CONCRETE CYLINDER MOLD INVESTIGATION
SUMMARY REPORT

OCTOBER, 1986

STUDY MADE BY
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INTRODUCTION

Oregon State Highway Department began using plastic single-use concrete cylinder molds as early as 1983 for trial mixes at OSHD Materials Laboratory. Subsequently, one prestress plant began using plastic molds for acceptance testing in the summer of 1984, and two additional plants switched to plastic molds in August of 1985.

In December of 1985 O.S.H.D. Material Laboratory began an investigation into the compressive strength difference between cylinders cast in steel molds versus plastic molds. This summary report briefly describes the various parameters investigated, lists tables of the compressive strength data obtained in each study, and presents the results of the statistical analyses which were performed.

The five research studies summarized are as follows:.

1. Eugene Sand & Gravel High-Strength Concrete Research Study

2. Eugene Sand & Gravel High-Strength Concrete Research Study, Phase Two Report

3. Morse Brothers, Inc., Concrete Cylinder Mold Investigation, Phase One Report

4. Morse Brothers, Inc., Concrete Cylinder Mold Investigation, Phase Two Report

5. Morse Brothers, Inc., Clackamas Concrete Cylinder Mold Investigation

SUMMARY

1. Eugene Sand and Gravel High-Strength Concrete Research Study.

This study analyzed five different test parameters to determine which, if any, were the cause of strength differences in cylinders cast at the Eugene Sand and Gravel Prestress Plant. The parameters studied were:

Test 1. Differences due to test lab & equipment. (ES&G vs OSHD)

Test 2. Differences due to type of test mold. (plastic vs steel)

Test 3. Differences due to method of long-term cure. (water bath vs moist room)

Test 4. Differences due to intermediate cure. (immediate transport vs 4-day field cure before transport)

Test 5. Differences due to method of transport. (sand bed, supporting rack, loose in pickup bed)

The results of this study are presented in Table 1 below.

TABLE 1
Eugene Sand and Gravel Research Project
Summary of Statistical Analysis of Cylinder Strength Data

Test	Cylinder Group	Mean Strength (PSI)	% Mean Difference	Standard Deviation	Std. Error of Mean	Std. Error of Mean Diff	Mean Difference	Mean Diff/ M Df Std Er	Student t Statistic	Confidence level
1	ES&G Lab	7515	5.5	182	57.55	119.45	392	3.28	3.25	99
	OSHD Lab	7123		331	104.67					
2	Steel	7284	15.7	180	56.92	78.73	987	12.54	3.25	99
	Plastic	6297		172	54.39					
3	Water Tank	7122	2.3	331	104.67	119.15	162	1.36	3.25	85
	Moist Room	7284		180	56.92					
4	Immed Trans	6292	4.3	171	54.07	69.29	258	3.72	3.25	99
	Temp Storage	6034		137	43.32					
5	ASTM Sand	6034	1.2	137	43.32	67.09	69	1.03	3.25	80
	OSHD Rack	5965		162	51.23					
	ASTM Sand	6034	1.8	137	43.32	61.05	106	1.74	3.25	95
	Rack/Pickup	5928		136	43.01					

2. Eugene Sand & Gravel High-Strength Concrete Research Study, Phase Two Report.

This study analyzed different methods of fabricating concrete cylinders as well as reanalyzing the difference in mold types. Five sets of cylinders were fabricated as follows:

Set A. ES&G sealed steel cylinders, hand rodded, and covered with glass plates.

Set B. O.S.H.D. sealed steel cylinders, hand rodded, and covered with glass plates.

Set C. ES&G unsealed steel cylinders, hand rodded, and covered with plastic bags.

Set D. ES&G unsealed steel cylinders, machine vibrated and covered with plastic bags.

Set E. O.S.H.D. plastic cylinders, hand rodded, and covered with plastic lids.

The different sets of cylinders were studied statistically to determine which parameters, if any, caused the strength differences in cylinders cast at the Eugene Sand and Gravel Prestress Plant.

The 28-day compressive strength data for each set of cylinders are shown in Table 1.

Table II shows the results for ES&G sealed steel cylinders vs. ES&G unsealed steel cylinders; and, ES&G rodded steel cylinders vs ES&G vibrated steel cylinders.

Table III shows the results for hand-rodded steel cylinders vs hand-rodded plastic cylinders.

COMPRESSIVE STRENGTH OF CYLINDERS

TABLE I

CATEGORY	A	B	C	D	E
TYPE	STEEL	STEEL	STEEL	STEEL	PLASTIC
OWNER	ES&G	OSHD	ES&G	ES&G	OSHD
SEAL	SEALED	SEALED	UNSEALED	UNSEALED	SEALED
CONSOLIDATION	RODDED	RODDED	RODDED	VIBRATED	RODDED
COVER	GLASS	GLASS	BAGGY	BAGGY	PLASTIC
	6170	6850	6075	7015	5605
	6530	6735	6290	7230	5760
	5945	6445	6265	6960	5830
	6460	6600	6260	7190	5900
	6210	6150	6450	6775	5640
	6155	6790	6200	6970	5765
	6210	6630	6195	7145	5810
	6225	6445	6395	6975	5775
	6870	6120	6410	6780	6075
	6820	6675	6225	6965	5725
MEAN	6359.5	6544.0	6276.5	7000.5	5788.5
STD. DEV.	287.08	239.36	108.77	146.16	125.70
STD ERROR	90.78	75.69	34.40	46.22	39.75

STATISTICAL COMPARISON OF CATEGORIES

Molds, Seals, and Consolidation

TABLE II

TYPE	ES&G vs OSHD	SEALED vs UNSEALED	VIBRATED vs RODDED
CATEGORY	A vs B	A vs C	C vs D
MEAN DIFF.	184.5	83.0	724.0
% MEAN DIFF.	2.9 %	1.3 %	11.5 %
STD. ERROR (of mean diff.)	118.19	97.08	57.62
RATIO	1.561	0.855	12.570
(0.5-AREA)2	0.119	0.390	0.000
CONFIDENCE LVL	88	61	99

STATISTICAL COMPARISON OF CATEGORIES

Steel vs Plastic

TABLE III

TYPE	ES&G vs PLASTIC	OSHD vs PLASTIC	COMBINED vs PLASTIC
CATEGORY	A vs E	B vs E	A&B vs E
MEAN DIFF.	571.0	755.5	663.3
% MEAN DIFF.	9.9 %	13.1 %	11.5 %
STD. ERROR (of mean diff.)	99.10	85.49	75.53
RATIO	5.762	8.837	8.782
(0.5-AREA)2	0.000	0.000	0.000
CONFIDENCE LVL	99	99	99

3. Morse Brothers, Inc., Concrete Cylinder Mold Investigation Phase One, Report.

This study was conducted to further isolate the cause of lower 28-day compressive strength in plastic molds. The theory tested is that the reduction in compressive strength is greatest due to the flexibility of plastic molds. This study compared three sets of cylinders as follows:

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

The compressive strength data for each set of cylinders is shown in Table I. Table II shows the results of the statistical analysis.

COMPRESSIVE STRENGTH OF CYLINDERS

TABLE I

CATEGORY	A	B	C
	7430	7320	7920
	7935	7390	8285
	7740	7390	7875
	7750	7540	7940
	7695	7390	7790
	7595	7340	8250
	7370	7320	7835
	7675	7490	7725
	7525	7285	8135
	7630	7670	8395
MEAN	7634.5	7413.5	8015.0
STD. DEV.	165.13	119.58	232.98
STD, ERROR	52.22	37.81	73.66

STATISTICAL COMPARISON OF CATEGORIES

TABLE II

CATEGORY	A vs B	A vs C	B vs C
MEAN DIFF.	221.0	380.5	601.5
% MEAN DIFF.	3.0	5.0	8.1
STD. ERROR (of mean diff.)	64.47	90.29	82.80
RATIO	3.428	4.214	7.264
AREA VIA TABLES	0.4997	0.5000	0.5000
(0.5-AREA)2	0.001	0.000	0.000
CONFIDENCE LVL	99	99	99

A = Plastic molds

B = Plastic molds with sheet metal jackets

C = Steel molds

4. Morse Brothers, Inc., Concrete Cylinder Mold Investigation Phase Two Report.

When the Morse Brothers Phase One Report failed to show that flexibility was the cause of lower compressive strengths in plastic molds, a second study was conducted to determine if thermal conductivity in the molds could be the cause.The theory tested is that 3-day compressive strength will be lower in cylinders cast in a more thermal conductive mold, such as steel. Thus, with lower initial cure temperatures, 28-day strengths would be higher in steel molds. This study compared three sets of cylinders at 3-days as follows:

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

The compressive strength data for each set of cylinders is shown in Table I. Table II shows the results of the statistical analysis.

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

STATISTICAL 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. ERROR (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
CONFIDENCE LVL	50	95	99

5. Morse Brothers, Inc., Clackamas-Concrete Cylinder Mold Investigation.

With the reduced compressive strength of cylinders cast in plastic molds fairly well established, another study was conducted at a different prestress plant to determine if the low-strength problem is wide-spread and to better quantify the problem. This study analyzed the difference in strength in paired steel molds versus plastic single-use molds. The theory tested is that steel molds produce the same strength as plastic molds. The study compared two sets of cylinders as follows:

Category A. Steel Molds.
Category B. Plastic Molds.

Table I shows the average strength obtained from 32 sets of cylinders cast from different batches of concrete in steel and plastic molds (two cylinders each). The strengths shown are calculated assuming all cylinders have nominal 6-inch diameters. Table II shows the same data corrected for typical measured diameters.

Because the study compared the difference between steel and plastic molds for 32 different batches of concrete, a pairwise statistical analysis of the data was performed. The results are shown in Table III for both the nominal and corrected.

COMPRESSIVE STRENGTH OF CYLINDERS
(Nominal Cylinder Diameter)

TABLE I

CATEGORY TYPE	A STEEL	B PLASTIC
	8512.5	8165.0
	8040.0	7237.5
	8287.5	7675.0
	8165.0	7702.5
	7915.0	7472.5
	5895.0	5345.0
	7182.5	6747.5
	6990.0	6287.5
	6952.5	6615.0
	6855.0	6485.0
	7032.5	6325.0
	6935.0	6325.0
	6980.0	7040.0
	6117.5	5842.5
	7155.0	7197.5
	7215.0	7160.0
	6757.5	6477.5
	6487.5	6062.5
	7037.5	6870.0
	6147.5	5962.5
	7675.0	7252.5
	8125.0	7587.5
	8062.5	8025.0
	7635.0	7275.0
	7850.0	7795.0
	7320.0	7462.5
	7955.0	7902.5
	8125.0	7677.5
	7955.0	7737.5
	8355.0	7810.0
	7240.0	7045.0
	8102.5	7630.0
MEAN	7408.1	7068.6
STD. DEV.	703.69	717.87
STD. ERROR	124.40	126.90

COMPRESSIVE STRENGTH OF CYLINDERS
(Corrected for diameters)

TABLE II

CATEGORY TYPE	A STEEL	B PLASTIC
	8580	8080
	8100	7170
	8350	7600
	8230	7630
	7970	7400
	5940	5290
	7240	6680
	7040	6230
	7000	6550
	6910	6420
	7080	6260
	6990	6260
	7030	6970
	6160	5780
	7210	7130
	7270	7090
	6810	6410
	6540	6000
	7090	6800
	6190	5900
	7730	7180
	8180	7510
	8120	7950
	7690	7200
	7910	7720
	7370	7390
	8010	7820
	8180	7600
	8010	7660
	8420	7730
	7290	6980
	8160	7550
MEAN	7462.5	6998.1
STD DEV	708.7	711.4
STD ERROR	125.28	125.75

STATISTICAL COMPARISON OF CATEGORIES

TABLE III

TYPE	STEEL vs. PLASTIC	STEEL vs. PLASTIC
CATEGORY	A vs. B	A vs. B
DIAMETER	NOMINAL	CORRECTED
MEAN DIFF.	339.54	464.4
% MEAN DIFF	4.8%	6.6%
t VALUE	7.96	10.84
CONFIDENCE LVL	99	99