44

Louisiana Highway Research

CONCRETE PROBE-STRENGTH STUDY

Louisiana Department of Highways – Research & Development Section

CONCRETE PROBE-STRENGTH STUDY

by

S. M. LAW
ASSISTANT RESEARCH ENGINEER

and

W. T. BURT III
PAVEMENT RESEARCH ENGINEER

Final Report

Research Report No. 44

Research Project No. 68-2C(B)
Louisiana HPR 1 (7)

Conducted by
LOUISIANA DEPARTMENT OF HIGHWAYS
Research and Development Section
In Cooperation with
U. S. Department of Transportation
Federal Highway Administration
BUREAU OF PUBLIC ROADS

December 1969

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

SYNOPSIS

This report is an evaluation of the effectiveness of the Windsor Probe-Test System in determining the compressive strength of concrete.

The Windsor Probe-Test System is a rapid non-destructive system for determining concrete compressive strength. The probe test compresses a section of the concrete by actually penetrating the materials. This is accomplished by the forced entry of a hardened alloy probe driven into the concrete by use of a powder charge fired by a special driving unit (gun). Depth of penetration of the probe into the concrete is the basis of measuring compressive strength.

Concrete test slabs were poured at the laboratory and concrete cylinders and beams were molded along with these slabs. At various ages the slabs were tested with the probe test system and the concrete cylinders were tested for compressive strength. The slabs were also cored and the cores tested for compressive strength. The compressive strength results of the probe test system were compared with the cylinder and core strength results. The concrete beams were tested with the probes to observe the effect of narrow widths of the beams and small edge distances on the depth of penetration and cracking pattern. The probe tests caused a great amount of cracking and affected the probe results when used closer than five to six inches from the edge of the structure, in this case concrete beams.

Two strength curves were derived from these comparative results. One curve showed the relationship of cylinder compressive strengths plotted against exposed inches of probe, and another curve showed the relationship of core compressive strength plotted against exposed inches of probe.

Field projects in North and South Louisiana were chosen to validate these two curves using the same type aggregate from different sources. One roadway pavement project was chosen in the Baton Rouge area using the same type and source of aggregate as was used in the laboratory study, and one roadway pavement project was chosen in North Louisiana in the Monroe area, with a different source of aggregate. The same procedure was used in the field as in the laboratory phase of the research study. The results of field cylinder and core compressive strengths were compared with strengths taken from the laboratory curves using the probe depths as found with the Windsor Probe-Test System. One project in the Baton Rouge area was also chosen to check vertical wall tests with the probe test system. This was accomplished on a twin box culvert.

The two laboratory curves produced a correlation coefficient of 0.95 for the

cylinder curve and a correlation coefficient of 0.99 for the core curve. However field compressive strengths for cylinders and cores appear to vary considerably from the laboratory curves, with concrete core compressive strengths especially varying.

The manufacturer of the Probe-Test System has developed some curves for determining compressive strength using the Moh's hardness scale as the third dimensional coordinate. The laboratory curves seem to fit the actual results much better for our test data.

The number of individual tests required for valid results is contingent upon the information required. A minimum of three individual tests (probes) is required for statistical data, such as standard deviations or coefficients of variation, while more may be needed for other purposes. The cost of a Windsor probe test is $1.75 for the probe, plus the cost of two to four minutes of testing time. A standard formula for the cost used for coring is $\frac{\$1.00}{\text{dia.-inch}}$ x inches-depth, plus costs for transporting, squaring ends, soaking and capping. This quoted figure would amount to approximately $2.50 for a four-inch core with a depth of ten inches.

Conclusions were as follow:

(1) The Windsor Probe-Test System is fast, simple and easy to use, and less expensive than coring.

(2) Probe measurements give statistically good results when using the same material, aggregate source, mix type and proportions, and water-cement ratio. Quality of the cylinders or cores may affect correlation results.

(3) Probe strengths can be correlated to strengths of cores and cylinders. Tests can be made at any age and are not limited in use as is the case with cylinders.

(4) The Bureau of Public Roads has stated that the type and size of aggregate have an effect on the results obtained with the probes; therefore a correlation will have to be made for each change of type or size of aggregate. Results of this study tend to substantiate this conclusion.

(5) Probe tests are fairly accurate although in this study results were not as good as the manufacturer's claims of accuracy within ±5 percent. The results of this study averaged within ±8 percent accuracy. Results obtained in this study do not give a satisfactory correlation with the manufacturer's curves using the Moh's hardness scale.

(6) Problems do exist in the use of probes in chert or hard aggregate, such as probes breaking, entering concrete crooked, being loose and causing spalling of the concrete. This leaves a marred appearance on the concrete surface.

(7) Operator technique does play a part in obtaining good results and creating a safe operation.

(8) Probe tests could be useful in concrete pipe testing, in comparing strengths in various areas of structures, or in determining strength gain in structures. However, no great advantage can be seen over the Schmidt hammer in checking strength gain in structures.

(9) Further studies should be made.

Recommendations are as follow:

(1) Final judgment should be delayed until all evidence is in on the Windsor Probe-Test System. In addition to the material covered in this study the final report of the Bureau of Public Roads and any other supporting evidence from other groups or agencies should also be considered.

(2) Studies should be made comparing the Windsor Probe-Test System to ultrasonic devices, nuclear probes and surface hammers with rebound measurements. Further depth studies of cylinder and core comparisons should also be made under varying conditions.

(3) In the meantime, use of the Windsor Probe-Test System is not recommended as a device to replace cylinders or cores for determining the compressive strength of concrete. The Windsor Probe-Test System could be used in the determination of strength gain or comparison of strengths of various areas of concrete structures, in place of, or in conjunction with, the Schmidth hammer when requested.

INTRODUCTION

The need for improved field testing of concrete has been generally recognized. There are some questions arising as to what comprises the true compressive strength of concrete. At present the two most widely accepted means of obtaining compressive strengths of concrete are (1) molded cylinders tested in compression, and (2) concrete cores tested in compression. Generally compressive strengths of concrete cores are slightly higher than compressive strengths of molded cylinders. Other means of obtaining compressive strengths include nuclear probes, ultrasonic devices and surface hammers with rebound measurements.

The Windsor Probe-Test System was designed to conform to the A.C.I. Standards of Concrete Control 214-65. The Windsor Probe-Test System is useful in checking strength development and predicting 28 day strength as early as 3 days. A Windsor probe is driven into the concrete by use of a driving unit (gun). The depth of penetration of the probe is a measure of the strength of the concrete.

The Bureau of Public Roads has done some research in evaluating the Windsor Probe-Test System. The variables listed in their research program were type of aggregate, size of aggregate and time of curing, with the primary concern being the effect of aggregate type and size on the relation between cylinder strength and probe penetrations. The Bureau's studies indicated that both type and size of aggregate have an effect on the results obtained with the probe.

The original curve provided by the manufacturer of the instrument was based on core strengths. Later curves were developed from the Bureau of Public Roads test data on cylinder strengths. This data produced a computerized curve which is a composite line for limestone, quarzitic gravel and trap rock. The Windsor curve represents the average strength of the top and bottom sides of the slabs. The manufacturer states that drilled cores should show lower strengths than Windsor values with the reduction in value (strength) being in the order of 10 to 15 percent. The core and cylinder strength relationship is one that is not settled to the authors' satisfaction.

The manufacturer's test data consisted of 360 probe tests compared to 190 molded cylinders over a period of fourteen months. This evaluation was correlated to A.S.T.M. Standards C-39 and C-42. The manufacturer used twelve other reports mostly from consulting engineers, with their tests to compute a coefficient of correlation of 98.8 percent.

Later curves developed by the manufacturer relate concrete compressive strength versus probe measurements to Moh's aggregate hardness scale. The scratch test is used to obtain the Moh's hardness and then the strength is obtained by using the probe measurement on the appropriate hardness line.

The Louisiana Department of Highways is evaluating the Windsor Probe-Test System with one type of aggregate (chert) as a basis of comparison to fit Louisiana aggregate conditions. It is the researchers' opinion that this information along with previous research accomplished by the Bureau of Public Roads will be meaningful in evaluating this device for obtaining compressive strengths of concrete, especially in the field.

PURPOSE

The purpose of this research study was to evaluate the Windsor Probe-Test System for determining the compressive strength of concrete and make recommendations on the future use of this system.

SCOPE

The scope of this research study was to compare probe strengths versus compressive strengths obtained from cylinders and cores taken from laboratory and field-poured concrete. Advantages and disadvantages of the system were a prime consideration in the evaluation and comparisons were made between compressive strengths obtained from cylinders and cores and the Windsor Probe-Test System. Cost and efficiency were also taken into account.

METHOD OF PROCEDURE

There were two phases to this research study, laboratory and field. The laboratory phase compared the Windsor Probe-Test System penetration values against compressive strengths obtained by cylinders and cores. Two curves were derived by plotting cylinder or core compressive strengths against exposed inches of probes. The field phase of the research study validated the laboratory curve strength values against field strength values obtained by cylinders or cores.

The laboratory phase of the study consisted of the following:

(1) pouring four*-36" x 48" x 8" concrete slabs (no steel reinforcement).

(2) normal field curing (seven days with a wet burlap covering).

(3) molding twelve-6" x 12" concrete cylinders and eight-6" x 6" x 20" concrete beams for each set of slabs and cured with a wet burlap covering.

(4) testing each individual slab with the Windsor Probe-Test System, one slab being tested at each age, the time intervals generally being 4, 7, 14 and 28 days.

(5) testing three cylinders in compression at each age (the age varied due to existing conditions).

(6) coring the slab (two cores) that was tested at each age interval and obtaining core compressive strengths.

(7) testing the beams with the Windsor Probe-Test System at each age interval to note the effect probes have on narrow width beams.

(8) comparing the compressive strengths obtained by these methods.

(9) developing two curves, one with the average exposed inches of probe plotted against the average cylinder compressive strength and the other with the average exposed inches of probe plotted against the average core compressive strength.

* Actually two sets of slabs (total of eight) were poured in the laboratory phase of the study due to existing conditions of bad weather and equipment breakdowns. However all results acquired were used in the evaluation.

(10) noting the general observations.

The field phase of the study consisted of the following:

(1) selecting field projects to use in the evaluation, one roadway pavement in South Louisiana (Baton Rouge area) using the same source of aggregate as in the laboratory phase of the study, and one roadway pavement in North Louisiana (Monroe area) using a different source of aggregate, and an additional project for a study of vertical wall strength determinations (a twin box culvert in the Port Allen area near Baton Rouge).

(2) obtaining mix data.

(3) molding nine concrete cylinders on each project when the slab was poured, and curing these cylinders in the same manner the slab was cured.

(4) testing at 7, 14 and 28 days with the Windsor Probe-Test System on each project, using the statistical setup as shown in Figure 1.

(5) taking two cores at each age and testing for compressive strength on both cores and concrete cylinders.

(6) comparing actual cylinder and core strength with laboratory computed (curve) results.

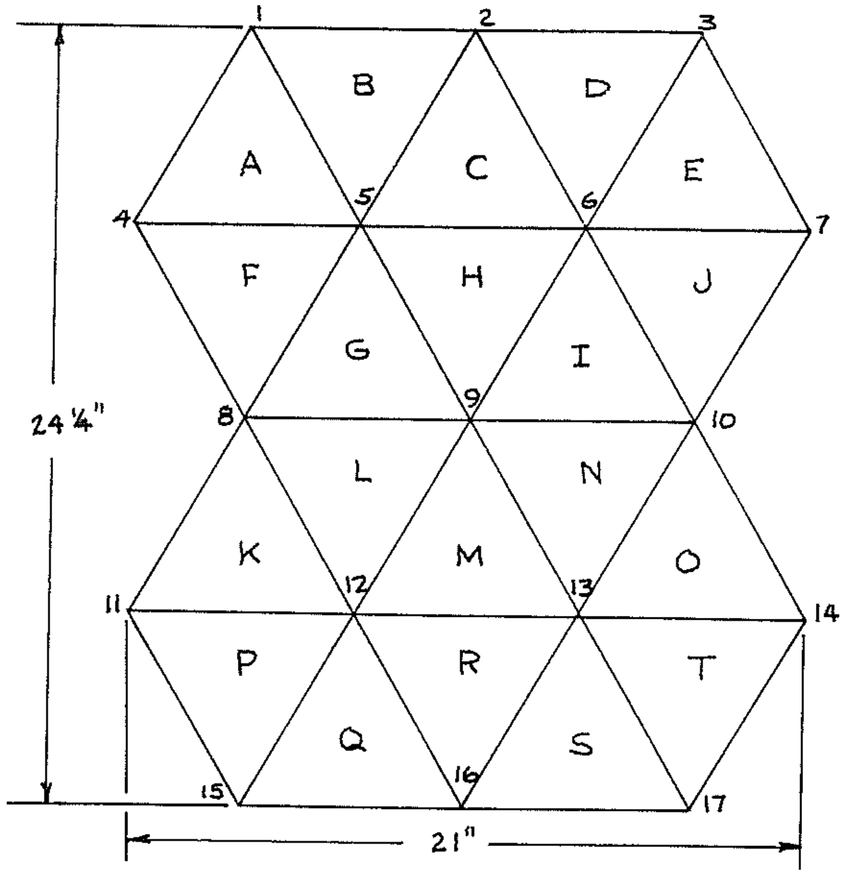
(7) noting general observations.

Samples of aggregate were taken from each source and Moh's hardness was determined. Using the manufacturer's probe-strength hardness curves, comparisons were made with test data obtained.

FIGURE 1

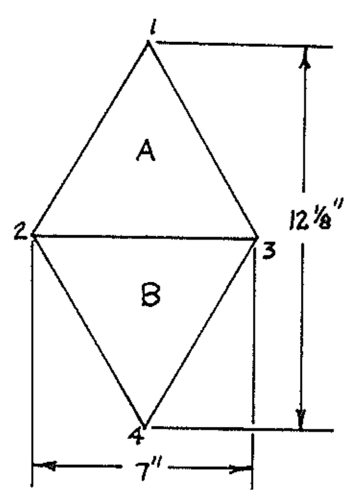
SKETCH OF PROBE CONFIGURATIONS

Slabs



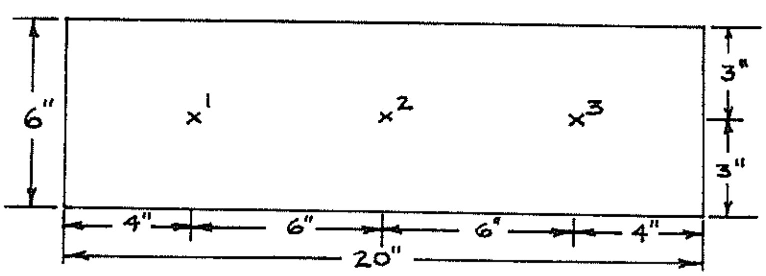
17 Probes
20 Triangles

Vertical Wall



4 Probes
2 Triangles

Beams



3 Probes

DISCUSSION OF RESULTS

The data from the closely controlled laboratory concrete pour includes probe penetrations, concrete cylinder strengths and concrete core compressive strengths. Two strength curves were derived from data obtained from laboratory concrete pours. One curve, shown in Figure 10, compares concrete cylinder compressive strengths versus probe penetrations, while the other curve, shown in Figure 12, compares concrete core compressive strengths versus probe penetrations. Each data point plot is included with both of the two curves to delineate data scattering from the curve. Figures 11 and 13 show the individual point plots derived from their respective field strength values for cylinders and cores with the laboratory-derived curves superimposed to delineate field data point scattering from the laboratory curves.

The laboratory curves produced a correlation coefficient of 0.95 for the cylinder curve and a correlation coefficient of 0.99 for the core curve. However field compressive strengths for cylinders and cores appear to vary considerably from the curves, with concrete core compressive strengths especially varying as shown in Figure 13. Field cylinder compressive strengths, as shown in Figure 11, appear to fit fairly well with the laboratory curve except for the "E" pour (North Louisiana field pour) data.

The aggregate source for the North Louisiana project is different from the South Louisiana projects; however the aggregate is still chert. Therefore the hardness is essentially the same, with a Moh's hardness of 7. Since many variables influence concrete's strength-age relationship, it is difficult to determine exactly what the reason is for the high strength shown and the lack of compatability with the laboratory cylinder curve. Possibly the curing of the cylinders or the making of the cylinders could have influenced the high strength.

Other curves which are useful in showing test results are shown in Figures 14 through 20. Figure 14 shows exposed inches of probe versus age of concrete in days. One can see that the probe measurements do increase uniformly and all field data for the probes do not vary appreciably. Figure 15 shows cylinder compressive strength versus age of concrete in days. Again, one can see the high compressive strength and gain in strength for the "E" pour as compared to the other pours. However Figure 16 shows a less drastic difference in strength for the cores. Figures 17 and 18 show cylinder and core compressive strength ranges respectively in relation to their laboratory curves.

The manufacturer of the Probe-Test System has developed curves for determining compressive strength using the Moh's hardness scale as a third dimensional coordinate. Figures 19 and 20 show cylinder and core compressive strength ranges plotted with their respective laboratory curves on the manufacturer's hardness curves. As one can see, in Figures 19 and 20 considering the Louisiana aggregate (chert) to have a Moh's hardness of 7, the actual cylinder and core compressive strength results are considerably above the manufacturer's No. 7 curve. For any single probe measurement the manufacturer's No. 7 curve gives a much higher strength than the actual cylinder or core breaks. The authors' constructed curves seem to fit the actual results much better for our test data.

Table 1 on pages 13 and 14 of the Appendix gives direct comparisons of test results. For cylinder strengths, actual cylinder breaks (column 4) can be compared against constructed cylinder curve compressive strengths (column 6a). For core strengths, actual core breaks (column 5) can be compared against constructed core curve compressive strengths (column 6b). Column 6c gives the compressive strength obtained from the manufacturer's hardness curve No. 7. As one can see, the hardness curve values are generally much higher than actual strength values obtained from either cylinder or core breaks.

Tables 2 through 5 give the statistical data for the project test results. Table 2 gives cylinder and core compressive strengths, probe measurements, and hardness curve values with their means, average standard deviations, and the coefficients of variation for the various concrete pours.

Definitions of statistical terms are as follow:

$$\text{Mean} = \frac{\text{summation of values}}{\text{number of samples}} = \frac{\sum x}{n}$$

$$\text{Degree of Freedom (D.F.)} = \text{Number of samples} - 1 = n-1$$

$$\text{Variance} = \frac{\text{Summation Squared Deviations}}{\text{D.F.}}$$

$$\text{Standard Deviation} = \sqrt{\text{Variance}}$$

$$\text{Coefficient of Variation} = 100 \times \frac{\text{Standard Deviation}}{\text{Mean}}$$

The main observation is that the coefficients of variation of the cylinder compressive strengths ranged from 9.44 to 18.86 percent, the coefficients of variation of the core compressive strengths ranged from 2.98 to 28.29 percent, hardness curve coefficients of variation ranged from 14.29 to 44.65 percent, and probe measurement coefficients of variation ranged from 0.97 to 7.60 percent. The probe measurements gave better results for repeatability.

Good correlation results were dependent primarily on compressive strength results.

Good coefficients of correlation are obtained for the derived cylinder and core curves. A coefficient of correlation of 0.95 was obtained for the laboratory curve for cylinders, while a coefficient of correlation of 0.99 was obtained for the laboratory curve for cores. Actually if you would combine all cylinder and core results for the laboratory concrete pours and derive a combined curve, the coefficient of correlation also would be good, 0.96. However when you use all the data including the field data to construct curves, the coefficients of correlation drop off to approximately 0.89 as seen in Tables 3, 4 and 5.

The number of individual tests required for valid results is contingent upon the information required. A minimum of three individual tests (probes) is required for statistical data, such as standard deviations or coefficients of variation, while more may be needed for other purposes. The cost of a Windsor probe-test is \$1.75, for the probe, plus the cost of two to four minutes of testing time. A standard formula for the cost used for coring is $\frac{\$1.00}{\text{dia.-inch}} \times$ inches-depth, plus costs for transporting, squaring ends, soaking and capping. This quoted figure would amount to approximately \$2.50 for a four-inch core with a depth of ten inches.

Advantages and Disadvantages of the Windsor Probe-Test System

Some of the advantages of the probe-test system are as follow:

(1) It is fast, simple, easy to use and less expensive than coring.

(2) It can accurately differentiate relative strengths of various areas of structures or strength gain in one area. Probe results reflect strength development when measured at 3, 7, 14 and 28 days. Considering 3 to 28 days as 100 percent of the compressive strength gain, then from 3 to 7 days would be approximately 50 percent, 7 to 14 days would be an additional 25 percent, and from 14 to 28 days would be another 25 percent. In this manner strength development may be estimated at an early age.

(3) Enough tests can be taken to provide average strength of mass.

(4) The results are not affected by variations in transporting, placing and compacting as with cylinders.

(5) It is not subject to variables in taking cores.

(6) It is not subject to capping or compression machine calibration error.

Some of the disadvantages of the probe-test system are as follow:

(1) Tests will leave surface spalled areas, giving a bad appearance to the concrete surface. These spalled areas are difficult to patch.

(2) The probe tests will cause a great amount of cracking and affect the probe results if used nearer than approximately six inches to the edge of the structure.

(3) With the hard aggregate found in Louisiana and used on this study, a large number of broken probes will result. In addition, some probes will enter the concrete crooked.

(4) Different probes must be used for low or high strength ranges, under 1500 p.s.i. or over 7000 p.s.i., although this would not be of significant importance.

(5) There are problems associated with triangulation system of measurement as used by the manufacturer. On common corners in network of triangles, when probes are broken or lost, several triangular measurements are negated; therefore one should use only individual measurements.

(6) A different correlation curve should be used for different gradation or type aggregate. Too many variables can affect correlation, changes in mix design, curing of cylinders, making of cylinders, etc.

(7) A question arises as to what to relate a correlation curve to--cylinders or cores. What is true strength of concrete?

Some statements which the manufacturer makes are questionable or need clarifing:

(1) Probe measurements give true strength of concrete.

(2) Probe measurements are not affected by operator technique.

(3) Probe measurements are not affected by steel or large hard aggregate.

(4) There is a constant energy output (575 foot-pounds).

(5) Probe measurements are not limited in use and not related to mass as cylinders and cores are.

(6) Probe takes into account hardness, aggregate type.

(7) Accuracy is within ±5 percent. Our average results were within ±8 percent;

however there was some variation.

Cost, efficiency, accuracy and validation with sufficient test results are prime considerations in evaluating this device.

CONCLUSIONS

Conclusions from this study are as follow:

(1) The Windsor Probe-Test System is fast, simple and easy to use and less expensive than coring.

(2) Probe measurements give statistically good results when using the same material, aggregate source, mix type and proportions and water-cement ratio. Quality of the cylinders or cores may affect correlation results.

(3) Probe strengths can be correlated to strengths of cores and cylinders. Tests can be made at any age and are not limited in use as is the case with cylinders. The number of cylinders that are made determine how many tests are made and when these tests are made.

(4) The Bureau of Public Roads has stated that the type and size of aggregate have an effect on the results obtained with the probes; therefore a correlation will have to be made for each change of type or size of aggregate. Results of this study tend to substantiate this conclusion.

(5) Probe tests are fairly accurate although in this study results were not as good as the manufacturer's claims of accuracy within ±5 percent. The results of this study averaged within +8 percent accuracy. Results obtained in this study do not give a satisfactory correlation with the manufacturer's curves using the Moh's hardness scale.

(6) Problems do exist in use of probes in chert or hard aggregate, such as probes breaking, entering concrete crooked, being loose and causing spalling of the concrete. This leaves a marred appearance on the concrete surface.

(7) Operator technique does play a part in obtaining good results and creating a safe operation.

(8) Probe tests could be useful in concrete pipe testing, in comparing strengths in various areas of structures and in determining strength gain in structures. However no great advantage can be seen over the Schmidt hammer in checking strength gain in structures.

(9) Further studies should be made, whether by this Department or some other group. The Bureau of Public Roads has conducted a program of tests on the Windsor Probe-Test System already; however final results of their study are not known at this time.

RECOMMENDATIONS

The recommendations from this study are as follow:

(1) Final judgment should be delayed until all evidence is in on the Windsor Probe-Test System. In addition to the material covered in this study the final report of the Bureau of Public Roads and any other supporting evidence from other groups or agencies should also be considered.

(2) Studies should be made comparing Windsor Probe-Test System to ultrasonic devices, nuclear probes and surface hammers with rebound measurements. Further depth studies of cylinder and core comparisons should also be made under varying conditions.

(3) In the meantime, use of the Windsor Probe-Test System is not recommended as a device to replace cylinders or cores for determining the compressive strength of concrete. The Windsor Probe-Test System could be used in the determination of strength gain or comparison of strengths of various areas of concrete structures, in place of, or in conjunction with, the Schmidt hammer when requested.

APPENDIX

TABLE 1

SUMMARY TEST DATA
CONCRETE PROBE-STRENGTH STUDY

(1) Pour Data	(2) Age Days	(3) Exposed In. Probe (Ave)	(4) Cylinder Break Strength, psi		(5) Core Break Strength, psi		(6) Compressive Strength Values		
			Average	Individual	Average	Individual	Cylinder (A) Curve, psi	Core (B) Curve, psi	Hardness #7 (C) Curve, psi
"A"-1st Lab.	4	1-1.58	1-1615	1615	-	-	1583	1775	1100
pour	7	1-1.73	2-2173	2509 1837	2-2414	2363 2465	2328	2459	2400
11-8-68	11	3-1.85	3-3174	3268 3233 3021	-	-	2924	3006	3450
6.0 Sack Conc. Agg.S.G.-2.53	17	3-1.92	3-3675	3639 3569 3816	-	-	3272	3375	4050
Slump - 5"	28*	5-1.98	3-3693	3516 3816 3746	-	-	3570	3598	4600
"B"-2nd Lab. pour	7	15-1.79	3-2432	2473 2420 2403	2-2820	2856 2784	2626	2732	2935
11-25-68	10	15-1.89	3-3062	2968 3162 3056	2-3134	3061	3123	3088	3800
6.0 Sack Conc. Agg.S.G.-2.53	15*	13-1.99	3-3374	3445 3304 3374	-	-	3620	3644	4675
Slump -3"	25*	11-2.03	2-3666	3781 3551	1-3837	3837	3819	3826	5025

*Cold Weather

TABLE 1 (CONTINUED)

SUMMARY TEST DATA
CONCRETE PROBE -STRENGTH STUDY

(1) Pour Data	(2) Age Days	(3) Exposed In. Probe (Ave)	(4) Cylinder Break Strength, psi		(5) Core Break Strength, psi		(6) Compressive Strength Values		
			Average	Individual	Average	Individual	Cylinder (A) Curve, psi	Core (B) Curve, psi	Hardness #7 (C) Curve, psi
"C" Field Pour Slab-South La.	7	13-1.93	3-3250	3180 3286 3286	2-2653	2857 2449	3322	3370	4150
5-20-69 Type"B", 5.8	14	12-2.04	3-3640	3710 3640 3569	2-3755	2939 4571	3868	3871	5100
Sack Conc. Agg.S.G.-2.53 Slump-31/2"	28	11-2.09	4-4028	3993 4134 4064 3922	2-4653	4816 4490	4117	4099	5525
"D"-Field Pour Vertical Wall	7	2-1.90	3-3004	2933 2933 3145	-	-	3173	3234	3900
8-29-69 Class "A", 6.0	14	3-2.00	3-3545	3534 3498 3604	-	-	3670	3689	4750
Sack Conc. Agg.S.G.-2.53 Slump-2 3/4"	28	3-2.05	4-4232	4170 4382 4240 4134	-	-	3918	3917	5200
"E"-Field Pour Slab-North La.	7	15-1.88	3-3820	3960 3890 3610	2-3620	3580 3660	3073	3142	3750
9-8-69 Type"B", 5.8	14	13-2.03	3-4487	4500 4250 4710	2-3939	3740	3819	3826	5020
Sack Conc. Agg.S.G.-2.54 Slump - 2"	28	13-2.05	3-4707	4920 4460 4740	2-4496	4615 4377	3918	3917	5200

TABLE 2

STATISTICAL DATA FOR SUMMARY TEST RESULTS

Concrete Pour	Cylinder, P.S.I.			Core, P.S.I.			Probe, Exposed In.			Hardness Curve, p.s.i.		
	Mean, $\bar{x}$	Std. Dev., σx	Coeff. Var., %	Mean, $\bar{x}$	Std. Dev., σx	Coeff. Var., %	Mean, $\bar{x}$	Std. Dev., σx	Coeff. Var., %	Mean, $\bar{x}$	Std. Dev., σx	Coeff. Var., %
"A" Lab.	3270	617	18.86	2414	72	2.98	1.92	0.04	2.11	3120	1393	44.65
"B" Lab.	3085	476	15.42	3149	419	13.31	1.92	0.29	4.82	4106	941	22.91
"C" Field	3678	347	9.44	3687	1047	28.39	2.02	0.33	5.61	4925	704	14.29
"D" Field	3656	549	15.00	-	-	-	1.98	0.03	1.85	4617	660	14.29
"E" Field	4385	447	10.20	4018	424	10.54	1.99	0.33	3.57	4657	790	16.97
Overall Average	3615	487	13.78	3317	490	13.80	1.97	0.20	3.59	4285	898	22.62

Mean, $\bar{x} = \sum x/n$

Standard Deviation, $\sigma x = \dfrac{\sqrt{\sum (xi - x)^2}}{n-1}$

Coefficient of Variation $= \sigma x/\bar{x}$ (100)

$= \dfrac{\text{Standard Deviation}}{\text{Mean}}$

TABLE 3

CORRELATION CURVE DATA FOR CYLINDERS

Sample	Coefficient of Correlation, R	R^2	a	b
A & B(Lab Curve)	0.9548	0.9117	-6267.21	4968.37
A - D	0.9566	0.9152	-6230.61	4936.47
A - E	0.8988	0.8079	-6932.22	5366.00

y - a + bx The best correlation was a straight line.

TABLE 4

CORRELATION CURVE DATA FOR CORES

Sample	Coefficient of Correlation, R	R^2	a	b
A & B(Lab Curve)	0.9941	0.9883	-5423.63	4556.39
A, B, C	0.8887	0.7898	-6735.71	5216.19
A, B, C, E	0.8721	0.7606	-7060.97	5443.51

$y = a + bx$ The best correlation was a straight line.

TABLE 5

CORRELATION CURVE DATA FOR COMBINED CYLINDERS AND CORES

Sample	Coefficient of Correlation, R	R^2	a	b
A & B(Lab Curve)	0.9603	0.9222	-6044.92	4861.79
A - D	0.9326	0.8698	-6359.61	5009.40
A - E	0.8901	0.7924	-6959.71	5384.36

$y = a + bx$ The best correlation was a straight line.

TABLE 6

QUANTITIES

Quantity	Item	No. Probes	No. Cyls.	No. Cores
8	Lab. Poured Slabs (8"x36"x48")	84	24	8
16	Concrete Beams (6"x6"x20")	48	-	-
2	Roadway Slabs	102	19	12
1	Box Culvert (Vertical Wall)	12	10	-
-	TOTAL	246	53	20

TABLE 7

LIST OF SAMPLING AND TESTING PROCEDURES

Name	LDH Procedure	AASHO Procedure	ASTM Procedure
1. Fresh Concrete	LDH S301	AASHO T141	ASTM C172
2. Making and Curing Concrete Compression and Flexure Test Specimens in the Field	LDH S302	AASHO T23	ASTM C31
3. Method of Test for Slump of Portland Cement Concrete	LDH TR207	AASHO T119	
4. Method of Test for Compressive Strength of Molded Concrete Cylinders		AASHO T22	ASTM C39
5. Securing Core Specimens from Hardened Concrete	LDH S312		
6. Method of Test for Preparing and Testing Core Specimens from Hardened Concrete	LDH TR 225		
7. Securing, Preparing and Testing Specimens from Hardened Concrete for Compressive and Flexural Strengths		AASHO T24	ASTM C42

DESCRIPTION OF TESTING DEVICE

The Windsor Probe-Test System (as described by manufacturer)

1. A hardened alloy probe (approximately 3 inch x 5/16 inch) is driven into concrete at high velocity (600 fps) by a driving unit (gun). The energy level is 575 foot-pounds.

2. Three 'Windsor' probes are driven into the concrete by using a locating template that spaces the probes in a seven-inch triangular pattern. The driver is loaded separately for each probe.

3. Said probe is resisted only by the concrete being penetrated and the aggregate components of the concrete are broken and forced radially against the mortar.

4. A compaction bulb of compression-stressed concrete material is created as the energy is depleted by the resistance to penetration.

5. Said compaction bulb is measurable and expressed in p.s.i. Mathematically expressed, the p.s.i. is the product of the energy - volumetric displacement, factored by time and friction. Aggregate type and hardness affects all concrete compression tests.

6. The probe value is precisely the measure of compressibility of a localized area of concrete. The value is expected to vary due to the inherent variation in mass concrete.

7a. Measurements are made by placing the Base Gage Plate over the three probes. This is a triangular plate approximately nine-inch equilateral. Three holes are provided thru which the probes extend. It can be secured by compression springs provided for vertical or overhead work.

b. The upper or top Gage Plate is placed over the three probes. Both lower and upper plates will provide a mechanical average of the concrete surface and the projection of the probes respectively.

c. The depth gage provided is inserted through the appropriate hole in the top Gage Plate and the exposed height of the probes is recorded. This is accomplished in inches and referred to a graph or curve directly in p.s.i.

Note 1: Any single probe can be measured separately if desired. A single probe cap is provided for this purpose.

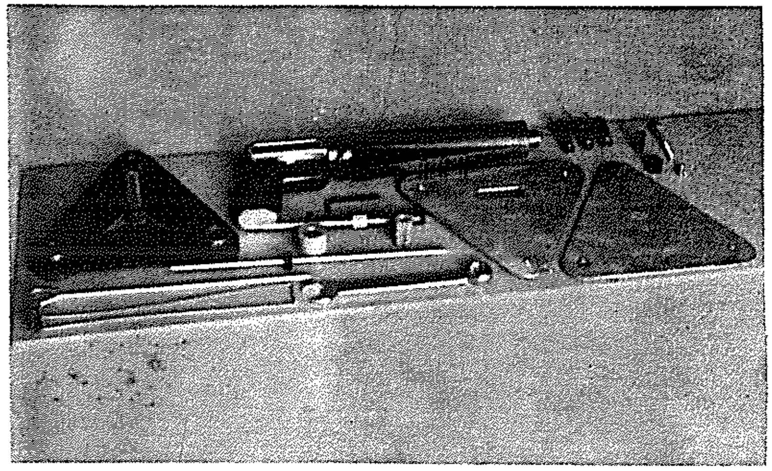
Note 2: There is a circle inscribed on the Base Gage Plate that indicates accept or reject values. If the point of the depth gage falls within the limit circle, acceptance is indicated. If the point of the depth gage falls outside the limit circle, acceptance should be rejected or the probe should be inspected for cause of failure.

Note 3: A reasonably smooth surface for test area should be selected.

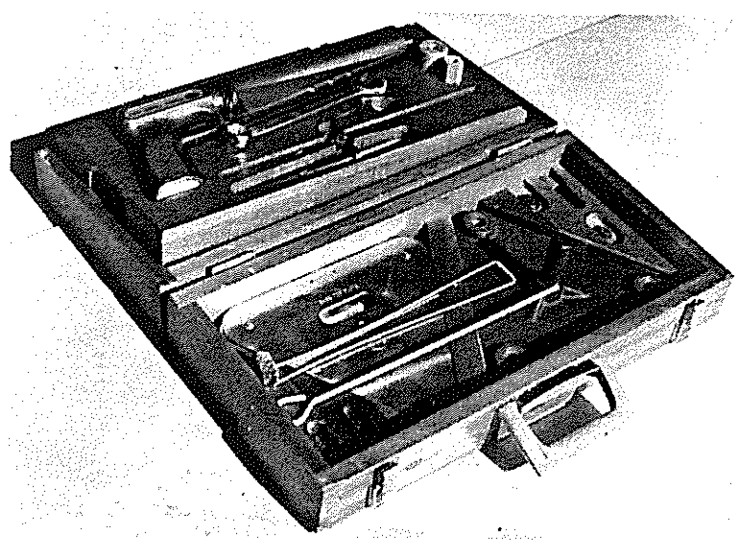
FIGURE 2

GENERAL VIEW OF INSTRUMENT, PARTS, CARRYING CASE, AND TEST KIT

WINDSOR PROBE TEST SYSTEM
Instrument Model CPT-532CF consists of:



1- Probe Locating Template
2- Top Gage Plate
3- Bottom Gage Plate
4- Bottom Gage Plate Retainers
5- Probe Withdrawal Kit
6- Single Probe Measuring Cap
7- Calibrated Depth Gage
8- Driver Unit Model 532CF
9- Probe Driving Head
10- Breech Plug
11- Operation & Instruction Manual
12- Test Area Cleaning Brush
13- Barrel Clearing Tool
14- Driver Maintenance Equipment



15- System is portably contained in furnished instrument carrying case
System and case total weight: 23 1/2 lbs.
Approximate shipping weight: 25 lbs.

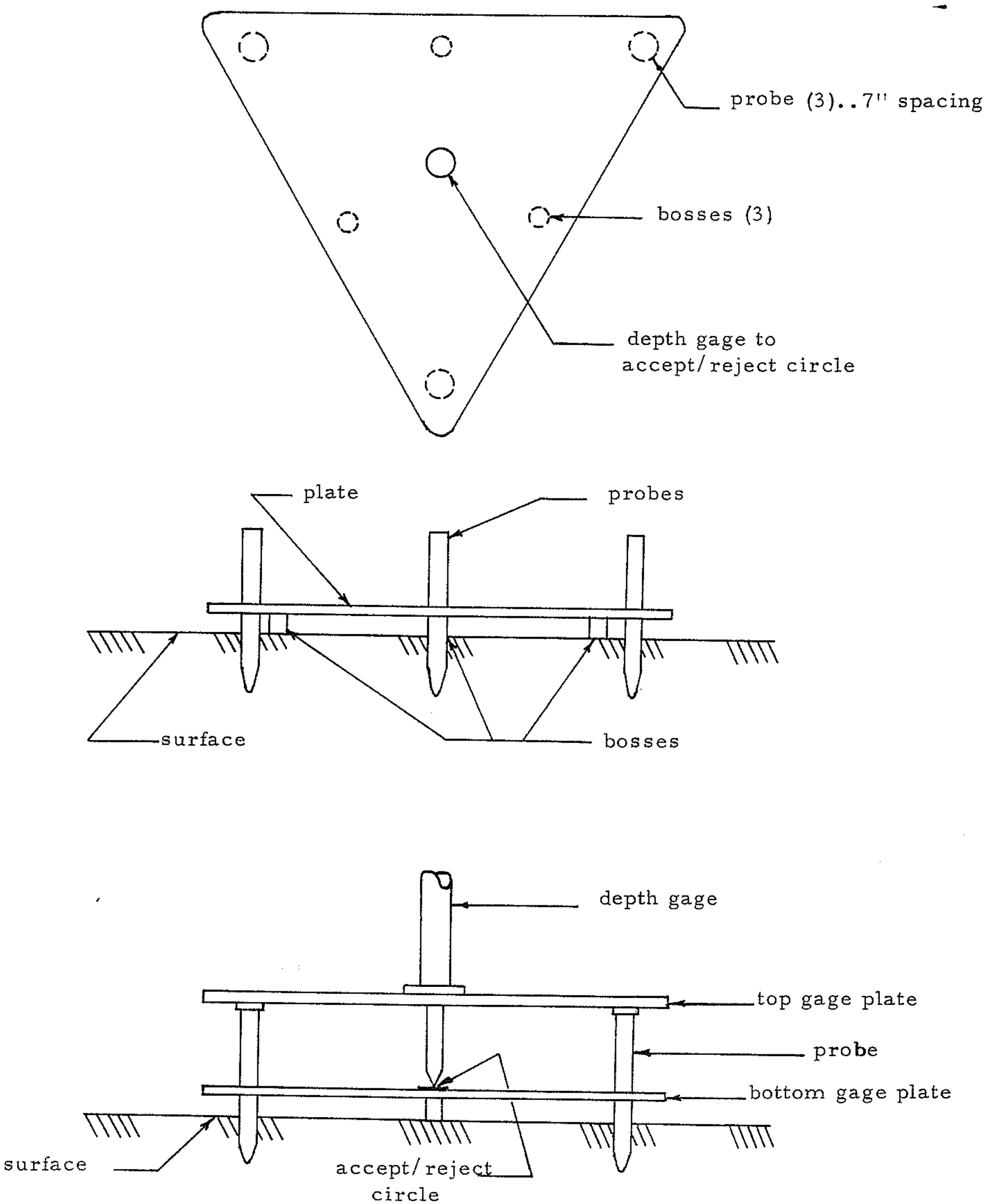
16- Certified kits are sold separately, each kit registered, and shipped in individual kit containers.
Total Weight: 5 oz.

WINDSOR CERTIFIED TEST KITS
for use in concrete from 1,500 - 7,000 p.s.i.
consists of:
Three (3) WMC Step Probes
and
Three (3) Matched Nickel Plated Power Loads

Note: Kits are available for conditions above 7,000 p.s.i. and for special applications. Consult Manufacturer for details.

FIGURE 3

SKETCH OF WINDSOR PROBE-TEST SYSTEM
(Probes and Plates)



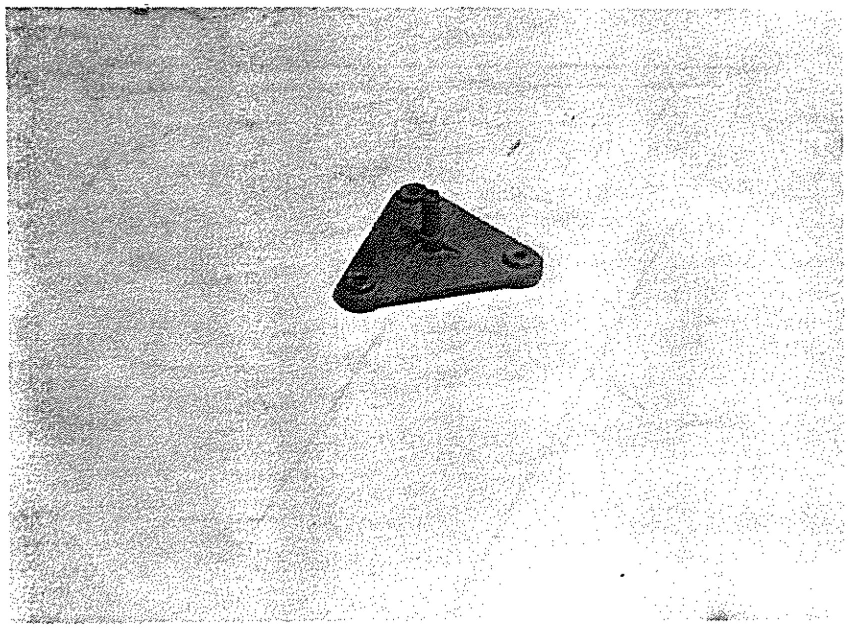


FIGURE 4
General View of Probe Locating Template in Position

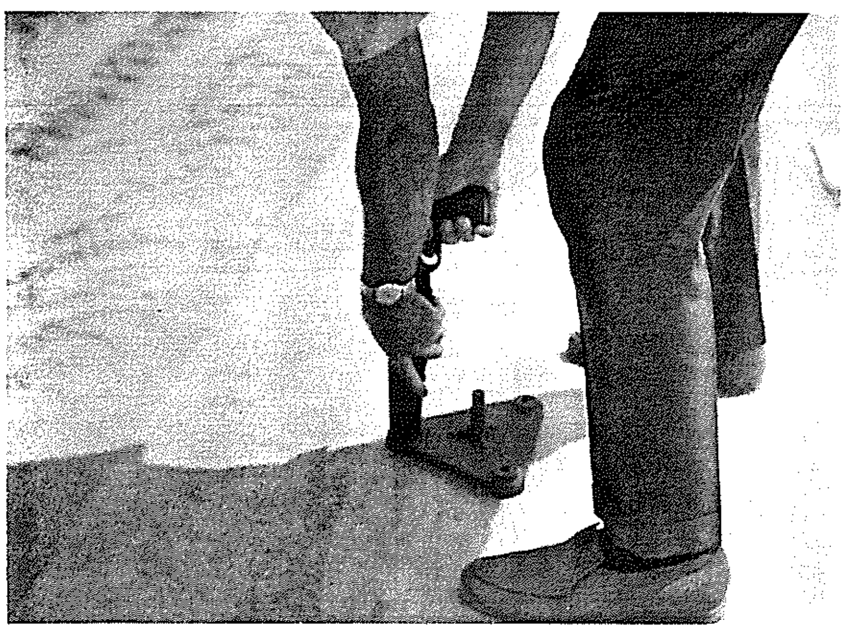


FIGURE 5
Driver Unit in Firing Position

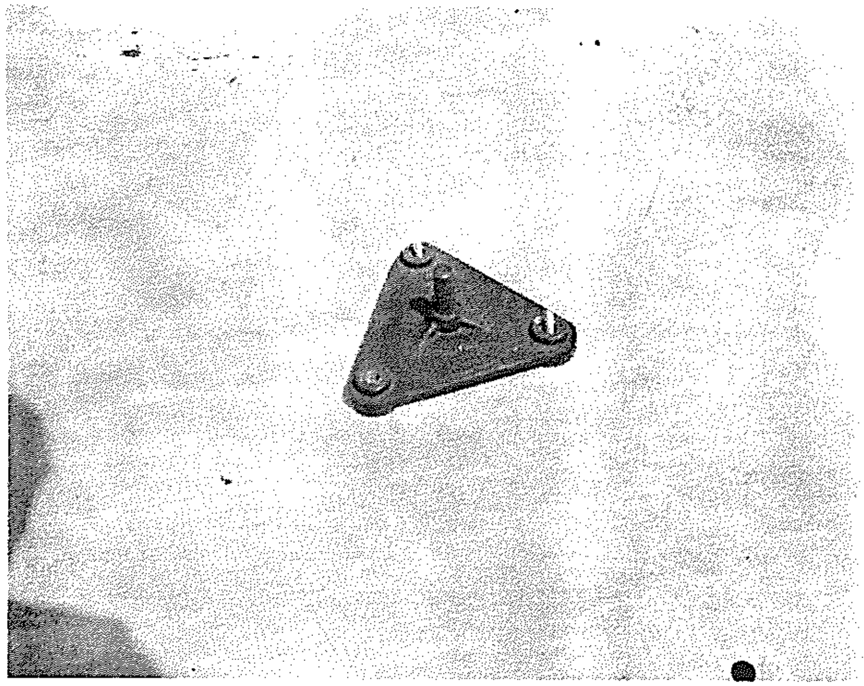


FIGURE 6
Probes Positioned by Probe Locating Template

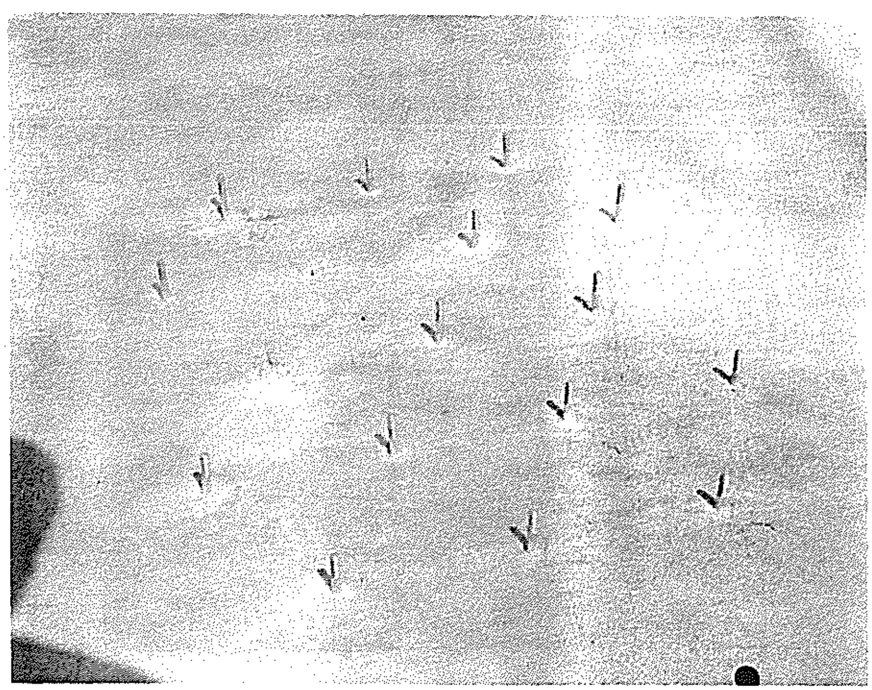


FIGURE 7
Probe Configuration in Concrete Slab on Monroe Project in North Louisiana

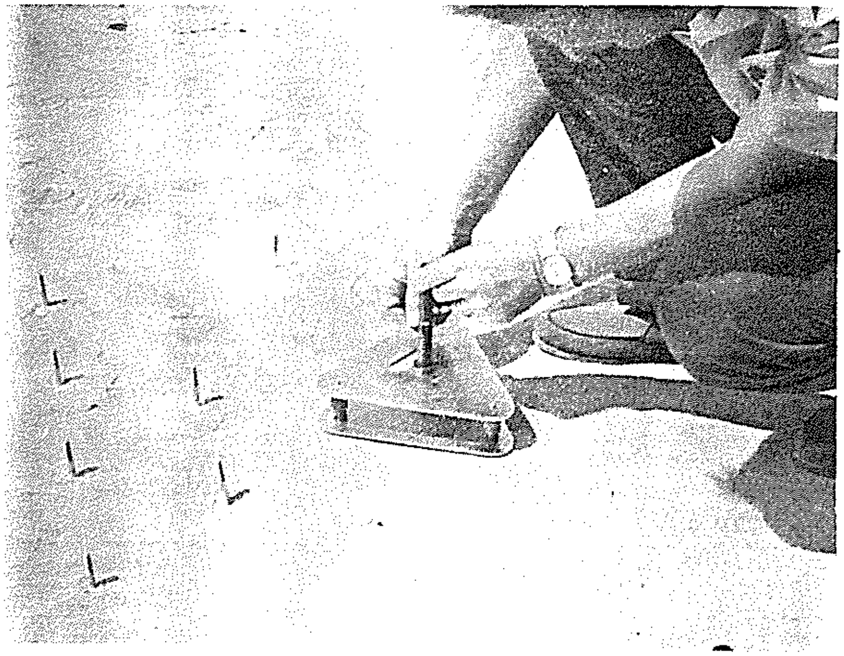


FIGURE 8
Depth Measuring System with Bottom and Top Gage Plates in Position

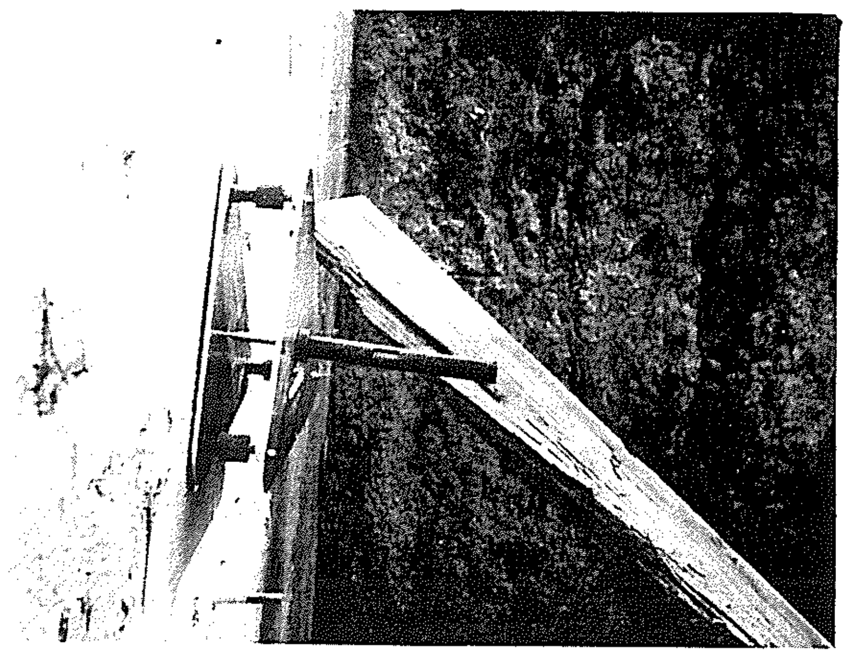


FIGURE 9
Depth Measuring System on Vertical Wall

FIGURE 10

LABORATORY DATA FOR CYLINDER CURVE DERIVATION

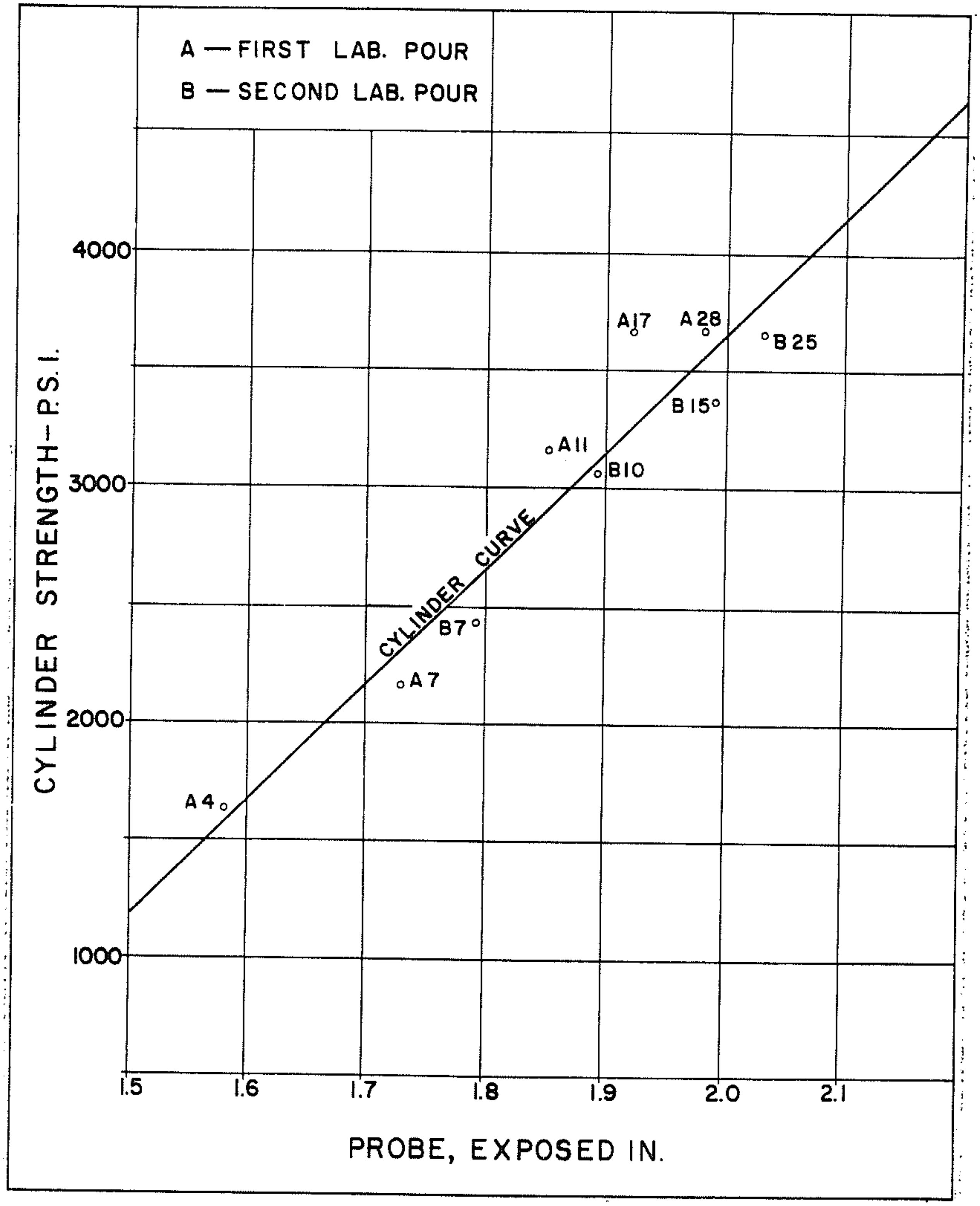


FIGURE 11

FIELD DATA FOR CYLINDER CURVE VALIDATION

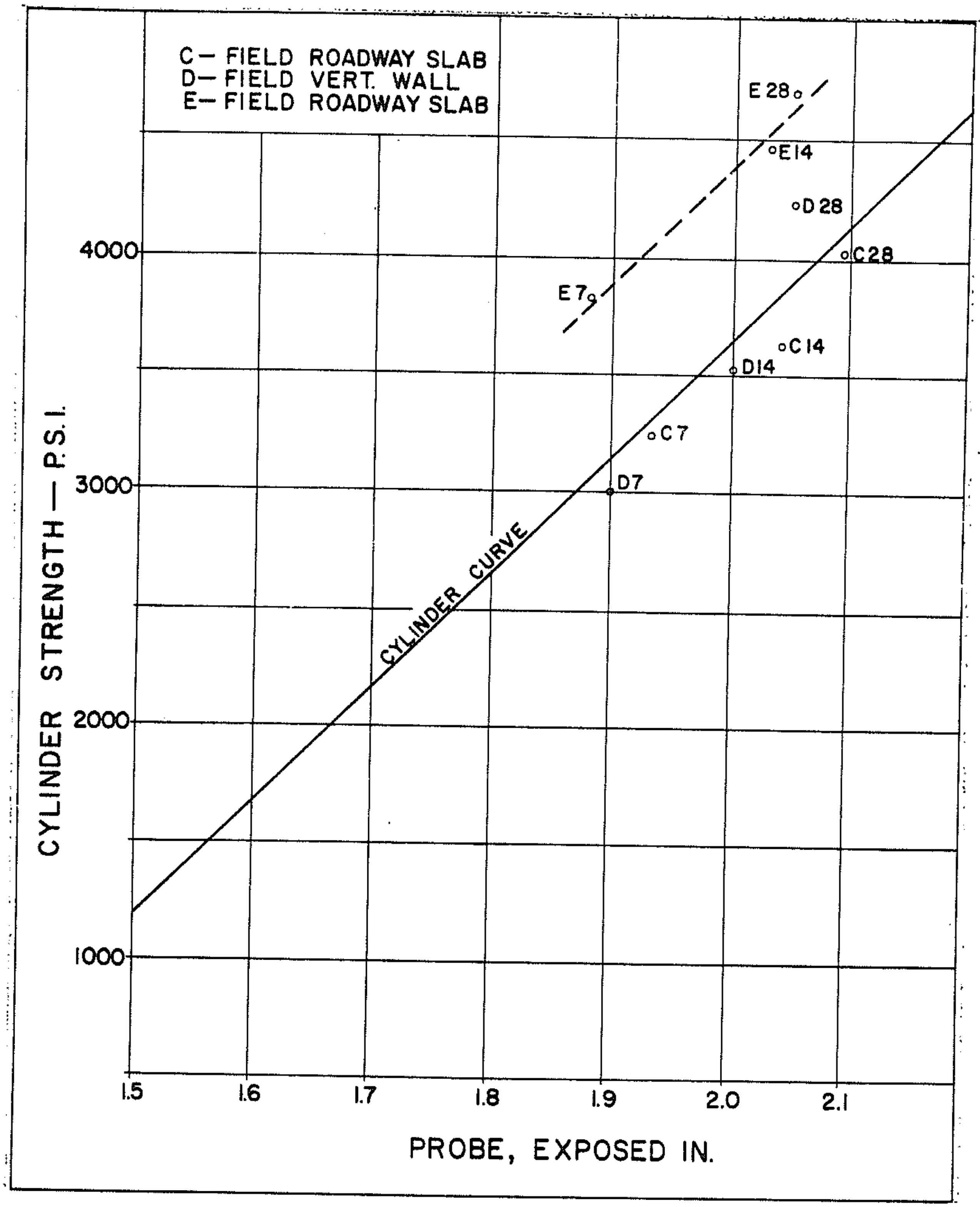


FIGURE 12

LABORATORY DATA FOR CORE CURVE DERIVATION

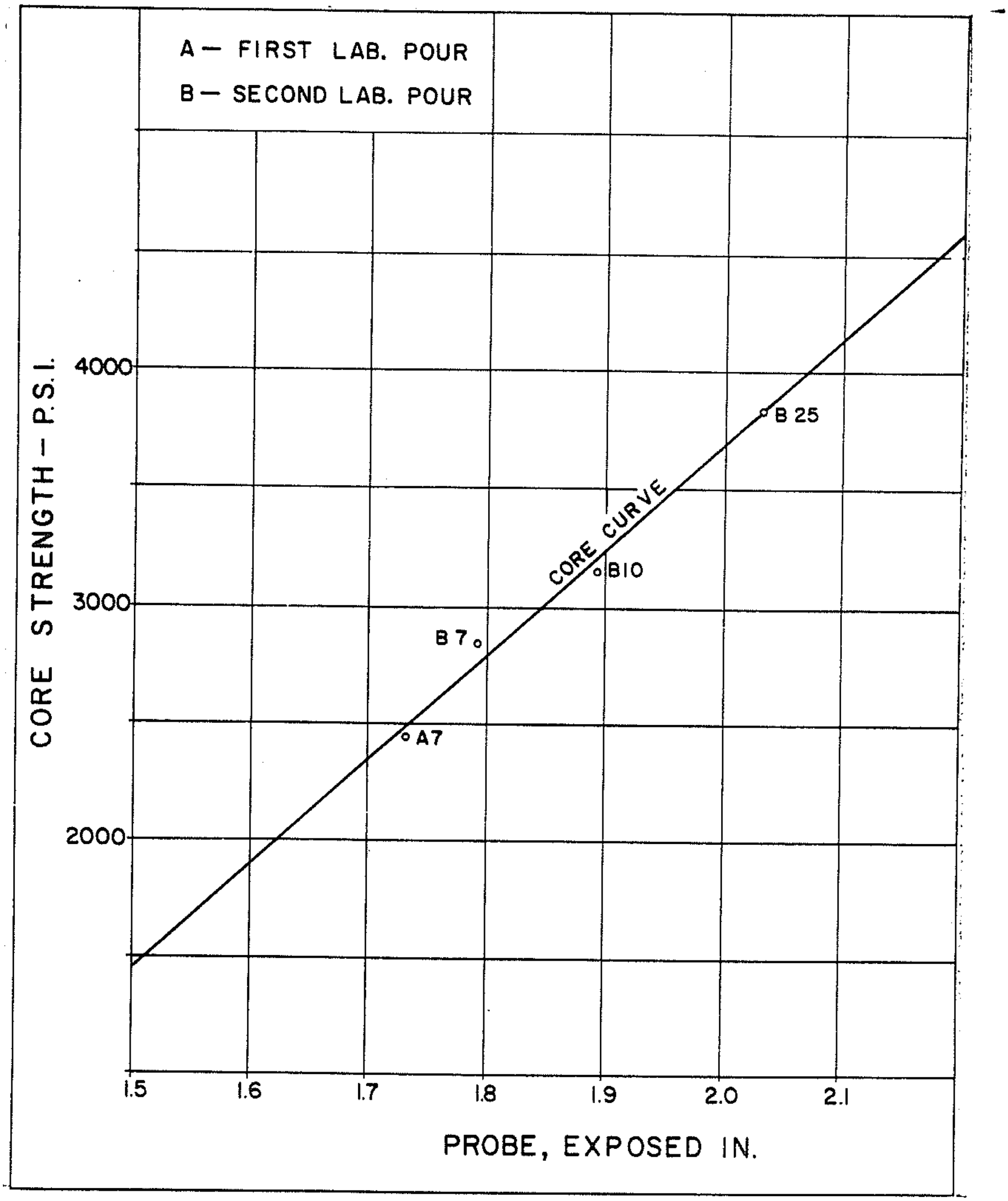


FIGURE 13

FIELD DATA FOR CORE CURVE VALIDATION

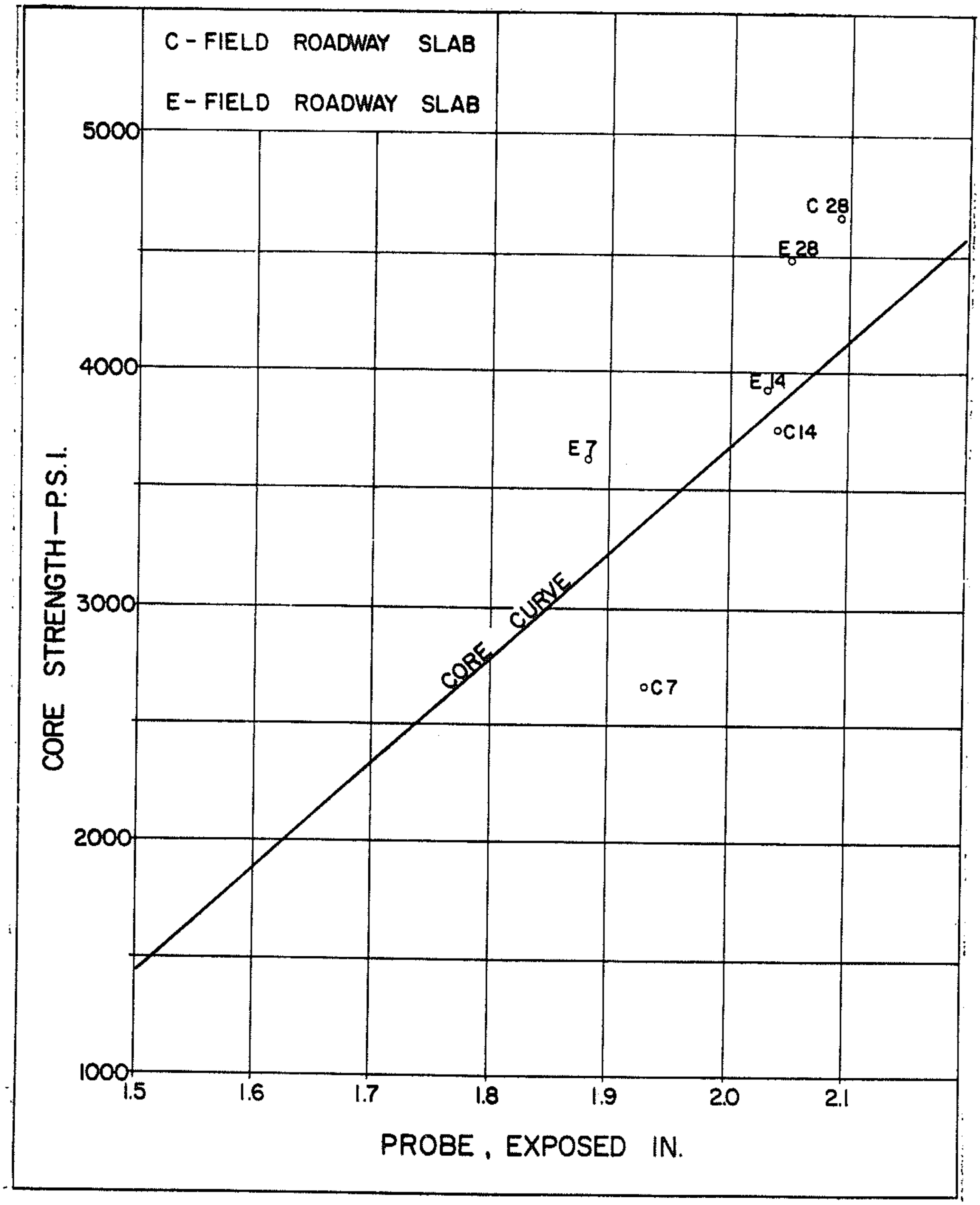


FIGURE 14

PROBE PENETRATION RESISTANCE WITH AGE

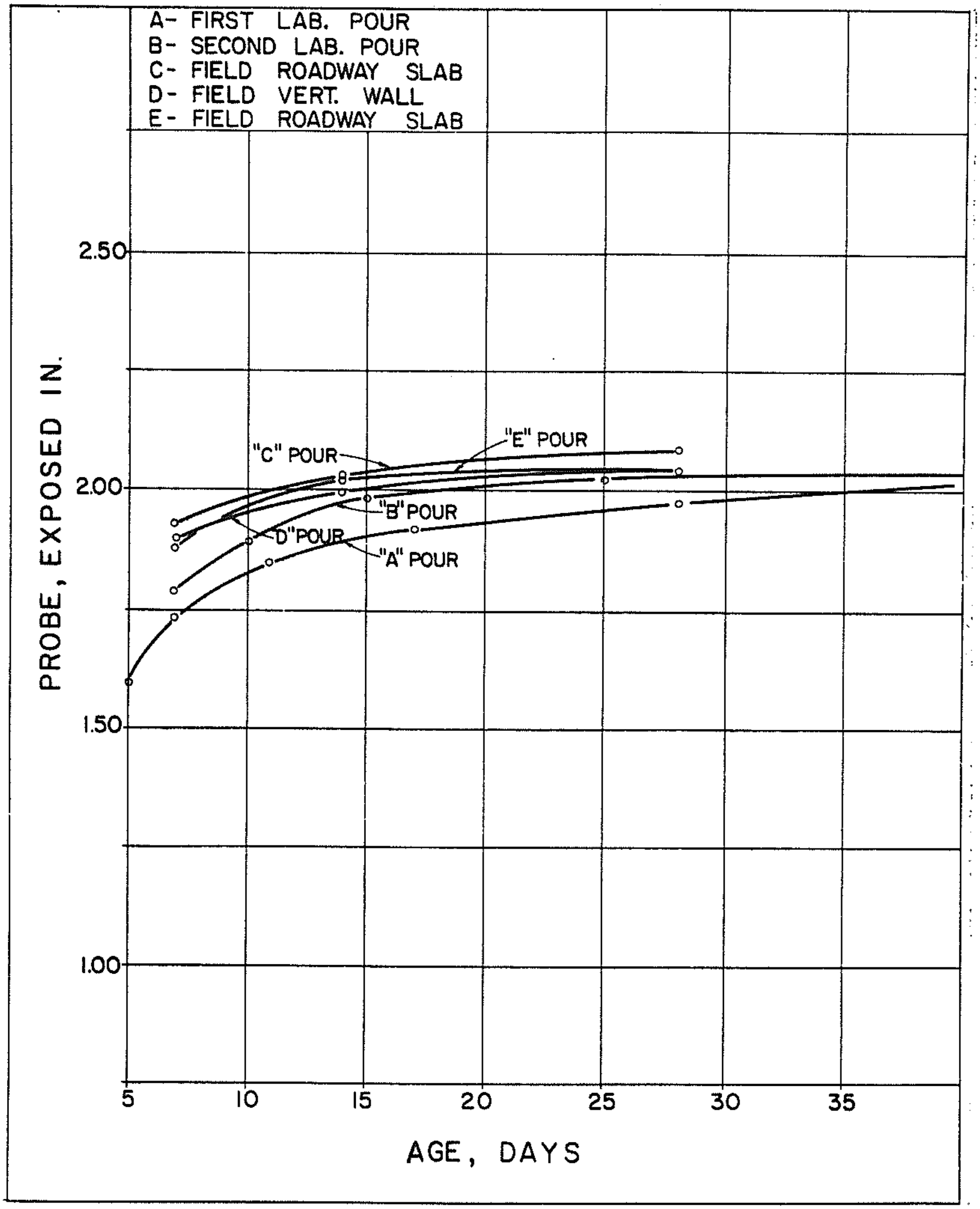


FIGURE 15

AVERAGE CYLINDER STRENGTH GAIN-ALL PROJECTS

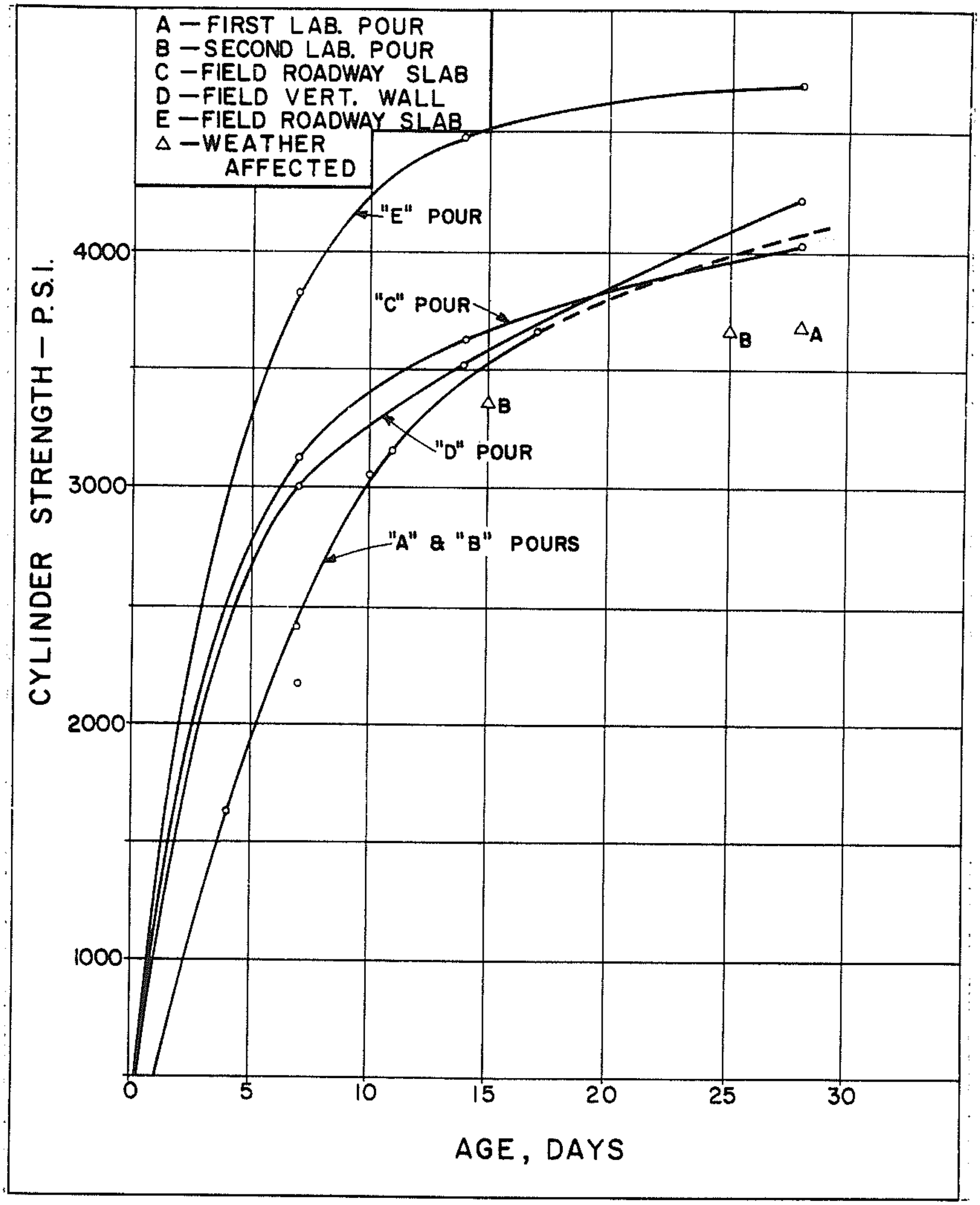


FIGURE 16

AVERAGE CORE STRENGTH GAIN-ALL PROJECTS

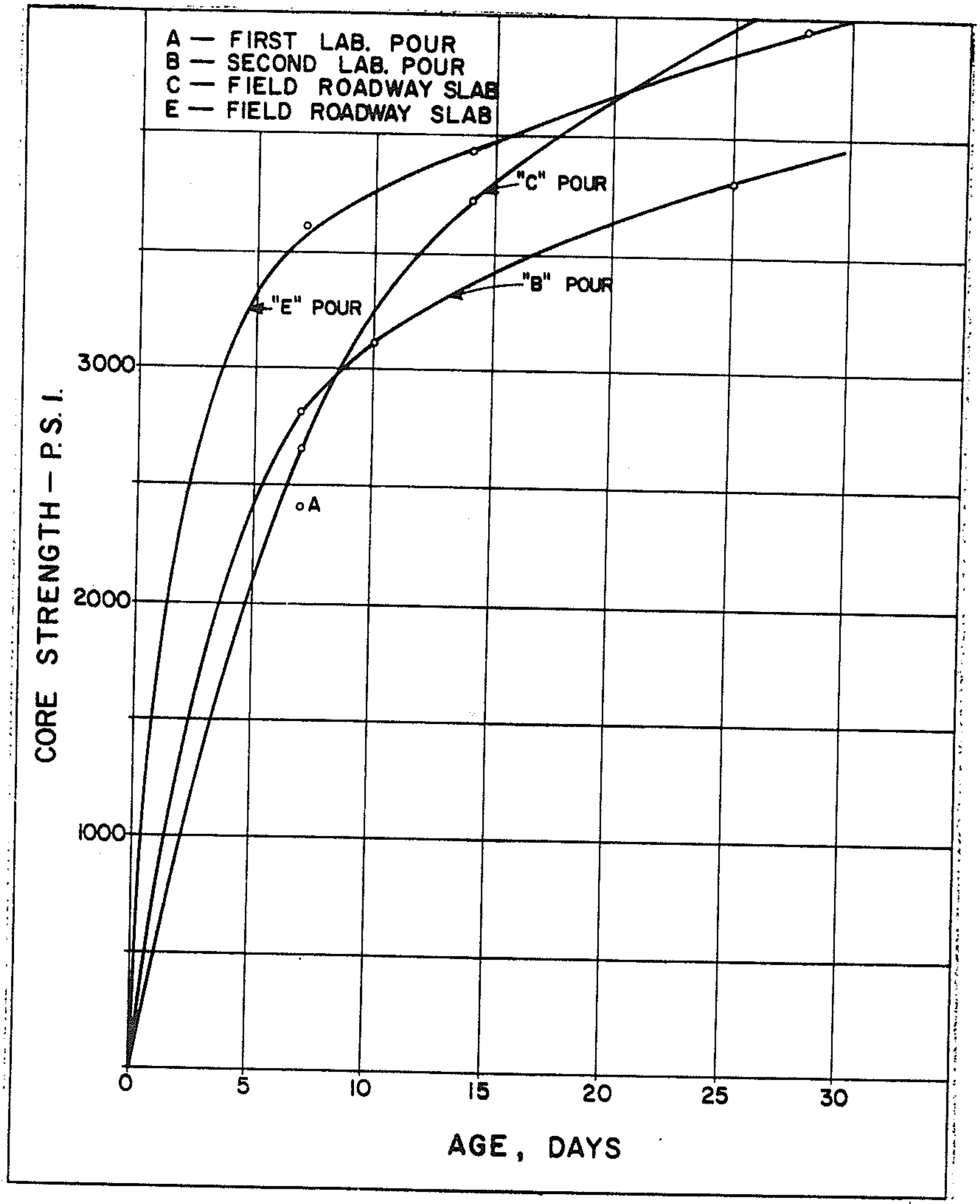


FIGURE 17

CYLINDER COMPRESSIVE STRENGTH VARIATIONS COMPARED TO CYLINDER CURVE

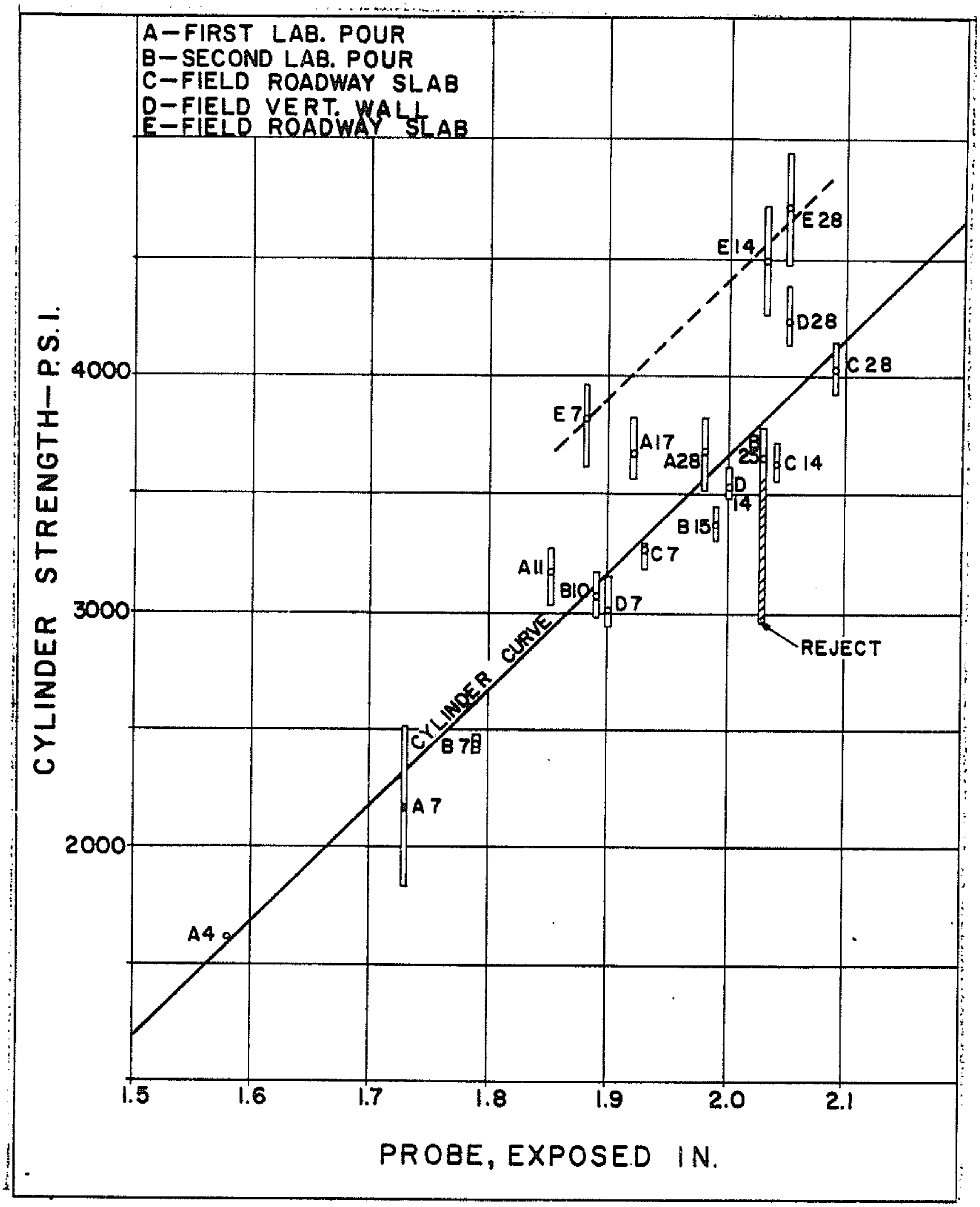


FIGURE 18

CORE COMPRESSIVE STRENGTH VARIATIONS COMPARED TO CORE CURVE

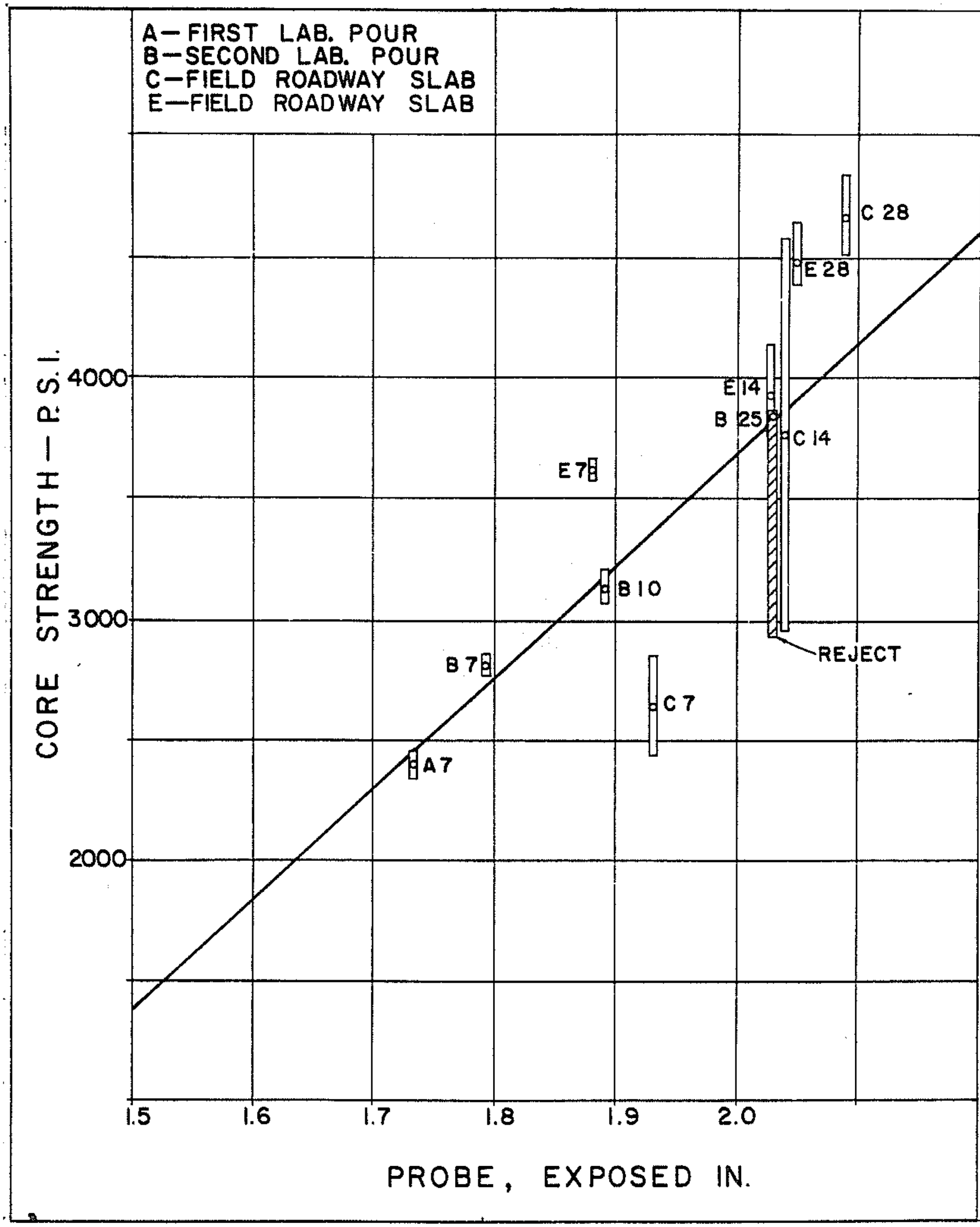


FIGURE 19

COMPARISON OF CYLINDER COMPRESSIVE STRENGTHS WITH MANUFACTURER'S HARDNESS CURVES AND L.D.H. CYLINDER CURVE

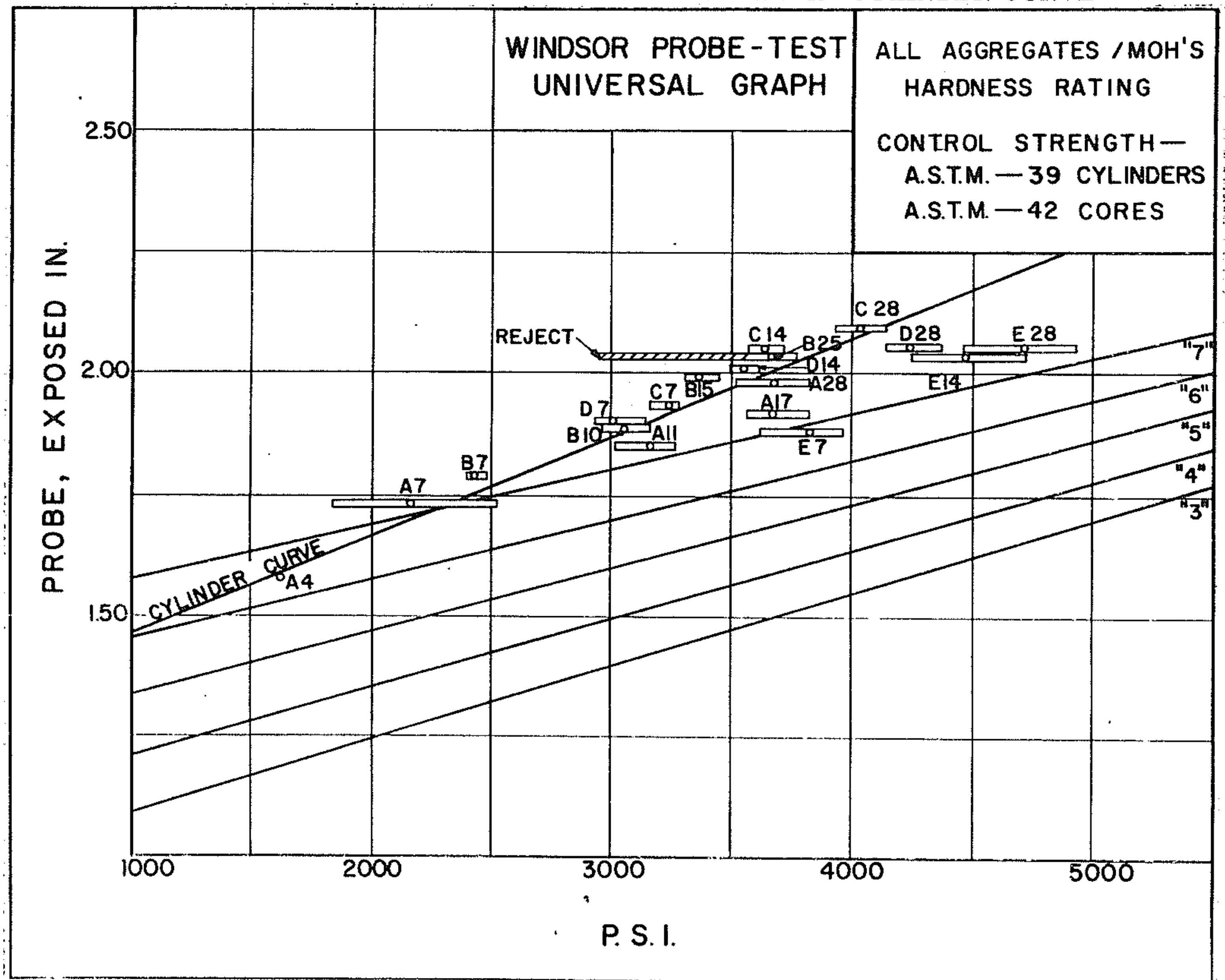


FIGURE 20

COMPARISON OF CORE COMPRESSIVE STRENGTHS WITH MANUFACTURER'S HARDNESS CURVES AND L.D.H. CORE CURVE