1971

Double punch test and tensile strength of concrete, February 1971 (72-16)

B. E. Trumbauer

W. F. Chen

DOUBLE PUNCH TEST AND TENSILE STRENGTH OF CONCRETE

by

B. E. Trumbauer

W. F. Chen

ABSTRACT

The tensile strength of concrete can be determined by several methods. The most popular method is the indirect split-cylinder test. The formula for computing the tensile strength of concrete for this test was first derived using the theory of linear elasticity. An identical formula was derived recently by Chen using the theory of perfect plasticity. As a result a new tensile test, the double punch test, was proposed.

The double punch test was examined experimentally, and the effects of several parameters were investigated. From the analysis of the results of the effects of the different parameters, and from a comparison to the tensile strength of concrete as determined by the split-cylinder test, a method for performing the double punch test for obtaining the tensile strength of concrete was proposed.

1. Introduction

The tensile strength of concrete can be determined by several methods. These methods include the direct tension test, the flexural test, the ring test, and the split-cylinder test.

Of all the methods introduced in recent years, the split-cylinder test is probably the most common of the tensile tests. The formula for computing the tensile strength of concrete from the split-cylinder test has been obtained from the theory of linear elasticity [1]. More recently, a plasticity treatment of this problem has been given by Chen [2]. It has been found that the result derived from the theories of perfect plasticity is identical to that derived from the theories of linear elasticity. The success in applying the theory of perfect plasticity to this problem has led to the suggestion of a new alternative test for concrete, the double punch test.

The double punch test has been proposed by Chen [3]. In this test, a concrete cylinder is placed vertically between the loading platens of the machine and is compressed by two steel punches placed concentrically on the top and bottom surfaces of the cylinder, Fig. 1 and 2. The specimen splits across many vertical diametric planes similar to the split-cylinder test, but the testing arrangement for the new test may be reduced.

The theory and derivation of the formula for computing the tensile strength of concrete for the double punch test has been proposed by Chen[3]. In that work, the new test showed promising results. It was noted [3], however, that further investigations were necessary before the test could be considered for practical use. The purpose of this report was, therefore, to investigate, through extensive experimental study, the effect of various parameters upon the observed strength and the uniformity of the new test results. Once these effects have been determined, a standard testing procedure for obtaining uniform results from the test will be proposed.

The areas of experimental investigation include

(1) the effect of the relative dimensions of the cylinders and metal loading punches,

(2) the effect of concrete mix, curing conditions and age,

(3) the effect of surface roughness between the specimen and the metal punches.

2. Computing the Tensile Strength

An ideal failure mode for a double punch test on a cylinder specimen consists of many simple tension cracks along the radial direction and two cone-shape rupture surfaces directly beneath the punches (Fig. 3). The cone shapes move toward each other and produce over those diametral planes an almost uniform tensile stress given by the formula [3]

$$f_t' = \frac{Q}{\pi(1.20\ bH-a^2)} \tag{1}$$

where f_t' = tensile stress

Q = applied load

b = radius of cylinder

H = height of cylinder

a = radius of punch

valid for $b/a \leq 5$ or $H/2a \leq 5$. For any ratio $b/a > 5$ or $H/2a > 5$, the limiting value $b = 5a$ or $H = 10a$ should be used in Eq. (1) for the computation of the tensile strength.

The formula gives an average tensile stress which exists over all of the cracked diametral planes (4 to 5 cracks were observed in Fig. 3) and thus a larger effective sample area than the split-cylinder test which contains only one such plane.

3. Experimental Work

3.1 Specimens

Specimens used in the double punch testing had a constant diameter of 6 inches, with heights of 10, 8, 6, and 4 inches. Cube specimens were formed by using 6 inch wide by 6 inch deep beam forms partitioned into 6 inch segments. Three specimens of identical configuration were cast for each set to minimize inconsistency in testing.

Standard control specimens were cast for each mix proportion and each curing condition. Compression and split-cylinder specimens were cast under ASTM standard methods C496. Six inch cubes were cast for compression testing, but diagonal split-cube testing was not feasible.

3.2 Materials

Portland cement was used in all specimens. An 1/2 inch crushed stone aggregate was used. The fineness modulus of the sand was 2.65.

The following mix ratios by weight were used in mixing the specimens:

Concrete mix one:		Concrete mix two:	
water:cement	1:2.45	water:cement	1:2.25
cement:sand	1:1.6	cement:sand	1:1.91
cement:stone	1:1.5	cement:stone	1:2.34

Each batch was mixed in a rotary type mixer and cast in accordance with ASTM Standard Methods C192; with the exception that specimens shorter than 6 inches were filled with only two layers.

The cylinders were cast in wax coated disposable cardboard molds. The molds were cut down to acheive the different height used. The cube specimens were made by inserting 6 inch wooden squares in a 6 inch deep by 6 inch wide metal form at 6 inch intervals. In most cases, the 6 inch tolerance of the cube was within 1/16 inch.

Specimens were placed under wet burlap and covered with plastic for a period of 24 hours after casting. The molds were then stripped from the specimens, and the specimens were placed in a 100% relative humidity curing room at about 75° F for the desired curing period. Those 28 day specimens which were partially air dried were removed from the moist room 14 days after they were put in and were allowed to air dry in the lab atmosphere until tested.

3.3 Test Apparatus

The loading punches were made of 1 inch thick tool steel with diameters of 1.0 inch., 1.5 inches, and 2.0 inches. All surfaces were machined. The punches were centered on the surfaces of the specimen by means of a template 6 inches in diameter with holes corresponding to the punch diameters at the center. A rope was used as a shock chord to prevent pieces of the specimen from exploding out of the machine. A 60 kip Baldwin hydraulic type testing machine was used for all double punch testing. A 120 kip machine was used for all split-cylinder testing, and a 300 kip Baldwin hydraulic machine was used for compression testing. All machines were fitted with spherical testing heads.

3.4 Testing Procedure

The concrete cylinder (or cube) was placed vertically between the loading platens of the machine and compressed by the two steel punches placed concentrically on the top and bottom surfaces of the specimen, Fig. 2. Load was applied at an approximate rate of 1 kip every 10 seconds, continuously to failure.

In tests where the 1/8 inch wooden disks were used, the disks were placed between the surface of the specimen and the metal punches while centering of the punches was taking place.

4. Results

All test results are summarized in Tables 1 and 2. The coefficient of variation in most cases is less that 5 percent (Table 1, Column 12).

The specimen generally failed with radial cracks emitting from the center in approximately equal sections. In some of the 10 inch and 8 inch specimens, fracture occurred in two halves indicating a possible eccentric loading caused by slight misalignment of the two punches. In the specimens 6 inches and smaller (including the cube specimens) failure occurred in three or more sections of radial failure. Examples of this multiple radial failure can be seen in Fig. 3.

4.1 Effects of Dimensions

The effect of changing the surface area/loaded area ratio was investigated by keeping the specimen diameter constant at 6 inches while varying the punch diameter from 1.0 inch to 1.5 inches to 2.0 inches. By varying the cylinder height, it was possible to determine the effect of height and loaded area vs. tensile strength.

In general, the 10 inch and 8 inch heights with the 1.0 inch punch, the calculated tensile strength was higher than the split-cylinder tensile strength. When the 1.5 inch and 2.0 inch punches were used, the tensile strength was less than the split-cylinder tensile strength. The problems of eccentricity due to slight off-center of the punches for the 10 inch and 8 inch specimens were significant. The 6 inch high cylinders with the 1.0 inch, 1.5 inch, and 2.0 inch punches gave a tensile strength close to that of the split-cylinder values. When the 1.0 inch punch was used, however, the results were less consistent than those for 1.5 inch and 2.0 inch punches. The 4 inch cylinder with the 1.0 and 1.5 inch punches gave values approximately equal to those of the split-cylinder test, but when 2.0 inch punches were used, the value increased greatly. A comparison of the tensile strengths can be observed in Table 1, Columns 9, 10, 11.

In Table 2, a comparison between the tensile strength for the 6 inch high cylinders and those for the 6 inch cubes is shown. It can be seen that the values of f_c'/f_t' in Column 7 are almost identical, indicating that the shape of the specimen has no effect on the test. The values f_c' used are those of the standard 6 inch by 12 inch compression cylinder and of a 6 inch compression cube. The values of f_t' are double punch tensile strengths.

4.2 Effects of Concrete Mix, Curing Condition, and Age

For investigation of age effects, specimens composed of the same mix proportions were cured for 7, 14, 21, and 28 days. Specimens of the same mix proportions were tested at 28 days after moist curing for the full period, and also after air-drying for half the period to determine the effect of curing conditions. It was found that the 28 day moist cured specimens gave the most consistent results in the double-punch test. The 28 day air dry and lesser day moist specimens gave good results, but with a little less consistency than the 28 day moist. Results can be compared in Table 1, Columns 9, 10, and 11, Sets 1 through 72, for different ages and curing conditions.

Specimens of two different mix proportions were tested at 28 days to investigate the effect of change in composition. The relationship between the split-tensile strength and the double-punch test for the different mixes was approximately the same. This can be seen in Table 1, Column 11, Sets 49 through 72 as compared with Sets 73 through 96 that the ratios of the split cylinder tensile strength to that of the double punch tensile strength correspond closely for both mixes.

4.3 Effects of Wooden Disk

Plywood disks, 1/8 inch thick and with diameters corresponding to those of the metal punches were used to determine the effects of surface roughness between the punch and the specimen. From Table 1, Columns 5 and 8, it can be seen that the wood disk caused a lower load at failure but the difference is not significant. If the surfaces of the specimen were troweled smooth during casting, no wooden disks were necessary.

5. Double-Punch vs. Split Cylinder Testing Procedure

The double punch test has two major advantages over the popular split-cylinder test, however, They involve the relative simplicity of performance of the double punch test over that of the split-cylinder test, and the fact that a smaller machine can be used to perform the double punch test.

In the split-cylinder test it is necessary to lay the specimen lengthwise between the platens of the testing machine, being careful to keep the specimen perfectly centered. Wooden strips must be placed on the top and bottom contact surfaces of the cylinder, and then metal plates are placed over the strips. The head of the machine must then be lowered until contact is made with the specimen, being careful that the specimen remains centered. Upon failure, the specimen frequently 'explodes' in the machine, after destroying the fracture pieces. In order to keep the specimen intact, a special device must be used.

In the double punch test one simply centers the punches on the top and bottom surfaces with the templates, being careful that there is no misalignment, tie a rope around the perimeter of the cylinder to act as a shock chord, lower the head of the machine, and load to failure.

The shock chord will hold the specimen together after failure.

The split cylinder test requires a load at failure of approximately 50 to 70 kips, while the proposed double punch test requires only 30 to 40 kips. Since a smaller machine is required for the double punch test, it may be possible to perform the test in the field on small portable testing machines, or in laboratories which do not have larger machines.

The doulbe punch test also works satisfactorily under the same procedure for a cube specimen. The procedure for performing a tensile test on a cube specimen is much easier than performing a diagonal split-cube test. For this reason, the double punch test would be good for use in those countries which use cubes for testing.

5. Conclusions

Recommended Procedure for Performing Double Punch Test

The testing procedure proposed for most consistency is one using a 6 inch high by 6 inch diameter cylinder with two 1.5 inch diameter punches. No wood between the punches and the surfaces of the specimens is recommended, providing the surfaces are reasonable smooth. A smooth surface can be obtained by careful trowling immediately after pouring.

For those countires which use cubes for testing, a 6 inch cube with 1.5 inch diameter punches and no wood is recommended.

6. Acknowledgements

The research reported herein was supported by the National Science Foundation under Grant GY-7459 to Lehigh University for undergraduate research participation (lambert Tall, project director); and as part of the research to be conducted under Grant GK-14274 to Lehigh University.

7. References

1. Timoshonko, S.
   Theory of Elasticity, McGraw-Hill Book Company, New York, pp. 104-108, 1934.

2. Chen, W. F.
   Extensibility of Concrete and Theorems of Limit Analysis, Journal of Engineering Mechanics Division, ASCE, Vol. 96, EM3, June, 1970, pp. 341-352.

3. Chen, W. F.
   Double Punch Test for Tensile Strength of Concrete, Journal of the American Concrete Institute, Vol. 67, December, 1970, pp. 993-995.

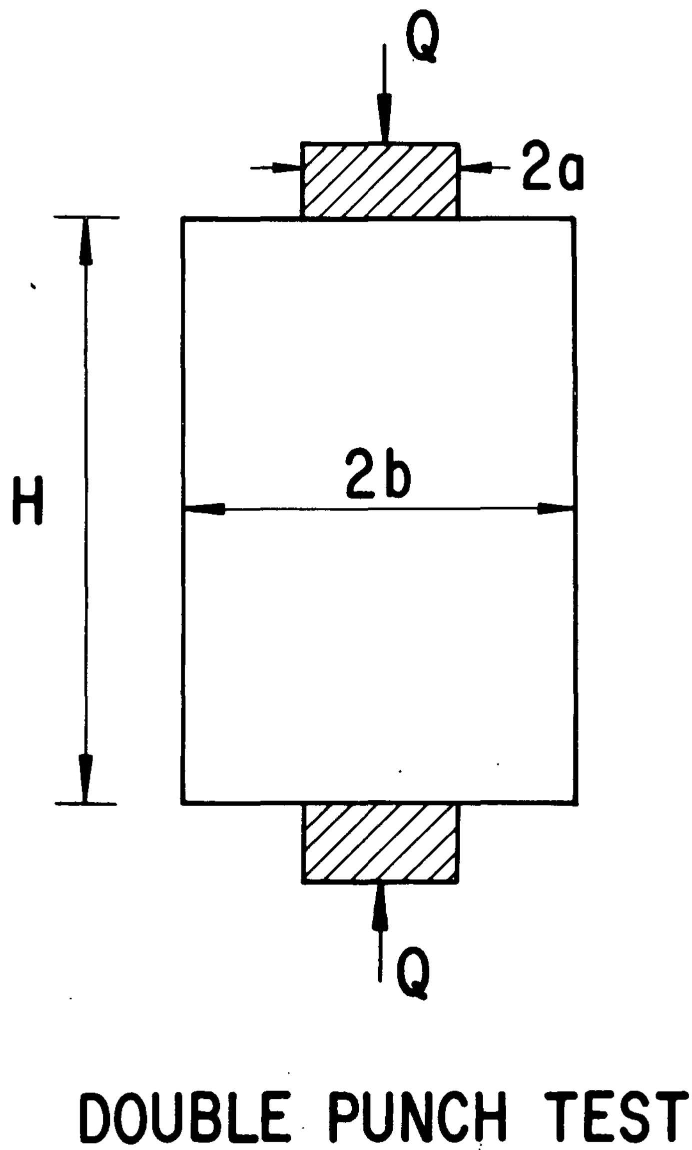

Fig. 1 Specimen Configurations for the New Test

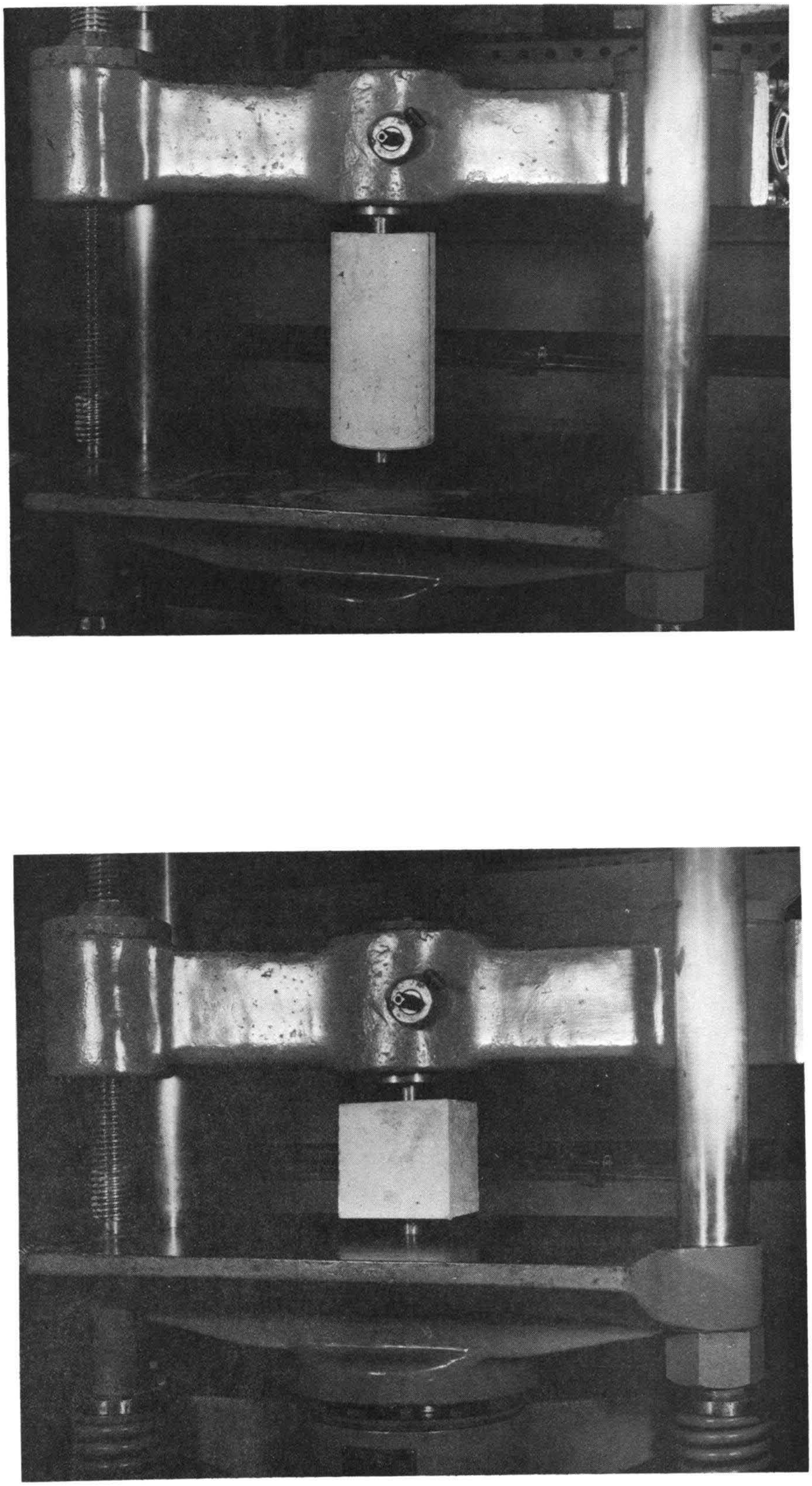

Fig. 2 Overall Picture of Setup

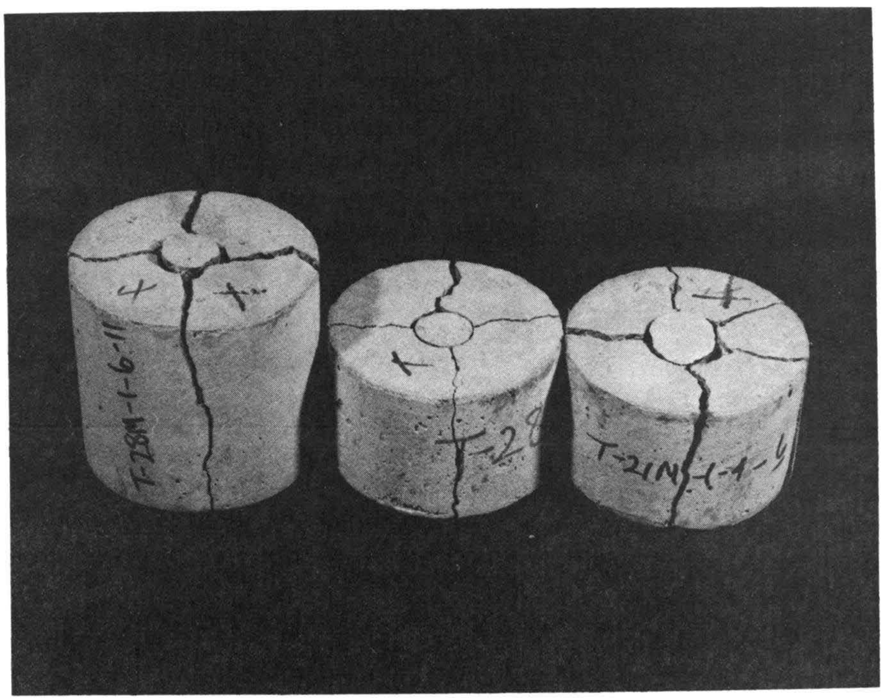

Fig. 3 Failure Modes

Table 1

Tensile Strength Computed from Double Punch Test and Split Cylinder Test

(1) Set	(2) Concrete Mix No.	(3) Curing Cond. days	(4) Punch Diameter in. (cm)	(5) Surface Cond.	(6) Specimen Height in. (cm)	(7) No. Tested	(8) Average Ultimate Load Q kip (kgf)	(9) Double Punch f'_t psi (kgf/cm^2)	(10) Split Cylinder f'_t psi (kgf/cm^2)	(11) $\frac{f'_{tSPL.}}{f'_{tD.P.}}$	(12) D.P. Coef.of Variation %
1	One	7 Moist	1.0 (2.55)	Natural	10 (25.50)	3	24.28 (11.0)	524 (36.8)	507 (35.6)	0.97	1.54
2					8 (20.40)	3	24.78 (11.2)	534 (37.4)	507 (35.6)	0.95	2.72
3					6 (15.30)	3	20.55 (9.35)	443 (31.1)	507 (35.6)	1.14	1.51
4					4 (10.20)	3	17.70 (8.02)	480 (33.7)	507 (35.6)	1.06	0.28
5				Wood	10 (25.50)	3	24.00 (10.9)	517 (36.3)	507 (35.6)	0.98	2.36
6					8 (20.40)	3	23.05 (10.4)	497 (34.9)	507 (35.6)	1.02	1.63
7					6 (15.30)	3	21.09 (9.56)	454 (31.8)	507 (35.6)	1.12	0.28
8					4 (10.20)	3	16.50 (7.47)	447 (31.4)	507 (35.6)	1.13	1.51
9		14 Moist	1.5 (3.82)	Natural	10 (25.50)	3	33.40 (15.2)	402 (28.2)	504 (35.4)	1.25	2.50
10					8 (20.40)	3	36.73 (16.6)	443 (31.1)	504 (35.4)	1.14	0.89
11					6 (15.30)	3	28.65 (13.0)	434 (30.5)	504 (35.4)	1.16	2.90
12					4 (10.20)	3	23.30 (10.6)	536 (37.6)	504 (35.4)	0.94	1.43
13				Wood	10 (25.50)	3	38.28 (17.4)	461 (32.4)	504 (35.4)	1.09	0.19
14					8 (20.40)	3	33.73 (15.3)	406 (28.4)	504 (35.4)	1.24	3.90
15					6 (15.30)	3	28.73 (13.0)	435 (30.5)	504 (35.4)	1.16	2.33
16					4 (10.20)	3	23.50 (10.7)	541 (38.0)	504 (35.4)	0.93	2.65
17		21 Moist	2.0 (5.10)	Natural	10 (25.50)	6	43.80 (19.9)	398 (27.9)	497 (34.8)	1.25	2.97
18					8 (20.40)	3	43.28 (19.7)	496 (34.8)	497 (34.8)	1.00	8.27
19					6 (15.30)	3	35.38 (16.1)	547 (38.4)	497 (34.8)	0.91	0.35
20					4 (10.20)	3	31.45 (14.3)	749 (52.5)	497 (34.8)	0.66	2.60
21				Wood	10 (25.50)	3	47.85 (21.7)	436 (30.6)	497 (34.8)	1.14	0.21
22					8 (20.40)	3	44.43 (20.2)	509 (35.8)	497 (34.8)	0.98	5.15
23					6 (15.30)	3	36.35 (16.5)	562 (39.4)	497 (34.8)	0.89	2.66
24					4 (10.20)	3	31.35 (14.2)	745 (52.2)	497 (34.8)	0.67	2.64

Table 1 (con't.)

(1) Set	(2) Concrete Mix No.	(3) Curing Cond. days	(4) Punch Diameter in. (cm)	(5) Surface Cond.	(6) Specimen Height in. (cm)	(7) No. Tested	(8) Average Ultimate Load Q kip (kgf)	(9) Double Punch f'_t psi (kgf/cm^2)	(10) Split Cylinder f'_t psi (kgf/cm^2)	(11) $\frac{f'_{tSPL.}}{f'_{tD.P.}}$	(12) D.P. Coef. of Variation %
25	One	28 Moist	1.0 (2.55)	Natural	10 (25.50)	3	33.45 (15.2)	721 (50.6)	550 (38.6)	0.76	1.20
26					8 (20.40)	3	33.17 (15.1)	714 (50.1)	550 (38.6)	0.77	3.75
27					6 (15.30)	3	26.70 (12.1)	575 (40.3)	550 (38.6)	0.96	1.17
28					4 (10.20)	3	21.15 (9.60)	573 (40.2)	550 (38.6)	0.96	2.05
29				Wood	10 (25.50)	3	30.60 (13.9)	660 (46.3)	550 (38.6)	0.84	3.50
30					8 (20.40)	3	29.55 (13.4)	637 (44.7)	550 (38.6)	0.86	2.34
31					6 (15.30)	3	25.50 (11.6)	551 (38.6)	550 (38.6)	1.00	1.83
32					4 (10.20)	3	20.96 (9.50)	568 (39.8)	550 (38.6)	0.97	3.63
33			1.5 (3.82)	Natural	10 (25.50)	6	42.48 (19.3)	512 (35.9)	550 (38.6)	1.07	4.00
34					8 (20.40)	3	41.72 (18.9)	502 (35.2)	550 (38.6)	1.10	1.73
35					6 (15.30)	3	31.32 (14.2)	473 (33.2)	550 (38.6)	1.16	1.83
36					4 (10.20)	3	26.44 (12.0)	608 (42.7)	550 (38.6)	0.91	3.00
37				Wood	10 (25.50)	3	37.86 (17.1)	456 (32.0)	550 (38.6)	1.20	5.00
38					8 (20.40)	3	38.88 (17.7)	467 (32.8)	550 (38.6)	1.18	4.14
39					6 (15.30)	3	31.35 (14.2)	475 (33.4)	550 (38.6)	1.16	3.16
40					4 (10.20)	3	27.77 (12.6)	639 (44.9)	550 (38.6)	0.86	3.52
41			2.0 (5.10)	Natural	10 (25.50)	6	43.55 (19.8)	396 (27.8)	550 (38.6)	1.39	4.50
42					8 (20.40)	3	44.30 (20.1)	507 (35.6)	550 (38.6)	1.08	0.91
43					6 (15.30)	3	38.15 (17.3)	590 (41.4)	550 (38.6)	0.93	0.00
44					4 (10.20)	3	33.68 (15.3)	797 (55.9)	550 (38.6)	0.69	2.87
45				Wood	10 (25.50)	3	45.35 (20.5)	412 (28.9)	550 (38.6)	1.33	5.74
46					8 (20.40)	3	45.45 (20.6)	521 (36.6)	550 (38.6)	1.05	7.16
47					6 (15.30)	3	36.56 (16.6)	565 (39.6)	550 (38.6)	0.98	0.88
48					4 (10.20)	3	34.46 (15.6)	819 (57.5)	550 (38.6)	0.67	3.11

Table 1 (con't.)

(1) Set	(2) Con-crete Mix No.	(3) Curing Cond. days	(4) Punch Diameter in. (cm)	(5) Sur-face Cond.	(6) Specimen Height in. (cm)	(7) No. Tested	(8) Average Ultimate Load Q kip (kgf)	(9) Double Punch f'_t psi (kgf/cm^2)	(10) Split Cylinder f'_t psi (kgf/cm^2)	(11) $\frac{f'_{tSPL.}}{f'_{tD.P.}}$	(12) D.P. Coef. of Varia-tion %
49					10 (25.50)	6	30.18 (13.7)	650 (45.6)	526 (36.9)	0.81	3.60
50					8 (20.40)	3	30.58 (13.9)	659 (46.2)	526 (36.9)	0.80	0.32
51				Natural	6 (15.30)	3	31.82 (14.5)	685 (48.1)	526 (36.9)	0.77	0.89
52			1.0 (2.55)		4 (10.20)	3	25.84 (11.7)	700 (49.1)	526 (36.9)	0.75	4.81
53					10 (25.50)	3	28.57 (13.0)	615 (43.2)	526 (36.9)	0.85	3.00
54				Wood	8 (20.40)	3	28.96 (13.2)	624 (43.8)	526 (36.9)	0.84	2.09
55					6 (15.30)	3	27.65 (12.5)	597 (41.9)	526 (36.9)	0.88	1.93
56					4 (10.20)	3	23.48 (10.6)	637 (44.7)	526 (36.9)	0.83	1.32
57					10 (25.50)	6	38.37 (17.4)	462 (32.4)	526 (36.9)	1.14	4.13
58					8 (20.40)	3	40.06 (18.2)	482 (33.8)	526 (36.9)	1.09	1.06
59				Natural	6 (15.30)	3	33.72 (15.3)	510 (35.8)	526 (36.9)	1.03	4.00
60	One		1.5 (3.82)		4 (10.20)	3	30.78 (14.0)	713 (50.0)	526 (36.9)	0.74	2.63
61		28 Air Dry			10 (25.50)	6	36.28 (16.5)	437 (30.6)	526 (36.9)	1.20	3.31
62				Wood	8 (20.40)	3	39.72 (18.0)	478 (33.6)	526 (36.9)	1.10	1.68
63					6 (15.30)	3	33.46 (15.2)	506 (35.5)	526 (36.9)	1.04	2.46
64					4 (10.20)	3	30.70 (13.9)	706 (49.5)	526 (36.9)	0.75	2.83
65					10 (25.50)	3	46.30 (21.0)	421 (29.5)	526 (36.9)	1.25	4.49
66					8 (20.40)	3	46.10 (20.9)	528 (37.1)	526 (36.9)	1.00	3.14
67				Natural	6 (15.30)	3	38.94 (17.7)	602 (42.3)	526 (36.9)	0.88	4.76
68			2.0 (5.10)		4 (10.20)	3	34.73 (15.7)	825 (57.9)	526 (36.9)	0.64	0.14
69					10 (25.50)	3	46.18 (20.9)	419 (29.4)	526 (36.9)	1.25	5.49
70				Wood	8 (20.40)	3	43.75 (19.8)	501 (35.2)	526 (36.9)	1.05	2.98
71					6 (15.30	3	39.33 (17.8)	608 (42.7)	526 (36.9)	0.87	2.17
72					4 (10.20)	3	33.35 (15.1)	792 (55.6)	526 (36.9)	0.66	1.19

Table 1 (con't.)

(1) Set	(2) Concrete Mix No.	(3) Curing Cond. days	(4) Punch Diameter in. (cm)	(5) Surface Cond.	(6) Specimen Height in. (cm)	(7) No. Tested	(8) Average Ultimate Load Q kip (kgf)	(9) Double Punch f'_t psi (kgf/cm^2)	(10) Split Cylinder f'_t psi (kgf/cm^2)	(11) $\frac{f'_{tSPL.}}{f'_{tD.P.}}$	(12) D.P. Coef.of Variation %
73	Two	28 Air Dry	1.0 (2.55)	Natural	10 (25.50)	3	32.25 (14.6)	696 (48.8)	586 (41.1)	0.84	6.38
74					8 (20.40)	3	30.27 (13.7)	653 (45.8)	586 (41.1)	0.90	1.56
75					6 (15.30)	3	29.15 (13.2)	629 (44.1)	586 (41.1)	0.93	3.86
76					4 (10.20)	3	26.22 (11.9)	711 (49.8)	586 (41.1)	0.82	1.42
77				Wood	10 (25.50)	3	30.20 (13.7)	650 (45.6)	586 (41.1)	0.90	2.16
78					8 (20.40)	3	28.96 (13.1)	624 (43.8)	586 (41.1)	0.94	2.00
79					6 (15.30)	3	28.06 (12.7)	604 (42.4)	586 (41.1)	0.97	0.07
80					4 (10.20)	3	25.22 (11.4)	684 (47.9)	586 (41.1)	0.86	0.83
81			1.5 (3.82)	Natural	10 (25.50)	3	42.30 (19.2)	509 (35.7)	586 (41.1)	1.15	1.32
82					8 (20.40)	3	39.19 (17.8)	472 (33.1)	586 (41.1)	1.24	0.67
83					6 (15.30)	3	38.18 (17.3)	578 (40.6)	586 (41.1)	1.01	1.55
84					4 (10.20)	3	32.06 (14.5)	738 (51.8)	586 (41.1)	0.80	0.19
85				Wood	10 (25.50)	3	41.13 (18.6)	494 (34.7)	586 (41.1)	1.19	0.56
86					8 (20.40)	3	39.19 (17.8)	472 (33.1)	586 (41.1)	1.24	3.44
87					6 (15.30)	3	34.42 (15.6)	521 (36.5)	586 (41.1)	1.12	0.94
88					4 (10.20)	3	30.77 (14.0)	708 (49.7)	586 (41.1)	0.83	2.06
89			2.0 (5.10)	Natural	10 (25.50)	3	52.10 (23.6)	473 (33.2)	586 (41.1)	1.24	1.92
90					8 (20.40)	3	46.78 (21.2)	536 (37.6)	586 (41.1)	1.09	1.22
91					6 (15.30)	3	40.17 (18.2)	621 (43.6)	586 (41.1)	0.94	3.80
92					4 (10.20)	3	33.31 (15.0)	792 (55.6)	586 (41.1)	0.74	1.77
93				Wood	10 (25.50)	3	51.33 (23.3)	466 (32.7)	586 (41.1)	1.26	2.45
94					8 (20.40)	3	49.70 (22.6)	569 (39.9)	586 (41.1)	1.03	1.71
95					6 (15.30)	3	41.52 (18.8)	642 (45.0)	586 (41.1)	0.91	1.20
96					4 (10.20)	3	33.92 (15.4)	806 (56.6)	586 (41.1)	0.73	2.46

Table 2

Double Punch Test for 6 Inch High Cylinders and Cubes

(1) Specimen	(2) Curing Cond. Days	(3) Punch Diameter in. (cm)	(4)* Average Ultimate Load Q kip (kg)	(5) Double Punch f'_t psi (kgf/cm^2)	(6) Simple Compression f'_c psi (kgf/cm^2)	(7) $\frac{f'_c}{f'_t D.P.}$
6" Cylinder (15.30 cm) Cylinder	28 Moist	1.0 (2.55)	26.70 (12.1)	575 (40.3)	6510 (457)	11.3
		1.5 (3.82)	31.32 (14.2)	473 (33.2)	6510 (457)	13.7
		2.0 (5.10)	38.15 (17.3)	590 (41.4)	6510 (457)	11.0
	28 Air Dry	1.0 (2.55)	31.82 (14.5)	685 (48.1)	6960 (488)	10.2
		1.5 (3.82)	33.72 (15.3)	510 (35.8)	6960 (488)	13.6
		2.0 (5.10)	38.94 (17.6)	602 (42.2)	6960 (488)	11.5
6" Cube (15.30 cm) Cube	28 Moist	1.0 (2.55)	28.96 (13.1)	624 (43.8)	7188** (505)	11.5
		1.5 (3.82)	34.18 (15.5)	549 (38.6)	7188 (505)	13.1
		2.0 (5.10)	39.62 (18.0)	613 (43.0)	7188 (505)	11.7
	28 Air Dry	1.0 (2.55)	28.70 (13.0)	619 (43.4)	7188 (505)	11.6
		1.5 (3.82)	33.46 (15.2)	507 (35.6)	7188 (505)	14.1
		2.0 (5.10)	40.74 (18.5)	631 (44.3)	7188 (505)	11.4

*Average of three tests with natural surface

**Compression cube