STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

Summary of Results of Cooperative Tests

made by

California Cement Mill
and
California Division of Highways

on

Control of Gypsum in Portland Cement

by

Expansion-Contraction Tester

July, 1959

59-23
DND

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD.
SACRAMENTO 19, CALIFORNIA

PLEASE REFER TO
FILE No.

August 7, 1959

To Participants in
Co-operative SO_3 Tests

This is to advise that the proposed meeting of cement mill chemists and representatives of California Division of Highways has been scheduled definitely for 10 AM on Tuesday, August 18, 1959.

The meeting will be held at the Division of Highways office, 1352 W. Olive Street, Fresno. There is an interchange on the Fresno Freeway at West Olive Street. The highway office is located to the East of the freeway and West of the old route of U.S. 99.

Attached for your prior study is a compilation of results obtained in the co-operative tests. We are also attaching a proposed agenda for the meeting. It is presented merely as an outline for conducting an orderly meeting. Other subjects can be introduced as time permits.

Yours very truly

F. N. Hveem
Materials & Research Engineer

By Bailey Tremper

Bailey Tremper
Supervising Materials and
Research Engineer

BT:fp
Attachments - Agenda
Report of Compilation of Results of
SO_3 Co-operative Tests

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

INTRA-DIVISION CORRESPONDENCE

DATE August 10, 1959

To: Mr. F. N. Hveem

Attention of Bailey Tremper

File Reference
Cement Mills Chemists
Meeting Aug. 18

From: Mr. W. L. Welch Dist. VI
Hdqrs.

Reference is made to your letter of August 5, 1959 regarding the meeting of Cement Mill Chemists on Tuesday, August 18.

We have reserved our Conference Room, No. 137, for this meeting.

We will have a slide projector and screen set up and there is also a blackboard in this room.

Arrangements have been made for luncheon at the Fresno Motel for approximately 25 people. The motel is just a short walk from the District Office.

We will have a car available to provide transportation from the airport if necessary.

Reservations have been made for Mr. Tremper and Mr. Haskell at the Motel Fresno for the nights of August 17 and 18. While a kitchenette is not available, the reservation clerk assured that the use of a hot plate would not conflict with any of their rules and regulations.

If a late arrival is expected, please advise as the motel requires a guarantee on holding this type of reservation.

If there is anything further we can do to make your meeting run smoothly, please do not hesitate to contact us.

W. L. WELCH
District Engineer

Original Signed J. W. Newlin

By
J. W. Newlin
District Administrative
Assistant

JWN:EB
CC:RSP
RFJ

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AGENDA

Meeting on Control of Gypsum in Portland Cement
to be held in Fresno, August 18, 1959

Statement on need for minimum volume change in cement.

Equipment and supplies used in the expansion-contraction test.

Interpretation of test results.

Review of co-operative test data.

Discussion by mill chemists of differences in cement samples upon which different indicated optimum SO_3 percentages were found.

Effect on apparent optimum SO_3 produced by adding pulverized gypsum to test sample compared to mill grinding in presence of full amount of gypsum.

Determination of proper value of the coefficient of contraction, "p" for individual cements.

Relative cost of gypsum and clinker.

Problems in mill proportioning to secure desired SO_3 content.

Circumstances under which it might be desirable to produce cement with SO_3 content differing from optimum.

Is control of SO_3 by the expansion-contraction test technically feasible? Within what limits?

What further experimental work is needed?

Statement of position of Division of Highways.

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Summary of Results of Co-operative Tests

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Co-operative Expansion-Contraction Tests

This co-operative testing program, between each of the cement mills in California and the laboratory of the California Division of Highways, consists of expansion-contraction tests performed at monthly intervals on samples supplied by the mills. Using each of these samples, both the mill and the Division of Highways performed the expansion-contraction test and interchanged results. The plan called for each mill to furnish a total of 12 samples at intervals of approximately one month. The program was started early in 1958 and has continued to date. Several of the mills have completed the program. The others have partially completed it.

The method of performing the extraction test was supplied to each of the participants.

The results are summarized in the following pages. One page is devoted to each mill. A code letter is assigned to each mill, which letter was used in a preliminary report to ASTM. A study of the data shows that results of other mills could not be used to commercial advantage by any cement company and therefore the name of the mill is indicated on each sheet.

Separate sheets are devoted to expansion and contraction tests. Absolute values of expansion for the original cement and the cement containing an addition of gypsum are arranged in such a way that convenient comparisons of mill

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and Division of Highways test results can be made.

Data of contraction tests are similarly arranged for convenient comparison of results by the two laboratories. The tabulations show first the contraction measured on the cement with added gypsum. Directly below these values are shown the contraction measured for the original cement. Below these values are shown the change in contraction produced by the addition of gypsum. Adjacent columns show the calculated departure of the cement from the optimum percentage of gypsum. These values have been calculated by means of the formula

$$r = 0.018\ (g + 0.25)$$

where r = change in contraction

g = content of SO_3 of the original cement in percent relative to its optimum percentage.

A table giving numerical solutions of this equation is attached.

The coefficient, 0.018, is not strictly correct for all cements according to limited data now available. However, this value appears to be representative of the average of the cements involved. If the cement as tested contains SO_3 within about 0.5 percent of its optimum, the use of an arbitrarily selected coefficient does not appear to introduce serious error.

A column giving the SO_3 content of the original cement contains the values that were determined by the

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Division of Highways. In general, reasonably good agreement for SO_3 was obtained by the two laboratories but there were some glaring discrepancies. Complete test results for SO_3 are tabulated on separate sheets.

The last columns show the computed optimum SO_3 content for each cement. These values were obtained by simple addition or subtraction of the computed departure from optimum and the SO_3 content of the original cement as determined by California Division of Highways. In some cases different values would have been obtained had the SO_3 results reported by the mills been used. It would have complicated the tabulation to include values for optimum SO_3 computed from both sets of SO_3 determinations. The reason for poor agreement in results for SO_3 as determined in the two laboratories is not known. Since the objective of the program was a study of the expansion-contraction test, no further discussion of SO_3 determinations is given.

A study of the data for computed departure from optimum shows rather poor agreement between laboratories in some of the earlier tests. As the work progressed better agreement was obtained. Some of the early test results have been eliminated in the computations of averages and the standard deviation of laboratory differences as shown at the bottom of each sheet. It is believed that these values are more nearly representative of results to be expected after

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laboratories have gained experience with the test.

Detailed discussion of the data is not attempted in this report. A cursory perusal of the tabulations for optimum SO_3 indicates that among the samples submitted by some mills, the optimum percentage is relatively constant. In other cases, some of the samples show marked departure from the general average.

The mills were requested to submit samples of their own selection without regard for the relationship of SO_3 content to optimum. There was no restriction on composition or fineness of grind except that in general, the samples were to be of Type II, low-alkali cement.

Study will be required by each of the mills to determine if those samples that depart markedly from the general run are in fact of different composition or were burned or ground under different conditions and thus could be expected to require different amounts of SO_3 to produce optimum.

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TESTS FOR EXPANSION

Cement Mill: Blue Diamond

Code Letter A

Sample Number	Expansion - Original Cement			Expansion - Added SO_3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0052	.0069	.0017	.0035	.0069	.0034
2	.0038	.0101	.0063	.0125	.0396	.0271
3	.0048	.0053	.0005	.0100	.0075	.0025
4	.0030	.0078	.0048	.0100	.0125	.0025
5	.0090	.0022	.0068	.0185	.0212	.0027
6	.0108	.0063	.0045	.0080	.0055	.0025
7	.0055	.0069	.0014	.0148	.0130	.0018
8	.0145	.0169	.0024	.0228	.0233	.0005
9	.0078	.0072	.0008	.0180	.0183	.0003
10	.0015	.0049	.0034	.0082	.0134	.0052
11	.0020	.0028	.0008	.0012	.0014	.0002
12	.0062	.0078	.0016	.0068	.0065	.0003
13	.0030	.0055	.0025	.0028	.0046	.0018
Average 7 to 13	.0058	.0074		.0107	.0115	
Standard deviation of difference Mill-Highways 7 to 13			.0013			.0022

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TESTS FOR EXPANSION

Cement Mill: Ideal
San Juan Bautista

Code Letter B

Sample Number	Expansion - Original Cement			Expansion - Added SO_3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0032	.0040	.0008	.0062	.0070	.0008

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TESTS FOR EXPANSION

Cement Mill: Calaveras

Code Letter C

Sample Number	Expansion - Original Cement			Expansion - Added SO_3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0045	.0050	.0005	.0058	.0087	.0029
2	.0030	.0069	.0039	.0060	.0107	.0047
3	.0042	.0064	.0022	.0060	.0079	.0019
4	.0020	-----	-----	.0048	-----	-----
5	.0055	.0028	.0027	.0080	.0049	.0031
6	.0052	.0050	.0002	.0090	.0111	.0021
7	.0070	.0054	.0016	.0090	.0086	.0004
8	.0055	.0033	.0027	.0075	.0060	.0015
9 Lab Ground	.0070	.0067	.0003	.0038	.0057	.0019
10 Lab Ground	.0125	.0206	.0081	.0140	.0206	.0066
11	.0028	-----	-----	.0050	-----	-----
Average 5 to 10	.0071	.0073		.0086	.0095	
Standard deviation of difference Mill-Highways 5 to 10			.0040			.0034

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TESTS FOR EXPANSION

Cement Mill: California Portland Cement
Colton

Code Letter D

Sample Number	Expansion - Original Cement			Expansion - Added SO3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0038	.0055	.0017	.0038	.0065	.0027
2	.0035	.0040	.0005	.0088	.0050	.0038
3	.0028	.0067	.0039	.0090	.0085	.0005
4	.0038	.0052	.0014	.0050	.0052	.0002
5	.0070	.0073	.0003	.0092	.0095	.0003
6	.0032	.0055	.0023	.0035	.0048	.0013
7	.0040	.0080	.0040	.0050	.0100	.0050
8	.0032	.0070	.0038	.0030	.0080	.0050
9	.0038	.0080	.0042	.0040	.0077	.0037
10	.0055	.0065	.0010	.0050	.0070	.0020
11	.0018	.0070	.0052	.0092	.0085	.0007
12	.0020	.0050	.0030	.0075	.0100	.0025
13	.0012	.0080	.0068	.0065	.0120	.0055
Average 2 to 10	.0041	.0065		.0058	.0073	
Standard deviation of difference Mill - Highways 2 to 10			.0016			.0028

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TESTS FOR EXPANSION

Cement Mill: California Portland Cement
Mojave

Code Letter E

Sample Number	Expansion - Original Cement			Expansion - Added SO_3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0055	.0032	.0023	.0078	.0072	.0006
2	.0060	.0050	.0010	.0125	.0110	.0015
3	.0048	.0060	.0012	.0055	.0095	.0040
4	.0040	.0040	.0000	.0090	.0075	.0015
5	.0055	.0078	.0023	.0048	.0095	.0047
6	.0020	.0050	.0030	.0055	.0085	.0030
7	.0042	.0050	.0008	.0130	.0090	.0040
8	.0028	.0058	.0030	.0105	.0165	.0060
9	.0028	.0088	.0060	.0060	.0108	.0048
10	.0045	.0070	.0025	.0045	.0088	.0043
11	.0040	.0075	.0035	.0038	.0078	.0040
12	.0040	.0060	.0020	.0065	.0085	.0020
13	.0045	.0050	.0005	.0060	.0088	.0028
Average 1 to 10	.0042	.0058		.0079	.0098	
Standard deviation of difference Mill-Highways 1 to 10			.0024			.0035

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TESTS FOR EXPANSION

Cement Mill: Pacific Cement & Aggregates
Davenport

Code Letter F

Sample Number	Expansion - Original Cement			Expansion - Added SO3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0038	-----	-----	.0050	-----	-----
2	.0022	-----	-----	.0032	-----	-----
3	.0052	-----	-----	.0040	-----	-----
4	.0050	.0064	.0014	.0062	.0061	.0001
5	.0050	.0045	.0005	.0055	.0039	.0016
6	.0052	.0053	.0001	.0062	.0073	.0011
7	.0068	.0056	.0012	.0050	.0045	.0005
8	.0030	.0036	.0006	.0038	.0025	.0013
9	.0035	.0053	.0018	.0030	.0061	.0031
10	.0000	.0017	.0017	.0000	.0021	.0021
11	.0020	.0045	.0025	.0040	.0068	.0028
12	.0032	.0043	.0011	.0075	.0075	.0000
Average 7 to 12	.0030	.0042		.0039	.0049	
Standard deviation of difference Mill-Highways 7 to 12			.0015			.0019

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TESTS FOR EXPANSION

Cement Mill: Permanente
Cushenbury

Code Letter G

Sample Number	Expansion - Original Cement			Expansion - Added SO_3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0070	.0037	.0033	.0125	.0058	.0067
2	.0050	.0015	.0035	.0095	.0038	.0057
3	.0050	.0025	.0025	.0092	.0050	.0042
4	.0012	.0075	.0063	.0052	.0083	.0031
5	.0018	.0028	.0010	.0018	.0037	.0019
6	.0035	.0063	.0028	.0028	.0063	.0035
7	.0038	.0080	.0042	.0080	.0090	.0010
Average 5 to 7	.0030	.0057		.0042	.0063	
Standard deviation of difference Mill-Highways 5 to 7			.0016			.0013

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TESTS FOR EXPANSION

Cement Mill: Permanente

Code Letter H

Sample Number	Expansion - Original Cement			Expansion - Added SO_3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0020	-----	-----	.0018	-----	-----
2	.0028	.0053	.0025	.0072	.0065	.0007
3	.0042	.0048	.0006	.0045	.0073	.0028
4	.0098	.0055	.0043	.0105	.0077	.0028
5	.0030	.0043	.0013	.0050	.0073	.0023
6	.0090	.0068	.0022	.0092	.0073	.0019
7	.0085	.0057	.0028	.0112	.0117	.0005
8	.0052	.0043	.0009	.0055	.0048	.0007
9	.0050	.0058	.0008	.0090	.0070	.0020
10	.0052	.0047	.0005	.0055	.0057	.0002
11	.0055	.0050	.0005	.0065	.0063	.0002
12	.0060	.0060	.0000	.0060	.0050	.0010
13	.0038	.0040	.0002	.0030	.0060	.0030
Average 2 to 12	.0058	.0053		.0073	.0070	
Standard deviation of difference Mill-Highways 2 to 12			.0020			.0017

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TESTS FOR EXPANSION

Cement Mill: Riverside
Oro Grande

Code Letter I

Sample Number	Expansion - Original Cement			Expansion - Added SO3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0052	.0040	.0012	.0120	.0110	.0010
2	.0035	.0110	.0075	.0097	.0100	.0003
3	.0085	.0120	.0035	.0150	.0170	.0020
4	.0080	.0060	.0020	.0125	.0150	.0025
5	.0040	.0033	.0007	.0058	.0075	.0017
6	.0078	.0110	.0032	.0100	.0110	.0010
7	.0060	.0085	.0025	.0085	.0110	.0025
8	.0037	.0010	.0027	.0082	.0065	.0017
9	.0042	.0020	.0022	.0112	.0060	.0052
10	.0058	.0080	.0022	.0055	.0080	.0025
11	.0045	.0010	.0035	.0048	.0020	.0028
Average 1 to 11	.0056	.0062		.0094	.0095	
Standard deviation of difference Mill-Highways 1 to 11			.0034			.0026

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TESTS FOR EXPANSION

Cement Mill: Southwestern (Victor) Code Letter J

Sample Number	Expansion - Original Cement			Expansion - Added SO_3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0055	.0110	.0055	.0080	.0155	.0075
2	.0070	.0043	.0027	.0052	.0063	.0011
3	.0050	.0055	.0005	.0092	.0073	.0019
4	.0042	.0055	.0013	.0045	.0088	.0043
5	.0055	.0043	.0012	.0095	.0090	.0005
6	.0055	.0045	.0010	.0112	.0103	.0009
7	.0050	.0068	.0018	.0070	.0098	.0028
8	.0062	.0060	.0002	.0082	.0110	.0028
9	.0052	.0070	.0018	.0100	.0125	.0025
10	.0040	.0060	.0020	.0028	.0075	.0047
11	.0045	.0035	.0010	.0030	.0055	.0025
12	.0020	.0045	.0025	.0035	.0060	.0025
Average 3 to 12	.0047	.0054		.0069	.0088	
Standard deviation of difference Mill-Highways 3 to 12			.0021			.0022

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TESTS FOR EXPANSION

Cement Mill: Monolith

Code Letter K

Sample Number	Expansion - Original Cement			Expansion - Added SO3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0065	.0021	.0044	.0038	.0020	.0018
2	.0075	.0091	.0016	.0068	.0066	.0002
3	.0045	.0043	.0002	.0042	.0056	.0014
4	.0035	.0069	.0034	.0028	.0077	.0049
5	.0020	.0062	.0042	.0028	.0079	.0051
6	.0030	.0052	.0022	.0030	.0032	.0002
7	.0038	.0018	.0020	.0082	.0064	.0018
8	.0038	.0047	.0009	.0025	.0040	.0015
Average 1 to 8	.0043	.0050		.0043	.0054	
Standard deviation of difference Mill-Highways 1 to 8			.0028			.0027

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TESTS FOR EXPANSION

Cement Mill: Riverside
Crestmore

Code Letter L

Sample Number	Expansion - Original Cement			Expansion - Added SO3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0055	.0090	.0035	.0038	.0100	.0062
2	.0060	.0030	.0030	.0075	.0065	.0010
3	-----	.0040	-----	-----	.0070	-----
4	.0028	.0080	.0052	.0042	.0105	.0063
5	.0070	.0055	.0015	.0080	.0080	.0000
6	.0035	.0050	.0015	.0048	.0075	.0027
7	.0035	.0030	.0005	.0042	.0060	.0018
Average 1 to 7	.0047	.0056		.0054	.0081	
Standard deviation of difference Mill-Highways, 1 to 7			.0031			.0031

Note: Sample No. 3 omitted from computation of average and standard deviation.

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TESTS FOR EXPANSION

Cement Mill: Ideal
Redwood City

Code Letter M

Sample Number	Expansion - Original Cement			Expansion - Added SO3		
	Div. of Highways	Cement Mill	Difference	Div. of Highways	Cement Mill	Difference
1	.0013	-----	-----	.0058	-----	-----
2	.0040	-----	-----	.0045	-----	-----
3	.0025	-----	-----	.0080	-----	-----

7.8
2.0

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Lower value original

TESTS FOR CONTRACTION

Cement Mill: Blue Diamond

Code Letter A

Sample Number	Contraction: Div. of Highways	Contraction: Cement Mill	Departure from Optimum: Div. of Highways	Departure from Optimum: Cement Mill	SO_3	Optimum SO_3: Div. of Highways	Optimum SO_3: Cement Mill
1	.0512 .0647 -.0135	.0453 .0547 -.0094	-1.00	-0.77	1.68	2.68	2.45
2	.0545 .0420 +.0125	.0500 .0183 +.0317	+0.43	+1.51	2.47	2.04	0.96
3	.0445 .0432 +.0013	.0400 .0370 +.0030	-0.17	-0.09	2.00	2.17	2.09
4	.0405 .0318 +.0087	.0430 .0390 +.0040	+0.23	-0.03	2.16	1.93	2.19
5	.0412 .0360 +.0052	.0552 .0402 +.0150	+0.03	+0.58	2.51	2.48	1.93
6	.0422 .0530 -.0108	.0530 .0550 -.0020	-0.84	-0.36	1.85	2.69	2.21
7	.0438 .0358 +.0080	.0580 .0490 +.0090	+0.19	+0.25	2.09	1.90	1.84
8	.0602 .0432 +.0170	.0636 .0499 +.0137	+0.70	+0.50	2.75	2.05	2.25
9	.0475 .0408 +.0067	.0584 .0495 +.0089	+0.11	+0.24	2.26	2.15	2.02
10	.0408 .0345 +.0063	.0523 .0430 +.0093	+0.09	+0.27	2.14	2.05	1.87
11	.0428 .0590 -.0162	.0471 .0664 -.0193	-1.14	-1.31	0.90	2.04	2.21
12	.0438 .0518 -.0080	.0605 .0717 -.0112	-0.70	-0.89	1.04	1.74	1.93
13	.0510 .0625 -.0115	.0465 .0548 -.0083	-0.89	-0.72	1.24	2.13	1.96
Average 7 to 13			-0.23	-0.24			
Standard deviation of difference Mill-Highway 7 to 13			0.1764				

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TESTS FOR CONTRACTION

Cement Mill: Ideal (San Juan Bautista) Code Letter B

Sample Number	Contraction		Departure from Optimum		SO_3	Optimum SO_3	
	Div. of Highways	Cement Mill	Div. of Highways	Cement Mill		Div. of Highways	Cement Mill
1	.0408 .0335 +.0073	.0390 .0340 +.0050	+0.15	+0.02	1.90	1.75	1.88

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TESTS FOR CONTRACTION

Cement Mill: Calaveras

Code Letter C

Sample Number	Contraction Div. of Highways	Contraction Cement Mill	Departure from Optimum Div. of Highways	Departure from Optimum Cement Mill	SO_3	Optimum SO_3 Div. of Highways	Optimum SO_3 Cement Mill
1	.0345 .0322 +.0023	.0337 .0345 -.0008	-0.13	-0.29	1.46	1.59	1.75
2	.0395 .0320 +.0075	.0471 .0324 +.0147	+0.16	+0.56	2.15	1.99	1.59
3	.0400 .0407 -.0007	.0356 .0321 +.0035	-0.28	-0.06	1.74	2.02	1.80
4	.0410 .0328 +.0082	Not Done	+0.21	-----	1.89	1.68	----
5	.0400 .0325 +.0075	.0351 .0307 +.0044	+0.16	0.00	1.78	1.62	1.78
6	.0415 .0328 +.0087	.0391 .0296 +.0095	+0.22	+0.27	2.09	1.87	1.82
7	.0430 .0360 +.0070	.0422 .0367 +.0055	+0.13	+0.05	1.90	1.77	1.85
8	.0402 .0315 +.0087	.0406 .0323 +.0083	+0.22	+0.21	1.81	1.59	1.60
Lab 9 Gr	.0410 .0505 -.0095	.0323 .0371 -.0048	-0.78	-0.52	1.00	1.78	1.52
Lab 10 Gr	.0538 .0562 -.0024	.0288 .0313 -.0025	-0.38	-0.38	2.65	3.03	3.03
11	.0445 .0355 +.0090	------	+0.25	-----	2.05	1.80	----
Average 5 to 10			-0.07	-0.06			
Standard deviation of difference Mill - Highways 5 to 10			0.1425				

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TESTS FOR CONTRACTION

Cement Mill: California Portland Cement Company, Colton

Code Letter D

Sample Number	Contraction		Departure from Optimum		SO_3	Optimum SO_3	
	Div. of Highways	Cement Mill	Div. of Highways	Cement Mill		Div. of Highways	Cement Mill
1	.0350 .0440 -.0090	.0332 .0322 +.0010	-0.75	-0.20	1.85	2.60	2.05
2	.0362 .0340 +.0022	.0340 .0330 +.0010	-0.14 ✓	-0.20	1.98	2.12	2.18
3 3Pbl	.0400 .0295 +.0105	.0370 .0330 +.0040	+0.32 ✓	-0.03	1.90	1.58	1.93
4	.0355 .0435 -.0080	.0310 .0375 -.0065	-0.70	-0.61	2.07	2.77	2.68
5	.0418 .0382 +.0036	.0380 .0353 +.0027	-0.05 ✓	-0.13	2.13	2.18	2.26
6	.0358 .0448 -.0090	.0392 .0495 -.0103	-0.75	-0.81	1.96	2.71	2.77
7	.0375 .0460 -.0085	.0420 .0475 -.0055	-0.73	-0.57	1.99	2.72	2.56
8	.0285 .0342 -.0057	.0355 .0425 -.0070	-0.56	-0.64	2.00	2.56	2.64
9	.0348 .0400 -.0052	.0407 .0455 -.0048	-0.54	-0.51	2.09	2.63	2.60
10	.0372 .0490 -.0118	.0380 .0460 -.0080	-0.90	-0.70	1.96	2.86	2.66
Average 2 to 10			-0.45	-0.47			
Standard deviation of difference Mill - Highways 2 to 10			0.1637				

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TESTS FOR CONTRACTION

Cement Mill: California Portland Cement Company, Mojave

Code Letter E

Sample Number	Contraction		Departure from Optimum		SO_3	Optimum SO_3	
	Div. of Highways	Cement Mill	Div. of Highways	Cement Mill		Div. of Highways	Cement Mill
1	.0458 .0390 +.0068	.0370 .0312 +.0058	+0.12	+0.07	1.99	1.87	1.92
2	.0518 .0400 +.0118	.0462 .0376 +.0088	+0.40	+0.24	2.15	1.75	1.91
3	.0370 .0365 +.0005	.0422 .0432 -.0010	-0.22	-0.30	1.94	2.16	2.24
4	.0452 .0357 +.0095	.0322 .0297 +.0025	+0.28	-0.12	1.97	1.69	2.09
5	.0388 .0452 -.0064	.0420 .0483 -.0063	-0.67	-0.60	1.60	2.27	2.20
6	.0398 .0412 -.0014	.0420 .0465 -.0045	-0.33	-0.50	1.92	2.25	2.42
7	.0452 .0385 +.0067	.0435 .0405 +.0030	+0.11	-0.09	2.09	1.98	2.18
8	.0362 .0300 +.0062	.0430 .0370 +.0060	+0.09	+0.08	2.11	2.02	2.03
9	.0405 .0380 +.0025	.0470 .0445 +.0025	-0.12	-0.12	2.02	2.14	2.14
10	.0372 .0407 -.0035	.0415 .0410 +.0005	-0.45	-0.23	1.84	2.29	2.07
Average 1 to 10			-0.08	-0.16			
Standard deviation of difference Mill - Highways 1 to 10			0.1685				

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TESTS FOR CONTRACTION

Cement Mill: Pacific Cement & Aggregates
Davenport

Code Letter F

Sample Number	Contraction		Departure from Optimum		SO_3	Optimum SO_3	
	Div. of Highways	Cement Mill	Div. of Highways	Cement Mill		Div. of Highways	Cement Mill
1	.0315 .0358 -.0043	----	-0.50	----	1.90	2.40	----
2	.0268 .0315 -.0047	----	-0.52	----	1.94	2.46	----
3	.0360 .0422 -.0062	----	-0.60	----	2.00	2.60	----
4	.0288 .0380 -.0092	.0041 .0056 -.0015	-0.76	-0.33	1.61	2.37	1.94
5	.0308 .0348 -.0040	.0331 .0355 -.0024	-0.48	-0.39	1.92	2.40	2.31
6	.0305 .0318 -.0013	.0267 .0350 -.0083	-0.32	-0.72	1.96	2.28	2.68
7	.0300 .0362 -.0062	.0293 .0420 -.0127	-0.59	-0.95	1.65	2.24	2.60
8	.0295 .0333 -.0038	.0268 .0333 -.0065	-0.47	-0.61	1.74	2.21	2.35
9	.0310 .0352 -.0042	.0330 .0370 -.0040	-0.49	-0.48	1.86	2.35	2.34
10	.0330 .0362 -.0032	.0304 .0350 -.0046	-0.43	-0.51	1.93	2.36	2.44
11	.0382 .0340 -.0042	.0342 .0325 +.0017	-0.49	-0.16	2.26	2.75	2.42
12	.0405 .0338 +.0067	.0325 .0305 +.0020	+0.11	-0.15	2.33	2.22	2.48
Average 7 to 12			-0.39	-0.48			
Standard deviation of difference Mill - Highways 7 to 12			0.2410				

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TESTS FOR CONTRACTION

Cement Mill: Permanente
Cushenbury

Code Letter: G

Sample Number	Contraction		Departure from Optimum		SO_3	Optimum SO_3	
	Div. of Highways	Cement Mill	Div. of Highways	Cement Mill		Div. of Highways	Cement Mill
1	.0580 .0422 +.0158	.0496 .0376 +.0120	+0.63	+0.41	2.09	1.46	1.68
2	.0578 .0410 +.0168	.0550 .0390 +.0160	+0.69	+0.64	1.85	1.16	1.21
3	.0573 .0415 +.0158	.0360 .0290 +.0070	+0.63	+0.13	1.87	1.24	1.74
4	.0468 .0358 +.0110	.0305 .0310 -.0005	+0.35 ✓	-0.27	1.98	1.63	2.25
5	.0388 .0558 -.0170	.0423 .0713 -.0290	-1.19	-1.36	1.76	2.95	3.12
6	.0378 .0492 -.0114	.0348 .0448 -.0100	-0.88	-0.80	1.90	2.78	2.70
7	.0512 .0425 +.0087	.0317 .0360 -.0043	+0.23 ✓	-0.50	1.94	1.71	2.44
Average 5 to 7			-0.61	-0.89			
Standard deviation of difference Mill - Highways 5 to 7			0.4147				

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TESTS FOR CONTRACTION

Cement Mill: Permanente

Code Letter H

Sample Number	Contraction Div. of Highways	Contraction Cement Mill	Departure from Optimum Div. of Highways	Departure from Optimum Cement Mill	SO_3	Optimum SO_3 Div. of Highways	Optimum SO_3 Cement Mill
1	.0358 .0390 -.0032	----	-0.42	----	1.17	1.59	----
2	.0498 .0372 +.0126	.0470 .0328 +.0142	+0.44	+0.53	1.72	1.28	1.19
3	.0470 .0375 +.0095	.0515 .0415 +.0100	+0.28	+0.30	2.03	1.75	1.73
4	.0525 .0438 +.0087	.0532 .0453 +.0079	+0.23	+0.19	1.73	1.50	1.54
5	.0420 .0340 +.0080	.0453 .0350 +.0103	+0.19	+0.31	1.27	1.08	0.96
6	.0448 .0375 +.0073	.0456 .0395 +.0070	+0.14	+0.13	1.93	1.79	1.80
7	.0520 .0422 +.0098	.0593 .0503 +.0090	+0.29	+0.25	2.23	1.94	1.98
8	.0352 .0322 +.0030	.0403 .0348 +.0055	-0.09	+0.05	1.00	1.09	0.95
9	.0432 .0362 +.0070	.0458 .0408 +.0050	+0.13	+0.02	1.46	1.33	1.44
10	.0342 .0302 +.0040	.0403 .0367 +.0036	-0.03	-0.05	1.18	1.21	1.23
11	.0418 .0372 +.0046	.0477 .0393 +.0084	0.00	+0.23	2.16	2.16	1.93
12	.0295 .0470 -.0175	.0315 .0425 -.0110	-1.22	-0.86	0.70	1.92	1.56
13	.0342 .0420 -.0078	.0430 .0380 +.0050	-0.69	+0.02	0.79	1.48	0.77
Average 2 to 12			+0.03	+0.10			
Standard deviation of difference Mill - Highways 2 to 12			0.1382				

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TESTS FOR CONTRACTION

Cement Mill: Riverside, Oro Grande

Code Letter I

Sample Number	Contraction		Departure from Optimum		SO_3	Optimum SO_3	
	Div. of Highways	Cement Mill	Div. of Highways	Cement Mill		Div. of Highways	Cement Mill
1	.0555 .0412 +.0143	.0570 .0460 +.0110	+0.54	+0.35	2.04	1.50	1.69
2 III	.0497 .0402 +.0095	.0550 .0430 +.0120	+0.28 ✓	+0.41	2.94	2.66	2.53
3	.0505 .0372 +.0133	.0500 .0390 +.0110	+0.48 ✓	+0.35	1.95	1.47	1.60
4 III	.0638 .0522 +.0116	.0710 .0590 +.0120	+0.39 ✓	+0.41	2.44	2.05	2.03
Low C_3A 5	.0555 .0405 +.0150	.0485 .0370 +.0115	+0.57	+0.39	1.39	0.82	1.00
6	.0582 .0485 +.0097	.0600 .0565 +.0035	+0.28 ✓	-0.06	2.20	1.92	2.26
7	.0520 .0412 +.0108	.0560 .0445 +.0115	+0.34 ✓	+0.38	1.99	1.65	1.61
8	.0460 .0350 +.0110	.0340 .0325 +.0015	+0.35 ✓	-0.18	1.82	1.47	2.00
9	.0452 .0347 +.0105	.0420 .0340 +.0080	+0.33 ✓	+0.19	1.92	1.59	1.73
10	.0305 .0465 -.0160	.0390 .0550 -.0160	-1.13	-1.13	0.91	2.04	2.04
11	.0307 .0360 -.0053	.0350 .0310 +.0040	-0.55	-0.48	1.02	1.57	1.50
Average 1 to 11			+0.17	+0.06			
Standard deviation of difference Mill - Highways 1 to 11			0.1957				

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Error

TESTS FOR CONTRACTION

Cement Mill: Southwestern, (Victor) Code Letter J

Sample Number	Contraction Div. of Highways	Contraction Cement Mill	Departure from Optimum Div. of Highways	Departure from Optimum Cement Mill	SO3	Optimum SO3 Div. of Highways	Optimum SO3 Cement Mill
1	.0720 .0500 +.0120	.0545 .0405 +.0140	Stored - 8 months +0.41	+0.52	2.09	Age of Cement 1.68	1.57
2	.0342 .0440 -.0098	.0413 .0455 -.0042	-0.79	-0.49	1.76	2.55	2.25
3	.0420 .0440 -.0020	.0393 .0393 .0000	-0.36	-0.25	1.78	2.14	2.03
4	.0432 .0525 -.0093	.0360 .0405 -.0045	-0.77	-0.50	1.93	2.70	2.43
5	.0392 .0405 -.0013	.0388 .0405 -.0017	-0.32	-0.34	1.91	2.23	2.25
6	.0400 .0385 +.0015	.0443 .0423 +.0020	-0.18	-0.15	1.99	2.17	2.14
7	.0365 .0395 -.0030	.0290 .0320 -.0030	-0.42	-0.42	1.85	2.27	2.27
8	.0378 .0398 -.0020	.0355 .0335 +.0020	-0.36	-0.15	2.06	2.42	2.21
9	.0395 .0368 +.0027	.0285 .0300 -.0015	-0.11	-0.33	1.80	1.91	2.13
10	.0365 .0442 -.0077	.0400 .0463 -.0063	-0.68	-0.60	1.65	2.33	2.25
11	.0370 .0440 -.0070	.0330 .0380 -.0050	-0.64	-0.53	1.83	2.47	2.36
12	.0380 .0422 -.0042	.0343 .0373 -.0030	-0.50	-0.42	1.94	2.44	2.36
Average 3 to 12			-0.43	-0.37			
Standard deviation of difference Mill - Highways 3 to 12			0.1338				

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TESTS FOR CONTRACTION

Cement Mill: Monolith

Code Letter K

P = .016

Sample Number	Contraction		Departure from Optimum		SO_3	Optimum SO_3	
	Div. of Highways	Cement Mill	Div. of Highways	Cement Mill		Div. of Highways	Cement Mill
1	.0313 .0407 -.0094	.0295 .0395 -.0100	-0.77	-0.80	1.44	2.21	2.24
2	.0312 .0370 -.0058	.0327 .0406 -.0079	-0.57	-0.69	1.78	2.35	2.47
3	.0332 .0344 -.0012	.0314 .0348 -.0034	-0.31	-0.44	2.25	2.56	2.69
4	.0312 .0380 -.0068	.0399 .0502 -.0103	-0.63	-0.82	1.82	2.45	2.64
5	.0342 .0330 +.0012	.0367 .0359 +.0008	-0.19	-0.21	2.03	2.22	2.24
6	.0350 .0437 -.0087	.0345 .0429 -.0084	-0.73	-0.72	1.68	2.41	2.40
7	.0445 .0352 +.0093	.0469 .0372 +.0097	+0.27	+0.28	2.57	2.30	2.29
8	.0335 .0400 -.0065	.0468 .0367 -.0101	-0.61	-0.80	1.82	2.43	2.62
Average 1 to 8			-0.44	-0.52			
Standard deviation of difference Mill - Highways 1 to 8			0.0849				

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TESTS FOR CONTRACTION

Cement Mill: Riverside (Crestmore) Code Letter L

Sample Number	Contraction		Departure from Optimum		SO_3	Optimum SO_3	
	Div. of Highways	Cement Mill	Div. of Highways	Cement Mill		Div. of Highways	Cement Mill
1	.0338 .0312 +.0026	.0370 .0300 +.0070	-0.13	+0.13	2.13	2.26	2.00
2	.0385 .0355 +.0030	.0340 .0283 +.0057	-0.09	+0.06	1.96	2.05	1.90
3	Not Rec'd.	.0450 .0390 +.0060	Not Rec'd.	+0.08	2.20 Mill	----	2.12
4	.0432 .0365 +.0067	.0575 .0465 +.0110	+0.11	+0.35	2.35	2.24	2.00
5	.0388 .0372 +.0016	.0410 .0362 +.0048	-0.18	+0.01	1.96	2.14	1.95
6	.0425 .0408 +.0017	.0430 .0400 +.0030	-0.18	-0.09	1.96	2.14	2.05
7	.0428 .0405 +.0023	.0440 .0400 +.0040	-0.13	-0.03	1.85	1.98	1.88
Average 1 to 7			-0.10	+0.07			
Standard deviation of difference Mill - Highways 1 to 7			0.0843				

Note: No. 3 omitted from averages and standard deviations.

All Mill Grind

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TESTS FOR CONTRACTION

Cement Mill: Ideal (Redwood City) Code Letter M

Sample Number	Contraction		Departure from Optimum		SO_3	Optimum SO_3	
	Div. of Highways	Cement Mill	Div. of Highways	Cement Mill		Div. of Highways	Cement Mill
1	.0458 .0355 +.0103	----	+0.33 ✓	----	1.97	1.64	----
2	.0365 .0458 -.0093	----	-0.77	----	2.00	2.77	----
3	.0400 .0405 -.0005	----	-0.27 ✓	----	2.50	2.77	----

Mill Samples

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SO_3 CONTENTS OF CEMENTS

Cement Mill: Blue Diamond — Code Letter A

Sample Number	Div. of Highways	Cement Mill	Sample Number	Div. of Highways	Cement Mill
1	1.68	1.67	8	2.75	2.54
2	2.47	2.52	9	2.26	2.23
3	2.00	2.06	10	2.14	2.20
4	2.16	2.08	11	0.90	1.03
5	2.51	2.47	12	1.04	1.11
6	1.85	1.94	13	1.24	1.20
7	2.09	2.09			

Cement Mill: Ideal, San Juan Bautista — Code Letter B

1	1.90	2.18			

Cement Mill: Calaveras — Code Letter C

1	1.46	1.49	7	1.90	2.03
2	2.15	2.13	8	1.81	1.74
3	1.74	1.67	9	1.00	0.97
4	1.89	1.81	10	2.65	2.46
5	1.78	1.68	11	2.05	1.83
6	2.09	1.90			

Cement Mill: California Portland Cement Colton — Code Letter D

1	1.85	1.93	8	2.00	2.02
2	1.98	2.00	9	2.09	2.06
3	1.90	2.00	10	1.96	2.05
4	2.07	2.04	11	2.16	2.14
5	2.13	2.11	12	2.09	2.15
6	1.96	1.96	13	2.08	2.06
7	1.99	2.02			

Continued

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SO_3 Contents of Cements

Cement Mill: California Portland Cement, Mojave — Code Letter E

Sample Number	Div. of Highways	Cement Mill	Sample Number	Div. of Highways	Cement Mill
1	1.99	2.05	8	2.11	2.18
2	2.15	2.20	9	2.02	2.00
3	1.94	1.90	10	1.84	1.82
4	1.97	1.93	11	1.77	1.75
5	1.60	1.58	12	1.79	1.81
6	1.92	1.94	13	2.09	2.12
7	2.09	2.12			

Cement Mill: Pacific Cement and Aggregates — Code Letter F

1	1.90	1.84	7	1.65	1.67
2	1.94	1.90	8	1.74	1.95
3	2.00	1.97	9	1.86	1.86
4	1.61	1.73	10	1.93	1.86
5	1.92	1.77	11	2.26	2.29
6	1.96	1.91	12	2.33	2.36

Cement Mill: Permanente, Cushenbury — Code Letter G

1	2.09	2.40	5	1.76	1.77
2	1.85	1.77	6	1.90	2.11
3	1.87	1.88	7	1.94	1.93
4	1.98	2.06	8	1.93	2.13

Cement Mill: Permanente — Code Letter H

1	1.17	1.20	8	1.00	1.05
2	1.72	1.75	9	1.46	1.23
3	2.03	1.97	10	1.18	1.21
4	1.73	1.59	11	2.16	2.14
5	1.27	1.22	12	0.70	0.79
6	1.93	2.15	13	0.79	1.10
7	2.23	2.06	14	1.86	1.89

Continued

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SO_3 Content of Cements

Cement Mill: Riverside, Oro Grande — Code Letter I

Sample Number	Div. of Highways	Cement Mill	Sample Number	Div. of Highways	Cement Mill
1	2.04	2.02	7	1.99	1.90
2	2.94	2.92	8	1.82	1.89
3	1.95	1.89	9	1.92	1.89
4	2.44	2.18	10	0.91	0.98
5	1.39	1.32	11	1.02	1.03
6	2.20	2.19			

Cement Mill: Southwestern, (Victor) — Code Letter J

1	2.09	1.95	7	1.85	1.95
2	1.76	1.61	8	2.06	1.90
3	1.78	1.87	9	1.80	2.00
4	1.93	1.8	10	1.65	1.6
5	1.93	1.9	11	1.83	1.7
6	1.99	1.9	12	1.94	1.8

Cement Mill: Monolith — Code Letter K

1	1.44	1.50	6	1.68	1.67
2	1.78	1.57	7	2.57	2.57
3	2.25	2.25	8	1.82	1.81
4	1.82	1.72	9	2.44	2.46
5	2.03	1.97			

Cement Mill: Riverside, Crestmore — Code Letter L

1	2.13	1.86	5	1.96	1.90
2	1.96	1.97	6	1.96	1.96
3	----	2.20	7	1.85	1.85
4	2.35	2.20	8	2.02	2.12

Sample No. 3 was never received by Calif. Div. of Highways

Cement Mill: Ideal, Redwood City — Code Letter M

1	1.97	----			
2	2.00	1.87			
3	2.50	2.42			

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Numerical solutions of equation

$$r = 0.018\ (g + 0.25)$$

where r = change in contraction
g = deficiency or excess of SO_3 relative to optimum

r	g	r	g
0.020	0.87	0.000	-0.25
0.019	0.82	-0.001	-0.30
0.018	0.76	-0.002	-0.36
0.017	0.70	-0.003	-0.42
0.016	0.64	-0.004	-0.48
0.015	0.58	-0.005	-0.53
0.014	0.52	-0.006	-0.58
0.013	0.46	-0.007	-0.64
0.012	0.41	-0.008	-0.70
0.011	0.35	-0.009	-0.75
0.010	0.30	-0.010	-0.80
0.009	0.25	-0.011	-0.86
0.008	0.19	-0.012	-0.91
0.007	0.13	-0.013	-0.97
0.006	0.08	-0.014	-1.03
0.005	0.02	-0.015	-1.08
0.004	-0.03	-0.016	-1.13
0.003	-0.09	-0.017	-1.19
0.002	-0.15	-0.018	-1.24
0.001	-0.20	-0.019	-1.30
0.000	-0.25	-0.020	-1.36

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