COMPARISON OF COMPRESSIVE STRENGTHS OF MOLDED AND SAWED CONCRETE SPECIMENS

by

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SYNOPSIS

When standard concrete test cylinders fail to yield the specified 28-day compressive strength, it is the usual practice to test cores or prisms taken from the concrete in place. So far, there is no generally accepted method of correlating the strengths of cores or sawed prisms and molded specimens. It is therefore essential that the relationship between their strengths be established, so that the results can be interpreted correctly.

This experiment was designed to compare the compressive strengths of molded and sawed prisms that were cast, cured, and tested under similar conditions. Opportunity also existed to investigate the relationship between the ratio of prism

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widths, d , to maximum sizes of coarse aggregate, a, and the strength of test specimens. In all, three series of test were made. Since series III was an improvement over the first two, all conclusions are based on the results obtained from this series.

The results indicate that the compressive strength of 4-in.sawed specimens is significantly less than that of 4-in. molded specimens. The statistical analysis does not show any significant difference in the compressive strengths of 2-in. prism. For 1.33-in. specimens the difference is significant at $\alpha = .05$ and not significant at $\alpha = .025$.

Though no simple relationship between the ratio of prism width to maximum size of coarse aggregate and the strength of the test specimen is apparent, the results do indicate that there is increasing influence of coarse aggregate on the variance of strength properties of specimens as the edge dimension of the specimen approaches the diameter of the maximum size of coarse aggregate.

INTRODUCTION

The compressive strength of standard concrete cylinders is the foundation of our concrete design and is usually used as the criterion of concrete quality. The strength of almost every concrete structure is computed on the basis of the apparent strengths obtained from test specimens. Therefore, it is important that this property be determined as correctly as possible.

Unfortunately, there are many factors influencing the indicated strength of molded concrete test specimens. Such factors sometimes lead to erroneous results. If the indicated 28-day strength of molded cylinders fails to yield the specified minimum strength, it is often necessary to test cores or prisms taken from the concrete in place to confirm that results previously obtained were not chance events.

There is only a limited amount of data on the relationship between compressive strengths of cores and molded cylinders in the literature. This limited amount of available data shows considerable conflict.

The Bureau of Reclamation Concrete Manual(1) states that tests of drilled cores taken from structures almost invariably show strengths greater than those obtained from control cylinders which are standard cured for 28 days.

Numbers in parenthesis--thus(1)--refer to corresponding items in the bibliography.

W. H. Price[2] observed that core strengths were almost all higher than control strengths in the case of cores taken from structures which had some curing; and he states that if cores were taken from columns of buildings (which were cured and were protected from moisture), the cores might show higher strengths than the moist-cured control specimens. Core strengths ranged from about 70 to 180 percent of control cylinder strengths, but were for the most part higher.

F. E. Legg, Jr.,[4] compared compressive strengths of standard molded cylinders and cores drilled from pavement slabs at ages 28 days, 90 days, one year, and five years. With core data corrected to a ratio of length to diameter of 2.00 (using a factor of 0.94 for a ratio of 1.25), cores tested 121, 113, 101 and 100 percent of standard cylinders at the four ages respectively.

W. K. Wagner[5] found that cores yield only about 67 percent of the 28-day cylinder strength and 85 percent of the 7 day cylinder strength. He compared the results of standard cylinders at 7 and 28-days with 4 by 8-inch diamond-drilled cores taken from the same concrete after field curing.

Average core strengths at 28 days, as obtained by R. A. Lapinas[6], ranged from 61 to 74 percent of standard 28 day cylinders for concrete containing type I cement. Where type IV cement was used and the peak temperature ranged from 110 to 120 F, cores gave substantially the same strengths as companion standard cylinders at 28 days.

Bryant Mather and W. O. Tynes(7) observed that standard cylinders and cores yielded approximately equal strengths for low-strength concrete, but cores yielded lower results than cylinders for high-strength concrete.

Research conducted by R. D. Gaynor(8) indicated that at 95 days, cores from well cured slabs gave strengths ten percent less than 28 day standard cylinders.

Apparently, a greater understanding of the significance of tests of cores is needed. The work reported here was designed to compare the compressive strengths of sawed and molded concrete prisms that were cast, cured, and tested under similar conditions.

Opportunity also existed to investigate the relationship between the ratio of prism width, d, to maximum size of coarse aggregate, a, and the strength of the test specimen.

EXPERIMENTAL WORK

Scope

The main purpose of this experiment was to compare the compressive strengths of molded specimens with those of corresponding sawed specimens. Care was taken to ensure similar casting, curing and testing of both kinds of specimens.

Since the specimens compared had the same ratio of d/a, an opportunity existed to observe the relationship, if any, between the ratio d/a and the compressive strength.

The experiment was conducted in three series as shown in

Table I. Since about nine specimens are required to make proper statistical inferences, nine specimens of each size were cast wherever possible.(11) However, this could not be achieved in every case, due to various handicaps. The concrete mixer used for series I did not have enough capacity to mix the required batch. For series III, only four 4-inch specimens could be cast because the vibrating table was not big enough to accomodate a bigger mold. But according to Tucker, as quoted by Mather(7), "If we reduce the diameter of the test specimen, we need only make the number of specimens proportional to the ratio of the areas to obtain equal statistical information." Thus it is inferred that four 4-inch cubes are statistically equivalent to sixteen 2-inch cubes.

Preparation of Specimens

Materials. Portland Cement Association's(9) recommendations were followed in designing the mix. Six gallons of water, 245 pounds of Kaw River sand (Fineness Modulus 3.00), and 255 pounds of crushed pseudo-quartzite were used per sack of normal portland cement.

Series I had 3/4-in. maximum aggregate size, and the maximum size of aggregate was 3/8 in. for the other two series. This change was made to keep the least specimen size at least three times the maximum nominal size of the aggregate.(10)

The change of aggregate size made it necessary to change the proportions of sand and rock also. To provide the same grain size distribution in all the three series, 16.7 percent

TABLE I.--NUMBER AND SIZE OF SPECIMENS TESTED.

Specimen size	Maximum Aggregate size in inches	Ratio Specimen width to maximum Aggregate size (d/a)	Number Tested	
			Molded	Sawed
(1)	(2)	(3)	(4)	(5)
Series I				
8.0 in. cubes	3/4	10.67	7	9
6.0 in. cubes		8.00	7	6
4.0 in. cubes		5.33	6	6
3.0 in. cubes		4.00	9	9
Series II				
4.0 in. cubes	3/8	10.67	9	9
3.0 in. cubes		8.00	8	9
2.0 in. cubes		5.33	9	9
1.5 in. cubes		4.00	6	9
Series III[a]				
4.0 in. cubes	3/8	10.67	4	4
2.0 by 2.0 by 2.0 in.		5.33	16	16
1.33 by 1.33 by 4.0 in.		3.56	6	7

[a]Tested as cast and corrected to (1/d) = 2.00 according to ASTM Designation: C 42.[10]

rock and 83.3 percent sand were used for series II and III.

Fresh Concrete. Ten-cubic-foot and two-cubic-foot concrete mixers were used for series I and the other two series respectively. The properties of fresh concrete are shown in Table II.

TABLE II.--PROPERTIES OF FRESH CONCRETE

Series (1)	Concrete Batch Size ft.^{3} (2)	Slump inch (3)	Unit Weight lb./ft.^{3} (4)
I	10.0	5.5	147.0
II	1.5	0.0	142.8
III	1.0	0.3[a]	142.0

[a]Added a pound of extra water to achieve some workability.

Molding and Curing. Figure 1 shows a typical mold used in series I and II. Each mold was partitioned into two parts. Three beams were cast in one part; as many as nine cubes were cast in the other part.

Test specimens for series I were molded and cured in accordance with ASTM Designation : C 192. The beams were taken out of the fog room on the sixth day, and three cubes were sawed from each beam. All test specimens were then capped with a commerical capping compound and their dimensions were recorded. Testing was done on the seventh day.

The same procedure was adopted for series II, with two exceptions. Instead of a 5/8 in. tamping rod, a hand vibrator was used for compaction, and the specimens were kept submerged in water for curing.

Series III was designed to remove some of the variables inherent in series I and II. Instead of using different molds for different sizes, only one mold was used. This mold was partitioned into various different sizes as shown in Fig. 2. The entire mold was then fastened securely to a vibrating table. Concrete was vibrated for 20 seconds when the mold was half full, and for a minute when the mold was full. This procedure was followed to achieve uniform compaction for all specimens. The mold was then left undisturbed and fully covered with a polyethylene sheet for six days, after which the specimens were removed from the mold. The slab was sawed into different sizes as shown in Fig. 6. All specimens were left in water until the next day, when they were capped and tested.

Methods of Test

Both sawed and molded specimens were tested in accordance with the applicable provisions of the Method of Test for Compressive strength of Molded Concrete Cylinders (ASTM Designation: C 39).[10]

Table III shows the testing machines used for various specimens.

TABLE III.--TESTING MACHINES USED.

Series (1)	Size of specimen tested, in inches (2)	Machine used (3)	Capacity of the machine, in pounds (4)
I	3 and 4	Southwark Emery	120,000
	6 and 8	Universal Hydraulic	300,000
II	1.5 and 2.0	Emery Hydraulic	75,000
	3 and 4	Southwark Emery	120,000
III	1.33 and 4	Southwark Emery	120,000

Only one testing machine was used for series III to eliminate between-machine variation. All specimens were tested in the as-cast position.

Results.

The results of these tests have been summarized in Table IV for ready reference. Detailed results are given in Tables VI, VII, and VIII in the Appendix.

In Table IV, relative compressive strengths have been calculated for each series based on the average compressive strength of the molded cubes for which d/a is 10.67 as 100 percent. In all but three cases, values are lower for sawed specimens than for molded specimens. Series I and II show a marked increase in strength with decreasing specimen size (decreasing d/a); there is no clear-cut trend in series III.

TABLE IV.--COMPRESSIVE STRENGTHS, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION.

Specimen size in inches	Max. aggregate size (a) in inches	Ratio specimen width to max. aggregate size (d/a)	Molded				Sawed			
			Average strength pounds per inch	Relative strength as a percent	Standard deviation in pounds per sq. inch	Coefficient of variation in percent	Average strength in lbs. per sq. inch	Average strength as percent	Standard deviation	Coefficient of variation in percent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Series I--All cubical specimens.										
8.0		10.67	4620	100.0	110	2.38	4470	96.80	270	6.04
6.0	3/4	8.00	6090	131.8	251	4.12	5360	116.00	227	4.24
4.0		5.33	6590	142.6	170	2.58	6390	138.20	82	1.28
3.0		4.00	6520	141.1	484	7.43	6750	145.50	496	7.35
Series II--All cubical specimens.										
4.0		10.67	4090	100.0	273	6.67	4240	103.80	117	2.75
3.0		8.00	4390	107.3	344	7.84	4380	107.00	131	2.76
2.0	3/8	6.00	4580	112.0	107	2.34	4200	102.70	208	4.95
1.5		4.00	5050	123.5	266	5.27	4940	120.80	210	4.25
Series III--All specimens 4 in. high.[a]										
4.0 x 4.0		10.67	3400	100.0	26	0.76	3040	89.4	125	4.11
2.0 x 2.0	3/8	5.33	3030	89.2	119	3.93	2930	86.2	133	4.54
1.33 x 1.33		3.56	3250	95.6	133	4.09	3020	89.0	201	6.66

[a]Results corrected to l/d = 2.00 according to ASTM Designation: C 42(10); see Fig. 5.

Series III shows an increase in coefficient of variation with decreasing specimen size; there is no such trend in series I and II. For series III, the coefficient of variation is larger for sawed specimens than for molded specimens for each of the three sizes.

The maximum coefficient of variation is 7. 84 percent for the 3-in. molded specimens (d/a = 8.00) of series II. The minimum coefficient of variation is 0.76 percent for the 4-in. molded specimens (d/a = 10.67) of series III.

Test of Significance.

This test is performed only on the results obtained for series III. Table V shows the three analyses. The analyses were carried out seperately because of the unequal number of test specimens and the differing variances for the three sizes.

The analyses, therefore, indicate that the differences in the strengths of the sawed vs. molded specimens was significant for 4-in. size specimens and not significant for 2-in. sizes specimens. For 1.33-in. size specimens the difference in the compressive strengths of molded and sawed specimens was significant at $\alpha = .05$ and not significant at $\alpha = .025$.

Table V -- Analysis of Variance - Tables for Strength test data.

Source	Degrees of Freedom	Sum of squares	Mean sum of squares	"F"	Decision
4-in. size					
Total		298,000			
Treatment	1	251,000	251,000	32.06 (5.99)	significant
Within	6	47,000	7,830		
2-in. size					
Total		542,000			
Treatment	1	30,000	30,000	1.76 (4.17)	Not significant
Within	30	512,000	17,067		
1.33-in. size					
Total		490,000			
Treatment	1	182,000	182,000	5.91 (4.96)	significant
Within	10	308,000	30,800		

[a] Values in parenthesis are the "F"-table values. The sum of squares are computed on the basis of table IX (see appendix).

DISCUSSION OF RESULTS

All inferences have been based on the compressive strength test data from series III. Proper control over some of the variables affecting compressive strength could not be exercised for the first two series. Lack of uniform compaction, different molds for different sizes, and different testing machines were a few of those uncontrolled variables. Though both the beams and molded specimens of series II were submerged in water for curing, yet the molded specimens had six faces in contact with water while the still un-sawed specimens had only four. In series III, however, these variables were eliminated.

The relative compressive strengths for series III show lower values for sawed specimens than for molded specimens, which is in accord with some of the previous findings. Though the strength of 4-in. sawed specimens is significantly lower than that of 4-in. molded specimens, it is not significantly different for 2-in. specimens. Also the strength of 1.33-in. sawed specimens is significantly less than that of 1.33-in. molded specimens at $\alpha = .05$, and not significantly less at $\alpha = .025$.

No simple relationship between the ratio of prism width to maximum size of coarse aggregate and the strength of test specimens is apparent from the results obtained. However, it is apparent that the compressive strength decreases as the ratio d/a increased except where d/a = 10.67. Also, the within-cell variance increases as the size of specimen decreases. In other words, the data are more hetrogeneous for the smaller sized specimens. This effect may be attributed to the increasing influence of coarse aggregate on the strength properties of specimens as the edge dimension of the cube approaches the diameter of the maximum size of coarse aggregate.

CONCLUSION

From the experimental data obtained from this study, the following conclusions may be drawn:

1. The 4-in. sawed specimens were significantly weaker than the 4-in. molded specimens.
2. There was no statistically significant difference between the compressive strengths of molded and sawed concrete specimens of 2-in size.
3. The strengths of 1.33-in. molded specimens are significantly lower than those of 1.33-in. molded specimens at $\alpha = .05$, and the difference in their strengths is not singificant at $\alpha = .025$.
4. The coefficient of variation decreased as the ratio d/a increased.

The conclusions drawn above hold good only when the concrete mix design remained fixed with a cement factor of 5.5 sacks per cu. yd.; the water cement ratio was 0.53; aggregate gradation was fixed; and, molding and fabricating procedures were held constant.

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BIBLIOGRAPHY

(1) "Concrete Manufacturing" Concrete Manual, United States Department of Interior, Bureau of Reclamation, United States Government Printing Office, Washington, D. C., 7th Ed., 1963, p. 277.

(2) "Factors Influencing Concrete Strength," by W. H. Price, Proceeding American Concrete Institute, Vol. 47, 1951, p. 417.

(3) "Static and Fatigue Strength of Hardened Concrete," by C. E. Kesler and C. P. Siess, Special Technical Publication, American Society for Testing and Materials, No. 169, 1956.

(4) "Experimental Fly Ash Concrete Pavement in Michigan," by F. E. Legg, Jr., Presented at Annual Meeting of Highway Research Board, January 1964.

(5) "Effect of Sampling and Job Curing Procedures on Compressive Strength of Concrete," by W. K. Wagner, Materials Research and Standards, Vol. 3, No. 8, 1963, pp. 629 to 634.

(6) "Strength Development of High Cement Content Concrete Cast in Large Sections," by R. A. Lapinas, Presented at Fall Meeting of American Concrete Institute, Toronto, Ontario, November 1963.

(7) "Investigation of Compressive Strength of Molded Cylinders and Drilled Cores of Concrete," by Bryant Mather and W. O. Tynes, Journal of the American Concrete Institute, January 1961, pp. 767-778.

(8) "Research Highlight" by R. D. Gaynor, Presented at 34th Convention of National Ready Mixed Concrete Association, February 1964.

(9) "Design and Control of Concrete Mixture," Bulletin, Portland Cement Association, Chicago, Illinois, 10th Ed. p. 16.

(10) "Standards Book," American Society for Testing and Materials, Philadelphia, Pa., 1963.

(11) "The Numbers of Specimens or Test of Concrete and Concrete Aggregates Required for Reasonable Accuracy of the Average," by R. W. Crum, Report on Significance of Tests of Concrete and Concrete Aggregates, American Society for Testing and Materials, 1935, pp. 111 to 120.

(12) "Statistical Methods," by G. W. Snedcor, The Iowa State University Press, Ames, Iowa, 5th Ed. 1956, p. 246.

(13) "Experimental Statistics," by H. C. Fryer, Kansas State University, Manhattan, Kansas, 1964, pp. 221-242.

(14) "Effects of Aggregate Size on Properties of Concrete," by S. Walker and D. L. Bloem, Journal of the American Concrete Institute, September, 1960, pp. 283-298.

APPENDIX

TABLE VI.--SERIES I--COMPRESSIVE STRENGTHS, STANDARD DEVIATION AND COEFFICIENTS OF VARIATIONS.

Specimen Identification (1)	Length in inches (2)	Breadth in inches (3)	Area in square inches (4)	Load in pounds (5)	Stress in pounds per square inch (6)	Average stress in pounds per square inch (7)	Standard deviation in pounds per square inch (8)	Coefficient of variation in percent (9)
Molded Eight Inch Cubes--Loading Rate 120,000 lb./min.								
T1	8.06	7.94	64.00	299,500	4680			
T2	8.00	7.97	63.76	299,500	4697			
T3	8.00	7.97	63.76	300,000[a]				
M1	8.01	7.94	63.60	298,500	4693			
M2	7.98	7.98	63.68	287,000	4507	4620	110	2.38
M3	7.97	7.99	63.68	300,000[a]				
B1	8.00	7.99	63.92	282,200	4415	(100%)		
B2	7.95	7.96	63.28	295,600	4671			
B3	8.02	8.02	64.32	298,500	4641			
Sawed Eight Inch Cubes--Loading Rate 120,000 lb./min.								
T1	8.00	8.03	64.24	287,000	4467			
T2	7.98	7.94	63.36	274,500	4332			
T3	8.00	7.96	63.68	284,000	4460			
M1	8.02	7.98	64.00	264,800	4138	4470	270	6.04
M2	8.02	7.95	63.76	275,500	5125			
M3	7.96	7.98	63.52	283,500	4462	(96.8%)		
B1	7.99	7.99	63.84	277.500	4347			
B2	8.01	8.04	64.40	282,000	4379			
B3	7.97	7.95	63.36	284,500	4490			

[a]Capacity of Testing Machine = 300,000 lb.

TABLE VI (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Molded Six Inch Cubes--Loading Rate 70,000 lb./min.								
T1	5.94	6.00	35.64	219,000	6148			
T2	5.98	5.93	35.46	229,600	6475			
T3	6.03	6.03	36.36	222,000	6105			
E1	6.03	6.13	36.96	231,400	6260	6090	251	4.12
B1	6.16	5.97	36.78	209,000	5683	(131.8%)		
B2	5.98	6.13	36.67	218,100	5950			
B3	5.96	6.01	35.82	214,000	5974			
Sawed Six Inch Cubes--Loading rate 70,000 lb./min.								
T1	6.09	6.13	37.33	196,000	5250			
T2	5.90	6.11	36.05	192,600	5343			
M1	6.15	5.93	36.47	183,500	5032	5360	227	4.24
M2	5.89	5.90	35.28	186,800	5294			
B1	6.15	6.07	37.33	212,000	5680			
B2	5.93	6.05	35.88	198,600	5536			
Molded Four Inch Cubes--Loading Rate 30,000 lb./min.								
T1	3.99	3.98	15.88	102,800	6474			
T2	4.00	4.05	16.20	104,700	6463			
M1	4.03	3.99	16.08	108,700	6760	6590	170	2.58
M2	4.04	3.97	16.04	103,500	6453	(142.6%)		
B1	3.98	3.98	15.84	104,000	6566			
B2	3.98	4.00	15.92	109,000	6847			

TABLE VI (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			Sawed Four Inch Cubes--Loading Rate 30,000 lb./min.					
T1	3.95	4.07	16.08	102,700	6388			
T2	4.04	3.98	16.08	102,600	6381			
M1	4.13	3.96	16.36	102,700	6279	6390 (138.2%)	82	1.28
M2	4.03	3.96	15.96	103,000	6454			
B1	3.95	4.10	16.20	105,500	6514			
B2	4.09	3.91	16.00	101,600	6350			
			Molded Three Inch Cubes--Loading Rate 17,000 lb./min.					
T1	2.93	3.05	8.94	58,100	6499			
T2	3.05	3.00	9.15	55,600	6077			
T3	3.00	3.00	9.00	63,800	7089			
M1	3.05	2.95	9.00	61,100	6789			
M2	3.01	2.99	9.00	55,800	6200	6510 (141.0%)	484	7.43
M3	3.01	3.00	9.03	55,900	6190			
B1	3.00	3.00	9.00	63,100	7011			
B2	3.02	3.05	9.21	65,400	7101			
B3	3.01	2.93	8.82	50,000	5669			

TABLE VI (Concluded)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Sawed Three Inch Cubes--Loading Rate 17,000 lb./min.								
T1	2.98	2.99	8.91	58,300	6543			
T2	3.12	2.98	9.30	60,200	6474			
T3	3.06	3.02	9.24	68,900	7456			
M1	3.03	3.05	9.24	62,000	6709	6750	496	7.35
M2	3.08	3.08	9.49	63,600	6704	(145.5%)		
M3	2.98	3.10	9.24	60,900	6592			
B1	3.15	3.00	9.45	68,100	7206			
B2	2.98	3.10	9.24	66,500	7199			
B3	3.05	3.00	3.15	53,500	5847			

TABLE VII.--SERIES II--COMPRESSIVE STRENGTHS, STANDARD DEVIATION AND COEFFICIENTS OF VARIATION.

Specimen (1)	Length in inches (2)	Breadth in inches (3)	Area in square inches (4)	Load in pounds (5)	Stress in pounds per square inch (6)	Average stress in pounds per square inch (7)	Standard deviation in pounds per square inch (8)	Coefficient of variation in per cent (9)
Molded Four Inch Cubes--Loading Rate 30,000 lb./min.								
1	4.00	4.00	16.00	64,700	4044			
2	4.00	4.05	16.20	68,300	4216			
3	4.01	3.97	15.92	66,800	4196			
4	4.00	4.00	16.00	63,000	3936	4090 (100.0%)	273	6.67
5	4.00	4.00	16.00	69,500	4344			
6	4.00	4.02	16.08	63,200	3930			
7	3.98	4.07	16.20	71,000	4383			
8	4.01	4.04	16.20	57,500	3549			
9	4.02	4.01	16.12	68,200	4231			
Sawed Four Inch Cubes--Loading Rate 30,000 lb./min.								
1	3.80	4.00	15.20	63,400	4171			
2	4.00	3.82	15.28	64,000	4188			
3	4.01	4.10	16.40	66,400	4049			
4	3.90	4.01	15.60	68,500	4391	4240 (103.8%)	117	2.75
5	3.77	4.00	15.08	64,100	4251			
6	4.00	3.78	15.12	66,800	4418			
7	4.00	4.00	16.00	68,800	4300			
8	3.89	4.00	15.56	64,700	4158			
9	3.94	4.00	15.76	66,200	4201			

TABLE VII (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Molded Three Inch Cubes--Loading Rate 17,000 lb./min.								
1	3.09	3.05	9.43	44,100	4679			
2	3.06	3.00	9.18	36,100	3932			
3	3.06	3.01	9.21	41,100	4462			
4	3.05	3.01	9.18	41,300	4498	4390 (107.3%)	344	7.84
5	3.06	3.01	9.21	42.300	4592			
6	3.04	2.96	9.00	42,200	4689			
7	3.01	2.95	8.88	35,300	3975			
8	3.00	3.02	9.06	38,900	4284			
9	3.00	3.00	9.00	31,900	3544[a]			
Sawed Three Inch Cubes--Loading Rate 17,000 lb./min.								
1	2.98	3.00	8.94	41,600	4653			
2	3.01	2.88	8.64	37,900	4387			
3	3.00	2.94	8.82	37,300	4229			
4	2.90	3.01	8.70	39,200	4506	4380 (107.0%)	131	2.76
5	3.00	2.95	8.85	38,550	4356			
6	2.99	2.90	8.70	38,200	4391			
7	3.00	2.97	8.91	38,900	4366			
8	2.90	3.00	8.70	37,400	4299			
9	2.80	3.00	8.40	35,700	4250			

[a]Deleted--variation greater than 15 percent over average.

TABLE VII (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Molded Two Inch Cubes--Loading Rate 7500 lb./min.								
1	2.00	2.00	4.00	18,200	4550			
2	1.99	2.00	3.98	18,200	4573			
3	2.00	2.00	4.00	18,000	4500			
4	2.01	2.02	4.04	17,800	4406	4580	107	2.34
5	2.00	1.99	4.00	18,500	4625	(112.0%)		
6	2.00	2.02	4.04	18,500	4579			
7	2.01	2.02	4.06	19,000	4680			
9	2.00	2.00	4.00	19,100	4775			
Sawed Two Inch Cubes--Loading Rate 7500 lb./min.								
1	1.86	2.00	3.72	16,000	4301			
2	1.84	2.01	3.68	15,500	4212			
3	1.98	2.00	3.96	15,200	3838			
4	2.00	1.86	3.72	16,000	4301	4200	208	4.95
5	2.01	1.87	3.74	15,500	4144	(102.7%)		
6	1.99	1.86	3.72	16,300	4382			
7	2.00	1.95	3.90	17,250	4423			
8	2.00	1.86	3.72	14,850	3992			
9	1.87	2.00	3.74	15,800	4225			

TABLE VII (Concluded)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Molded one and one-half inch Cubes--Loading Rate 4,000 lb./ft.								
1	1.50	1.51	2.27	11,850	5232			
2	1.50	1.51	2.27	11,000	4857			
3	1.50	1.50	2.25	10,900	4844	5050 (123.5%)	266	5.27
4	1.49	1.50	2.14	10,400	4871			
5	1.51	1.50	2.27	11,300	4989			
6	1.49	1.50	2.14	11,750	5504			
Sawed one and one-half inch Cubes--Loading Rate 4,000 lb./ft.								
1	1.50	1.38	2.07	10,400	5024			
2	1.50	1.32	1.98	9,900	5000			
3	1.51	1.36	2.04	10,600	5196			
4	1.49	1.38	2.06	10,350	5036	4940 (120.8%)	210	4.25
5	1.50	1.35	2.03	10,000	4938			
6	1.49	1.41	2.10	10,550	5024			
7	1.40	1.50	2.10	9,650	4596			
8	1.36	1.49	2.03	9,200	4543			
9	1.51	1.37	2.07	10,550	5097			

TABLE VIII.--SERIES III--COMPRESSIVE STRENGTHS, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION

Specimen	Length in inches	Breadth in inches	Height in inches	Ratio height to least width (1/d)	Area in square inches	Load in pounds	Stress in pounds per square inch	Correction factor	Stress corrected to 1/d = 2.00	Average stress in pounds per square inch	Standard deviation in pounds per square inch	Coefficient of variation percent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Molded Four Inch Cubes--Loading Rate 40,000 lb./min.												
NW	3.97	3.98	4.13	1.04	15.80	61,700	3905	0.87	3400			
NE	3.97	3.97	4.13	1.04	15.76	61,600	3909	0.87	3400	3400	26	0.76
SW	4.03	3.98	4.10	1.03	16.04	63,100	3934	0.87	3420	(100.0%)		
SE	3.97	4.01	4.08	1.03	15.92	61,400	3857	0.87	3360			
Sawed Four Inch Cubes--Loading Rate 40,000 lb./min.												
NW	4.06	4.01	4.07	1.01	16.28	60,700	3729	0.85	3170			
NE	4.08	4.18	4.02	0.09	17.05	60,700	3560	0.84	2990	3040	125	4.11
SW	4.01	4.06	4.10	1.02	16.28	58,800	3612	0.86	3110	(89.4%)		
SE	4.06	4.00	4.07	1.02	16.24	54,500	3356	0.86	2890			

TABLE VIII (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
				2 by 2 by 4 in. Molded Prisms--Loading Rate 10.00 lb./min.								
NNW	1.98	1.95	4.14	2.12	3.86	11,220	2907	1.01	2940			
NNE	1.95	1.97	4.15	2.12	3.84	10,440	2719	1.01	2750			
NSW	1.96	1.95	4.14	2.12	3.82	11,060	2895	1.01	2920			
NSE	1.97	1.98	4.12	2.09	3.90	12,040	3087	1.01	3120			
WNW	1.98	1.97	4.13	2.09	3.90	12,000	3077	1.01	3110			
WNE	1.97	1.96	4.13	2.09	3.86	11,660	3021	1.01	3050			
										3030	119	3.93
WSW	1.97	2.01	4.13	2.09	3.96	11,820	2985	1.01	3010			
										(89.2%)		
WSE	2.00	2.00	4.13	2.07	4.00	12,680	3170	1.01	3200			
ENW	1.98	1.96	4.12	2.10	3.88	12,140	3129	1.01	3160			
ENE	1.98	1.97	4.13	2.09	3.90	12,040	3087	1.01	3120			
ESW	1.96	1.98	4.13	2.10	3.88	11,660	3005	1.01	3040			
ESE	1.97	1.96	4.11	2.09	3.86	12,140	3145	1.01	3180			
SNW	1.99	1.95	4.12	2.11	3.88	11,550	2977	1.01	3010			
SNE	2.00	1.98	4.10	2.07	3.96	11,800	2980	1.01	3010			
SSW	1.95	2.00	4.11	2.10	3.90	11,140	2856	1.01	2880			
SSE	2.00	1.97	4.10	2.08	3.94	11,760	2985	1.01	3010			

TABLE VIII (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
				2 by 2 by 4 in. Sawed Prisms--Loading Rate 10,000 lb./min.								
NNW	1.97	2.10	4.03	2.04	4.14	12,660	3058	1.00	3060			
NNE	2.09	1.98	4.03	2.03	4.14	11,260	2720	1.00	2720			
NSW	2.09	1.96	4.04	2.06	4.10	11,960	2917	1.01	2950			
NSE	2.04	1.93	4.05	2.09	3.94	10,200	2589	1.01	2610			
WNW	1.97	1.98	4.09	2.06	3.90	11,540	2960	1.01	2990			
WNE	1.93	1.93	4.05	2.06	3.72	11,380	3059	1.01	3090			
										2930	133	4.54
WSW	1.87	1.93	4.08	2.11	3.61	10,540	2920	1.01	2950			
										(86.2%)		
WSE	1.96	1.91	4.06	2.07	3.74	11,420	3054	1.01	3080			
ENW	2.01	2.00	4.00	2.00	4.02	11,480	2856	1.01	2860			
ENE	2.00	2.03	4.00	2.00	4.06	11,740	2892	1.01	2890			
ESW	2.07	2.05	4.01	1.95	4.24	12,560	2962	1.01	2960			
ESE	1.93	1.94	4.02	2.08	3.74	11,400	3048	1.01	3080			
SNW	2.04	2.00	4.10	2.05	4.08	11,550	2831	1.01	2960			
SNE	1.90	2.03	4.07	2.14	3.86	10,760	2788	1.01	2820			
SSW	2.02	2.02	4.10	2.02	4.08	12,220	2995	1.01	3000			
SSE	2.03	1.88	4.06	2.15	3.82	10,920	2859	1.01	2880			

TABLE VIII (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1.33 by 1.33 by 4.00 in. Molded Prisms--Loading Rate 4500 lb./min.												
NW	1.30	1.31	4.15			2825[a]						
N	1.25	1.31	4.18			3635[a]						
NE	1.35	1.31	4.14			2955[a]						
W	1.30	1.27	4.15	3.26	1.65	4805	2912	1.10	3200			
O	1.27	1.27	4.13	3.25	1.61	4975	3090	1.10	3400	3250	133	4.09
E	1.33	1.27	4.16	3.27	1.69	4970	2941	1.10	3240	(95.6%)		
SW	1.28	1.32	4.15		1.69	4820	2852	1.10	3140			
				3.24								
S	1.33	1.30	4.11		1.73	5365	3101	1.10	3410			
				3.16								
SE	1.31	1.32	4.13		1.73	4860	2809	1.10	3090			
				3.15								

[a]Deleted--spherical bearing block of testing machine did not break.

TABLE VIII (Concluded)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1.33 by 1.33 by 4.00 in. Sawed--Loading Rate 4500 lb./min.												
NW	1.12	1.32	4.07	3.63	1.48	5175	3497	1.14	3984[b]			
N[a]	1.38	1.32	4.10	3.10	1.82	3900	2143	1.09	2340[b]			
NE	1.33	1.24	4.05	3.26	1.65	4565	2767	1.10	3040			
W	1.37	1.40	4.07	2.97	1.92	5540	2885	1.08	3120			
										3020	201	6.66
O	1.41	1.18	4.06	3.44	1.66	4955	2985	1.12	3340			
										(89.0%)		
E	1.23	1.42	4.07	3.30	1.75	4750	2714	1.11	3010			
SW	1.26	1.33	4.09	3.24	1.68	4135	2461	1.10	2710			
S	1.28	1.34	4.08	3.18	1.72	4770	2773	1.10	3050			
SE	1.24	1.32	4.06	3.27	1.64	4240	2585	1.10	2840			

[a]Corner chipped

[b]Deleted--variation over 15 percent.

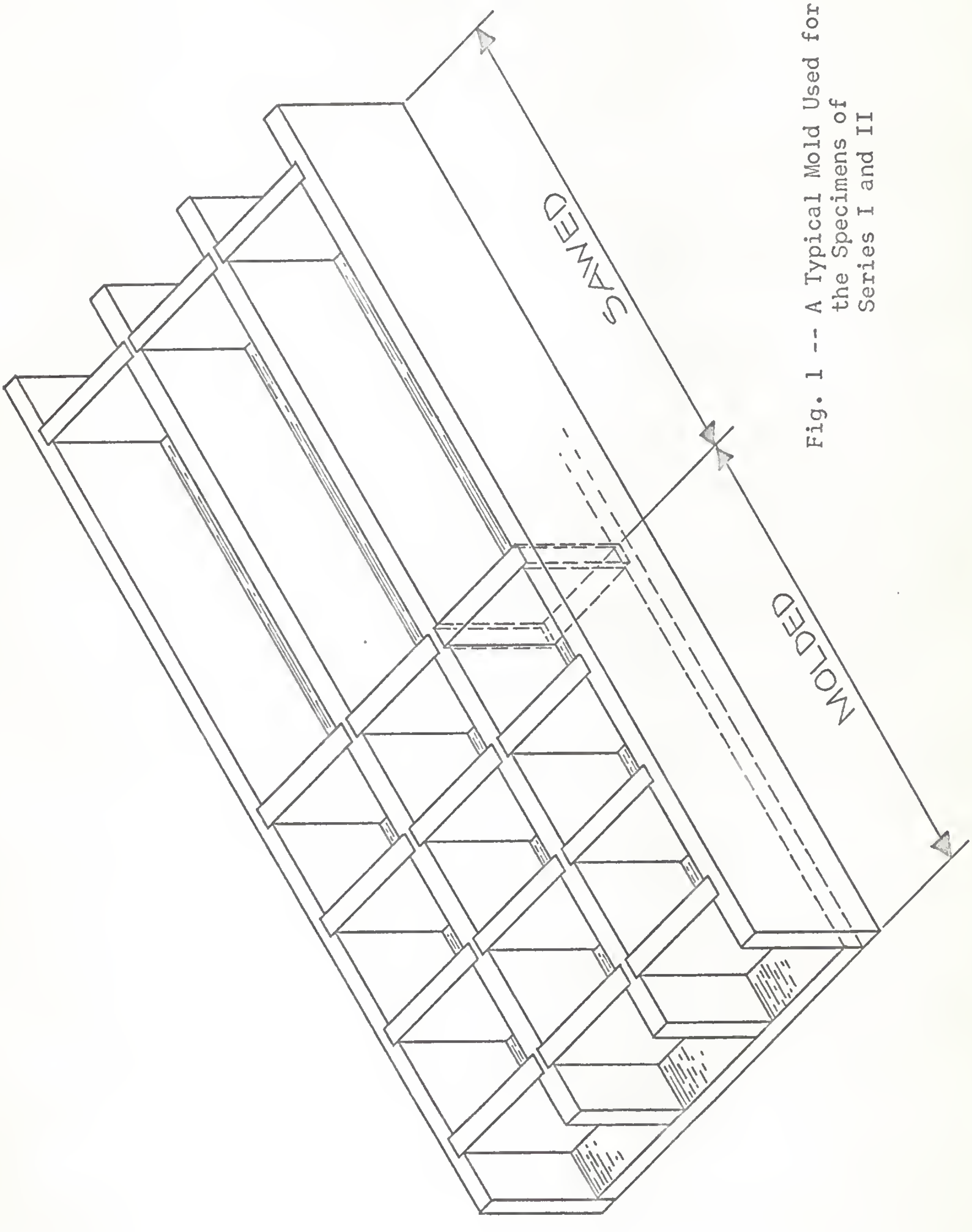

Fig. 1 -- A Typical Mold Used for the Specimens of Series I and II

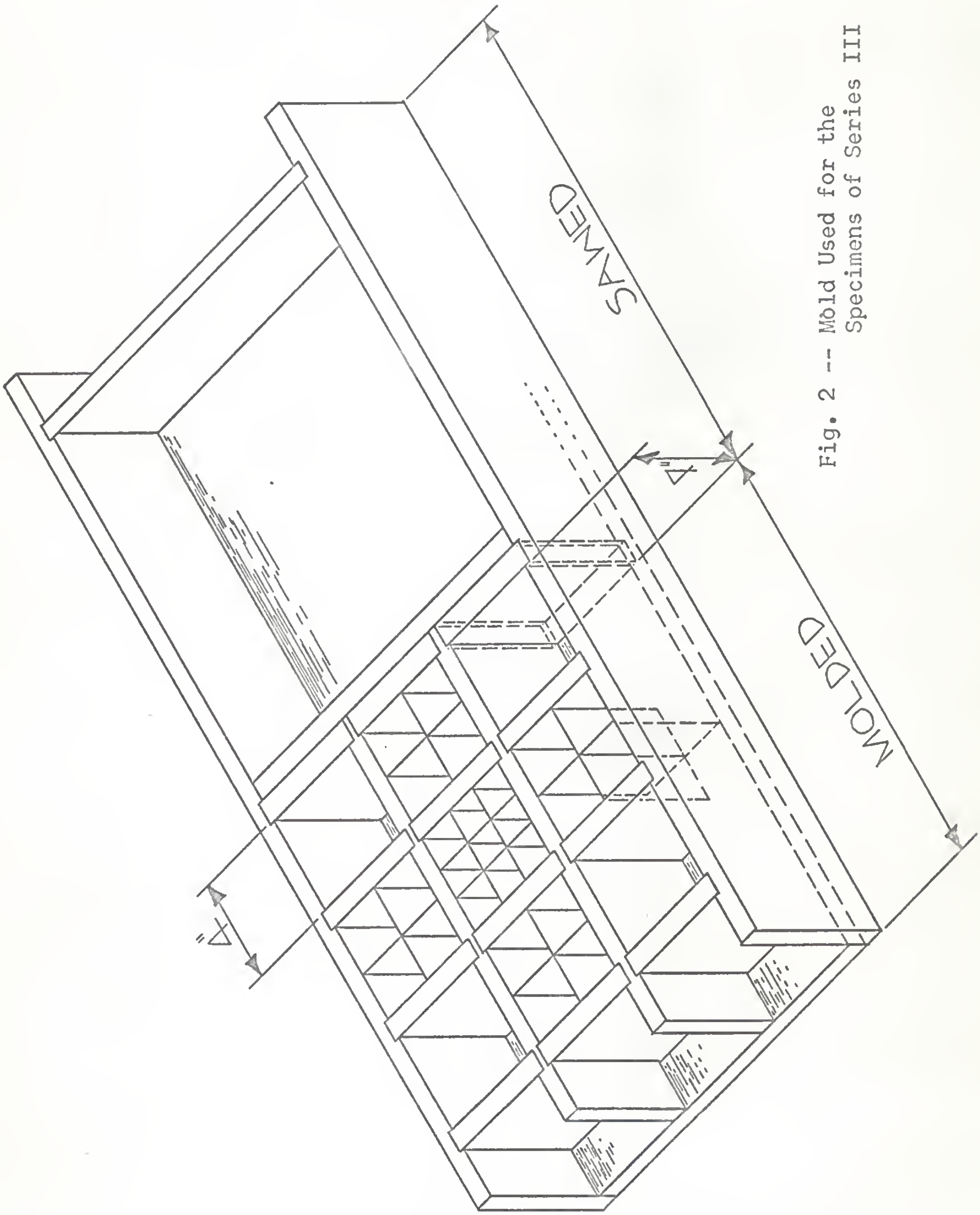

Fig. 2 -- Mold Used for the Specimens of Series III

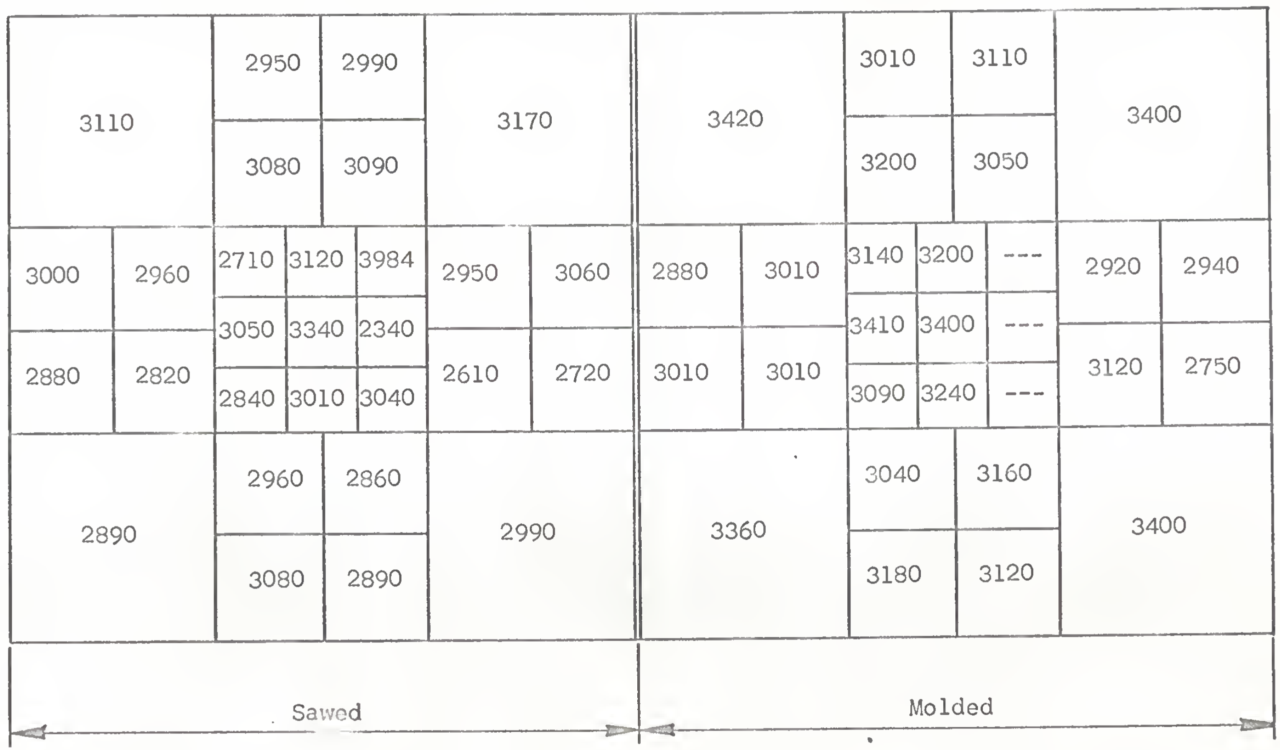

Fig. 3 -- Orientation and Compressive Strength of Sawed and Molded Concrete Prisms, Series III

Fig. 3

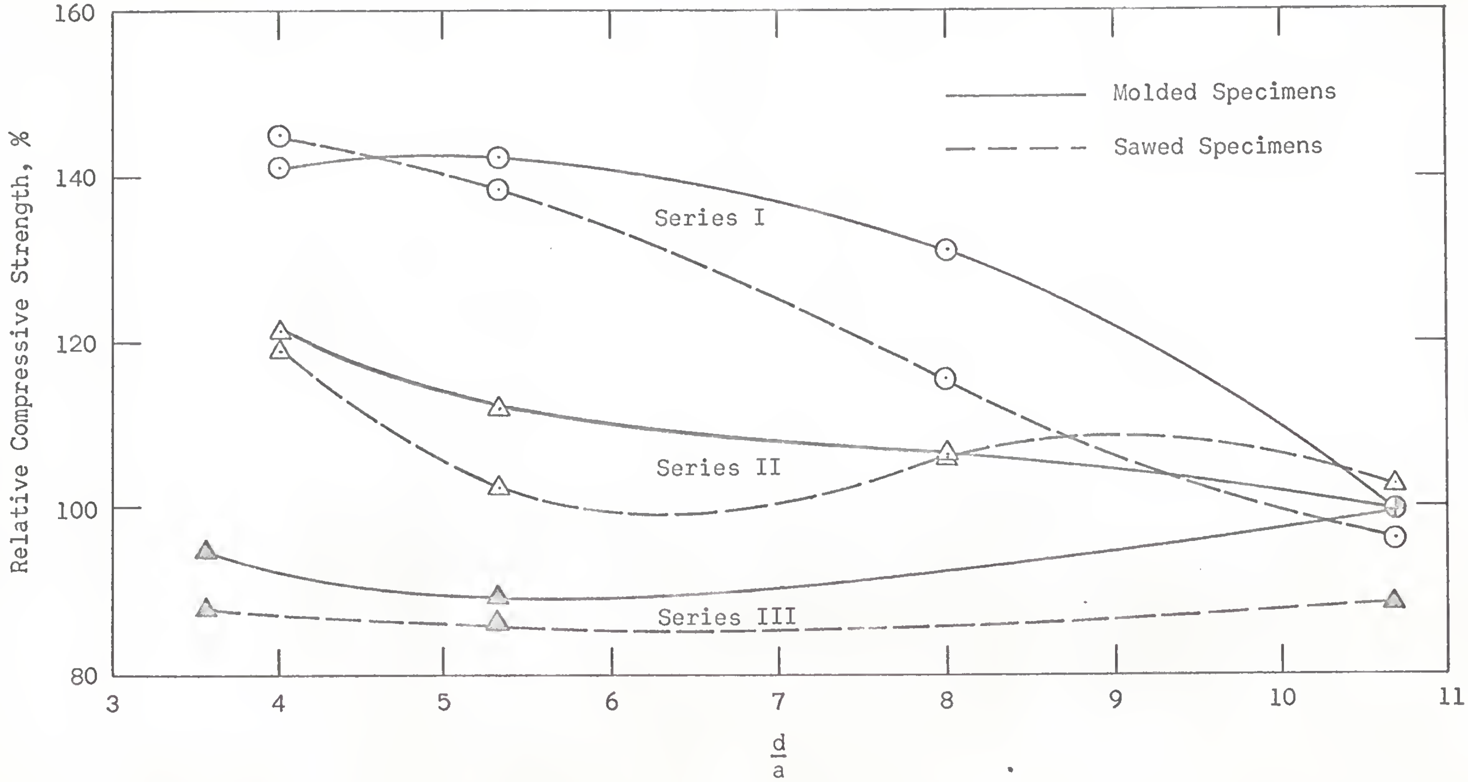

Fig. 4 -- Relative Compressive Strength of Molded and Sawed Specimens as a Function of the Ratio of Least Lateral Dimension, d, to Maximum Size of Aggregate, a, Based on Specimens with d/a = 10.67 as 100 Percent

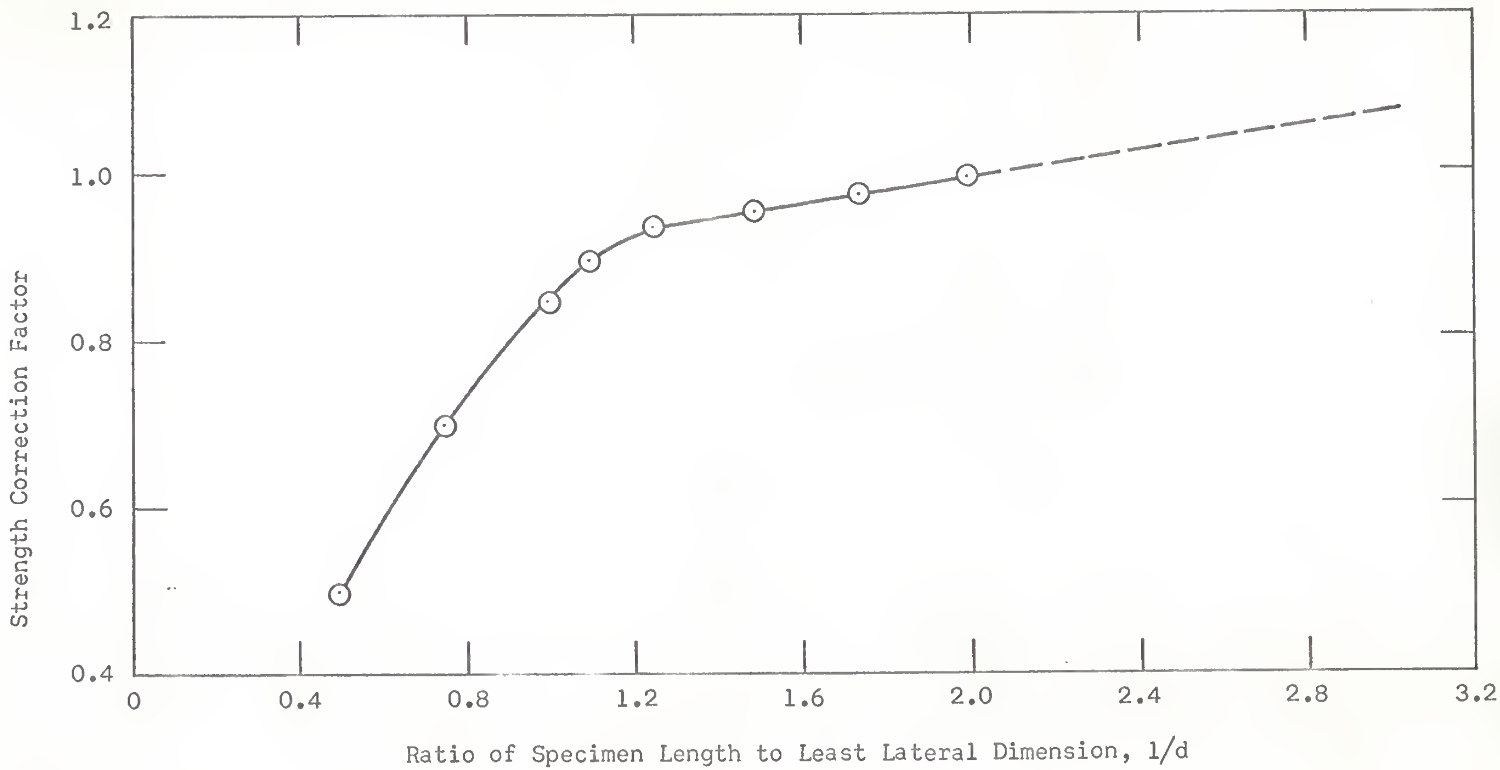

Fig. 5 -- Strength Correction Factors From ASTM Designation: C 42 - 49, Standard Methods of Securing, Preparing, and Testing Specimens from Hardened Concrete for Compressive and Flexural Strength (10)

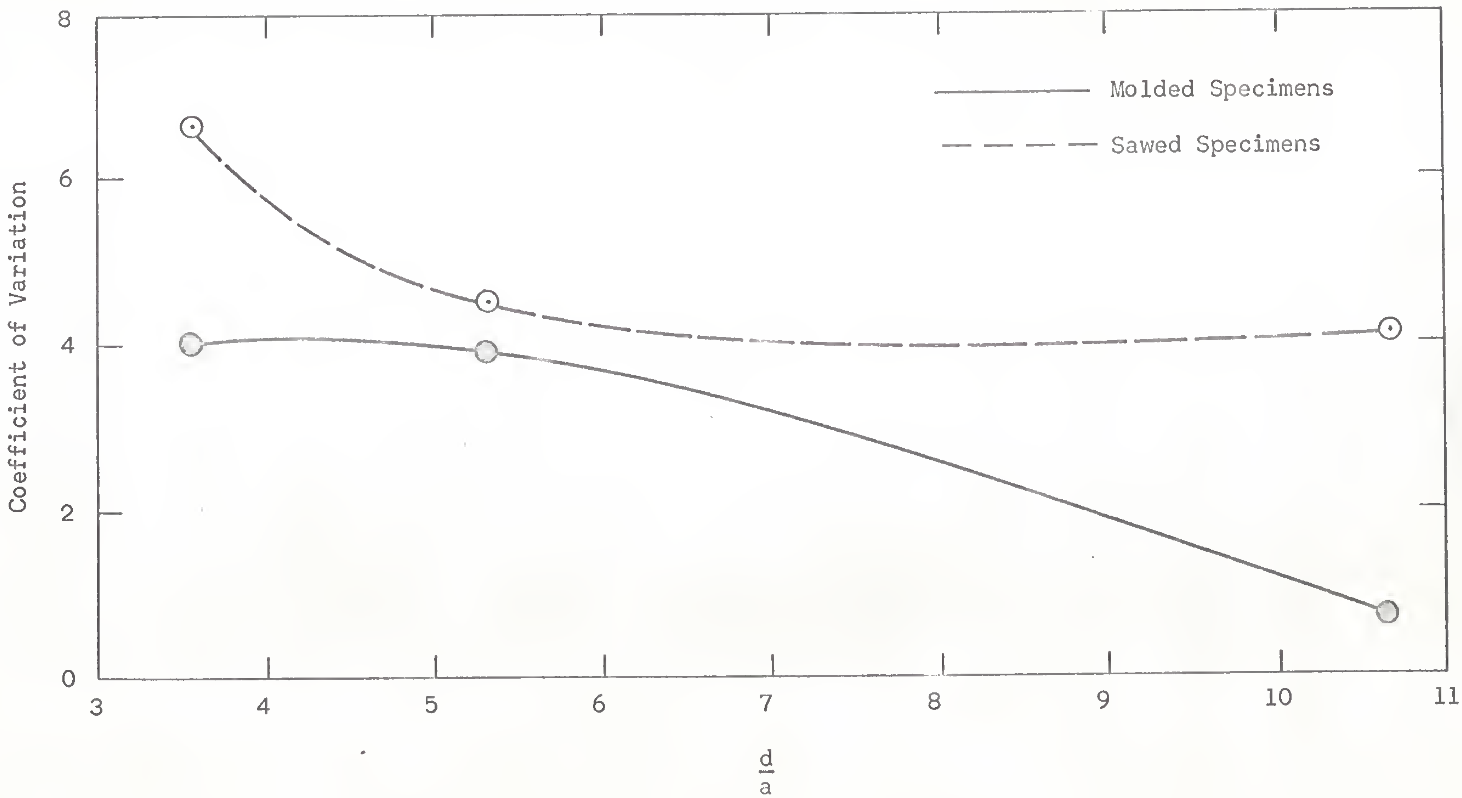

Fig. 6 -- Coefficient of Variation for Compressive Strength of Molded and Sawed Specimens of Series III as a Function of the Ratio of Least Lateral Dimension, d, to Maximum Size of Aggregate, a

Table IX -- Nested Classification.

Size / Kind (1)	4-in. (2)	2-in. (3)	1.33-in. (4)	Total Of Each Row (5)
Molded	3400	2940	3200	
	3400	2750	3400	
	3420	2950	3240	
	3360	3120	3140	
		3110	3410	
		3020	3090	
		3010		
		3200		
		3160		
		3120		
		3040		
		3180		
		3010		
		3010		
		2880		
		3010		
	13580	48510	19480	81570
Sawed	3170	3060	3040	
	2990	2720	3120	
	3110	2950	3340	
	2890	2610	2710	
		2990	3050	
		3090	2840	
		2950		
		3080		
		2860		
		2890		
		2960		
		3080		
		2960		
		2820		
		3000		
		2880		
	12160	46900	18100	77160
Total Of Each Column	25740	95410	37580	158730

RECOMMENDATIONS FOR FUTURE RESEARCH

1. Experimental Design.

Four 4-in. cubes,sixteen 2by 2 by 4-in.,nine 1.33 by 1.33 by 4-in. prisms and a slab were cast for series III. The slab was then sawed into various sizes as has been shown in Fig.6. Both unequal numbers and different error variances for the three sizes made a two-way analysis of variance,which would be desireable, difficult to interpret for the strength test data.

It would be desireable to increase the number of specimens for all sizes; however, it may still be desireable to use unequal numbers to gain the same precision for all comparisons. The analysis of variance technique would be complicated by the inhomogeneity of variances which equal numbers for each size would not overcome. Further investigation is needed on the relationship between variance (or coefficient of variation) and diameter to validate the quote from Tucker by Mather.[7]

2. Mix Design

A more comprehensive study in this field will be to compare the strengths of molded and sawed specimens by varying the concrete mix design variables such as water-cement ratio, cement factor, ratio d/a etc.

COMPARISON OF COMPRESSIVE STRENGTHS OF MOLDED AND SAWED CONCRETE SPECIMENS

by

MOHAN SITALDAS JETHWANI

B. S., Kansas State University, 1964

AN ABSTRACT OF MASTER'S THESIS

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When standard concrete test cylinders fail to yield the specified 28-day compressive strength, it is the usual practice to test cores or prisms taken from the concrete in place to confirm that results previously obtained were not chance events.

There is only a limited amount of data on the relationship between compressive strengths of cores and molded cylinders in the literature. These data show considerable conflict. Some show that cores are stronger than molded cylinders; others show that they are weaker.

So far there is no generally accepted method of correlating the strengths of cores or sawed prisms and molded specimens. It is, therefore, essential that the relationship between their strengths be established, so that the results can be interpreted correctly.

The work reported here was designed to compare the compressive strengths of sawed and molded concrete prisms that were cast, cured, and tested under similar conditions.

Opportunity also existed to investigate the relationship between the ratio of prism width, d, to maximum size of coarse aggregate, a, and the strength of the test specimen.

The experiment was conducted in three series. For the first two series, three beams, and as many as nine molded cubes were cast for every size. Only one mold was used for series III, and a slab, four 4-in. cubes, sixteen 2 by 2 by 4-in. prisms and nine 1.33 by 1.33 by 4-in. prisms were cast.

The beams of series I and II and the slab of series III were sawed into various sizes of cubes and prisms. All the specimens were tested in accordance with ASTM Designation: C 39. The results for series III were corrected to a ratio of length to diameter of 2.00.

All the conclusions have been drawn from the results of series III, as some of the variables inherent in first two series were eliminated in this series.

The results indicate that the 4-in. sawed specimens are significantly weaker than 4-in. molded specimens; the strengths of 2-in. specimens do not differ significantly; and the 1.33-in. sawed specimens have lower strengths at $\alpha = .05$ and the strengths of 1.33-in. molded and sawed specimens do not differ significantly at $\alpha = .025$; provided, that the concrete mix design remained fixed with cement factor of 5.5 sacks per cu. yd.; the water- cement ratio was 0.53; aggregate gradation was fixed; and, molding and fabricating procedures were held constant.