4 x 8 INCH CONCRETE CYLINDERS VERSUS 6 x 12 INCH CYLINDERS

by

Celik Ozyildirim
Research Scientist

Virginia Highway & Transportation Research Council
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ABSTRACT

Laboratory and field investigations were conducted to compare the compressive strengths obtained for 4 x 8 in. (100 x 200 mm) cylinders with those for standard 6 x 12 in. (150 x 300 mm) cylinders, both made with aggregate having a nominal maximum size of 1 in. (25 mm). In the lab, in addition to the effect of specimen size on strength, other factors as the mold type, aggregate type, and strength level were considered.

The results of the laboratory work indicate that the two sizes of cylinders yield equal compressive strength values at a strength level of about 3,200 psi (22.0 MPa). Above this level, the small specimens exhibit higher compressive strengths. The difference in the strength values between the two sizes increases with the strength level. The standard deviation of strength values was higher for the small specimens. For equal precision, more tests are needed for the small specimens than for the larger ones.

The field investigation included an examination of the effect of different specimen sizes when different types of mold and capping procedures were used for each size. The results of the field tests comparing specimen sizes were similar to those of the laboratory tests in terms of strength and variability. It is concluded that the results of tests on 3 small cylinders cast in plastic molds and tested with neoprene pads in steel end caps can be used to predict the strengths of A3 and A4 concretes obtained by tests of 2 large cylinders cast in steel molds and tested with sulfur-mortar caps.

The variability of small cylinders compared to that of larger ones prepared in the field was slightly higher, even though statistically not significant. Thus, the use of 3 small cylinders rather than 2 larger ones is recommended.

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INTRODUCTION

The potential strength of hydraulic cement concrete is generally determined by preparing and testing cylinders in accordance with ASTM test methods. One of these methods, ASTM C31, is used in making and curing concrete test cylinders in the field. In this method, the standard specimen size is specified as 6 x 12 in. (150 x 300 mm), if the maximum size of the aggregate does not exceed 2 in. (50 mm). Cylinders smaller than 6 x 12 in. (150 x 300 mm) are not permitted, unless so stated in the specifications for a project. However, a similar AASHTO test method, T23, permits the use of 4 x 8 in. (100 x 200 mm) cylinders when the nominal maximum size aggregate does not exceed 1 in. (100 mm). The advantages associated with use of the smaller 4 x 8 in. (100 x 200 mm) cylinders are that they are simple to fabricate, easier to handle, require less load to cause failure, require less storage space, and are more economical to make.(1) The disadvantages given for use of the smaller cylinders are the larger variability in test results, the possibility for more damage in handling because of their small size and lower weight, and restriction of the maximum aggregate size to 1 in. (25 mm).(2)

This study was planned to compare the results of compressive strength tests on 4 x 8 in. (100 x 200 mm) cylinders with those for the standard 6 x 12 in. (150 x 300 mm) cylinders. Additionally, the feasibility of using the smaller size specimens for quality control and acceptance was examined.

BACKGROUND

One of the earliest papers on the effect of specimen size on the compressive strength of concrete was presented by Gonnerman in 1925.(3) He concluded that the decrease in strength with the increase in size was not important for cylinders under 6 in. (150 mm) in diameter. Tucker has theorized that the compressive strength of the material is independent of the area of the specimen, if the length to diameter ratio is constant.(4) In relation to standard deviations, he states that they decrease with increases in the cylinder diameter in accordance with his "summation-strength" theory. To obtain equal precisions, the cross-sectional areas are made equal for the two sizes by specifying the numbers of cylinders to be tested. The Bureau of Reclamation also has published data on the effect of cylinder size on compressive strength.(5) The data show that the strength indicated for the 4 x 8 in. (100 x 200 mm) cylinders is 104% of that indicated for 6 x 12 in. (150 x 300 mm) cylinders. Neville has shown that the strengths of concrete specimens of different sizes can be related by simple expressions.(6) The two equations suggested in his paper indicate that smaller size cylinders give values slightly higher (by 3% and 4%) than those of the larger size specimen.

Malhotra, in his work on the size of specimens, has concluded that the difference in compressive strength indicated by the two sizes of cylinders increases with an increase in the strength level of the concrete.(2) The smaller sizes give the high values; however, he indicates that at low strength levels the reverse may be true. He also concludes that there is a higher variation in the test results when smaller cylinders are used, and that according to Tucker's summation theory, about twice as many small cylinders than large cylinders must be tested to obtain the same precision. He goes further and contends that considerably more than twice the number of large cylinders must be tested for equal precision.

Tests conducted by Concrete Technology Associates established a relationship between the strengths of the two sizes of cylinders.(7) They suggest that at the 2,000 psi to 3,500 psi (13.8 MPa to 24.1 MPa) range, strengths obtained for both sizes are equal; that at higher strength levels, the small size specimens give higher values; and that the difference between the results for the two sizes increases as the strength level increases. They have also concluded that the difference in the coefficient of variation between the two sizes is small, and that essentially equal precisions are attained by testing the same number of cylinders for both sizes.

Forstie and Schnormeier presented data which show that at 3,000 psi (20.7 MPa) both sizes of cylinders give essentially the same results. However, at about 5,000 psi (34.5 MPa), the small cylinders give significantly higher strengths. In the 7,000 psi (48.3 MPa) range, a difference of about 1,000 psi (6.9 MPa) is obtained.(1) They state that the smaller cylinders exhibit more variation in test results; however, this variation was found not to be great enough to preclude their use.(1)

OBJECTIVE AND SCOPE

The objective of this study was to compare the results of compressive strength tests for 4 x 8 in. (10o0 x 200 mm) cylinders with those for the standard 6 x 12 in. (150 x 300 mm) cylinders, and to investigate the feasibility of using 3 small-size specimens cast in plastic molds and tested with neoprene pads in steel end caps as an alternate to using 2 large cylinders cast in steel molds and tested with sulfur-mortar caps. To achieve the objectives of the study, a laboratory investigation and a field investigation were carried out. ; These are reported here as Part I and Part II, respectively. Following the description of the two investigations, the conclusions and recommendations from both are given.

While emphasis was on the effect of cylinder size on the compressive strength of concrete, other factors that might affect the strength values were also considered. In the laboratory, these were mold type (steel and cardboard), aggregate type (crushed stone and gravel) and strength level (3,000 psi [20.7 MPa], 4,000 psi [27.6 MPa], 5,000 psi [34.5 MPa], and 6,000 psi [41.4 MPa]). In the field investigation, the effect of different molds and different capping methods were included by comparing the results of tests on 3 small cylinders cast in plastic molds and tested with neoprene pads in steel end caps with those of tests on 2 large cylinders cast in steel molds and tested with sulfur-mortar caps. The neoprene pads were 1/2 in. (13 mm) thick, and had a 50 durometer hardness; the steel end caps had a 4-1/8-in. (105-mm) inside diameter. In the field, Virginia Department of Highways & Transportation class A3 and class A4 concretes were studied.(8) These have minimum 28-day compressive strengths of 3,000 psi (20.7 MPa) and 4,000 psi (27.6 MPa), respectively.

PART I - LABORATORY INVESTIGATION

Testing Program

For the laboratory work, the combinations of variables noted above under SCOPE were incorporated into different batches of concrete, and all the batches were duplicated. The batches with different variables prepared for each strength level are given in Table 1. From each batch, 6 small and 6 large cylinders were prepared in each type mold. A total of 384 cylinders were fabricated from 32 batches of concrete. Half of the cylinders were small size and the remainder large, and in each size group half were cast in steel molds and the other in cardboard molds. The specimens were capped with sulfur-mortar and tested in compression.

Table 1

Batches and Variables for Each Strength Level

Batch No.	Aggregate	Mold
1	Crushed Stone	Steel
2		
3		Cardboard
4		
5	Gravel	Steel
6		
7		Cardboard
8		

Materials and Mixture Proportions

The two types of coarse aggregate used had a nominal maximum particle size of 1 in. (25.4 mm). One was crushed stone containing granite gneiss and having a specific gravity of 2.78 and a dry rodded unit weight of 103.3 lb./yd.^{3} (1,650 kg/m.^{3}). The other was siliceous gravel with a specific gravity of 2.63 and a unit weight of 104.7 lb./ft.^{3} (1,676 kg/m.^{3}). The fine aggregate was a quartz sand with a specific gravity of 2.61 and a fineness modulus of 2.80. Type II cement was used and admixtures were not added.

Trial batches were made to determine the mixture proportions to attain the four desired strength levels. The proportions are given in Table 2.

Sample Preparation and Testing

The mixture proportions given in Table 2 yielded workable concretes. The 6 small and 6 large specimens from each batch were prepared in three layers and each layer was rodded 25 times. The specimens were moist cured and tested at 14 days. Prior to testing, they were capped with sulfur-mortar.

Table 2

Mixtures Proportions in lb./yd.^{3}

Level	Expected Strength, psi	Cement	w/c	Coarse Aggregate Type	Coarse Aggregate Content	Quartz Sand
1	3,000	450	0.65	Crushed	1,869	1,417
2	4,000	564	0.57		1,869	1,251
3	5,000	580	0.50		1,869	1,317
4	6,000	714	0.41		1,869	1,199
1	3,000	430	0.65	Gravel	1,894	1,342
2	4,000	540	0.55		1,894	1,207
3	5,000	611	0.47		1,894	1,174
4	6,000	800	0.36		1,894	1,015

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1 lb./yd.^{3} = 0.59 kg/m.^{3}

1 psi = 6.89 kPa

Results

Analysis of Variance

The compressive strength data were evaluated using statistical principles to determine the effect of (1) specimen size, (2) strength level, (3) mold type, (4) aggregate type, and (5) duplicate batches on the strength values obtained. To determine if each of the above factors had a significant influence on the strength values, a 5-level analysis of variance was planned. It was found that all of the above factors had a significant effect on the strength, except the type of mold.

The test results, shown in Tables 3 and 4, exhibited a wide range of strength values as desired, but they did not closely match the initially planned levels of 3,000 psi (20.7 MPa), 4,000 psi (27.6 MPa), 5,000 psi (34.5 MPa), and 6,000 psi (41.4 MPa). Deviations from the planned values were different for each aggregate type, and the analysis of variance showed that the type of aggregate had a significant effect on the strength values.

Table 3

14-Day Compressive Strength Data for Concretes Containing Crushed Stone

Strength Level	Mold Type	No. Batches	Compressive Strength, psi 4 x 8 in. X	σ	6 x 12 in. X	σ
1	Steel	1	3,370	105	3,210	95
		2	2,570	47	2,720	33
	Cardboard	1	2,860	191	2,550	42
		2	2,700	147	2,540	53
2	Steel	1	3,470	104	3,440	32
		2	3,740	138	3,690	34
	Cardboard	1	4,120	58	3,920	54
		2	3,430	215	3,490	109
3	Steel	1	4,640	43	4,590	52
		2	4,630	64	4,540	56
	Cardboard	1	5,280	201	4,830	53
		2	5,430	256	4,580	96
4	Steel	1	5,750	64	5,380	103
		2	5,820	147	5,440	94
	Cardboard	1	6,190	196	5,740	145
		2	5,800	359	5,390	103

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1 in. = 25.4 mm
1 psi = 6.89 kPa

Table 4

14-Day Average Compressive Strength Data for Concretes Containing Gravel

Strength Level	Mold Type	No. Batches	Compressive Strength, psi			
			4 x 8 in.		6 x 12 in.	
			X	σ	X	σ
1	Steel	1	2,810	189	2,860	15
		2	2,410	100	2,610	31
	Cardboard	1	2,350	50	2,450	87
		2	2,520	120	2,490	65
2	Steel	1	3,580	126	3,680	60
		2	3,180	194	3,540	85
	Cardboard	1	3,780	232	3,650	71
		2	3,340	168	3,490	69
3	Steel	1	5,100	97	4,880	111
		2	4,340	114	4,310	37
	Cardboard	1	4,470	454	4,250	91
		2	4,760	148	4,200	40
4	Steel	1	5,580	99	5,100	147
		2	5,460	78	5,240	95
	Cardboard	1	5,530	304	5,180	89
		2	4,790	345	5,000	58

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1 in. = 25.4 mm
1 psi = 6.89 kPa

Statistically significant differences were found in the strength values for duplicate batches. However, as explained below, this variability is not considered to be significant from the standpoint of engineering judgement. Table 3 shows the average strength values and the standard deviations for each batch for mixtures containing crushed stone, and Table 4 gives these data for the mixtures with gravel. The average standard deviation for the large specimens was 79 psi (0.5 MPa) for each aggregate type and for the smaller sizes 169 psi (1.2 MPa) for the mixtures with crushed stone and 206 psi (1.4 MPa) for the ones with gravel. The coefficient of variation values for each batch for the large cylinders showed good to excellent ratings of within-test variation; most of the time the rating was excellent according to ACI 214. The smaller size cylinders had more variability, with ratings ranging from poor to excellent. To determine the overall variation, standard deviations were obtained for the combined test results for duplicate batches. Also, the strength values for both mold types were combined, since the effect of mold type on strength was not significant. The results for each aggregate are summarized in Table 5. The average standard deviations for all the strength levels for large cylinders were 208 psi (1.4 MPa) for the mixtures with crushed stone and 189 psi (1.3 MPa) for the mixtures with gravel. For the smaller cylinders, the values were 332 psi (2.3 MPa) and 328 psi (2.3 MPa), respectively. Based on the ACI 214 information on the standards of concrete control, the large cylinders exhibited an overall variation for laboratory trial batches that was very good for the mixtures with the crushed stone and excellent for the mixtures with gravel. The small cylinders showed fair control. To obtain the same standard error for the smaller specimens as for the larger ones, about 3 times more tests are needed. Although the between batch variability was found to be statistically significant, from the standpoint of engineering judgement it would be considered insignificant, so the batches were combined for further analysis.

An analysis of variance was performed where batches were combined and the remaining four factors examined. Again, the effect of mold type on strength was found not to be significant and the other factors were significant.

For each aggregate type, strength values for duplicate batches and mold types were combined and a two-level analysis was made, the levels being specimen size and strength level. The results for crushed stone indicated that the effects of specimen size and the strength level on the strength values were significant. For gravel, specimen size was found not to be significant, but the differences for different strength levels were significant. The gravel mixtures in this study gave lower values than those with the crushed stone and, as will be shown later, at the low strength values of concrete, specimen size had little effect on the strength values, which could explain the finding of nonsignificance for the mixtures with gravel.

Table 5

Compressive Strength Data for
Both Mold Types Combined

		Compressive Strength, psi			
		4 x 8 in.		6 x 12 in.	
Strength Level	Aggregate Type	X	σ	X	σ
1	Crushed stone	2,870	334	2,750	284
2		3,690	310	3,640	205
3		4,990	401	4,640	133
4		5,890	271	5,490	184
1	Gravel	2,520	213	2,600	172
2		3,470	290	3,590	103
3		4,670	381	4,410	291
4		5,340	397	5,130	133

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1 in. = 25.4 mm
1 psi = 6.89 kPa

t-Test

To determine if the average strength values were statistically different for the two specimen sizes at different strength levels, t-tests were run. At each strength level, the average strength obtained using the small specimens was compared to that for the large specimens. The variabilities for the two sizes of specimens were assumed to be unknown and not necessarily equal to each other.(9) The test data for duplicate batches and mold types were combined. The results, summarized in Table 6, indicate that for the lower two strength levels the effect of specimen size on the average values was not significant for either aggregate type. However, at the two higher levels the averages were significantly different.

Table 6

t-Test for Average Values

Strength Level	Aggregate Type	Average Strength		u*	Significant Difference
		4 x 8 in.	6 x 12 in.		
1	Crushed stone	2,870	2,750	180	No
2		3,690	3,640	153	No
3		4,990	4,640	177	Yes
4		5,890	5,490	135	Yes
1	Gravel	2,520	2,600	112	No
2		3,470	3,590	128	No
3		4,670	4,410	197	Yes
4		5,340	5,130	175	Yes

*$u = t'_{1-\alpha/2}\sqrt{V_{4x8} + V_{6x12}}$, $V = (\text{Std.Dev.})^2/n$ (Ref.9) used here and in Tables 9 and 12.

1 in. = 25.4 mm
1 psi = 6.89 kPa

Linear Regression

Since the t-test indicated that specimen size affects the test results at higher strength levels, a relationship was sought between the test results for the two sizes of specimens. A linear regression analysis was made where the average strength value obtained for the small specimens for each batch of concrete was taken as the independent variable and correlated with the value obtained from the larger specimens for each aggregate type and then for both types combined. A plot of the total strength data for each batch and the two mold sizes is shown in Figure 1. The best linear fit obtained using all the specimens is also shown in the figure. The slope, intercept, standard error of estimate, and square of the correlation coefficient are given in Table 7. The best fit indicates that the difference in strengths obtained for the two sizes of specimens is dependent on the strength level. At about 3,200 psi (22.0 MPa) there was no difference, but as the strength increased, differences increased and the smaller specimens gave higher values. Indications are that the reverse may be true at low strength levels based on the best line of fit, even though there are not enough data at low strengths for definite conclusions.

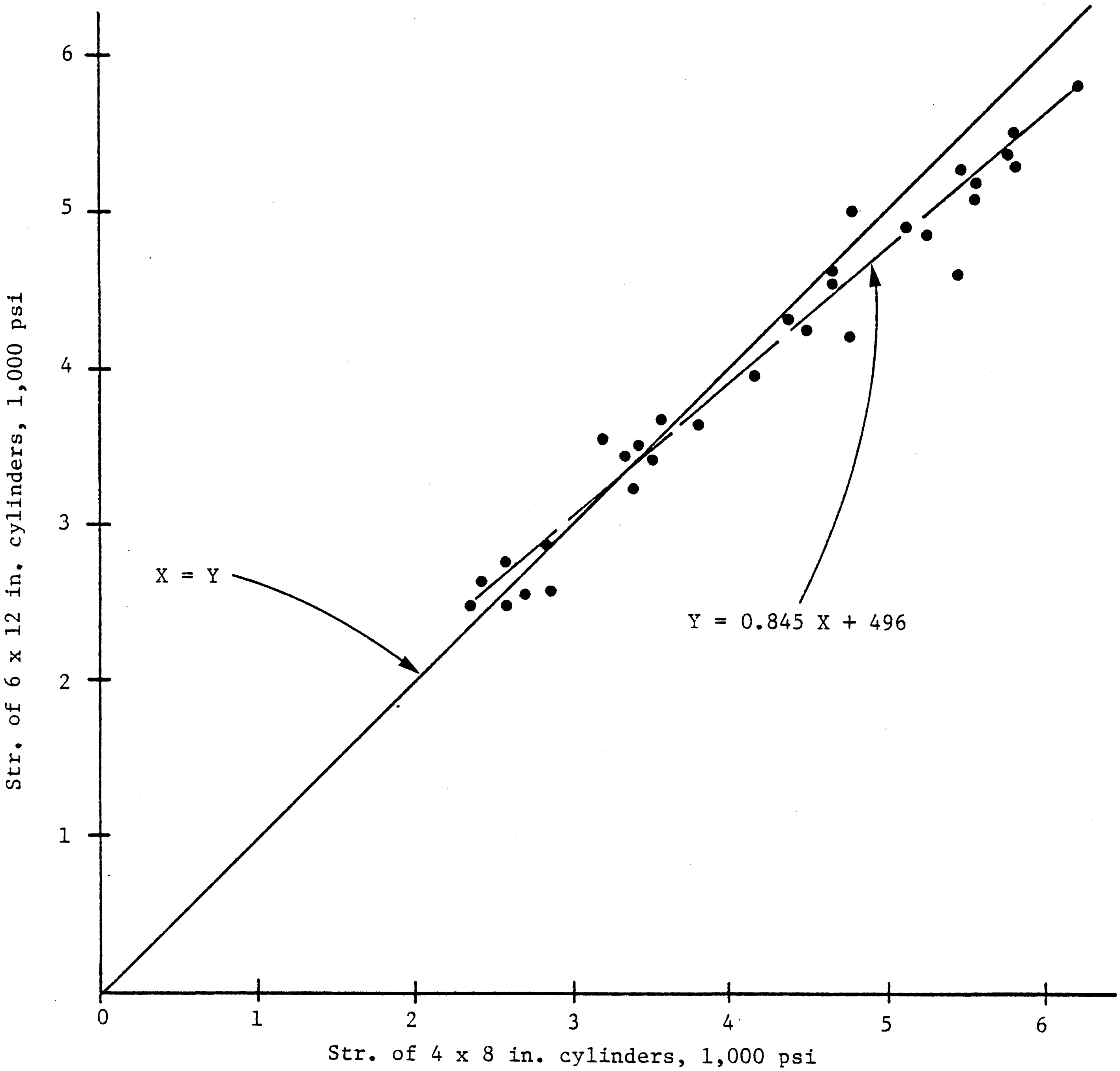

Figure 1. Linear regression analysis for laboratory data.
(1 psi = 6.89 kPa)

Table 7

Linear Regression Analysis

Aggregate Type	Slope	Intercept, psi	Standard Error of Estimate, psi	Correlation Coefficient^2
Crushed stone	0.863	365	187	0.97
Gravel	0.842	566	193	0.96
Both	0.845	496	192	0.97

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1 psi = 6.89 kPa

When all the specimens were included for the 3,000 psi (20.7 MPa) strength level, it was observed that the strengths for small specimens were 1% less than the strengths for the large specimens. However, at 4,000 psi (27.6 MPa), the small specimens exhibited 3% higher strength values, and at 5,000 psi (34.5 MPa) 6% higher values.

The ratios of strengths for the two specimen sizes were calculated from the line of best fit for certain strength levels for comparison with findings from another source. The results, summarized in Table 8, indicate that both size specimens yield about equal values at low strength levels, but that at high strength levels the small cylinders exhibit higher values.

Table 8

Strength Ratios of Small to Large Specimens at Different Strength Levels

Concrete Strength psi	Concrete Technology Assoc.*	Present Study
2,000 - 3,500	1.00	0.98
3,500 - 5,500	1.05	1.05
5,500 - 7,500	1.07	1.09
7,500 - 11,000	1.12	--

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*See reference 7

1 psi = 6.89 kPa

PART II -- FIELD INVESTIGATIONS

Testing Program

In the field, specimens were obtained from A3 and A4 concretes prepared for state jobs. Data were collected in two series. For the first series, small and large specimens were prepared at a ready-mixed concrete plant using A3 concrete from a truck mixer, and the specimens were tested at the Central Materials Laboratory at Elko. In the second series, specimens from 34 batches of A3 and A4 concretes produced for state projects were prepared and tested in two districts, Culpeper and Richmond. From each batch, 3 small cylinders and 2 large cylinders were cast. The small cylinders were cast in plastic molds and tested with neoprene pads in steel end caps and the larger cylinders were cast in steel molds and tested with sulfur-mortar caps. The large number of specimens for the small cylinders was to compensate for the higher variability in test results obtained in laboratory work as explained in Part I. Also, 3 specimens will enable easier decision making when the strength of 1 of the cylinders differs considerably from those of the others. The use of plastic molds would be convenient and economical since considerable time is required to prepare the steel molds for use in subsequent tests. The testing with neoprene pads in steel end caps had been studied at the Council on larger cylinders and satisfactory results were obtained when the majority ranged between 3,000 psi (21.0 MPa) and 5,500 psi (37.9 MPa), and their use had been recommended.(10) The use of neoprene pads instead of sulfur-mortar caps is advantageous in that it reduces the cost of tests, eliminates the hazards in handling the hot toxic materials, and eliminates the air pollution from sulfurous fumes.

The class A3 concrete obtained at the ready-mixed plant had a cement content of 588 lb./yd.^{3} (347 kg/m^3) and water-cement ratio of 0.48.

A statistical analysis indicated that to estimate the standard deviation of the compressive strength within 35% of its true value at a 95% confidence level, 16 samples were needed.(9) Thus, for this investigation sixteen 4 x 8 in. (100 x 200 mm) cylinders in plastic molds and sixteen 6 x 12 in. (150 x 300 mm) cylinders in steel molds were prepared. All the specimens were tested at 14 days; the small cylinders with neoprene pads in steel end caps and the larger cylinders with sulfur-mortar caps.

One of the test values obtained from the large cylinders was discarded as recommended in ACI 214, since it deviated from the mean by more than 3 times the standard deviation. The average strength for the 15 large cylinders was 5,440 psi (37.5 MPa) and the standard deviation 133 psi (0.92 MPa); for the small cylinders these values were 5,340 psi

(36.8 MPa) and 221 psi (1.52 MPa), respectively. The data were analyzed to compare the average values and the variability between the two test procedures, using the t-test and F-test, respectively, and the results are summarized in Table 9. The t-test indicated that at the 95% confidence level the average values did not differ.

For the 95% confidence level, the F value calculated was marginal but did not indicate a significant difference in variability between the two test procedures.

Table 9

Statistical Analyses
(See Reference 9)

t-test to Compare Average Value

4 x 8 in.		6 x 12 in.			Significant Difference
X	s	X	s	u	
5,340	221	5,440	133	134	No

F-test to Compare Variability

$F = s^2_{4 \times 8} / s^2_{6 \times 12}$	$F_{0.975\ (15,14)}$	Significant Difference
2.76	2.89	No

NOTE:

X = average strength, in psi (1 psi = 6.89 kPa). The subscripts are cylinder sizes in inches. (1 in. = 25.4 mm)

s = standard deviation, in psi

Second Series

Specimens

For the second series of tests, concrete was furnished by producers in the Culpeper and Richmond districts. Sets of specimens, 2 large in steel molds and 3 small in plastic molds, were cast from different batches. The A3 and A4 concretes in the Culpeper District were generally prepared on different dates and sent to different locations by one producer, whereas the batches of A3 concrete tested in the Richmond District were all prepared on the same day for the same paving job. Cylinders were cast at the plant. Similarly, half of the cylinders for the A4 concretes were also prepared the same day at the plant. Thus, the strength values obtained in the two districts cover the range of variability expected in the field, and the specimens from the Culpeper District would be expected to show a higher variability. The specimens were tested at 14 days, the large ones with sulfur-mortar caps and the small ones with neoprene pads in steel end caps.

The strength data, as averages of the results for 3 small and 2 large cylinders, are given in Table 10 for the Culpeper District and in Table 11 for the Richmond District. The average strength values obtained for the small cylinders in the Culpeper District, as summarized in Table 12, were slightly higher than those obtained for the larger cylinders. However, the reverse was true for the Richmond District. A statistical comparison of the average strength values for each class of concrete for each district was made using the t-test. The results, also summarized in Table 12, show that there was no significant difference in average strength values at the 95% confidence level, which indicates that one procedure could be substituted for the other.

A statistical comparison of variabilities for the classes of concrete in each district was made using the F-test at the 95% confidence level to determine if the differences were significant. It was found that, as summarized in Table 13, there was no significant difference in the variability of test results when the two cylinder sizes were used, even though the standard deviations given in Table 12 show that the small cylinders had a higher variability than the large cylinders.

Linear regression analyses were performed to obtain the relationships between the compressive strength values obtained for the two cylinder sizes for each district and then for both districts. The slope, intercept, standard error of estimate, and square of the correlation coefficient obtained from the analyses are summarized in Table 14. The line of best fit obtained using all the data, plotted in Figure 2, indicates that at about 4,200 psi (28.9 MPa) the two cylinder sizes gave equal compressive strengths. Above this level, the small cylinders gave higher strengths and below it they gave lower strengths. At 3,000 psi (20.7 MPa), when all the specimens were included the strengths for the small cylinders were 5% less (150 psi [1.03 MPa]) than the strength for the large cylinders. However, at the 5,000 psi (34.5 MPa) level, the small cylinders exhibited 2% (100 psi [0.69 MPa]) more strength than the large ones. These differences are considered small and were disregarded. Table 15 gives a comparison of the ratios of strengths for the two cylinders obtained from the line of best fit for certain strength levels with findings from another source,(7) and the results of the laboratory study described previously. In all cases, equal trends were observed. At a certain strength level, both cylinder sizes exhibited equal strengths, and above this level the small cylinders gave larger strength values. At the minimum design strengths for A3 and A4 concretes, 3,000 psi (20.7 MPa) and 4,000 psi (27.6 MPa) or 4,500 psi (31.0 MPa) for bridge decks, respectively, the differences in strengths were small and can be disregarded.

Table 10

14-Day Compressive Strength Data
From Culpeper District, in psi

	Class A3		Class A4	
	Cylinder Size		Cylinder Size	
Batch	4 x 8 in.	6 x 12 in.	4 x 8 in.	6 x 12 in.
1	4,460	4,500	5,110	5,080
2	3,520	3,820	5,320	5,570
3	3,360	3,370	4,300	4,640
4	5,420	5,780	5,380	5,890
5	3,900	4,310	4,130	4,180
6	4,080	4,230	4,350	4,390
7	3,890	4,020	4,080	4,180
8	3,540	3,660	4,890	4,940
9	3,480	3,660	4,300	4,180

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1 in. = 25.4 mm
1 psi = 6.89 kPa

Table 11

14-Day Compressive Strength Data
From Richmond District, in psi

	Class A3		Class A4	
	Cylinder Size		Cylinder Size	
Batch	4 x 8 in.	6 x 12 in.	4 x 8 in.	6 x 12 in.
1	4,170	3,950	4,430	4,220
2	3,600	2,820	4,310	4,070
3	3,520	3,570	4,780	4,610
4	3,820	3,640	5,670	5,400
5	3,390	3,410	5,200	4,890
6	3,550	3,450	4,860	4,620
7	3,660	3,960	5,100	5,240
8	3,850	3,790	5,460	5,450

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1 in. = 25.4 mm
1 psi = 6.89 kPa

Table 12

t-Test to Compare Average Performance
(see Reference 9)

		4 x 8 in.			6 x 12 in.		Significant Difference
District	Class	X	s	X	s	u	
Culpeper	A3	4,150	709	3,960	649	673	No
Culpeper	A4	4,780	635	4,650	522	578	No
Richmond	A3	3,570	369	3,700	245	336	No
Richmond	A4	4,810	524	4,980	474	530	No

Notes:

X = average strength, in psi
s = standard deviation, in psi

1 in. = 25.4 mm
1 psi = 6.89 kPa

Table 13

F-test to Compare Variability
(see Reference 9)

District	Class	$F = s^2_{4 \times 8}/s^2_{6 \times 12}$	$F_{.975}$	Significant Difference
Culpeper	A3	1.19	4.43	No
	A4	1.48	4.43	No
Richmond	A3	2.27	4.99	No
	A4	1.22	4.99	No

Note:

s = standard deviation, in psi (1 psi = 6.89 kPa)

Table 14

Linear Regression Analysis

District	Slope	Intercept, psi	Standard Error of Estimate, psi	$(\text{Corr. Coef.})^2$
Culpeper	0.909	235	172	0.94
Richmond	0.950	361	240	0.91
Both	0.892	449	252	0.88

---

1 psi = 6.89 kPa

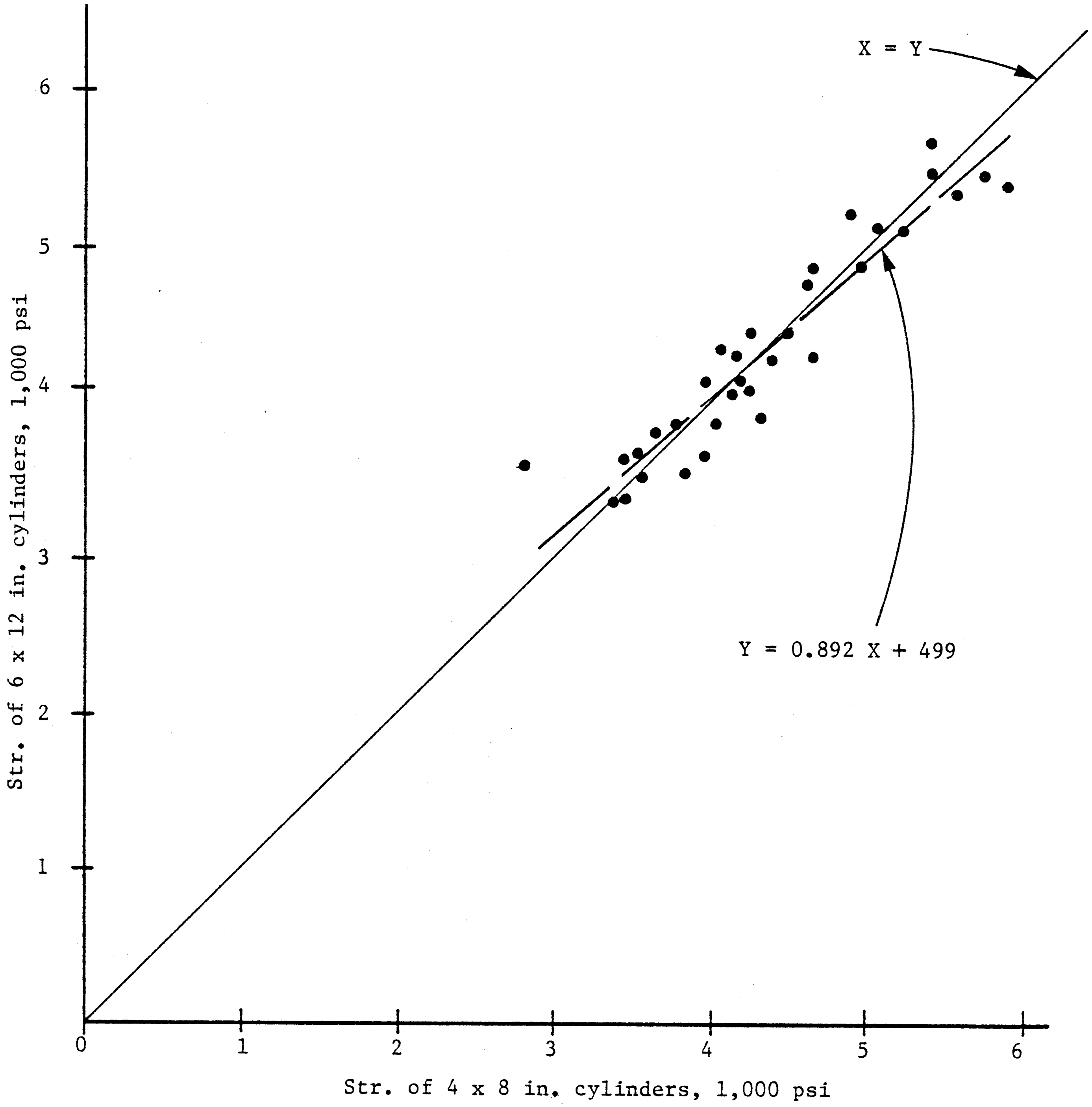

Figure 2. Linear regression analysis for field data.
(1 psi = 6.89 kPa)

Table 15

Strength Ratios of Small to Large Cylinders

Concrete Strength, psi	Strength Ratios Concrete Technology Assoc.*	Present Lab Study	Council Field Study
2,000 - 3,500	1.00	0.98	0.95
3,500 - 5,500	1.05	1.05	1.01
5,500 - 7,500	1.07	1.09	1.04
7,500 - 11,000	1.12	--	--

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*See reference 7

1 psi = 6.89 kPa

CONCLUSIONS

The results of the laboratory and field studies led to the following conclusions.

1. The differences between the compressive strengths for 4 x 8 in. (100 x 200 mm) concrete test cylinders and those for 6 x 12 in. (150 x 300 mm) cylinders depended on the strength level. At a certain level, which was about 3,200 psi (22.0 MPa) for the lab data and 4,200 psi (28.9 MPa) for the field data, the two specimen sizes gave equal strengths. At higher strength levels, the small cylinders yielded higher values.

2. The difference in the strength values indicated by the two sizes of cylinders increased as the strength level increased.

3. For the strength levels expected in A3 and A4 concretes, the 4 x 8 in. (100 x 200 mm) cylinders cast in plastic molds and tested with neoprene pads in steel end caps gave strength values that, for practical purposes, were equal to the values obtained for 6 x 12 in. (150 x 300 mm) cylinders cast in steel molds and tested with sulfur-mortar caps.

4. The standard deviation of strength values was higher when the smaller specimens were used. For the field specimens, the variability in compressive strengths was larger even when 3

small cylinders were used instead of 2 large ones; however, at the 95% confidence level, the differences in variability were not significant.

RECOMMENDATION

It is recommended that for highway construction three 4 x 8 in. (100 x 200 mm) cylinders cast in plastic molds and tested with neoprene pads in steel end caps be used to determine the compressive strength of A3 and A4 concretes incorporating aggregate with a nominal maximum size of 1 in. (25 mm) or less as an alternate to tests of two standard 6 x 12 in. (150 x 300 mm) cylinders. This will result in efficiency and economy, and also enable easy decisions if the value for one of the test cylinders differs considerably from those of the others.

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