first joined the Mines Branch in 1962. He is a graduate of both Delhi University and the University of Western Australia. His experience in concrete technology and soils engineering includes work on hydroelectric projects and in the construction industry in Australia, India, and Canada. Mr. Malhotra is the author of numerous technical papers in the field of concrete technology and was the founding president of the Canadian Capital Chapter of ACI. Currently, he is chairman of ACI Committee 118, Use of Computers, and is a member of ACI Committees 214, Evaluation of Results of Strength Tests of Concrete, and 224, Cracking.

SCOPE OF INVESTIGATION

This investigation was undertaken to determine the feasibility of casting and testing 12 in. (30 cm) inside diameter ring test specimens, 3 in. (7.5 cm) high x 3 in. (7.5 cm) wide. A total of twenty-nine 2 cu ft (0.056 cu m) concrete mixes were made; twenty-one mixes were made with aggregate of ¾ in. (19 mm) maximum size and eight mixes were made with aggregate of ⅜ in. (9.5 mm) maximum size. The 28 day compressive strength of the concrete varied from 2510 to 7940 psi (176 to 558 kg/cm^2). Coarse aggregate consisted of crushed limestone and fine aggregate was natural sand. In all, 208 test specimens comprising seventy-nine 12 in. (30 cm) inside diameter rings, forty-two 6 in. (15 cm) inside diameter rings and eighty-seven 4 x 8 in. (10 x 20 cm) cylinders were cast and tested. The test results were analyzed statistically.

PRINCIPLE UNDERLYING THE RING TEST

In this test, hydrostatic pressure is applied radially against the inside periphery of a concrete ring specimen and the resulting tensile stresses developed in the ring specimen at the moment of failure are determined from the equations for the stress analysis of thick walled cylinders. Briefly the tensile stresses in the ring section vary nonlinearly from a maximum of 2.6 P_i at the inside periphery to 1.6 P_i at the outside periphery, where P_i is the applied hydrostatic pressure.

FABRICATION OF RING MOLDS AND TESTING JIG

The 12 in. (30 cm) inside diameter ring mold consists of a split outer ring of 18 in. (45 cm) inside diameter and 3 in. (7.5 cm) high (machined from mild steel) and a steel inner ring of the same height and 12 in. (30 cm) outside diameter. The outer and inner rings are mounted concentrically on a machined base plate, ½ in. (1.25 cm) thick, and secured with wing nuts. Each mold is provided with two lifting handles. To facilitate the removal of concrete rings during demolding, the inner ring is tapered over its full height so that the upper end is 0.003 in. (0.0076 cm), less in diameter than the lower end. In addition, four steel lugs ¼ x ¼ x 2 in. (0.6 x 0.6 x 5 cm) are welded to the inner ring at equal distances apart and ½ in. (1.25 cm) below the upper end, for applying gentle hammer strokes during the demolding operation.

To test the ring specimens, a special testing jig and nitrile rubber bladder had to be fabricated. Apart from their larger size, the testing jig and the rubber bladder were identical to those used for testing the 6 in. (15 cm) inside diameter concrete rings. During the second half of the investigation, the hand operated hydraulic pump was replaced by an automatic pumping unit. The complete test assembly is shown in Fig. 1.

ANALYSIS OF TEST RESULTS

Regression analysis were carried out to establish correlations between 12 in. (30 cm) inside diameter ring tensile strength and 4 x 8 in. (10 x 20 cm) cylinder compressive strength. Fig. 2 is the plot of tensile strengths of 12 in. (30

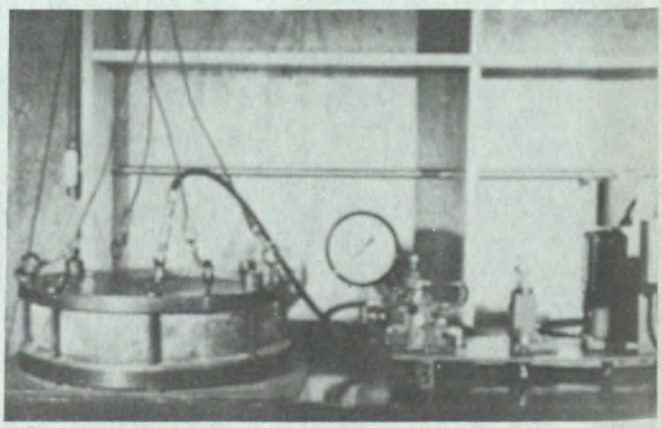

Fig. 1—Ring testing jig with automatic hydraulic pumping unit

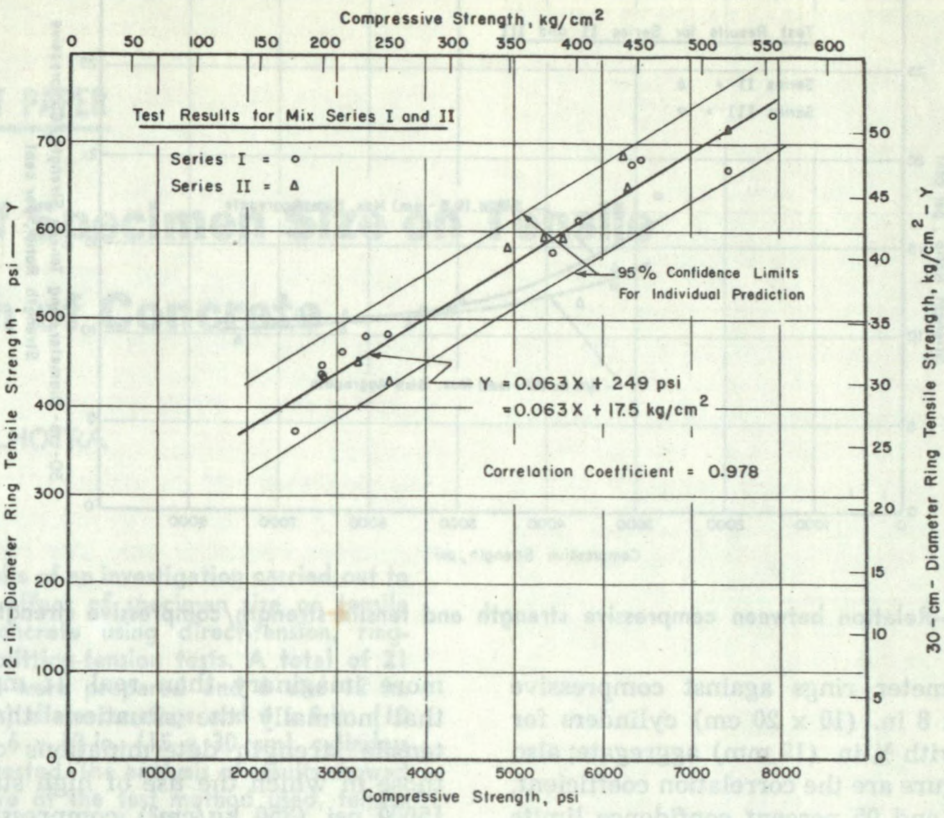

Fig. 2—Relation between compressive strength and ring tensile strength

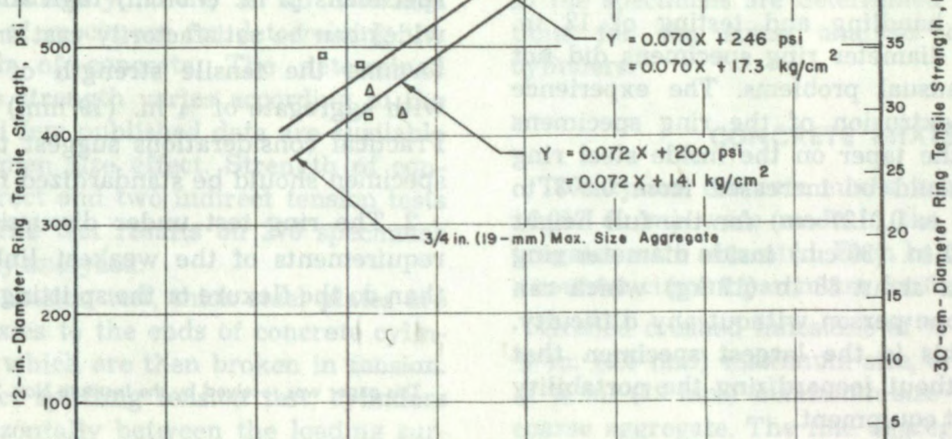

Fig. 3—Relation between compressive strength and tensile strength of concrete made with 3/8 and 3/4 in. maximum size aggregates

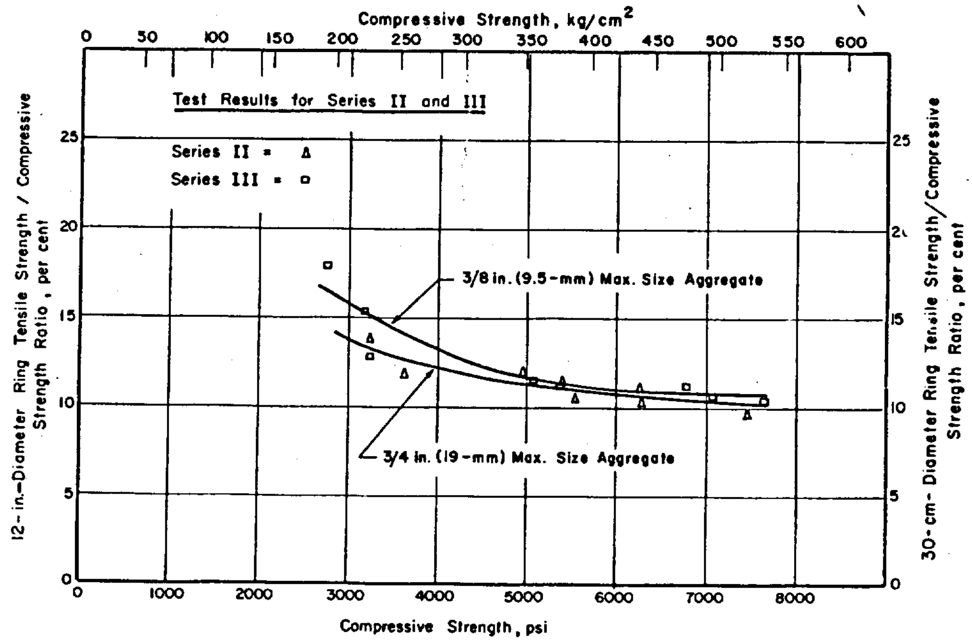

Fig. 4—Relation between compressive strength and tensile strength/compressive strength ratio

cm) inside diameter rings against compressive strengths of 4 x 8 in. (10 x 20 cm) cylinders for concrete made with ¾ in. (19 mm) aggregate; also shown on the figure are the correlation coefficient, line of best fit, and 95 percent confidence limits for the individual prediction.

Fig. 3 is the plot of tensile strengths of 12 in. (30 cm) inside diameter rings against compressive strengths of 4 x 8 in. (10 x 20 cm) cylinders for concretes made with ¾ in. (19 mm) and ⅜-in. (9.5 mm) aggregates.

Fig. 4 shows the tensile/compressive strength ratio plotted against the compressive strength for the same mix series.

DISCUSSION OF RESULTS

Casting, handling, and testing of ring specimens

The casting, handling and testing of 12 in. (30 cm) inside diameter ring specimens did not present any unusual problems. The experience gained in the extrusion of the ring specimens indicated that the taper on the inside steel ring of the mold should be increased from 0.003 to 0.005 in. (0.0076 to 0.0127 cm) for the full height of the ring. A 12 in. (30 cm) inside diameter ring specimen weighs about 38 lb (17 kg) which can be handled by one person without any difficulty. Furthermore, this is the largest specimen that can be used without jeopardizing the portability aspect of the test equipment.

Apparent limitation on maximum size aggregate

It may appear that the 3 x 3 in. (7.5 x 7.5 cm) ring section would limit the maximum size of aggregate to ¾ in. (19 mm). This limitation is more imaginary than real. It must be stressed that normally the situations that call for the tensile strength determinations of concrete are those in which the use of high strength concrete [5000 psi (350 kg/cm²) compressive strength or more at 28 days] is specified. Those who are familiar with the making and use of this type of concrete would readily appreciate that to achieve high compressive strengths a limitation has to be imposed on the maximum size of aggregate. This is generally set at ¾ in. (19 mm). The 3 x 3 in. (7.5 x 7.5 cm) section of the 12 in. (30 cm) inside diameter ring specimen is ample for incorporating aggregates of this size.

CONCLUSIONS

1. The 12 in. (30 cm) inside diameter ring specimens [3 in. (7.5 cm) high and 3 in. (7.5 cm) wide] can be satisfactorily cast and tested to determine the tensile strength of concrete made with aggregate of ¾ in. (19 mm) maximum size. Practical considerations suggest that this size of specimen should be standardized for the ring test.

2. The ring test under discussion satisfies the requirements of the weakest link theory better than do the flexure or the splitting tension tests.

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TITLE NO. 67-30

AN ACI DIGEST PAPER

Effect of Specimen Size on Tensile Strength of Concrete

By V. M. MALHOTRA

Presents results of an investigation carried out to determine the effect of specimen size on tensile strength of concrete using direct-tension, ring-tension, and splitting-tension tests. A total of 21 concrete mixes were prepared and 6 and 12 in. (15 and 30 cm) diameter rings and 4 x 8-in. (10 x 20 cm) and 6 x 12-in. (15 x 30 cm) cylinders were cast and tested. The analysis of results showed that irrespective of the test method used, tensile strength values decreased with increase in the size of specimens. The average decrease in strength varied from about 14 percent in the ring-tension test to about 7 percent in the direct-tension and splitting-tension tests.

Keywords: concretes; research; ring-tension test; specimens; splitting tensile strength; tensile strength; tests.

■ SPECIMEN SIZE AFFECTS the compressive strength of concrete. This is one of the reasons that specimens for the compression test have been standardized. Unfortunately, there is no standard method or size of specimens for determining the tensile strength of concrete. The determined value of tensile strength varies according to the test method and few published data are available as to the specimen size effect. Strength of concrete by one direct and two indirect tension tests were studied. The test results on 276 specimens were statistically analyzed.

In the direct-tension test, thick steel plates are glued with epoxies to the ends of concrete cylinders or prisms, which are then broken in tension.

In the indirect splitting tension test, cylinders are placed horizontally between the loading surface of a testing machine so that load is applied to the specimen sides along two opposite generatrices.

For the second indirect test, the ring-tension test, which was developed at the Canadian Mines Branch in 1965, hydrostatic pressure is applied radially against the inside periphery of a ring-shaped specimen. The resulting tensile stresses in the specimens are determined from the equations for the stress analysis of thick-walled cylinders.

CONCRETE MIXES

Twenty-one concrete mixes, each about 2 cu ft (0.057 cu m) were made in the laboratory. Aggregates were saturated. Each batch was mixed in a counter-current pan mixer for 6 min.

Graded crushed limestone of ¾ in. (19 mm) or ⅜ in. (9.5 mm) maximum size, or crushed gravel of ¾ in. (19 mm) maximum size was used as the coarse aggregate. The fine aggregate was natural sand. The bulk specific gravity (saturated surface dry) and absorption of the fine aggregate were 2.71 and 1.1 percent. The corresponding values for the limestone aggregate were 2.69 and 0.40 percent and for the gravel aggregate were

ACI member V. M. Malhotra is materials engineer, Construction Materials Section, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Ontario, Canada, where he is engaged in applied research in the field of concrete and concrete aggregates. Mr. Malhotra first joined the Mines Branch in 1962. He is a graduate of both Delhi University and the University of Western Australia. His experience in concrete technology and soils engineering includes work on hydroelectric projects and in the construction industry in Australia, India, and Canada. Mr. Malhotra is the author of a number of technical papers in the field of concrete technology and was the founding president of the Canadian Capital Chapter of ACI. Currently, he is chairman of ACI Committee 118, Use of Computers, and is a member of ACI Committees 214, Evaluation of Results of Strength Tests of Concrete, and 224, Cracking.

2.71 and 0.76 percent. Type I portland cement was used.

The water-cement ratio varied from 0.34 to 0.80 by weight, and the aggregate-cement ratio, also by weight, varied from 3.34 to 8.16. Immediately after mixing, the slump, unit weight, and air content of the concrete were determined using the ASTM test methods.

SPECIMENS

Both 4 x 8-in. (10 x 20 cm) and 6 x 12-in. (15 x 30 cm) cylinders were cast in steel molds. The rings were cast in specially fabricated molds described elsewhere.[1,2]

Molding and curing of cylinders were according to ASTM C 192.

The 6 in. (15 cm) inside diameter rings were cast by filling the steel molds and vibrating them on a vibrating table for 30 sec. The 12 in. (30 cm) inside diameter rings, however, were cast by filling the molds in two approximately equal successive layers and vibrating them on a vibrating table for 30 sec for each layer. The vibrating times were increased for concrete mixes having stiffer consistency. After casting the specimens were cured according to ASTM C 192.

TESTING SPECIMENS

Compression test

Compression cylinders were tested according to ASTM C 39.

Direct-tension test

Twenty-four days after casting, the test cylinders were removed from the moist-curing room and ¼ in. (0.63 cm), slices were sawn from the ends to remove excessive mortar. The cylinders were left in the laboratory atmosphere (72 F or 22.2 C and 40 to 50 percent relative humidity) for 1 day. A machined steel plate, 2 in. (5 cm) thick, was glued with an epoxy to each sawn end of the cylinders, which were then left in the laboratory air for 1 more day. Following this, the cylinders were returned to the moist-curing room for 2 additional days to attain saturation of the concrete. Just before testing, special jigs, with spherical seats connected to rods of 1½ in. (3.8 cm) diame-

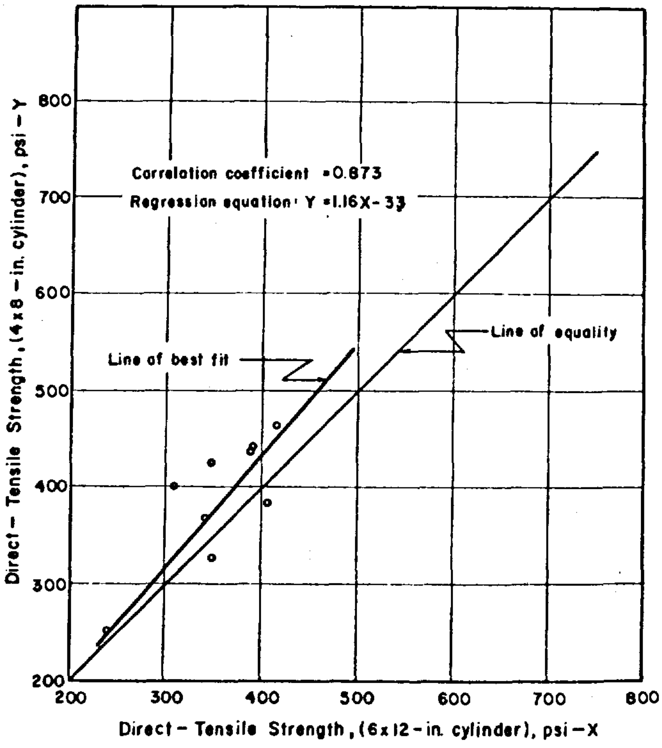

Fig. 1—Comparison of direct-tensile strengths of 4 x 8-in. (10 x 20 cm) and 6 x 12-in. (15 x 30 cm) cylinders

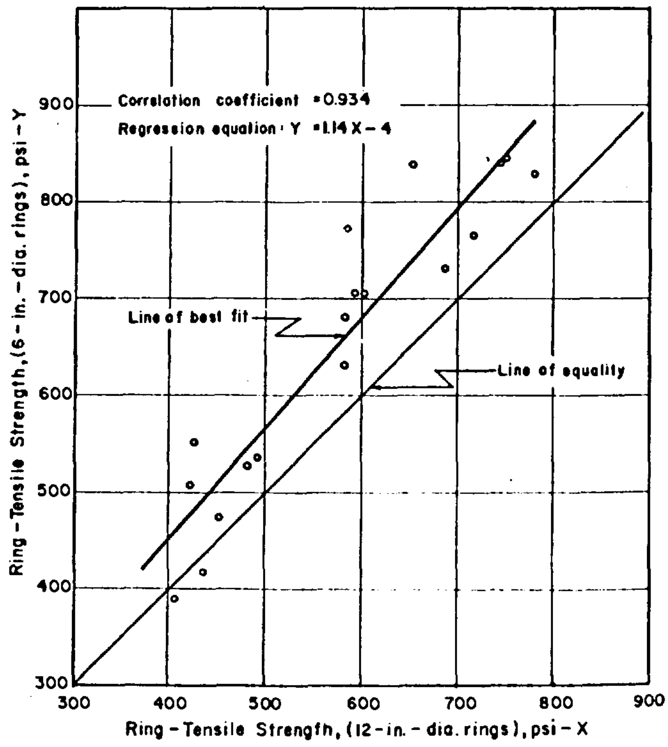

Fig. 2—Comparison of ring-tensile strengths of 6-in. (15 cm), and 12-in. (30 cm) inside diameter rings

ter, were bolted to the end plates. The spherical seats helped to achieve a nearly "true" axial stress in the specimen when the rods were held in the jaws of a universal testing machine.

Ring-tension test

The ring specimens were tested in a specially fabricated jig. The jig and the detailed testing procedure have been described elsewhere.[2,3]

Splitting-tension test

The splitting-tension test was according to ASTM C496-64T. Soft wood of 1 x ⅛ in. (2.5 x 0.3 cm) cross section served as packing.

TEST RESULTS

The test results were statistically analyzed. Plots of test results are shown in Fig. 1 through 3 together with the lines of quality and of best fit, correlation coefficients, and regression equations.

Discussion

The analyses of the test results indicate that the tensile strengths obtained by the direct- and indirect-tension tests are affected in varying degrees by the size of specimen under test. This effect is more pronounced for the ring-tension test than for the direct-tension and splitting-tension tests (See Fig. 1 through 3). The ring tensile strengths obtained by testing 6 in. (15 cm) diameter rings are about 14 percent higher than those obtained by testing 12 in. (30 cm) diameter rings. Both the direct-tensile and splitting-tensile strengths obtained by testing 4 x 8-in. (10 x 20 cm) cylinders are about 7 percent higher than those obtained by testing 6 x 12-in. (15 x 30 cm) cylinders. It is stressed that the above values are average values and that the results of individual tests may show the reverse trend. No attempt has been made to develop a generalized theory of the effect of specimen size on strength because test conditions are different in each case. However, it is believed that the percentage difference in strength values for different-sized specimens in each type of test may be related to the area under the load. The area under the load for 3 x 3 x 12 in. (7.5 x 7.5 x 30 cm) inside diameter rings is four times that for 1½ x 1½ x 6 in. (3.8 x 3.8 x 15 cm) inside diameter rings, whereas the area under load for 6 x 12-in. (15 x 30-cm) cylinders for both direct- and splitting-tension tests is only 9/4 that for 4 x 8-in. (10 x 20 cm) cylinders. Furthermore, in direct-tension tests the ratio of load area to circumference for 6 x 12-in. (15 x 30 cm) cylinders (1.5:1) compared to that of 4 x 8-in. (10 x 20 cm) cylinders (1:1) may also be related to the observed decrease in strength of the larger specimens.

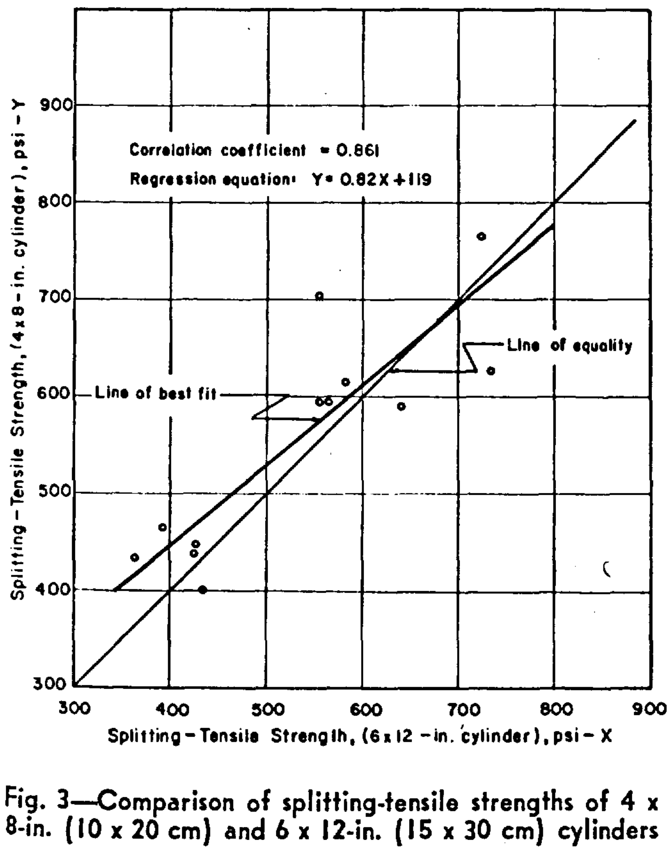

Fig. 3—Comparison of splitting-tensile strengths of 4 x 8-in. (10 x 20 cm) and 6 x 12-in. (15 x 30 cm) cylinders

CONCLUSION

Notwithstanding the limited nature of the investigation, it is indicated that the tensile strength of concrete is affected by the size of specimen under test, irrespective of the test method used. However, the loss in strength due to the increase in specimen size is dependent on the tension-test method being employed.

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