MORSE BROTHERS, INC.
CONCRETE CYLINDER MOLD INVESTIGATION
PHASE TWO REPORT

AUGUST, 1986

STUDY MADE BY
OREGON STATE HIGHWAY DIVISION
MATERIALS SECTION

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INTRODUCTION

On June 13, 1986 OSHD and Morse Brothers, Inc. decided to engage in a joint effort to isolate the differences in compressive strength, which result when cylinders are cast in plastic molds and steel molds. The first experiment performed on June 24, 1986 proved false the theory, "The reduction in compressive strength is greatest in the most flexible molds." This the second of two scheduled experiments will show what effect thermal conductivity has on compressive strength.

THEORY

It is theorized that the type of cylinder mold directly effects compressive strength due to the nature of thermal conductivity inherent to the mold substance. The K value for steel molds is 0.108 - 0.115 calories/sec./cm^2, and the K value for Plastic molds is 0.002 - 0.006 calories/sec./cm^2.*1 This heat loss results in lowering the temperature of the concrete inside the steel molds to a greater extent than the concrete inside the plastic molds. This difference results in a lower initial compressive strength, 3 days, and a higher 28 day break, when steel molds are used. The opposite is true for plastic molds. The parameters for temperature are outlined in AASTHO T23-85I, and temperatures outside these limits could follow a distorted strength gain curve.

SCOPE

For laboratory analysis three sets of ten cylinders were cast from the same batch of concrete at Morse Brothers' prestress yard in Harrisburg. The subsequent compressive strength testing was performed at OSHD materials laboratory in Salem.

The results were analyzed statistically at a 95% significance level. This was performed by calculating the mean difference and the standard error of the difference between the mean of the sample of two independent populations. Values from the area under the normal probability curve are compared to the accepted convention.*2 A significant result is a calculated probability less than 0.05, and a highly significant result is a calculated probability less than 0.01. For consistency with ACI 318-83 and ACI 301-84 the standard deviation was calculated with (n-1), the number of samples in the set, as the denominator.

*1 Handbook of Chemistry & Physics by Hodgman, 1963, 44th edition
*2 Probability and Statistics by Alder/Rossler, 1975, 6th edition

PROCEDURE

This procedure was developed with the premise that the concrete used to mold the cylinders was consistent throughout the batch. One cubic yard batch was used for the entire procedure.

On August 5, 1986 a class 6000 3/4 inch, 8 sack mix was batched from OSHD mix design #86-7140 at the Morse Brothers Harrisburg prestress yard. From this batch three sets of ten cylinders were molded. The three sets where as follows:

A. Plastic molds.
B. Plastic molds with protective sheet metal jackets.
C. Steel molds.

Immediately after the cylinders were cast and covered they were moved into the air conditioned office where the ambient temperature around the cylinders was maintained between 60 degrees F. and 80 degrees F. for 48 hours. After 48 hours the protective jackets were removed from set B, and all cylinders were removed from the molds. The stripped cylinders were imbedded in sand for transporting to OSHD Materials Laboratory.

On August 7, 1986 the cylinders arrived at the OSHD Materials Laboratory, and were promptly capped with sulfur mortar caps, and placed in a 73.4 degree F. + or - 3 degree F. moist cure room until August 8, 1986. On August 8, 1986 the cylinder diameter was recorded. The compressive strength was tested for a 3 day break.

TEST RESULTS

The compressive strength of each cylinder is listed in Table #1 by catagories as follows:

A. Plastic molds.
B. Plastic molds with protective sheet metal jackets.
C. Steel molds

The statistical comparison between catagories is listed in Table #2 and explained below:

1. For statistical analysis between Plastic molds and Plastic molds with protective sheet metal jackets, category A vs B, exhibited no significant difference. The value was 0.503.

2. For statistical analysis between Plastic molds and Steel molds, category A vs C, exhibited no significant difference. The value was 0.052. It would be significant at the 0.055 level.

3. For statistical analysis between Plastic molds with protective sheet metal jackets and Steel molds, category B vs C, exhibited a significant difference. The value was 0.013.

CONCLUSIONS

When testing for 3 day compressive strength, the relationship of thermal conductivity to compressive strength is proven false. As the theory states, strength should decrease with the use of a more thermal conductive substance, but the means of the categories did not follow that relationship.

The highest mean strength was found in Steel molds, but some of the strength gain could be attributed to the water loss through the seams of the Steel mold, since the steel molds did not comply with AASHTO TEST DESIGNATION: M 205-83I (ASTM DESIGNATION: C 470-81) for watertightness. Also eight of the ten cylinders cast in steel molds did not comply to the above test designation for average diameter. The average diameter of a mold shall not differ from the nominal diameter by more than 1%. Table III lists the average diameter of all cylinders tested. This excessive diameter will bias the compressive strength higher whenever the nominal area is used to calculate compressive strength. It shall be noted that Plastic single-use molds comply to the above test designation.

The statistical analysis between Plastic molds and Steel molds, category A vs. C, was not significant at the 5% level, but it would have been significant at the 5.5% level. This level of significance would decrease if the Steel molds complied to the requirements for watertightness described above for concrete cylinder molds.

Although Plastic molds with protective sheet metal jackets were cast in this batch, it was to further evaluate the relationship of mold flexibility. Again it proved the theory of mold flexibility false, because the Plastic molds mean value was higher than the mean value for Plastic molds with protective sheet metal jackets.

Currently OSHD intends to use Plastic single-use cylinder molds for all acceptance testing, and after evaluating both phases of this experiment. No change in our policy is recommended at this time.

COMPRESSIVE STRENGTH OF CYLINDERS

TABLE I

CATEGORY	A	B	C
	6115	6090	5950
	6270	5890	6395
	5960	6020	6065
	6055	6155	6385
	6125	6060	6105
	6040	6105	6330
	6100	6125	6270
	6190	6170	6305
	5925	5925	6005
	6105	6055	6245
MEAN	6088.5	6059.5	6205.5
STD. DEV.	101.33	92.51	161.44
STD. ERROR	32.04	29.25	51.05

A = Plastic molds

B = Plastic molds with sheet metal jackets

C = Steel molds

STATISICAL COMPARISON OF CATEGORIES

TABLE II

CATEGORY	A VS B	A VS C	B VS C
MEAN DIFF.	29.0	117.0	146.0
% MEAN DIFF.	0.48	1.92	2.41
STD. EEROR (OF MEAN DIFF)	43.38	60.27	58.84
RATIO	0.6685	1.9413	2.4813
AREA VIA TABLES	0.2486	0.4738	0.4934
(0.5-AREA)2	0.5028	0.0524	0.0132
SIGNIFICANCE	NONE	NONE	SIGNIFICANT
CONFIDENCE LVL	50	95	99

A. PLASTIC

B. PLASTIC MOLDS WITH SHEET METAL JACKETS

C. STEEL MOLDS

AVERAGE DIAMETER OF CYLINDERS

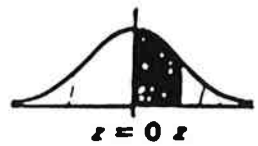
TABLE III

CATEGORY	A	B	C
	6.03	6.00	6.14
	6.03	6.00	6.05
	6.02	6.03	6.10
	6.03	6.00	6.07
	6.03	6.04	6.05
	6.02	6.02	6.10
	6.05	6.01	6.12
	6.04	6.00	6.09
	6.02	6.02	6.11
	6.03	5.99	6.10

ILLUSTRATION #1

Table I
Areas Under the Normal Probability Curve

The entries under *A* denote the area between the line of symmetry (that is, $z = 0$) and the given z-value.



z	A	z	A	z	A	z	A
0.00	0.0000	0.30	0.1179	0.60	0.2258	0.90	0.3159
.01	.0040	.31	.1217	.61	.2291	.91	.3186
.02	.0080	.32	.1266	.62	.2324	.92	.3212
.03	.0120	.33	.1293	.63	.2357	.93	.3238
.04	.0160	.34	.1331	.64	.2389	.94	.3264
.06	.0199	.36	.1368	.66	.2422	.96	.3289
.06	.0239	.36	.1406	.66	.2454	.96	.3316
.07	.0279	.37	.1443	.67	.2486	.97	.3340
.08	.0319	.38	.1480	.68	.2518	.98	.3365
.09	.0359	.39	.1517	.69	.2549	.99	.3389
.10	.0398	.40	.1554	.70	.2580	1.00	.3413
.11	.0438	.41	.1591	.71	.2612	1.01	.3438
.12	.0478	.42	.1628	.72	.2642	1.02	.3461
.13	.0517	.43	.1664	.73	.2673	1.03	.3485
.14	.0557	.44	.1700	.74	.2704	1.04	.3508
.15	.0596	.46	.1736	.75	.2734	1.06	.3531
.16	.0636	.46	.1772	.76	.2764	1.06	.3554
.17	.0675	.47	.1808	.77	.2794	1.07	.3577
.18	.0714	.48	.1844	.78	.2823	1.08	.3599
.19	.0754	.49	.1879	.79	.2852	1.09	.3621
.20	.0793	.50	.1915	.80	.2881	1.10	.3643
.21	.0832	.51	.1950	.81	.2910	1.11	.3665
.22	.0871	.52	.1985	.82	.2939	1.12	.3686
.23	.0910	.53	.2019	.83	.2967	1.13	.3708
.24	.0948	.54	.2054	.84	.2996	1.14	.3729
.25	.0987	.55	.2088	.85	.3023	1.15	.3749
.26	.1026	.56	.2123	.86	.3051	1.16	.3770
.27	.1064	.57	.2157	.87	.3078	1.17	.3790
.28	.1103	.58	.2190	.88	.3106	1.18	.3810
.29	.1141	.59	.2224	.89	.3133	1.19	.3830

ILLUSTRATION #2

Table I. Areas Under the Normal Probability Curve
(continued)

z	A	z	A	z	A	z	A
1.20	0.3849	1.55	0.4394	1.90	0.4713	2.25	0.4878
1.21	.3869	1.56	.4406	1.91	.4719	2.26	.4881
1.22	.3888	1.57	.4418	1.92	.4726	2.27	.4884
1.23	.3907	1.58	.4430	1.93	.4732	2.28	.4887
1.24	.3925	1.59	.4441	1.94	.4738	2.29	.4890
1.25	.3944	1.60	.4452	1.95	.4744	2.30	.4893
1.26	.3962	1.61	.4463	1.96	.4750	2.31	.4896
1.27	.3980	1.62	.4474	1.97	.4756	2.32	.4898
1.28	.3997	1.63	.4485	1.98	.4762	2.33	.4901
1.29	.4015	1.64	.4495	1.99	.4767	2.34	.4904
1.30	.4032	1.65	.4505	2.00	.4773	2.35	.4906
1.31	.4049	1.66	.4515	2.01	.4778	2.36	.4909
1.32	.4066	1.67	.4525	2.02	.4783	2.37	.4911
1.33	.4082	1.68	.4535	2.03	.4788	2.38	.4913
1.34	.4099	1.69	.4545	2.04	.4793	2.39	.4916
1.35	.4115	1.70	.4554	2.05	.4798	2.40	.4918
1.36	.4131	1.71	.4564	2.06	.4803	2.41	.4920
1.37	.4147	1.72	.4573	2.07	.4808	2.42	.4922
1.38	.4162	1.73	.4582	2.08	.4812	2.43	.4925
1.39	.4177	1.74	.4591	2.09	.4817	2.44	.4927
1.40	.4192	1.75	.4599	2.10	.4821	2.45	.4929
1.41	.4207	1.76	.4608	2.11	.4826	2.46	.4931
1.42	.4222	1.77	.4616	2.12	.4830	2.47	.4932
1.43	.4236	1.78	.4625	2.13	.4834	2.48	.4934
1.44	.4251	1.79	.4633	2.14	.4838	2.49	.4936
1.45	.4265	1.80	.4641	2.15	.4842	2.50	.4938
1.46	.4279	1.81	.4649	2.16	.4846	2.51	.4940
1.47	.4292	1.82	.4656	2.17	.4850	2.52	.4941
1.48	.4306	1.83	.4664	2.18	.4854	2.53	.4943
1.49	.4319	1.84	.4671	2.19	.4857	2.54	.4945
1.50	.4332	1.85	.4678	2.20	.4861	2.55	.4946
1.51	.4345	1.86	.4686	2.21	.4865	2.56	.4948
1.52	.4357	1.87	.4693	2.22	.4868	2.57	.4949
1.53	.4370	1.88	.4700	2.23	.4871	2.58	.4951
1.54	.4382	1.89	.4706	2.24	.4875	2.59	.4952

ILLUSTRATION #3

Table I. Areas Under the Normal Probability Curve
(concluded)

z	A	z	A	z	A	z	A
2.60	0.4963	2.86	0.4984	3.30	0.4996	3.66	0.4999
2.61	.4966	2.96	.4985	3.31	.4996	3.66	.4999
2.62	.4966	2.97	.4985	3.32	.4996	3.67	.4999
2.63	.4967	2.98	.4986	3.33	.4996	3.68	.4999
2.64	.4969	2.99	.4986	3.34	.4996	3.69	.4999
2.66	.4960	3.00	.4987	3.36	.4996	3.70	.4999
2.66	.4961	3.01	.4987	3.36	.4996	3.71	.4999
2.67	.4962	3.02	.4987	3.37	.4996	3.72	.4999
2.68	.4963	3.03	.4988	3.38	.4996	3.73	.4999
2.69	.4964	3.04	.4988	3.39	.4997	3.74	.4999
2.70	.4966	3.06	.4989	3.40	.4997	3.76	.4999
2.71	.4966	3.06	.4989	3.41	.4997	3.76	.4999
2.72	.4967	3.07	.4989	3.42	.4997	3.77	.4999
2.73	.4968	3.08	.4990	3.43	.4997	3.78	.4999
2.74	.4969	3.09	.4990	3.44	.4997	3.79	.4999
2.76	.4970	3.10	.4990	3.46	.4997	3.80	.4999
2.76	.4971	3.11	.4991	3.46	.4997	3.81	.4999
2.77	.4972	3.12	.4991	3.47	.4997	3.82	.4999
2.78	.4973	3.13	.4991	3.48	.4998	3.83	.4999
2.79	.4974	3.14	.4992	3.49	.4998	3.84	.4999
2.80	.4974	3.16	.4992	3.50	.4998	3.86	.4999
2.81	.4975	3.16	.4992	3.51	.4998	3.86	.4999
2.82	.4976	3.17	.4992	3.52	.4998	3.87	.5000
2.83	.4977	3.18	.4993	3.53	.4998	3.88	.5000
2.84	.4977	3.19	.4993	3.54	.4998	3.89	.5000
2.85	.4978	3.20	.4993	3.56	.4998		
2.86	.4979	3.21	.4993	3.56	.4998		
2.87	.4980	3.22	.4994	3.57	.4998		
2.88	.4980	3.23	.4994	3.58	.4998		
2.89	.4981	3.24	.4994	3.59	.4998		
2.90	.4981	3.25	.4994	3.60	.4998		
2.91	.4982	3.26	.4994	3.61	.4999		
2.92	.4983	3.27	.4995	3.62	.4999		
2.93	.4983	3.28	.4995	3.63	.4999		
2.94	.4984	3.29	.4995	3.64	.4999		