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PRELIMINARY EVALUATION OF WINDSOR PROBE EQUIPMENT FOR ESTIMATING THE COMPRESSIVE STRENGTH OF CONCRETE

by

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MINERAL PROCESSING DIVISION

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SUMMARY OF RESULTS

There is some degree of correlation between compressive strength of concrete and the exposed length of Windsor probe.

The probed 6 x 12-in. cylinders had lower compressive strengths than the companion unprobed cylinders; the difference in strength increased with increasing compressive strength of concrete. At 28 days, the difference in strength varied from 11.5 per cent for low-strength concrete to 17.5 per cent for high-strength concrete.

In one series of concrete mixes, where 6 x 6 x 66-in. beams were probed, the standard deviation and coefficient of variation of the exposed length of the probes were 0.062 inches and 3.4 per cent; the comparable values for compressive strength results (2 cylinders per test) were 99 psi and 2.0 per cent respectively.

For the same concrete, the exposed length of the probes increased with increasing age to indicate the usefulness of probe measurements for determining relative strength of concrete.

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INTRODUCTION

The standard methods of evaluating hardened concrete consist of testing concrete specimens in compression, flexure, and tension. The main disadvantages of such methods are the delay in obtaining test results and the fact that the test specimens may not be truly representative of the concrete in the structure. To overcome these problems there have been a large number of attempts over a period of about 35 years to develop quick, inexpensive, and non-destructive methods for testing concrete both in laboratory and in structure.

In 1966, a new method known as the Windsor probe test was advanced (1, 2) for testing concrete in the laboratory as well as in situ. Briefly, this test system consists of firing a hardened alloy probe into the concrete from a gun in which a charge develops 575 foot-pounds energy. The exposed length of the probe is recorded in inches and is related to compressive strength of the concrete. Allowance is made for hardness of the aggregate by using different, strength calibration charts depending upon the hardness of the aggregate as determined by the Mohs' hardness test. The originators of this test system claim this to be an economical alternative to cylinder and core testing especially when quality of concrete in situ is in question. Following the introduction of this test in the U.S.A. and Canada, several enquiries from industry (3, 4) were received by the Mineral Processing Division requesting data as to the usefulness of this new test system.

This preliminary investigation was therefore undertaken to evaluate the Windsor probe as to its applicability to estimating the compressive strength of concrete specimens made in the laboratory.

SCOPE OF INVESTIGATION

Two series of concrete mixes were made in the laboratory. The first series, consisting of seven mixes, was made with limestone aggregate and natural sand, and 6 x 12-in. cylinders were cast and probed and the results compared with compressive strength. In the second series, seven mixes were made with gravel aggregate and natural sand, and 6 x 6 x 66-in. beams were cast and probed for comparison with compressive strength. Before probing, rebound numbers were taken on all the test specimens of Series-I mixes, using the Schmidt test hammer for further comparative study. Following this, the test cylinders and 6-in. cubes sawn from the ends of beam specimens were tested in compression.

CONCRETE MIXES

A total of 14 concrete mixes were made in the Mines Branch laboratory between May 1970 and June 1970. A laboratory counter-current mixer was used for preparing the concrete batches.

Materials

Normal portland cement (ASTM Type I) was used for the concrete mixes. The physical properties and chemical analyses of the cement are given in Table 1.

Crushed limestone and river gravel with a maximum size of one inch were used as coarse aggregate in Mix Series I and II respectively, with local natural sand being the fine aggregate in each series. To keep the grading uniform for each mix, the sand was separated into different size fractions and then recombined to a specific grading.

The grading and physical properties of both the coarse and fine aggregates are given in Tables 2 and 3.

Mix Proportioning

Mix proportioning data for the concrete mixes are given in Table 4. The aggregates used were in a room-dry condition and allowance for absorption was made in the mixing water.

Darex air-entraining agent was used in all the mixes.

Properties of Fresh Concrete

The properties of fresh concrete, i.e., temperature, slump, unit weight, and air content, are given in Table 4.

TABLE 1

Physical Properties and Chemical Analyses of the Cement*

Description of Test	
Physical Tests, General	
Time of Set (Vicat Needle): Initial......	3 hr 00 min.
Final.......	5 hr 00 min.
Fineness: No. 200 (Passing)	96.60 per cent
Soundness - Autoclave.................	0.22 per cent
Physical Tests - Mortar Strength	
Compressive Strength of 2-in. cubes	
3-day......	2660 psi
7-day......	3860 psi
28-day	4720 psi
Chemical Analysis	
Insoluble Residue....................	0.10 per cent
Silicon dioxide (SiO_2)..................	20.60 per cent
Aluminum Oxide (Al_2O_3)...............	5.90 per cent
Ferric Oxide (Fe_2O_3).................	2.40 per cent
Calcium Oxide (CaO)	63.80 per cent
Magnesium Oxide (MgO)..............	3.00 per cent
Sulphur Trioxide (SO_3)	2.40 per cent
Loss on Ignition......................	0.43 per cent
Others.............................	1.37 per cent

*Test results and chemical analyses supplied by the cement manufacturing company.

TABLE 2

Grading of Aggregates

Coarse Aggregate		Fine Aggregate	
Sieve size	Cumulative percentage retained	Sieve size	Cumulative percentage retained
3/4 in.	33.3	No. 4	0
		No. 8	10.0
3/8 in.	66.6	No. 16	32.5
		No. 30	57.5
No. 4	100.0	No. 50	80.0
		No. 100	94.0
		Pan	100.0

TABLE 3

Physical Properties of Coarse and Fine Aggregates

	Crushed Limestone	Natural Sand
Specific Gravity	2.68	2.70
Absorption, %	0.40	0.50

TABLE 4

Mix Design Data

Mix Series	Mix No	Water Cement Ratio*	Aggregate Cement Ratio*	Properties of Fresh Concrete			
				Temp, °F	Slump, in.	Unit weight, lb/cu ft	Air content, per cent
I	1	0.75	8.15	70	3.2	140.8	5.0
	2	0.55	6.42	72	3.0	141.2	5.5
	3	0.56	6.35	70	3.0	143.2	5.2
	4	0.50	5.60	69	3.5	146.0	4.5
	5	0.49	5.45	72	3.2	142.8	5.1
	6	0.47	5.10	72	3.0	144.8	4.2
	7	0.36	3.18	70	4.0	148.4	3.0
II	1	0.66	7.75	75	1.7	148.0	3.0
	2	0.57	6.50	76	2.7	145.2	5.0
	3	0.52	5.92	77	2.7	146.0	4.2
	4	0.48	5.29	77	3.0	146.0	4.5
	5	0.42	4.55	75	3.7	147.6	4.0
	6	0.33	3.18	75	1.7	148.8	3.5
	7	0.33	3.05	75	1.7	148.0	3.0

* All ratios are by weight.

PREPARATION AND TESTING OF SPECIMENS

Ten 6 x 12-in. cylinders were cast from each batch in Series I whereas in Series II, two 6 x 12-in. cylinders and a 6 x 6 x 66-in. beam were cast from each batch. The test cylinders were prepared by filling 6 x 12-in. steel moulds in two approximately equal layers. Each layer was compacted with 1.125-in.-diameter internal vibrator, inserted once for 4 to 6 seconds. The beams were cast by filling the form progressively from one end, the compaction being carried out by an internal vibrator. After casting, all the moulded specimens were covered with water-saturated burlap and left in the casting room for 24 hours following which the cylindrical specimens were demoulded and transferred to the moist-curing room whereas the beams were left in the laboratory air (70 ± 5°F and 50% relative humidity) and kept covered with wet burlap for the next 27 days. At the ends of selected curing periods the specimens were tested.

All cylinders were capped using a sulphur and flint mixture.

The compression testing was carried out on a Armsler testing machine (600,000-lb capacity).

All test cylinders of Series I and II were subjected to Schmidt hammer testing before probing and compression testing. The rebound numbers on cylinders were taken using the procedure outlined in reference (5). A total of 45 readings were taken on three equally spaced lines along the full length of the cylinder.

Series I Mixes

At seven days, four cylinders from each mix were removed from the moist-curing room. Two of these were capped and tested in compression, the remaining two were probed, capped, and then tested in compression. The detailed procedure for testing the cylinders by Windsor probe is described later.

At 14 days, two cylinders from each mix were removed from the moist-curing room; one of the cylinders was capped and tested in compression whereas the other was probed, capped, and then tested in compression.

At 28 days, the remaining four cylinders from each mix were removed from the moist-curing room. Two of these were capped and tested in compression; the other two were probed, capped, and then tested in compression.

Series II Mixes

At 35 days, the two cylinders from each mix were removed from the moist room, capped, and tested in compression; the test beam from each mix was probed at four equally spaced points on the top surface. Following this, one 6-in. cube was sawn off from each end of the beam and tested in compression.

Windsor Probe Testing Procedure

The principle of the Windsor probe test has been described earlier. The procedure for probing the specimens was in accordance with the manufacturer's instructions (1). The power-actuated driver (Figure 1) was used to drive a probe (Figures 1, 2) having a diameter of 0.250 ± 0.0001 inches and a length of 3.125 ± 0.003 inches. The probe has a hardened frusto-conical point, 120 ± 20 degrees, which is capable of breaking the embedded coarse aggregate and of forcing the particles of aggregate against the surrounding mortar.

Initially, the cylinder specimens were held in a compression machine under a load of 500 psi to provide sufficient rigidity for probing; later, however, a holding jig supplied by the manufacturer (Figure 3) was used. Because the surface area for probing was rather limited, only one single probe per cylinder and four single probes per beam were used and, in each case, a single-probe locating templet* (Figure 1) was used. After probing, the projecting length of the probe was measured using a calibrated depth gauge (Figure 1). Before measuring the exposed length, the probes were tested for firmness of imbedment to make sure that they were firmly seated.

For low-strength concrete the input energy level of the probe was reduced by one-half by pushing the probe down-stream in the barrel of the driver a distance of 2.5 inches. The measured length of the probe was then divided by 2 to arrive at a corrected value for estimating the concrete strength.

No holding jigs of any kind were necessary for beams which were tested on the casting floor.

Figures 4 to 7 show test cylinders and beams after probing.

*In mass concrete, three probe gauges are driven using a suitable locating templet to provide a 7-in. equilateral triangular pattern.

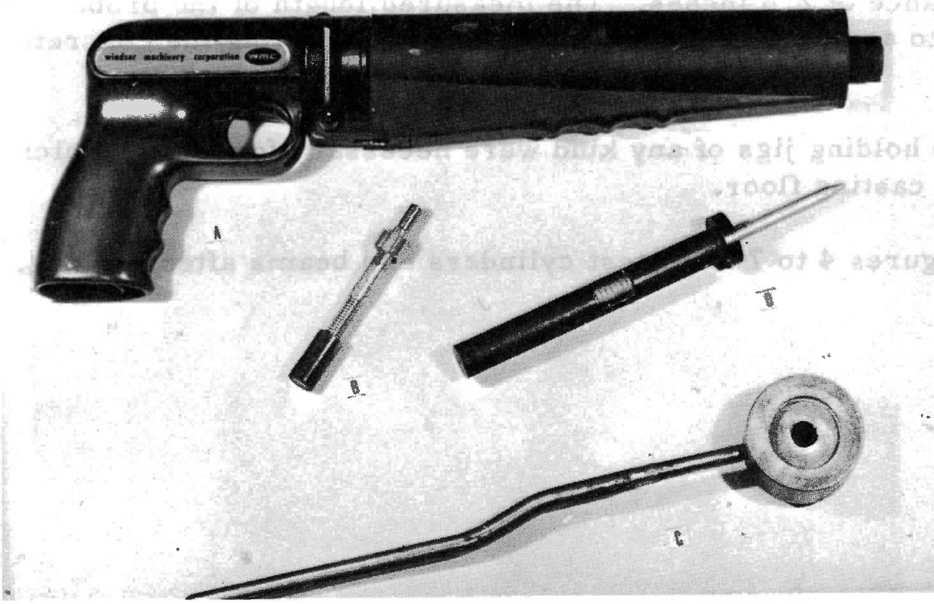
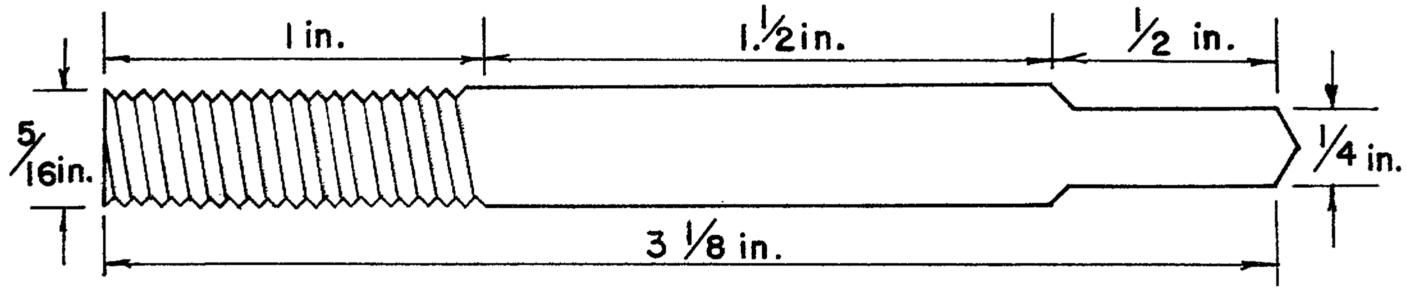
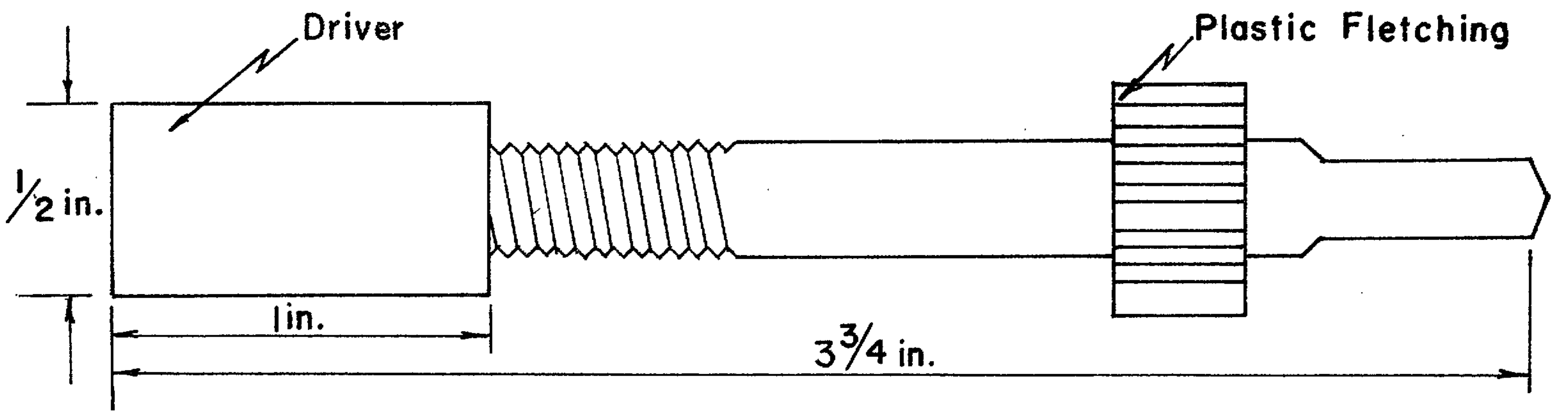


Fig. 1 - A view of the Windsor probe equipment.
A: driver unit, B: probe for normal-weight concrete.
C: single-probe templet, D: calibrated depth gauge.



Probe before Assembly



Assembled Driver and Probe

Fig. 2 - A view of the normal weight concrete probe before and after assembly.

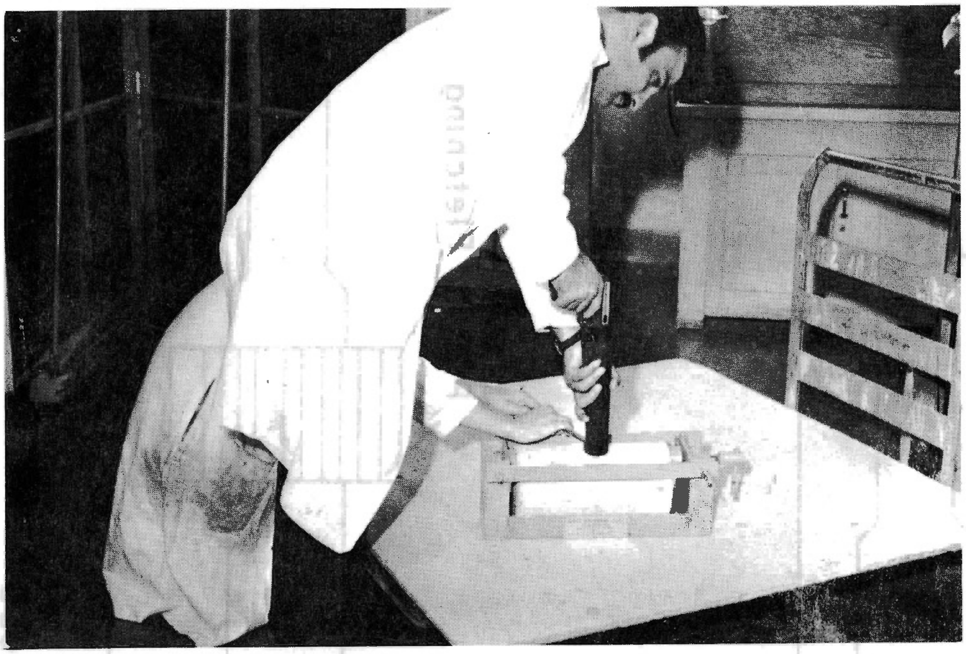


Fig. 3 - A view of the holding jig for test cylinders.

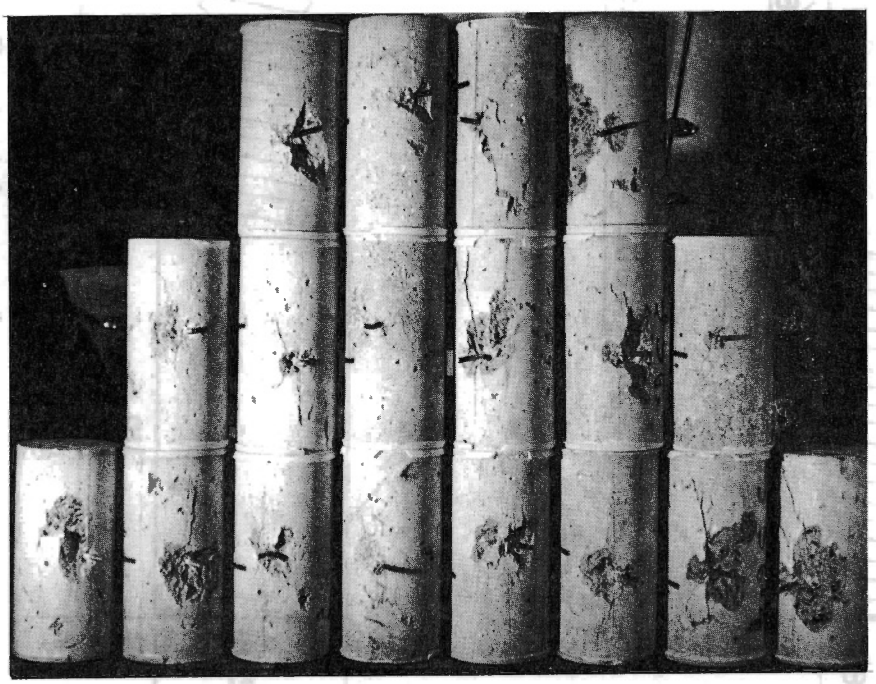


Fig. 4 - A view of the test cylinders after probing.

Fig. 5 - A close-up of the 6 x 12-in. cylinder after probing.

Fig. 6 - A view of the 6 x 6 x 66-in. test beams after probing.

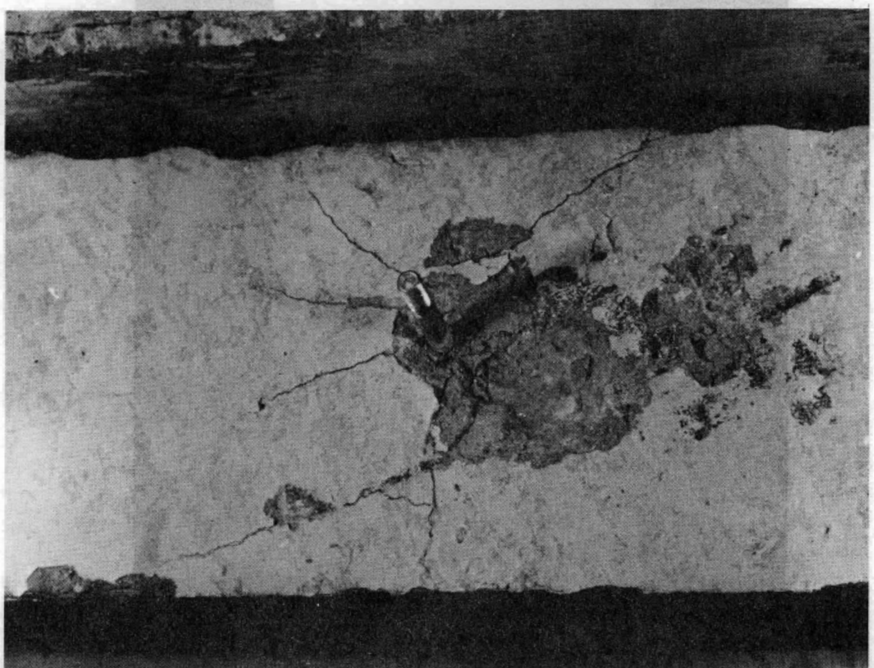


Fig. 7 - A close-up of the probed section of a beam.

TEST RESULTS AND THEIR ANALYSIS

A total of 84 test cylinders and 7 test beams were tested in this programme. The test results are summarized in Tables 5 to 8. Where possible, standard deviation and coefficient of variation for the test data were calculated and these are shown in Table 9.

The relationships between the exposed length of probe, rebound number, and compressive strength at various ages are shown in Figures 7 to 12 and 19. The relationship between rebound number and exposed length of probe are shown in Figures 13 to 15. A comparison of compressive strengths of unprobed and companion cylinders after probing is shown in Figures 16 to 18.

The limited nature of the data did not permit or justify the regression analysis or other detailed statistical treatment.

TABLE 5

Summary of Test Results at 7 Days - Mix Series I

Mix No	Test Cylinder: N*, Average of 45 results	Test Cylinder: Exposed length of Probe, in.	Test Cylinder: Compressive Strength of 6x12-in. Cyl after probing, psi	Companion Test Cylinder: N*, Average of 45 results	Companion Test Cylinder: Compressive Strength of 6x12-in. Cyl unprobed, psi
1	Cyl 1 20.8	1.190	1700	20.8	1890
	Cyl 2 23.2	1.180	1830	20.3	1840
	Av 22.0	Av 1.185	Av 1765	Av 20.5	Av 1865
2	Cyl 1 20.1	1.400	2480	20.5	2560
	Cyl 2 20.6	1.525	2520	21.2	2920
	Av 20.4	Av 1.462	Av 2500	Av 20.9	Av 2740
3	Cyl 1 23.1	1.590	2380	23.0	2820
	Cyl 2 21.8	1.370	2320	21.9	2850
	Av 22.5	Av 1.486	Av 2350	Av 22.5	Av 2380
4	Cyl 1 29.5	1.915	3440	29.3	4140
	Cyl 2 30.3	1.565	3360	27.4	3360
	Av 29.9	Av 1.740	Av 3400	Av 28.5	Av 3750
5	Cyl 1 27.2	1.810	3470	27.9	4000
	Cyl 2 27.0	1.720	3510	26.3	4120
	Av 27.1	Av 1.765	Av 3490	Av 27.1	Av 4060
6	Cyl 1 29.5	1.610	3700	29.7	4190
	Cyl 2 29.0	1.670	3350	30.1	4220
	Av 29.2	Av 1.640	Av 3525	Av 29.9	Av 4205
7	Cyl 1 34.1	1.790	4210	33.2	5690
	Cyl 2 35.1	2.050	4650	35.5	5710
	Av 34.6	Av 1.920	Av 4430	Av 34.3	Av 5700

* Rebound number by Schmidt test hammer; sum of 15 readings on each of three vertical lines, 120 degrees apart.

TABLE 6

Summary of Test Results at 14 Days - Mix Series I

	Test Cylinder			Companion Test Cylinder	
Mix No.	N*, Average of 45 results	Exposed length of Probe in.	Compressive Strength of 6x12-in. Cyl after probing, psi	N*, Average of 45 results	Compressive Strength of 6x12-in. Cyl unprobed, psi
1	23.9	2.118 +	2350	23.9	2380
2	22.0	1.485	2620	23.5	3330
3	25.6	1.435	2480	24.7	3250
4	31.3	probe failed to stay in position	Cylinder too damaged to be tested	31.0	4480
5	30.5	1.860	3560	29.1	4340
6	31.5	1.835	3310	32.0	4560
7	34.5	1.875	4480	35.5	5980

* Rebound number by Schmidt test hammer; sum of 15 readings on each three vertical lines, 120 degrees apart.
\+ Used half-power charge as recommended by the manufacturer.

TABLE 7

Summary of Test Results at 28 Days - Mix Series I

	Test Cylinder			Companion Test Cylinder	
Mix No.	N*, Average of 45 results	Exposed length of Probe in.	Compressive Strength of 6x12-in. Cyl after probing, psi	N* Average of 45 results	Compressive Strength of 6x12-in. Cyl unprobed, psi
1	Cyl 1 21.3	1.965	2320	22.9	2510
	Cyl 2 23.2	1.975	2280	24.7	2690
	Av 22.2	Av 1.970	Av 2300	Av 23.8	Av 2600
2	Cyl 1 24.7	1.710	3050	23.8	3610
	Cyl 2 25.1	Av 1.520	not tested	24.4	3660
	Av 24.9	1.615	Av 3050	Av 24.1	Av 3635
3	Cyl 1 26.6	1.400	2880	27.1	3560
	Cyl 2 27.8	Av 1.640	not tested	28.2	3330
	Av 27.2	1.520	Av 2880	Av 27.6	Av 3445
4	Cyl 1 31.7	probes failed to stay in position	4160	32.4	4890
	Cyl 2 33.7		3810	32.2	5060
	Av 32.7		Av 3985	Av 32.3	Av 4975
5	Cyl 1 32.2	1.695	3380	31.0	4730
	Cyl 2 31.4	1.850	3730	30.1	4565
	Av 31.8	Av 1.772	Av 3555	Av 30.5	Av 4650
6	Cyl 1 32.0	-----	not tested	31.8	5040
	Cyl 2 31.4	1.880	3860	32.1	5400
	Av 31.7		Av 3860	Av 31.5	Av 5220
7	Cyl 1 38.6	-----	5160	37.8	6010
	Cyl 2 38.6	2.035	----	38.8	6500
	Av 38.6		Av 5160	Av 38.3	Av 6255

* Rebound number by Schmidt test hammer; sum of 15 readings on each three vertical lines, 120 degrees apart.

TABLE 8

Summary of Test Results at 35 Days - Mix Series II

6 x 6 x 66 - in. Test Beams				Companion 6 x 12-in. cylinders	
Mix No.	Exposed length of probes at four equally spaced points, in.	Average length, in.	Compressive Strength of two 6-in. cubes sawn from ends of the test beams, psi	N, Average of 45 test results	Compressive Strength of 6x12-in. Cyl, psi
1	2.05, 2.078, 2.020, 2.095	2.081	Cube 1 = 6740 Cube 2 = 6060 Av 6400	Cyl 1 38.2 Cyl 2 38.1 Av 38.1	6635 6190 Av 6410
2	1.925, 1.923, 1.978, 2.045	1.968	* *	Cyl 1 39.2 Cyl 2 39.2 Av 39.2	6735 6685 Av 6710
3	2.028, 2.015, 1.820, 1.933	1.949	Cube 1 = 4850 Cube 2 = 5150 Av 5000	Cyl 1 32.6 Cyl 1 32.9 Av 32.7	4550 4750 Av 4650
4	1.878, 1.868, 1.874, 1.868	1.872	Cube 1 = 4610 Cube 2 = 4400 Av 4505	Cyl 1 30.2 Cyl 2 29.6 Av 29.9	4430 4380 Av 4405
5	1.712, 1.810, 1.872 ---	1.798	Cube 1 = 4300 Cube 2 = 4230 Av 4265	Cyl 1 28.6 Cyl 2 28.5 Av 28.5	4110 4050 Av 4080
6	1.807, 1.757, 1.697, 1.821	1.770	Cube 1 = 3810 Cube 2 = 3870 Av 3795	Cyl 1 24.6 Cyl 2 23.6 24.1	3760 3660 Av 3710
7	1.728, 1.620, 1.907, 1.786	1.760	Cube 1 = 3160 Cube 2 = 2640 Av 2900	Cyl 1 25.7 Cyl 2 24.5 Av 25.1	2900 2810 Av 2855

TABLE 9

Within-Batch Standard Deviation and Coefficient of Variation of Test Results

Mix No.	Mix Series I								Mix Series II			
	Test Results at 7 days				Test Results at 28 days				Test Results at 35 days			
	Exposed length of probe*		Companion** 6 x 12-in. Cylinders		Exposed length of probe*		Companion 6 x 12-in. Cylinders**		Exposed length of Probe***		Companion 6 x 12-in. Cylinders**	
	S. D.,+ in.	C. V.,++ %	S. D., psi	C. V., %	S. D., in.	C. V., %	S. D., psi	C. V., %	S. D., in.	C. V., %	S. D., psi	C. V., %
1	0.007	0.60	35	1.9	------	-----	---	---	0.023	1.1	315	4.9
2	0.088	6.00	254	9.3	0.1344	8.30	135	1.0	0.057	2.9	35	0.5
3	0.156	10.50	21	0.8	0.1700	11.20	162	4.7	0.096	4.9	141	3.0
4	0.247	14.20	550	14.7	------	-----	---	---	0.005	0.3	35	0.8
5	0.064	3.60	85	2.1	0.1100	6.21	117	2.4	0.081	4.5	42	1.0
6	0.042	2.60	21	0.5	------	-----	---	---	0.056	3.2	71	1.9
7	0.184	9.60	14	0.3	------	-----	---	---	0.120	6.8	64	2.2
Av	0.110	6.7	140	4.2	0.1381	8.6	138	2.7	0.062	3.4	99	2.0

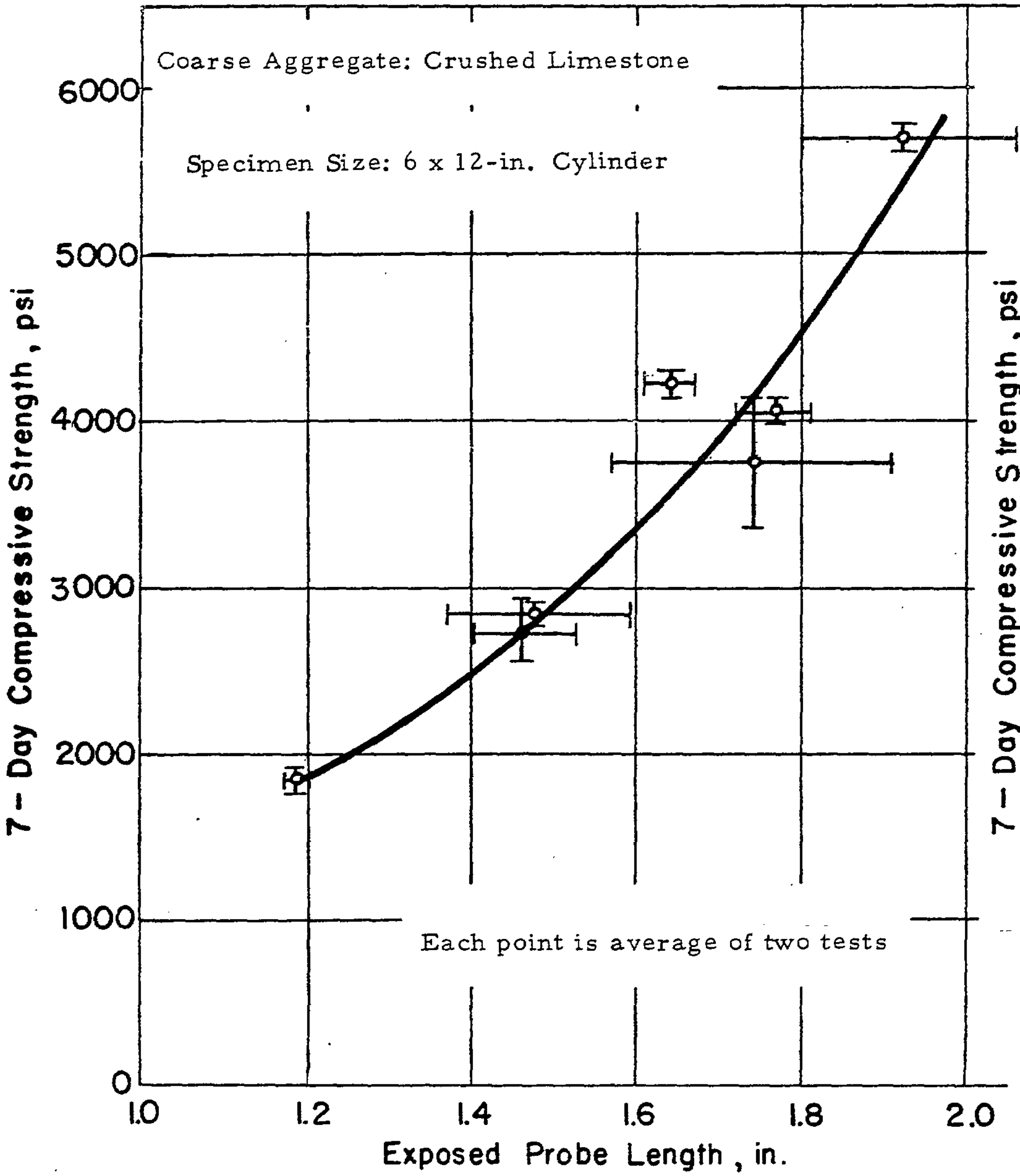
* One probe each on two different cylinders.

** Only two cylinders per test.

*** Four probes per beam.

\+ Standard deviation.

++ Coefficient of variation.



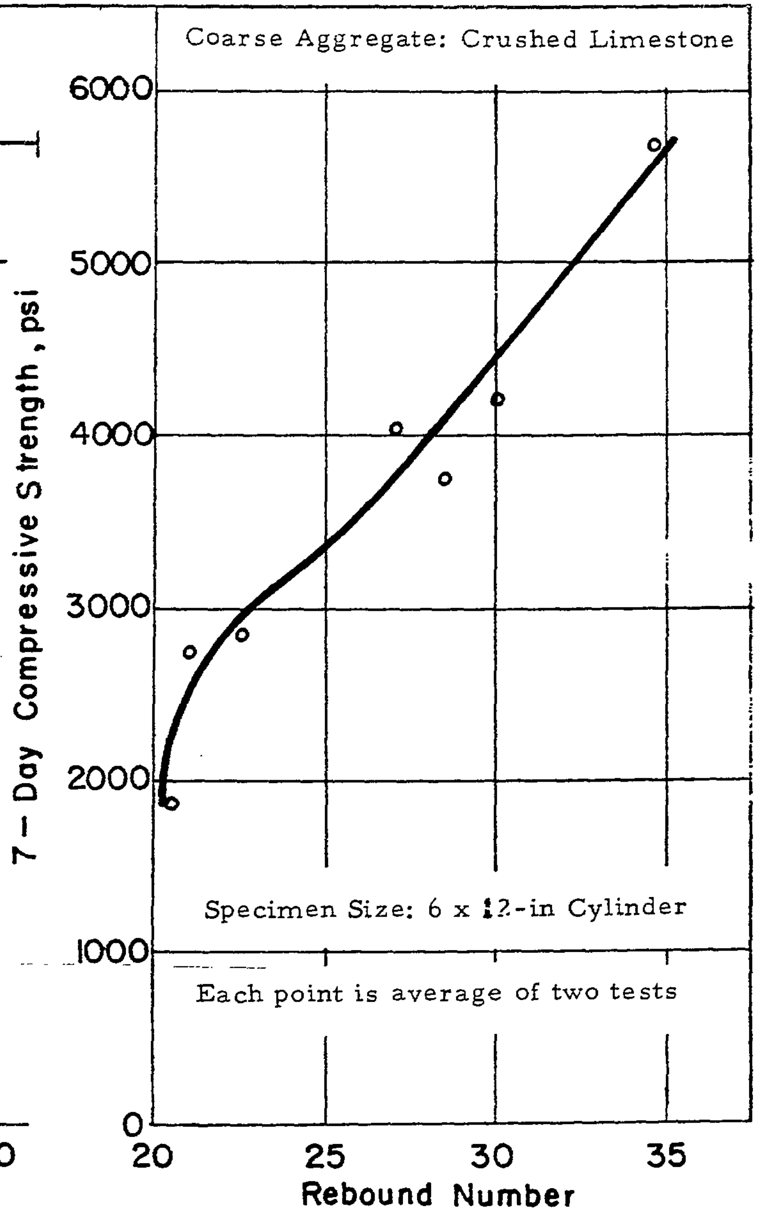


Fig. 8 - Relationship between exposed probe length and 7-day compressive strength of concrete cylinders

Fig. 9 - Relationship between rebound number and 7-day compressive strength of concrete cylinders

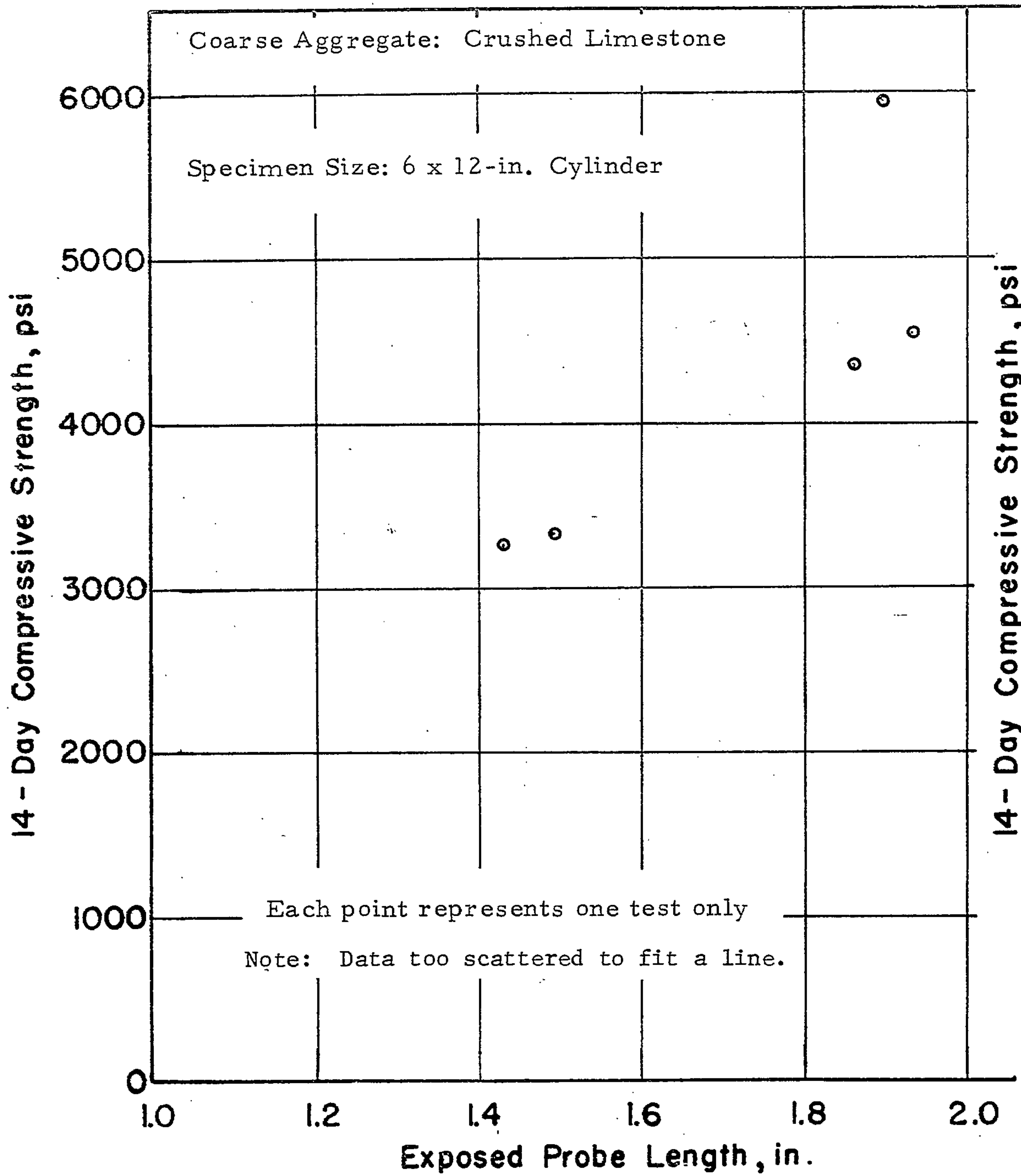


Fig. 10 - Relationship between exposed probe length and 14-day compressive strength of concrete cylinders

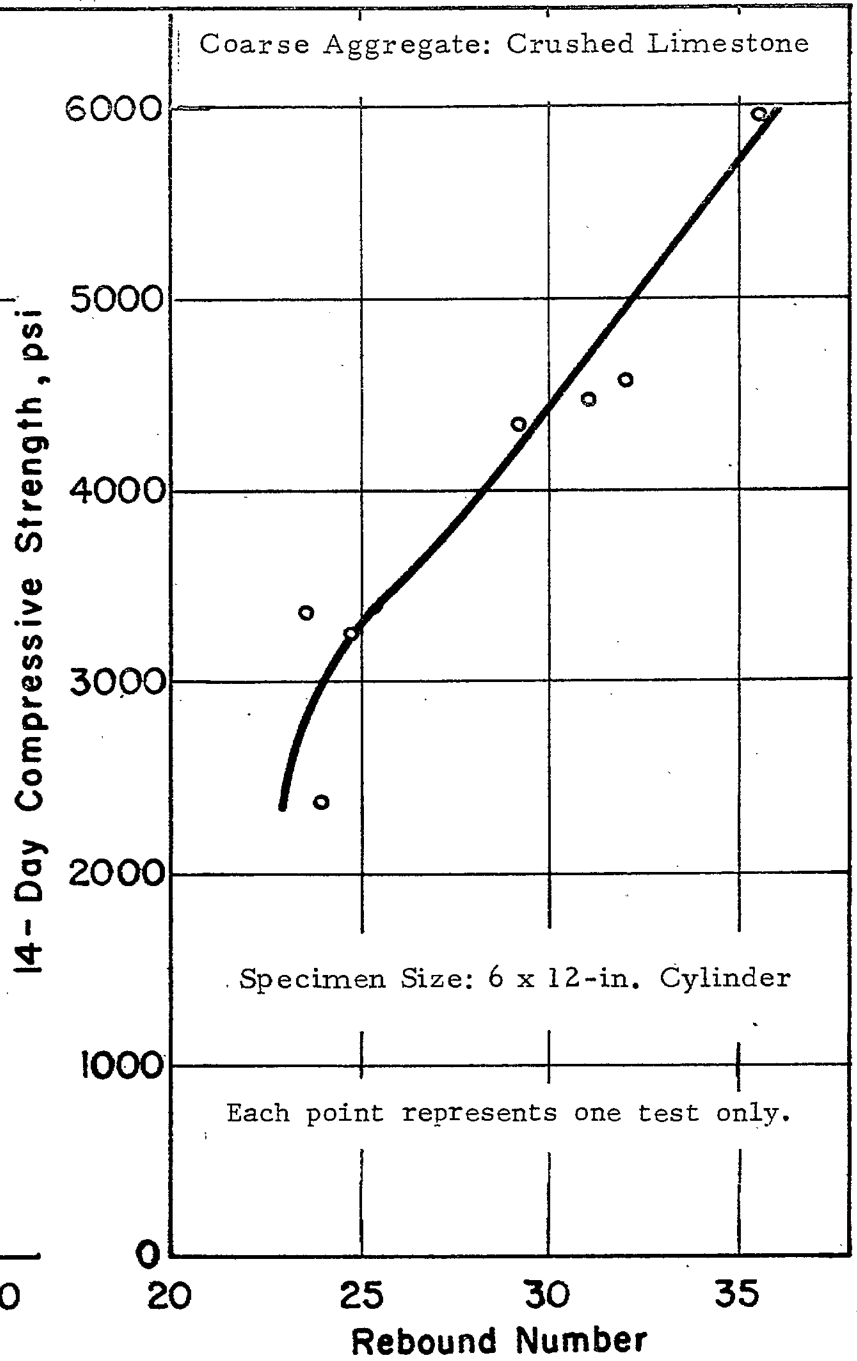


Fig. 11 - Relationship between rebound number and 14-day compressive strength of concrete cylinders.

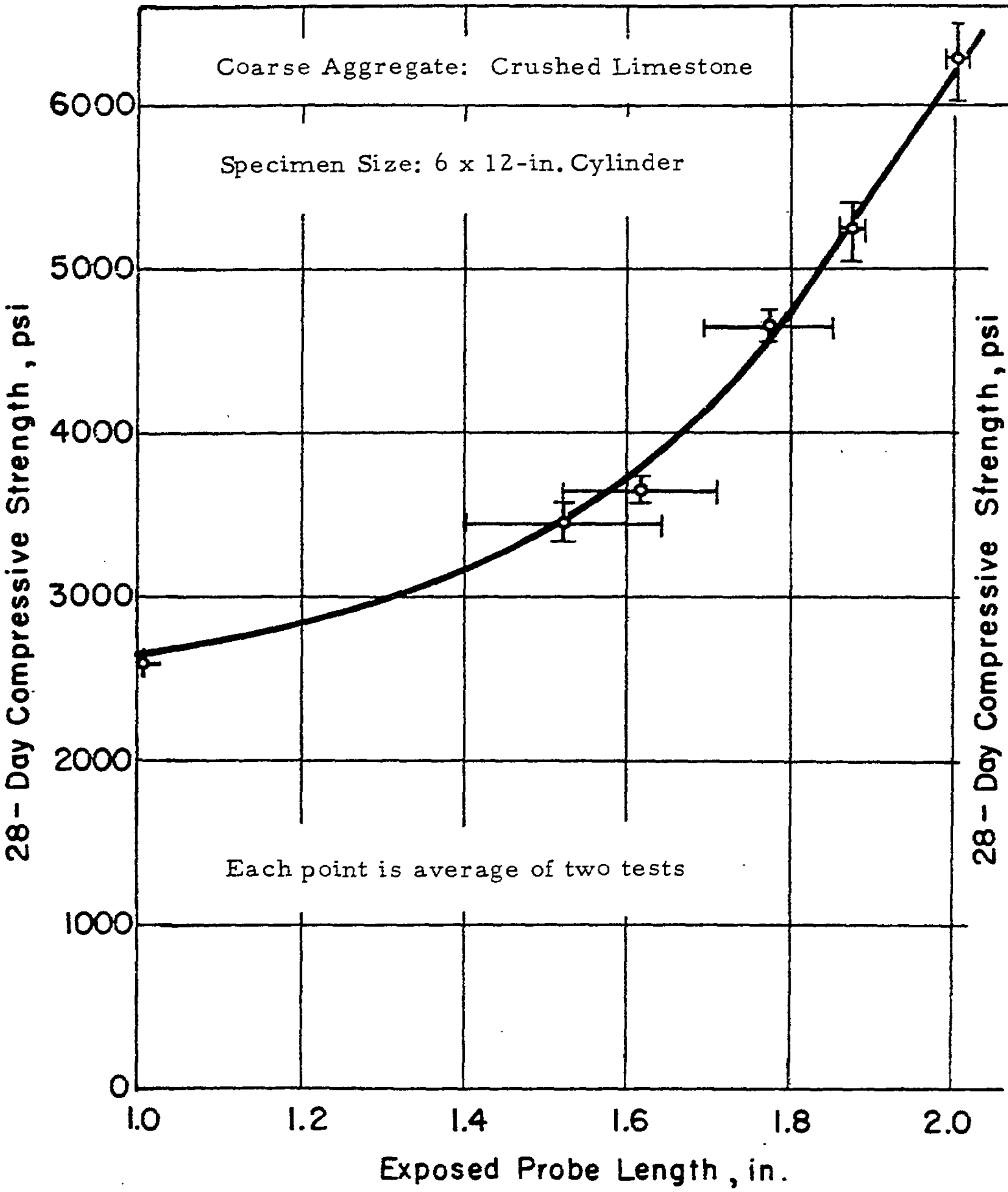


Fig. 12 - Relationship between exposed probe length and 28-day compressive strength of concrete cylinders

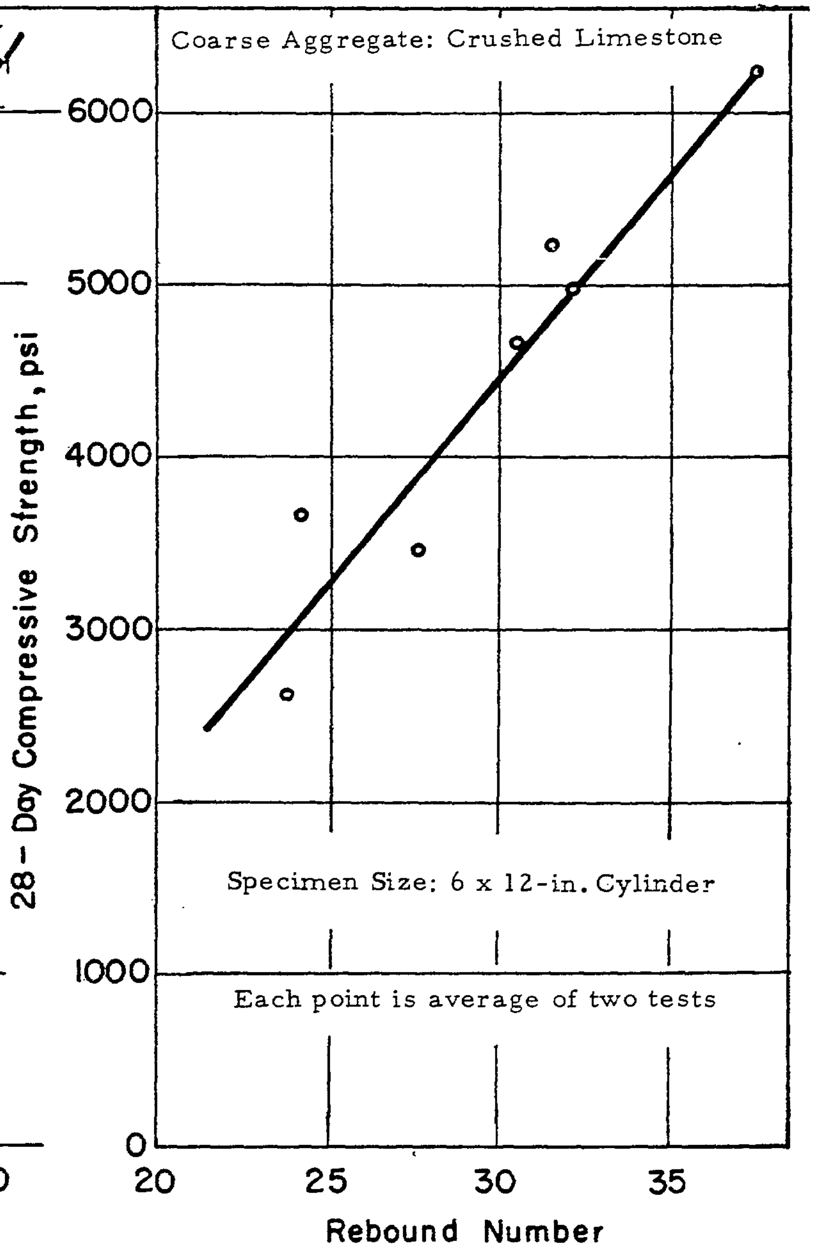
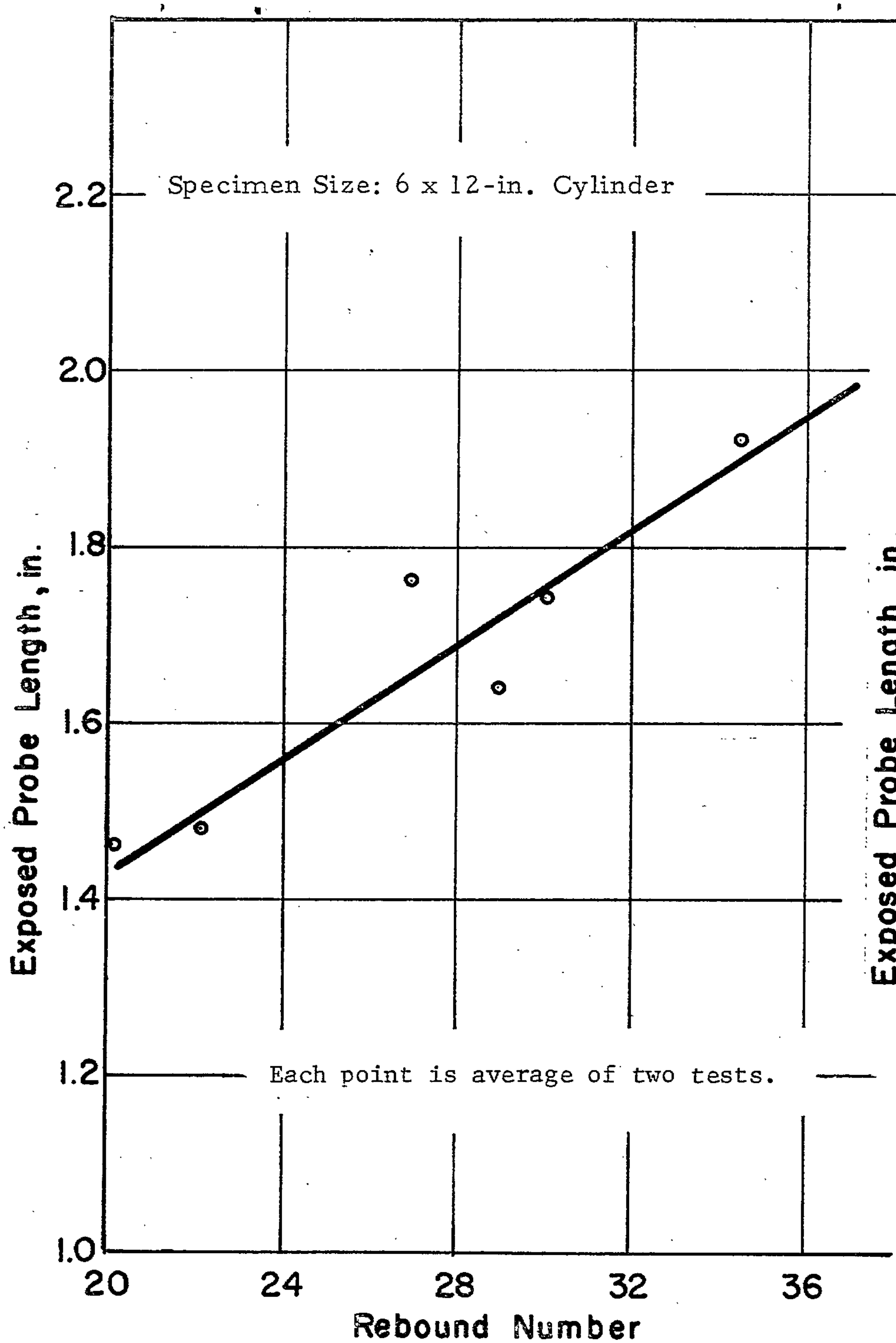


Fig. 13 - Relationship between rebound number and 28-day compressive strength of concrete cylinders



.ig. 14 - Relationship between rebound number and exposed probe length for 7-day concrete cylinders

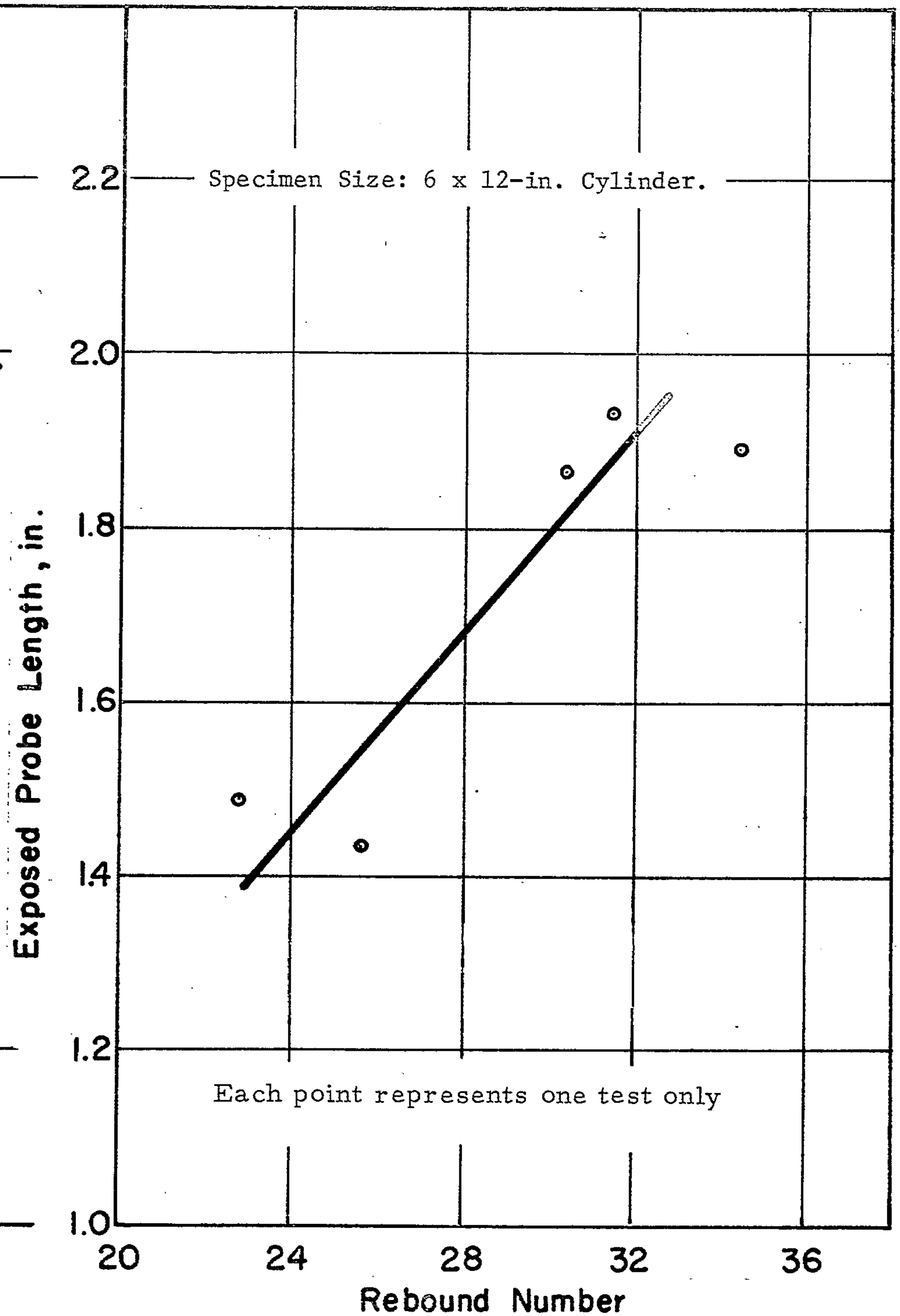


Fig. 15 - Relationship between rebound number and exposed probe length for 14-day concrete cylinders

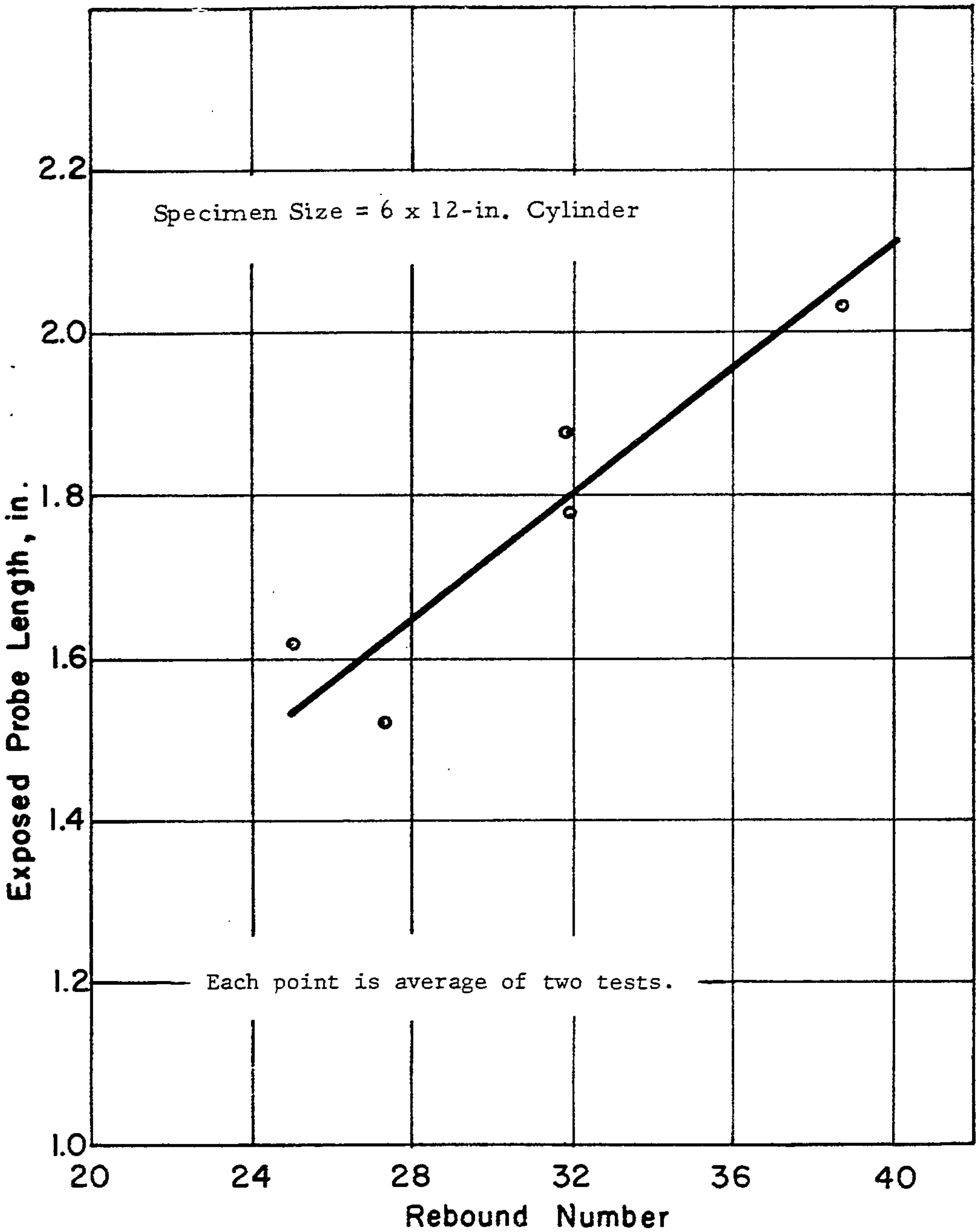


Fig. 16 - Relationship between rebound number and exposed probe length for 28-day concrete cylinders.

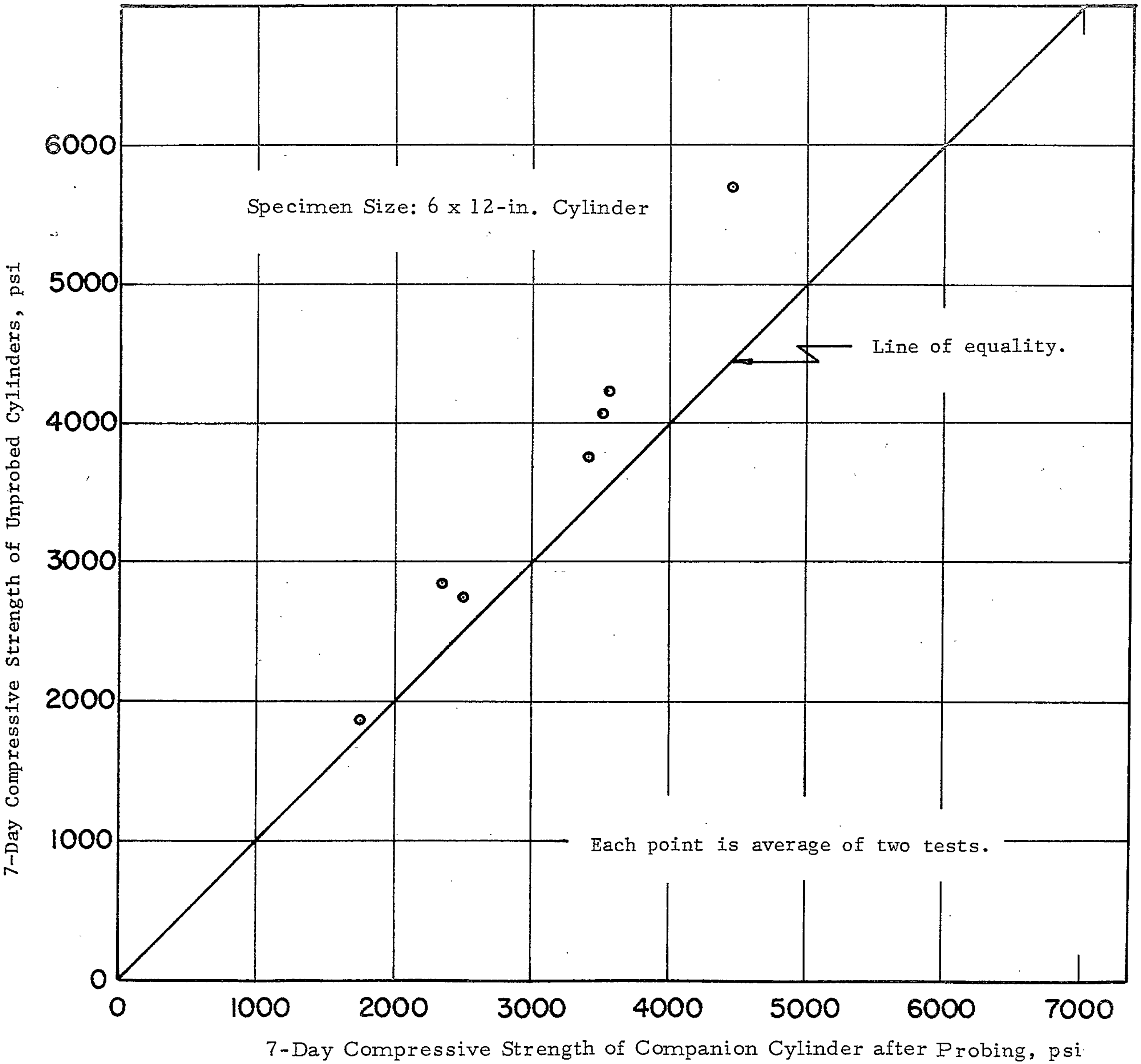


Fig. 17- Relationship between 7-day compressive strength of unprobed and companion probed cylinders

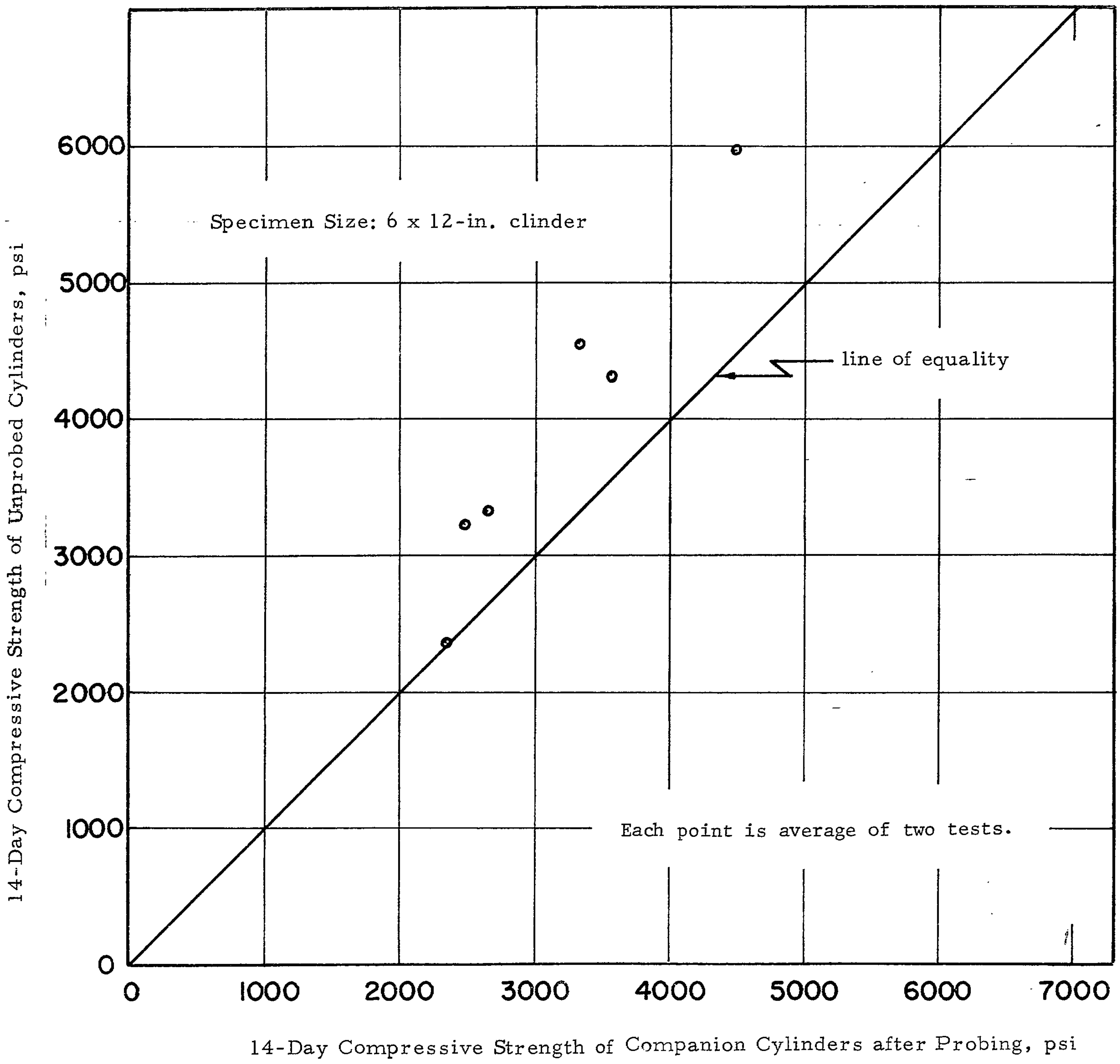


Fig. 18-Relationship between 14-day compressive strength of unprobed and companion probed cylinders

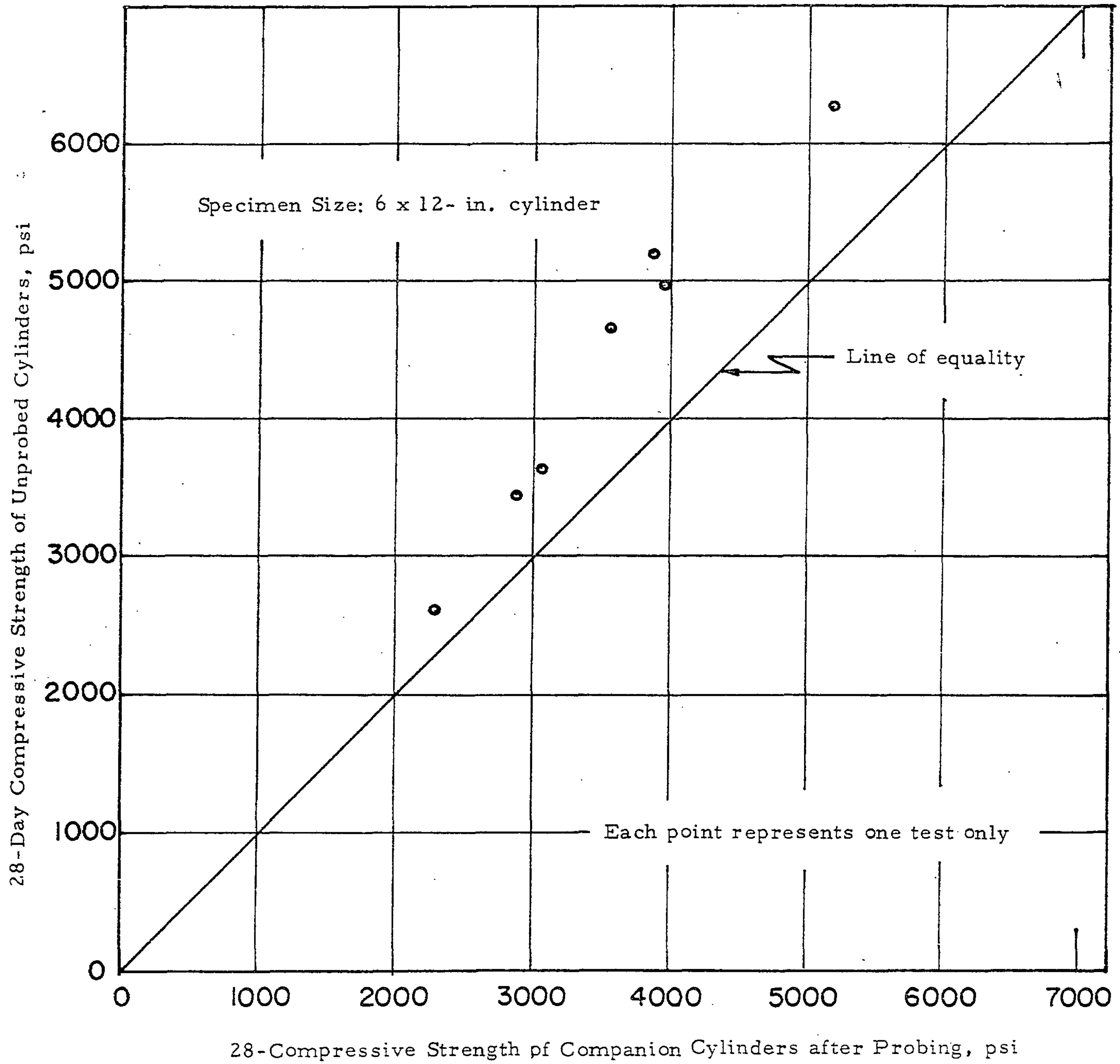


Fig. 19-Relationship between 28-day compressive strength of unprobed and companion probed cylinders

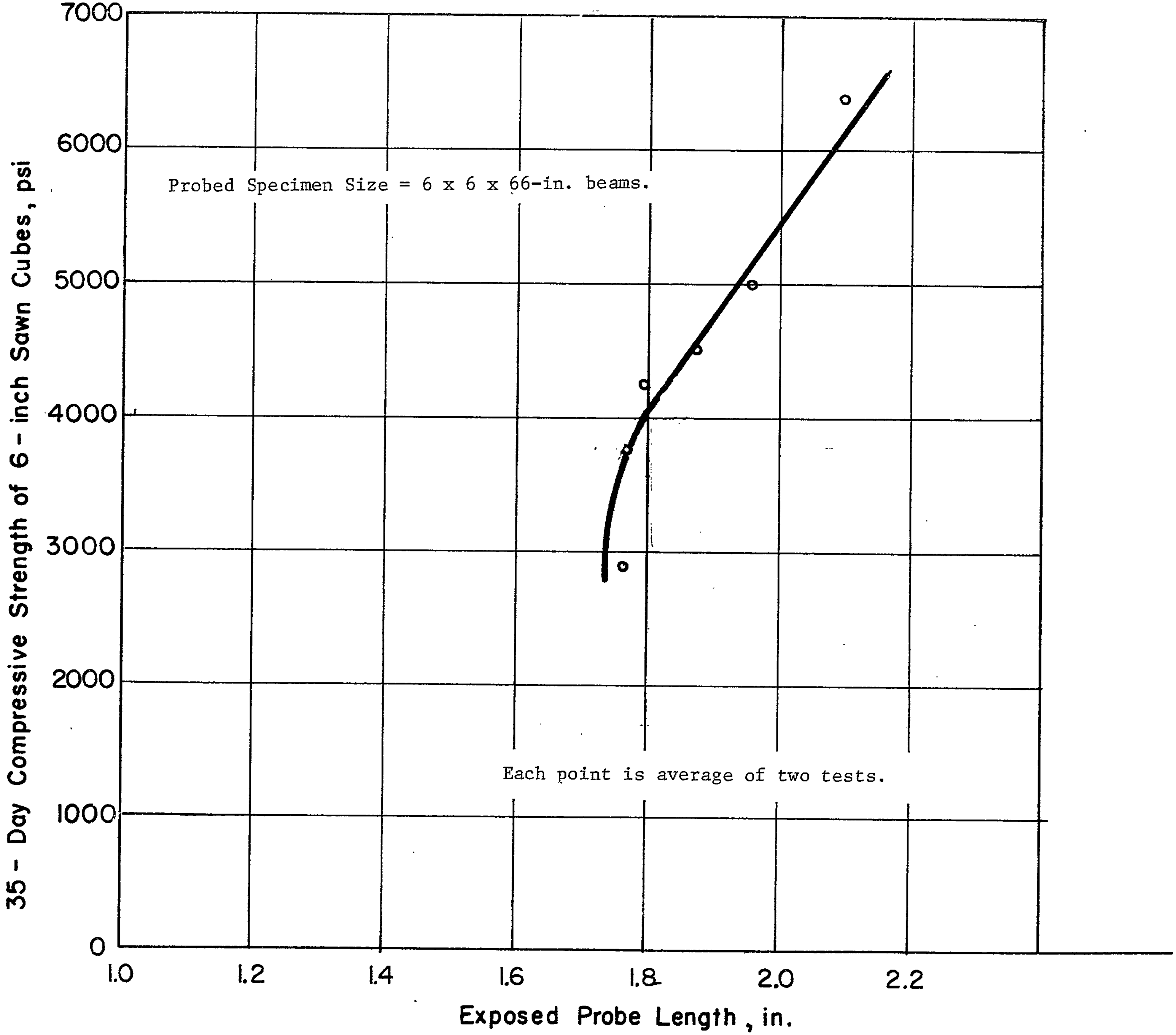


Fig. 20 - Relationship between exposed probe length and 35-day compressive strength of sawn cubes.

DISCUSSION OF TEST RESULTS

Operation of Windsor Probe Equipment

The Windsor Probe equipment is simple and within the easy grasp of an average laboratory technician. The equipment is well made, rugged, and needs little maintenance except occasional cleaning of the barrel of the gun. The system has a number of built-in safety features and these prevent accidental discharge or escape of the projectile from the gun. However, wearing of safety glasses is strongly advised. The replacement of the single probe locating template may be needed at times because in this programme some damage to the template was noticed near the end of the investigation.

Calibration of the Windsor Probe

The manufacturer of the probe system has published calibration tables relating exposed length of the probe with compressive strength of concrete. For each probe value, different values for compressive strength of concrete are given depending on the hardness of the aggregate being used. The aggregates used in this investigation were crushed limestone and gravel having hardness numbers of 5.5 and 6.5, respectively, on the Mohs' scale* of hardness. Table 10 gives compressive-strength values interpolated from the manufacturer's tables and those actually obtained. It is seen that manufacturer's tables cannot be used with satisfactory results and it is imperative for each user of the probe to calibrate his probe with the type of aggregate he is using.

Detection of Increase in Strength with Increasing Age

For the same concrete mix, the exposed length of the probes increased with increasing age. For example, for Mix I, Series I, the exposed length of probe increased from 1.920 inches at 7 days to 2.035 inches at 28 days. This indicates that probe measurement can be useful for comparative studies.

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*Named after mineralogist Mohs who devised a scale of hardness in which talc, the softest of all minerals, is given No. 1, while diamond, the hardest of all known substances, is numbered 10.

TABLE 10

Exposed Length of Probe and Compressive Strength

Mix Series I				Mix Series II			
Coarse Aggregate: Crushed Limestone Mohs' Hardness Number 5.5				Coarse Aggregate: River Gravel Mohs' Hardness Number: 6.5			
Mix No.	Average Exposed Length of Probe, in.	28-Day Compressive Strength, psi		Mix No	Exposed Length of Probe, in.	35-Day Compressive Strength, psi	
		Actual	From* Tables			Actual	From* Tables
1	0.985**	2600	***	1	1.760	2855	3065
2	1.615	3635	2715	2	1.770	3710	3150
3	1.520	3445	1965	3	1.798	4080	3385
4	-----	----	----	4	1.872	4405	4005
5	1.772	4650	3935	5	1.949	4650	4650
6	1.880	5220	4770	6	1.968	6710	4810
7	2.035	6255	5970	7	2.081	6410	5755

* From tables supplied by the manufacturer.
** Exposed length of probe divided by 2 to correct for the use of half power.
*** No corresponding figures available from the manufacturer's tables.

Compressive Strength of Probed Cylinders

The test cylinders were somewhat damaged after probing (Figures 3 and 4). There was surface spalling as well as some cracks. The probed cylinders when tested had lower strengths than the companion test cylinders. (Figures 17 to 19). The difference in strength increased with increase in the compressive strength of concrete. For 28-day test results, the difference in the strengths varied from 11.5 per cent for low-strength concrete (Table 7, Mix I) to 17.5 per cent for high-strength concrete (Table 7, Mix 7). The greater loss for high-strength concrete is probably due to the fact that the concrete surface gets harder with age and strength and consequently more shattering results as test cylinders are probed.

Use of Half-Power for Probes and Low-Strength Concrete

The manufacturer of the Windsor probe test system has suggested the use of half-power for probes when testing concrete with compressive strength below 2500 psi. This was tried in low-strength mixes of Series I Table 1) but unfortunately the corrected value of the exposed length of the probe did not fall in line with the other data. A few other exploratory probes were also fired using half-power but no satisfactory test results were obtained. It is considered that as far as possible, in a single test programme, the use of both full- and half-power for driving probes should be avoided. If low-strength concrete is to be tested using half-power for probes, then separate correlations should be established between the exposed length of the probe and the compressive strength of the concrete.

In some cases, when the strength of concrete exceeded 5000 psi at 28 days, the probes failed to remain in place after firing; hence no measurements of the exposed length of the probes were possible.

Variation in the Probe test Results

The standard deviation and coefficient of variation for the probe test results (Table 9) varied from 0.062 to 0.137 inches and 3.4 to 8.6 per cent, respectively. The corresponding values for the compressive strength test (Table 9) varied from 99 psi to 140 psi and from 2.0 to 4.2 per cent, respectively. Notwithstanding the limited nature of the data, the within-batch variation for the probe test is up to three times as high as in the strength test. In a test programme in which 625 probes were used, Cantor (6) obtained a standard variation of about 1550 psi, a coefficient of variation of about 35 per cent, and a range in predicted compressive strength of 5600 psi. This large variation in the probe test may be due to the fact that the test is essentially a point test on an area less than one sq. in; the corresponding area in compression for a 6 x 12-in. cylinder is 283 sq in. During this investigation no attempt was made to determine the uniformity of probes and loading charges.

Correlation between Compressive Strength and Probe Test Results

The correlations between compressive strength and probe test results are shown in Figures 8 to 13 and in Figure 20. The limited nature of the investigation did not allow the data to be subjected to regression analysis but nevertheless there is some degree of correlation and this is true for test results at all ages. The large variation in the probe test results makes it doubtful whether compressive strengths can be predicted with a reasonable degree of accuracy without resorting to a large number of probes per test. This aspect of the probe test system needs further study.

Because of the large variability in the probe test results, the usefulness of this new test approach lies in determining the relative quality of concrete in place rather than in its use as a means of quantitatively predicting the 28-day compressive strength of concrete.

Damage to Test Specimens caused by Probing

The claim that the Windsor probe is a non-destructive test is not exactly true. The test cylinders were badly damaged by probing and clearly visible cracks developed in the beams during testing (Figures 4 to 7). However, in testing of massive concrete sections, e.g., bridge abutments etc., the damage would be relatively small and may consist of a minor disturbance on a very small area with a 5/16-in. hole in the concrete for the depth of the probe. This damage would be of little consequence if testing is being carried out on the side of a wall which is to be backfilled; however, on an exposed face this damage would be unsightly and would require repairs. The test may be considered non-destructive to the extent that concrete can be tested in-situ and structural members need not be discarded after test.

Windsor Probe Versus Schmidt Test Hammer

The probe system is basically a hardness test. As the probe can penetrate up to 2 inches in concrete, it has a built-in superiority over the impact test hammer which is a surface hardness tester only. Because of the greater penetration in concrete, the probe test results should be influenced to a lesser degree by surface moisture, texture, and carbonation effects. Where cost is a critical factor, the above advantages of the Windsor probe test may be offset by the fact that the initial cost of the system is almost twice that of the test hammer and there are recurring expenses for the probes. Both tests have the disadvantage that they damage the concrete surface to varying degrees. The test hammer leaves surface blemishes on young concrete whereas the probe leaves a 5/16-in. diameter hole for the depth of the probe and may cause minor cracking.

Figures 9, 11, 13, show correlation between rebound number and compressive strength for the same set of cylinders as were used for the correlation between the probe and compressive strength. The two types of correlation appear very much alike (Figures 7-12).

The plots of the test data for the probe test and the rebound number (Figures 14-16) show wide scatter indicating poor correlation between these two parameters.

CONCLUSIONS

Nothwithstanding the limited nature of the investigation, it is concluded that:

1. The Windsor probe test is suitable for determining the relative quality of concrete test specimens and concrete in place in much the same way as is the Schmidt test hammer. However, its usefulness in quantitatively predicting the 28-day compressive strength of concrete is doubted because of relatively large within-batch variation in the probe test results.

2. The Windsor probe test system has a built-in superiority over the Schmidt test hammer because of the greater penetration of the probes in concrete. However, this advantage is offset by the higher initial cost for the system and recurring costs for the probes.

3. Each user of the Windsor probe equipment should prepare his own calibration chart for the type of concrete under test.

4. The test specimens once probed cannot be reused for determining compressive strength of concrete because of the damage sustained during probing.

RECOMMENDATION

It is suggested that the Windsor probe test be incorporated in any new concrete strength evaluation programme.

REFERENCES

1. Anon., "Probe Quickly Shows Concrete Strength", Engineering News Record, December 4, 1969.

2. Sidney Freedman, "Field Testing of Concrete Strength", Modern Concrete, February 1969, pp.32-37.

3. Letter dated January 21, 1970, from R.M. Bremner, Commissioner, Department of Public Roads, City Hall, Toronto, Ontario.

4. Letter dated March 4, 1970, from J. Hode Keyser, Chief Engineer, City of Montreal, Montreal.

5. V.M. Malhotra, "Nondustructive Methods for Testing Concrete", Mines Branch, Monograph 875, 1968.

6. T.R. Cantor, "Status Report on the Windsor Probe Test System", Draft Report Distributed at the meeting of Highway Research Board Committee A2-E3, Washington, January 1969.

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