REPORT NO. CDH-SMB-R-81-4

EVALUATION OF RAPID TEST PROCEDURES FOR WATER DETERMINATION OF PLASTIC PORTLAND CEMENT CONCRETE

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Final Report
December 1980

81-4

Prepared in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

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Technical Report Documentation Page

1. Report No.

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle

EVALUATION OF RAPID TEST PROCEDURES FOR WATER
DETERMINATION OF PLASTIC PORTLAND CEMENT CONCRETE
DOT-FH-11-8188

5. Report Date

April 1981

6. Performing Organization Code

1486AN

7. Author(s)

Kenneth P. Morrison

8. Performing Organization Report No.

CDH-SMB-R-81-4

9. Performing Organization Name and Address

Materials Laboratory
Colorado Division of Highways
4340 East Louisiana Avenue
Denver, Colorado 80222

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

DOT-FH-11-8188

12. Sponsoring Agency Name and Address

Colorado Department of Highways
4201 East Arkansas Avenue
Denver, Colorado 80222

13. Type of Report and Period Covered

Final

14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration

16. Abstract

This research project was designed to evaluate two different test procedures for determining the water content of plastic concrete.

The following procedures were evaluated: microwave oven method and the Kelly-Vail titration method. Tests were run on samples aged 15, 45, and 90 minutes to determine the effect of hydration on the results.

Seventy-five tests were run on trial mixes tested in the Central Laboratory, and 14 tests were run on concrete delivered to two selected field projects.

17. Key Words

water content, microwave oven, Kelly-Vail method, water-cement ratio, titration

18. Distribution Statement

No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	43	

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

Conversion Factors, U.S. Customary to Metric (S.I.) Units of Measurement

U.S. customary units of measurement can be converted to metric (S.I.) units as follows:

Multiply	By	To Obtain
pounds	.4536	Kilograms (Kg)
pounds per cubic yard (lbs/yd^3)	.59328	Kilograms per cubic metre (Kg/m^3)
psi, pounds (force) per square inch	6894	pascals
Fahrenheit (F^o)	5/9(F-32)	Celsius degrees

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Introduction

For several years the construction industry has recognized that one of the key factors in constructing durable portland cement concrete structures is the water-cement ratio of the plastic mix. Better control of the water-cement ratio would result in the placement of higher quality concretes. This would improve the service life and decrease maintenance on highway structures and pavements constructed of portland cement concrete.

This study evaluated two different test procedures for determining the water content of plastic concrete. One procedure used a microwave oven to evaporate the water in samples of plastic concrete. This test procedure is a modification of a method developed and studied by the North Dakota State Highway Department in 1978. The other procedure evaluated in this study uses the Kelly-Vail chemical titration method for determining the water content of plastic concrete. This test was developed by Kelly and Vail in England in 1968. In the first and longest phase of this study the two test methods were run on samples of concrete design mixes. During the second phase these tests were run on plastic concrete delivered to selected field projects.

Laboratory Testing

The testing procedure for both laboratory and field samples is basically the same; the only difference being that only one sample per test is run for field tests. For the laboratory tests a 12 to 15 kilogram sample of plastic concrete was obtained from the mixer. This sample is then broken down into nine separate test specimens; three for the microwave oven procedure and six for the Kelly-Vail procedure. The specimens for the microwave oven method are 1200 grams while the Kelly-Vail specimens weighed 1000 grams for maximum aggregate size of 1 inch and 2000 grams for 1½ inch maximum nominal sized aggregates. These test specimens are then placed into air tight containers and set aside to test after 15 minutes, 45 minutes and 90 minutes. This aging simulates the maximum allowable time between the initial addition of water to the mix and the depositing of the concrete in place as allowed by "Standard Specifications for Road and Bridge Construction" State of Colorado, State Department of Highways.

Microwave Oven Procedure

This procedure utilizes a microwave oven to drive the water out of 1200 gram specimens that had been set aside for testing. The microwave oven heats the specimen so rapidly that most of the water is vaporized and removed from the sample instead of being tied up by cement hydration.

Kelly-Vail Procedure

The Kelly-Vail method for determining water content of plastic concrete uses wet chemistry; a chemical titration, to measure the dilution of a solution of known concentration by the water in a specimen of plastic concrete.

After mixing the reagents to the proper concentrations, as listed in Appendix C, the test operator runs a blank equivalent constant and a three point calibration curve. The blank equivalent constant is a titration run to check the mixing of the reagent solutions. The calibration curve is run by measuring the dilution of the standard salt solution by known amounts of distilled water. The three volumes of the standard potassium thiocyanate solution needed to reach the end point of each calibration point can then be plotted versus the moisture content, in grams, to obtain the calibration curve. The end point of these titrations occurs when the first permanent reddish-brown or orange color appears.

To determine the water content of the plastic concrete a pair of specimens is selected from those specimens weighed out and set aside in bottles for testing by the Kelly-Vail method. Distilled water, 500 ml, is added to one bottle and this specimen is then referred to as the blank. The standard salt solution, 500 ml, is added to the other bottle and is referred to as the sample. The moisture in the plastic concrete dilutes the standard salt solution. It is this dilution that is measured chemically and compared to the calibration curves. These specimens are each thoroughly mixed and then allowed to set for a few minutes until most of the solids settle out of solution. A small amount, 25 ml, of solution is withdrawn from each specimen. Added to these solutions is a known amount of silver nitrate and nitric acid, nitrobenzene and the ferric alum indicator. The silver combines with the chlorides and precipitates as silver chloride. When the standard potassium thiocyanate solution is added it measures the remaining chloride ions. The titration of the blank gives a correction factor for the presence of chloride ions in any of the ingredients of the concrete. This correction factor added to the volume of potassium thiocyanate needed to titrate the sample is used with the calibration curve to obtain the moisture content of the concrete. See Figure 1 for a sample calibration curve. This procedure can be completed in approximately fifteen minutes.

Equipment

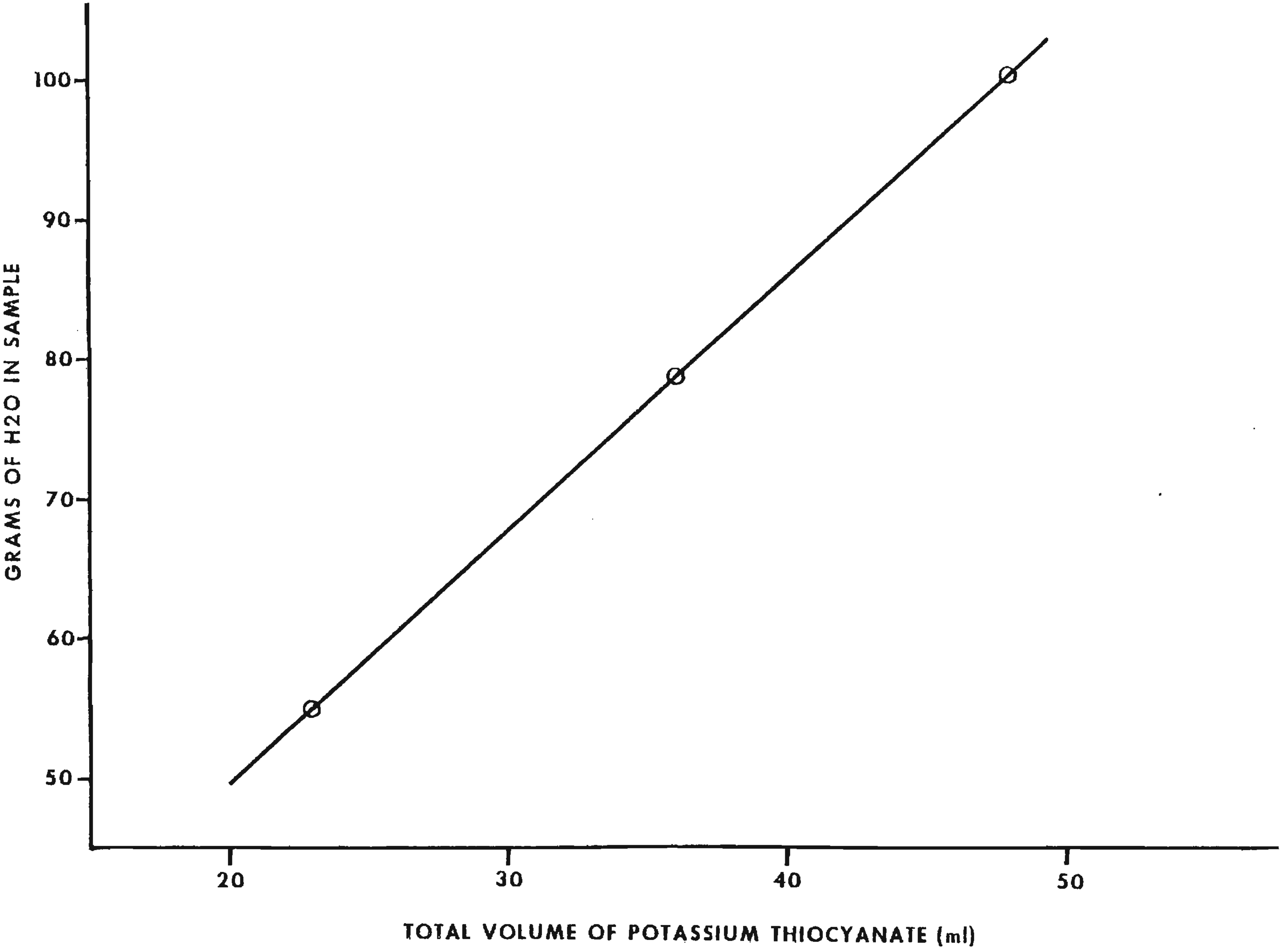
The microwave oven used for that portion of the research project was a Litton Model 455 "Minutemaster" developed for normal household use. Previous studies with microwave ovens have shown that high energy or power settings tend to fuse the cement due to the high temperatures produced. This problem can be circumvented by using the "defrost" or reduced power settings available on many ovens. The power is reduced automatically by cycling the microwave generators on and off. Pyrex bowls with lids were used in the microwave oven.

The equipment used for the Kelly-Vail procedure is described in Appendix C. The mixer was built out of parts available in the laboratory and is pictured in Appendix D.

Laboratory Phase

The laboratory work consisted of running the microwave oven and Kelly-Vail procedures on trial mixes made by the Concrete Unit to check the performance of design mixes submitted by various field districts. Seventy-five tests were run on twenty-five different design mixes.

FIGURE 1
SAMPLE CALIBRATION CURVE



Concrete Design Mixes

Tests were run on the following classes of concrete: A, B, D, DT, P, and lean concrete base. An explanation of these class designations and their uses is in Appendix E. Some of the mixes used fly ash as a partial cement replacement, up to 20 percent of weight of cement. Appendix A is the detailed breakdown of the concrete mixes tested in this study.

Aggregate

The aggregates used in the trial mixes are good quality, durable aggregates conforming to AASHTO Designation M43-54 Size Number 7, 67 and 467 for the course aggregates and AASHTO Designation M6-65 for the fine aggregate. The course aggregates varied from naturally rounded river rock with less than twenty percent fractured faces to quarry rock with one hundred percent crushed faces.

Most of the aggregates tested were produced from commercial pits in the Denver Metropolitan area. One trial mix used aggregates produced in Western Colorado near Grand Junction.

The aggregates used in the trial mixes were near saturated surface dry. Moisture corrections were applied to the fine aggregate to correct for free moisture when necessary.

The aggregate for the lean concrete base was from Northern Colorado near Greeley and had the following sieve analysis:

Passing Sieve	Percent
2"	100
1"	92
3/4"	87
1/2"	81
3/8"	76
#4	65
#8	50
#30	22
#100	8
#200	4.5

This aggregate was oven dried before use in the trial mix.

Cements and Fly Ash

The cements used in this research work were types 1 and 2 from the three major Colorado sources; the Portland and Boettcher plants of Ideal Basic Industries and the Lyons plant of Martin Marietta Cement Company.

Two classes of fly ash were used in this study: "Comanche Fly Ash" an ASTM Designation C618-80 Class C and "Jim Bridger" a Class F fly ash. See Appendix F for a table of their chemical composition.

Admixtures

All the concrete mixes tested were air entrained. The Class D and DT concrete mixes also utilized water reducing admixtures conforming to AASHTO Designation 194-80. The moisture contents of various admixtures were determined during the early phases of the microwave oven study.

Field Phase

The required equipment and chemical reagents were moved to two field laboratories and Kelly-Vail and microwave oven moisture determination tests were run at two field projects on three different classes of concrete. For these tests only one sample was run using each method. Further field tests will be run as the opportunity arises.

Cost Analysis

The cost of chemical apparatus required for the Kelly-Vail procedure is as follows:

4	-	1/2 gallon capacity wide mouth jars	$10.32
1	-	end over end mixer	55.00
2	-	conical beakers 500 ml	3.20
1	-	25 ml pipette	3.75
2	-	25 ml automatic burettes	65.72
2	-	amber reagent bottles 32 oz. capacity	2.43
1	-	10 ml automatic pipette	34.76
1	-	100 ml burette	12.78
2	-	500 ml volumetric flasks	21.38
2	-	carboys 2 gallon capacity	35.55
1	-	burette support	20.00
1	-	double burette holder	22.30
1	-	utility clamp	4.95
3	-	fixed volume dispensers	4.50
		Total	$296.64

These are 1980 prices and the cost of the mixer is estimated as it was fabricated out of parts available in the laboratory. Most of the equipment listed is plastic and should last indefinitely if not mishandled.

The cost of the reagents used for the Kelly-Vail procedure is as follows on a per test basis:

ferric alum indicator solution	5 lb. @ $3.34/lb	$0.02/test
nitric acid	1 pt. @ $3.22/pt.	0.03/test
nitrobenzene	1 pt. @ $5.78/pt.	0.03/test
potassium thiocyanate	1 lb. @ $8.53/lb.	0.04/test
silver nitrate	1 lb. @ $105.52/lb.	0.69/test
sodium chloride	5 lbs. @ $1.86/lb.	0.08/test
	Total	$0.89/test

The rapidly fluctuating price of silver could drastically affect the cost of chemicals per test.

The silver chloride that is precipitated by the titration in the Kelly-Vail test can be saved for recycling. If a market can be found for the silver chloride the cost of the test could be reduced.

The cost of the microwave oven and drying dishes is as follows in 1979 prices:

1	- Microwave oven with variable power setting	$275.00
2	- Pyrex or ceramic drying dishes	15.00
	Total	$290.00

The Pyrex drying dishes last for only about 6 or 7 tests before breaking. Ceramic dishes specifically produced for use with microwave oven should give better performance. The microwave oven and ceramic dishes should last indefinitely if not misused.

Evaluation of Test Results

The test results were analyzed by statistical methods to obtain the mean, standard deviation, coefficient of variation, and the range. Each trial mix tested was evaluated separately. Trial mixes that were designed at the same water-cement ratio were then grouped together for evaluation. The results of the tests and the statistical summary is presented in Appendix B.

A histogram was constructed of those tests run on trial mixes designed at a water-cement ratio of .417. An examination of this histogram reveals the microwave test results tend to cluster below the design W-C ratio while the Kelly-Vail test results are generally above the design W-C ratio. See Figure 2 for the histogram of the test results.

The water-cement ratio as determined by each test method was plotted against the "as mixed" water-cement ratio calculated from the weights of the ingredients used in each trial mix. It should be noted that the weight of the fine aggregate was corrected for free moisture but no correction was made for the moisture in the coarse aggregate. The water-cement ratio determined by testing is an average of from two to three specimens run on each trial mix. See Figures 3 and 4 for these graphs. Regression

FIGURE 2

CONCRETE DESIGNED AT
.417 W/C RATIO

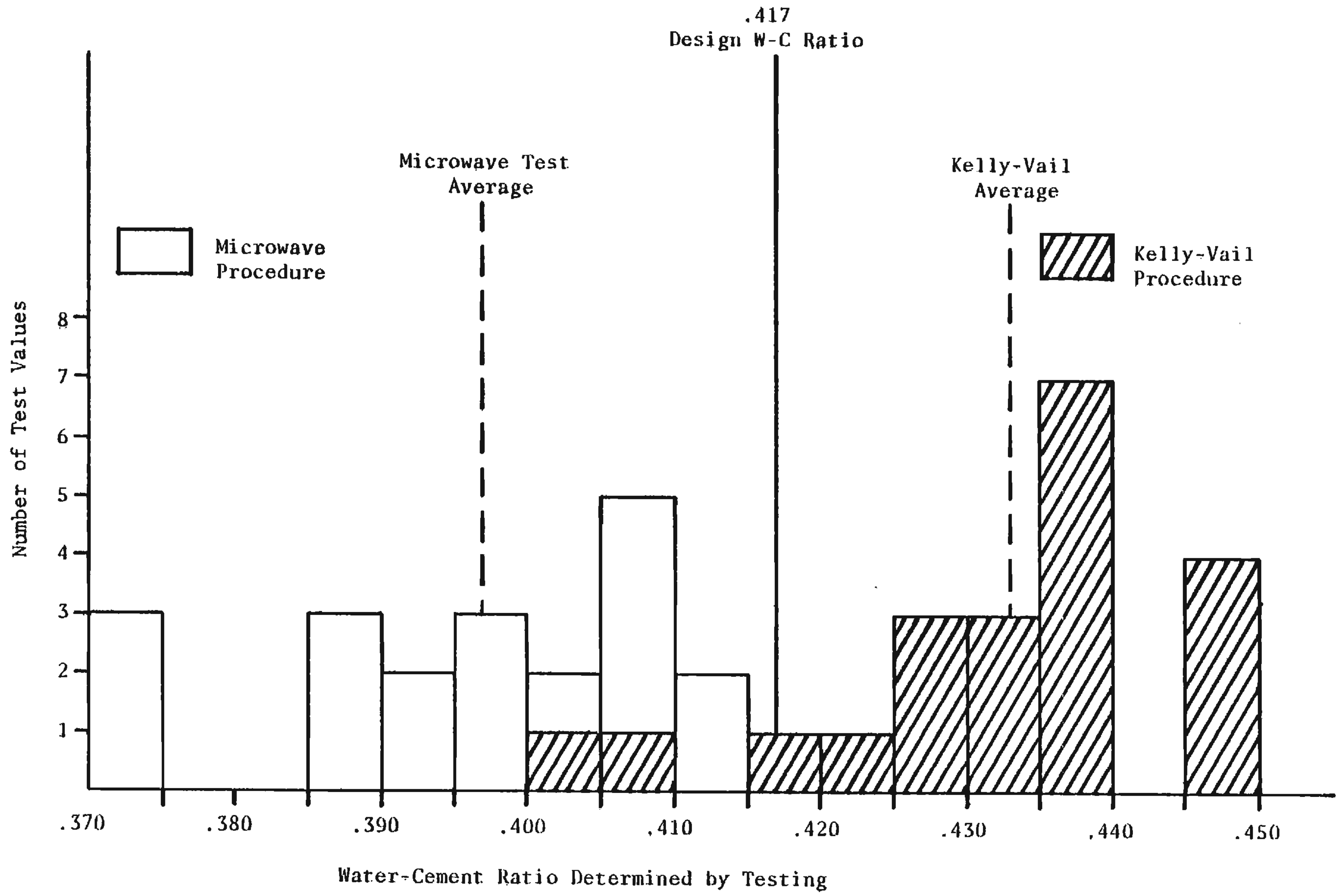


FIGURE 3
KELLY-VAIL RESULTS

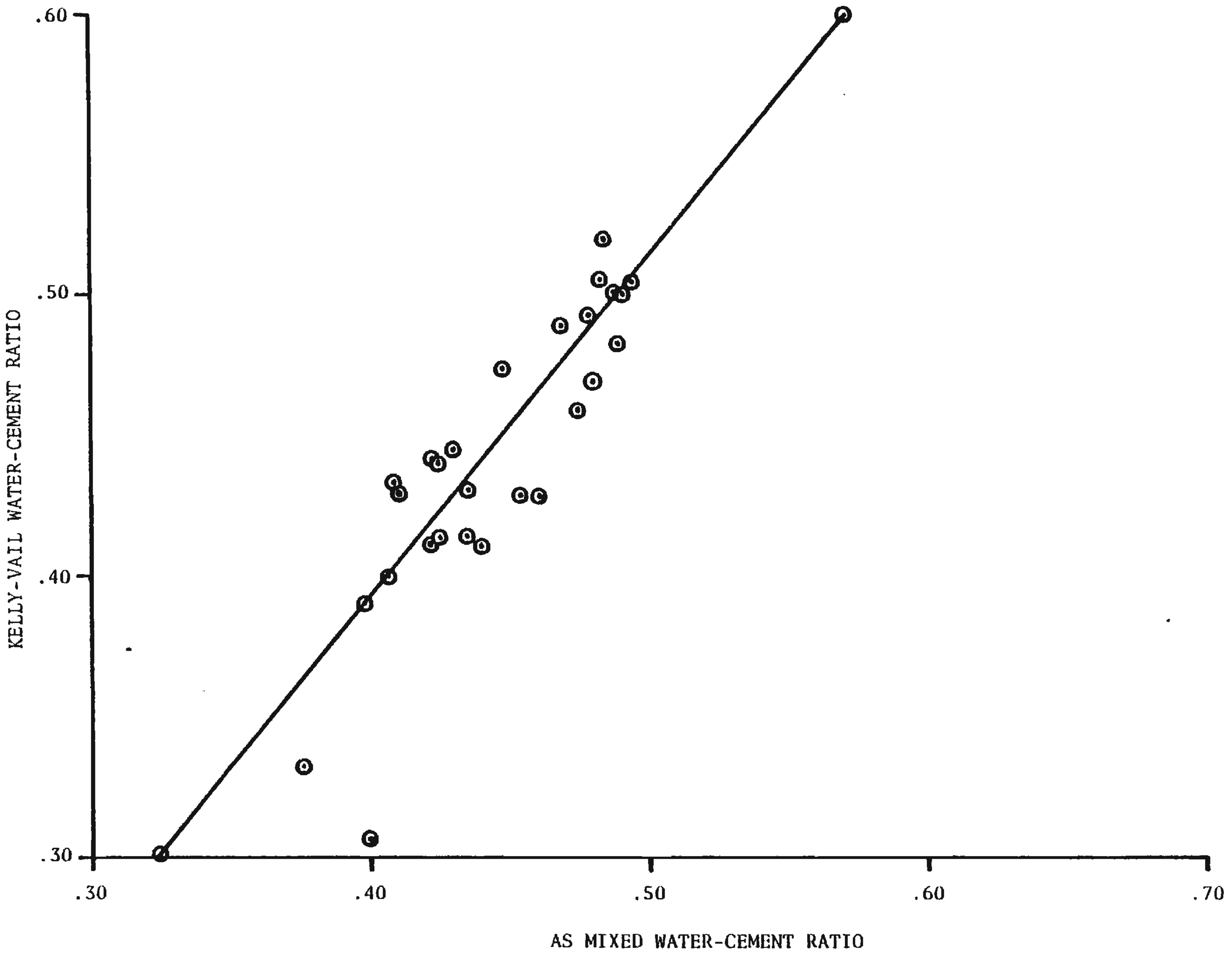
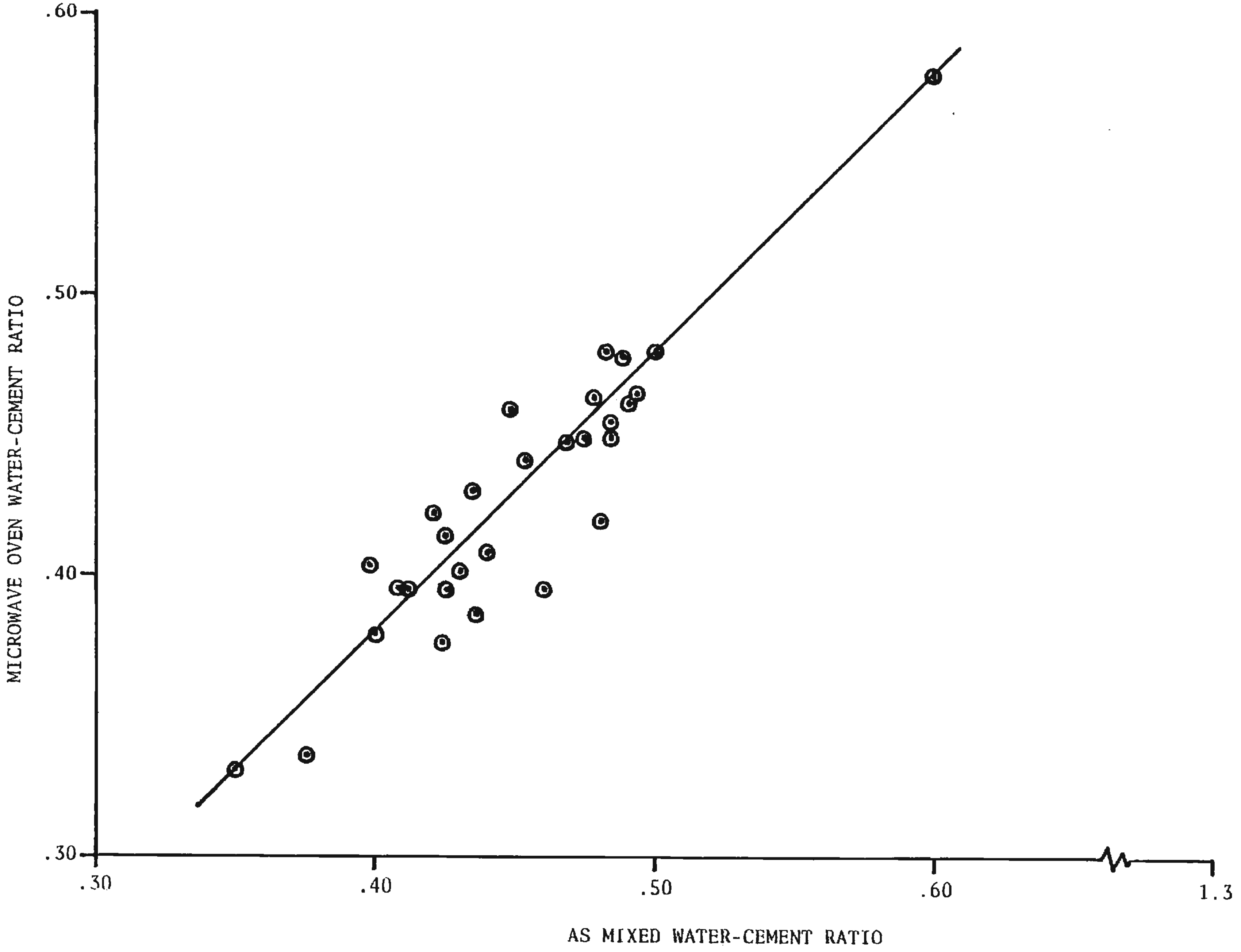


FIGURE 4
MICROWAVE RESULTS



equations were then calculated using the "as mixed" water-cement ratio and the water-cement ratio determined by testing. The line determined by the regression equation is also plotted on the graphs. The following table gives the regression equations and correlation coefficients.

	Regression Equation	Correlation Coefficient
Kelly-Vail Results	$y = 1.212\ X - 0.0935$	.885
Microwave Results	$y = .9949\ X - 0.0171$	.906

where y = As mixed W-C ratio
and x = Determined W-C ratio

The two test methods were then graphed and linear regression was used to determine the regression equation and correlation coefficient. The graph is shown on Figure 5 and regression equation and correlation coefficient is as follows:

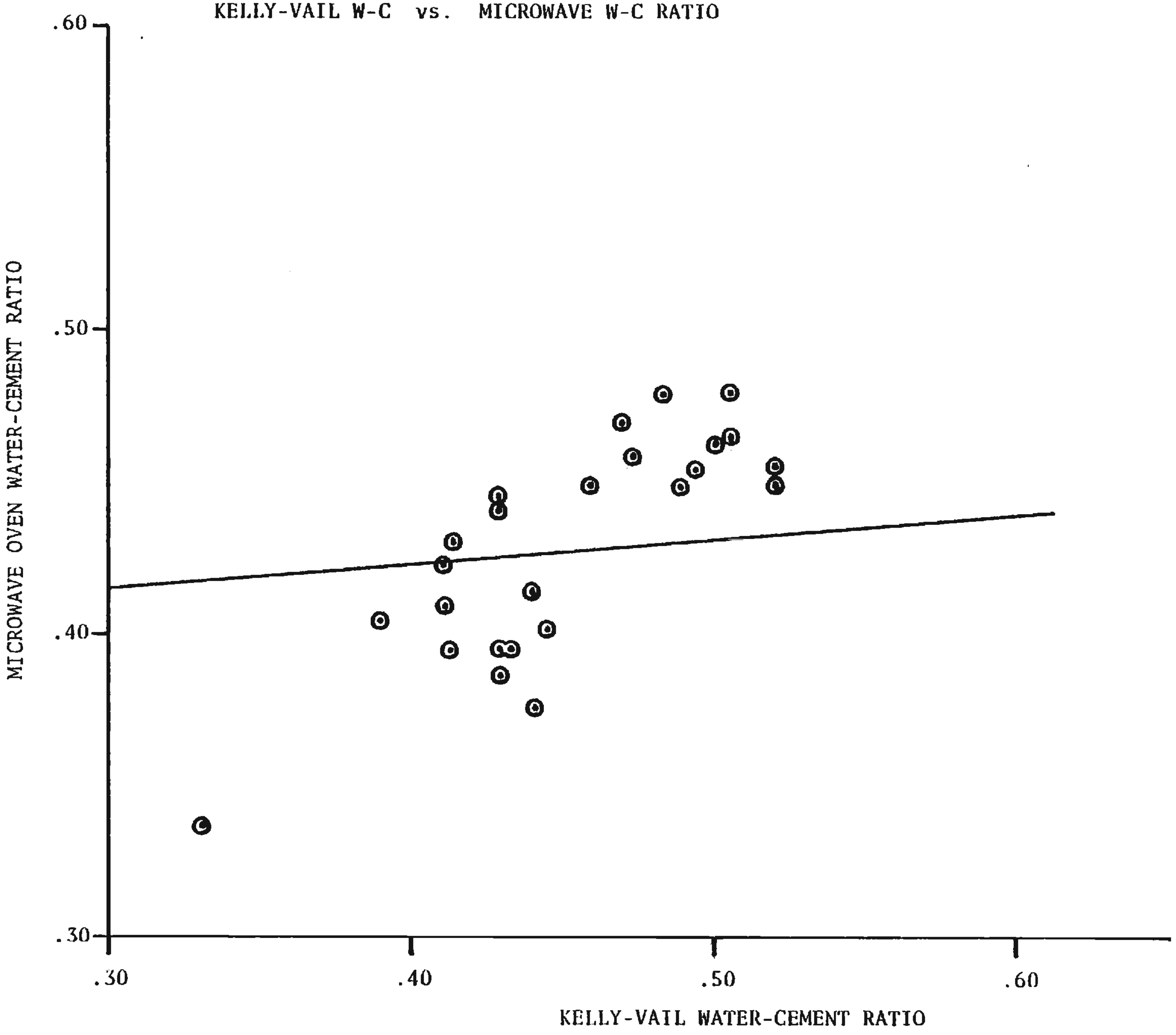
Regression Equation; $y = .0800\ x + 0.3919$
Correlation Coefficient; .219
Where y = Kelly-Vail W-C ratio
x = Microwave W-C ratio

Unfortunately not enough tests for water content could be run on a single design to allow an analysis to relate determined water-cement ratio and 28 day compressive strength. This could be pursued by selecting a suitable field project with ample quantities of concrete and continuing the evaluation of the two testing methods.

Conclusions

After evaluating the data it is apparent that either of the two test methods does an excellent job of determining the water-cement ratio of plastic concrete. However, the correlation between the two methods is not good. This is probably due to the bias of the two procedures. The microwave oven method tends to give results below the actual water-cement

FIGURE 5
KELLY-VAIL W-C vs. MICROWAVE W-C RATIO



ratio while the Kelly-Vail method yields results that are slightly above this ratio. The low results of the microwave oven method are probably due to the hydration of the cement and to less than total recovery of the moisture absorbed in the aggregates. The cement that adheres to aggregate as it is dried may seal the pores and prevent the evaporation of all the absorbed moisture. The high bias of the Kelly-Vail method cannot be explained.

The equipment required for the Kelly-Vail procedure can only be used for determining the water content of plastic concrete while the microwave oven could be used to test other construction materials such as moisture contents of soils, aggregates and asphaltic concretes.

The Kelly-Vail procedure can be completed in approximately fifteen minutes after the sample has been retrieved. The microwave oven procedure required more than one hour before the results are determined. Adjustments to the plastic concrete could be made utilizing the Kelly-Vail method before many loads of lower quality concrete were placed in any structure. When using the microwave oven method many loads would probably be batched before any change could be made.

Both test procedures are sufficiently portable to be used in specially equipped testing vehicles at the placement site.

One conclusion that can be drawn that is common to both methods is that the age of the sample tested makes little or no difference on the results obtained. This points out that hydration does not tie up much of the available water in the ninety minutes allowed in the specifications.

Problems

One problem common to both test methods is the necessity to obtain a specimen that is representative of the batch or production unit being tested. Obtaining a representative specimen becomes more difficult as the nominal size of the coarse aggregate increases. This might be overcome by testing as large a sample as possible for the microwave test. Elimination of the large aggregate by selective wet sieving is also one method to overcome this problem.

Reproducibility of the titration end points is a possible problem with the Kelly-Vail procedure. However, as the operator gains more experience this problem is moderated or negated. Using printed color standards would eliminate this problem as a source of error completely.

The problem unique to the microwave oven procedure is encountered during the calculation of the moisture contained in the specimen. Since the microwave oven drives off some of the absorbed moisture in the aggregates a correction must be made to determine only the free moisture evaporated. This requires another calculation or calculations. This method for obtaining the net moisture evaporated is shown in Appendix C.

Implementation

It is recommended that one or both of these testing procedures be adopted for use in testing plastic concrete. If end result specifications are adopted the use of one of these procedures may be necessary to achieve the quality control needed to insure that the desired service life of concrete structures and pavements is obtained. Included in Appendix C are the proposed Colorado Procedures for the two test methods. After review and possible adoption by the Sampling and Testing Committee one or both procedures could be included in the "Materials Manual" and be used to test concrete on construction projects.

The Concrete Unit of the Staff Materials Laboratory will continue using these two procedures to test trial mixes and concrete on selected field projects. In this way refinements in the testing procedures can be developed to improve both the accuracy and decrease the time needed to complete the procedures.

References

1. "ASTM Standards," American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA.

2. "Standard Specifications for Transportation Materials and Methods of Sampling and Testing," The American Association of State Highway and Transportation Officials, July 1978, 444 North Capitol Street, Washington, D.C.

3. "Standard Specifications for Road and Bridge Construction," State Department of Highways, Division of Highways, State of Colorado, 1976, 4201 East Arkansas Avenue, Denver, CO.

4. Peterson, Robert T. and Leftwich, Dave, "Determination of Water Content of Plastic Concrete Using a Microwave Oven," North Dakota State Highway Department, Bismarck, N.D.

APPENDIX A
CONCRETE DESIGN MIXES

Concrete 27-80

	Class P	Class P with 20% Fly Ash	Class P with 15% Fly Ash
Water-Cement Ratio	.434	.421	.406
Cement	565 lb/yd^3	455 lb/yd^3	480 lb/yd^3
Fly Ash		110 lb/yd^3	85 lb/yd^3
Fine Aggregate	1240 lb/yd^3	1230 lb/yd^3	1230 lb/yd^3
#67 Coarse Agg.	920 lb/yd^3	920 lb/yd^3	920 lb/yd^3
# 4 Coarse Agg.	930 lb/yd^3	930 lb/yd^3	920 lb/yd^3
Water	245 lb/yd^3	238 lb/yd^3	229 lb/yd^3
A.E.A.	6 oz/yd^3	6 oz/yd^3	6 ox/yd^3
Slump (inches)	3.0	2.5	2.5
% Air (total)	6.2	6.2	6.3
28 day Compressive Strength (psi)	4165	4585	4790

Used: Ideal Boettcher Type II Cement & Comanche Fly Ash.

Concrete 31-80 (Using Metro-Mix Proportions)

	Class A	Class B	Class D
Water-Cement Ratio	.469	.478	.417
Cement	565 lb/yd^3	565 lb/yd^3	660 lb/yd^3
Fine Aggregate	1100 lb/yd^3	1250 lb/yd^3	1200 lb/yd^3
#67 Coarse Agg.	1000 lb/yd^3	1800 lb/yd^3	1800 lb/yd^3
# 4 Coarse agg.	1000 lb/yd^3	---	---
Water	265 lb/yd^3	270 lb/yd^3	275 lb/yd^3
A.E.A.	6 oz/yd^3	7 oz/yd^3	7 oz/yd^3
W.R.A.	--	--	26 oz/yd^3
Slump (iches)	3.0	2.25	1.5
% Air (total)	4.5	5.7	4.6
Compressive Strength (psi 28 day)	4770	4840	6080

Used: Ideal Boettcher Type I Cement.

APPENDIX A
DESIGN MIXES

Concrete 25-80

	Class D
Water-Cement Ratio	.393
Cement	675 lb/yd^3
Fine Aggregate	1180 lb/yd^3
#67 Coarse Aggregate	1700 lb/yd^3
Water	281 lb/yd^3
A.E.A.	4 oz/yd^3
W.R.A.	10 oz/yd^3
Slump (inches)	3.0
% Air (total)	4.8
Compressive Strength (psi) (28-day)	6560

Used: Martin Marietta Type II Cement.

Concrete 11-80

	Class DT
Water-Cement Ratio	0.417
Cement	700 lb/yd^3
Fine Aggregate	1460 lb/yd^3
#7 Coarse Aggregate	1410 lb/yd^3
Water	292 lb/yd^3
A.E.A.	5 oz/yd^3
W.R.A.	10 oz/yd^3
Slump (inches)	2.5
% Air (total)	7.5
Compressive Strength (psi) (28-day)	6735

Used: Ideal Portland Type I Cement.

APPENDIX A
DESIGN MIXES

Concrete 37-80

	Class B	Class D	Class B
Water-Cement Ratio	.478	.417	.433
Cement	565 lb/yd^3	660 lb/yd^3	455 lb/yd^3
Fine Aggregate	1250 lb/yd^3	1200 lb/yd^3	1250
#67 Coarse Aggregate	1800 lb/yd^3	1800 lb/yd^3	1800
Water	270 lb/yd^3	275 lb/yd^3	264
A.E.A.	6 oz/yd^3	6 oz/yd^3	6 oz/yd^3
W.R.A.	---	10 oz/yd^3	---
Fly Ash	---	---	110 lb/yd^3
Slump (inches)	1.0	1.75	4.0
% Air (total)	5.3	6.2	9.0
Compressive Strength (psi) (28-day)	5575	5890	3945

Used: Martin Marietta Type II Cement and Comanche Fly Ash.

Concrete 38-80

Lean Concrete Base

Cement	225 lb/yd^3	Slump (inches)	0.75
Aggregate	3250 lb/yd^3	% Air (total)	5.8
Water	300 lb/yd^3	Compressive Strength	975 psi 28-day
A.E.A.	9 oz/yd^3		

APPENDIX A
DESIGN MIXES

Concrete 31-80

	Class A	Class B
Water-Cement Ratio	.469	.478
Cement (Ideal Boettcher Type I)	455 lb/yd^3	455 lb/yd^3
Fly Ash (Comanche)	110 lb/yd^3	110 lb/yd^3
Fine Aggregate	1100 lb/yd^3	1250 lb/yd^3
#67 Coarse Aggregate	1000 lb/yd^3	1800 lb/yd^3
#4 Coarse Aggregate	1000 lb/yd^3	--
Water	265 lb/yd^3	270 lb/yd^3
A.E.A.	6 oz/yd^3	7 oz/yd^3
Slump (inches)	2.5	2.75
% Air (Total)	5.3	6.4
Compressive Strength (psi)(28-day)	4715	4315

Concrete 40-80

	Class A	Class B	Class D	Class A	Class B
Water-Cement Ratio	.469	.478	.406	.434	.452
Cement (Martin Marietta Type I)	565 lb/yd^3	565	660	455	455
Fly Ash (Comanche)	---	---	---	110	110
Fine Aggregate	1100 lb/yd^3	1250	1200	1100	1250
#67 Coarse Aggregate	1000 lb/yd^3	1800	1800	1000	1800
#4 Coarse Aggregate	1000 lb/yd^3	--	--	1000	--
Water	265 lb/yd^3	270	268	246	256
A.E.A.	6 oz/yd^3	6	4	6	5
W.R.A.	---	---	26	---	---
Slump (inches)	2.5	2.25	2.5	3.5	3.0
Air Content (% Total)	6.3	7.5	6.2	7.2	7.2
Comp. Str. (psi)(28-day)	4825	4830	6245	4295	4870

Using Metro-Mix Design Mix Proportions.

APPENDIX A
DESIGN MIXES

Concrete 52-80

	Class B	Class D
Water-Cement Ratio	.478	.396
Cement (Martin Marietta Type I)	565 lb/yd^3	660
Fine Aggregate	1250 lb/yd^3	1200
#67 Coarse Aggregate	1800 lb/yd^3	1800
Water	270 lb/yd^3	261
A.E.A.	6 oz/yd^3	5 oz/yd^3
W.R.A.		26 oz/yd^3
Slump	2.5	3.0
Air Content (% Total)	5.1	6.2
Comp. Str. (psi)(28-day)	5120	5455

Concrete 54-80

	Class DT
Water-Cement Ratio	.417
Cement (Ideal Portland Type I)	700 lb/yd^3
Fine Aggregate	1420 lb/yd^3
#7 Coarse Aggregate	1420 lb/yd^3
Water	292 lb/yd^3
A.E.A.	5 oz/yd^3
W.R.A.	28 oz/yd^3
Slump (inches)	1.5
Air Content (% Total)	5.6
Comp. Str. (psi)(28-day)	6320

APPENDIX A
DESIGN MIXES

Concrete 35-80R

	Class B	Class D
Water-Cement Ratio	.496	.417
Cement (Ideal Portland Type I)	565 lb/yd^3	660
Fine Aggregate	1330 lb/yd^3	1200
#67 Coarse Aggregate	1690 lb/yd^3	1720
Water	280 lb/yd^3	275
A.E.A.	6 oz/yd^3	4
W.R.A.	---	26 oz/yd^3
Slump (inches)	3.5	2.50
Air Content (% Total)	7.4	5.9
Comp. Str. (psi)(28-day)	4250	5950

Concrete 57-80

	Class D
Water-Cement Ratio	.417
Cement (Ideal Portland Type I)	660 lb/yd^3
Fine Aggregate	1200 lb/yd^3
#67 Coarse Aggregate	1800 lb/yd^3
Water	275 lb/yd^3
A.E.A.	4 oz/yd^3
W.R.A.	30 oz/yd^3
Slump (inches)	2.0
Air Content (% Total)	5.8
Comp. Str. (psi)(28-Day)	7040

APPENDIX A
DESIGN MIXES

Concrete 59-80

	Class D
Water-Cement Ratio	.356
Cement (Martin Marietta Type I)	660 lb/yd^3
Fine Aggregate	1210 lb/yd^3
#7 Coarse Aggregate	360 lb/yd^3
#67 Coarse Aggregate	1460 lb/yd^3
Water	235 lb/yd^3
A.E.A.	5 oz/yd^3
W.R.A. (Mighty 150)	106 oz/yd^3
Slump (inches)	6.0
Air Content (% Total)	4.8
Comp. Str. (psi)(28-day)	8727

Using High Range Water Reducer.

Appendix B

Kelly-Vail and Microwave Oven Test Results and Statistical Summary

Concrete No.	Concrete Class	Aging Period	Cement lb/yd^3	W-C Ratio As Mixed	Kelly-Vail W-C Ratio	Microwave W-C Ratio	Avg. $\overline{X}$	Standard Deviation σ	Coeff. of Var.	Difference W-C A.M. minus W-C deter.	Diff. in gallons per Yd^3	% Error
27-80	P	35	565	.448	.473					.025	1.69	5.6
		60			.473					.025	1.69	5.6
		90			.476		.474	.0017	0.37	.028	1.90	6.2
		30				.474				.026	1.76	5.8
		65				.442	.458	.0226	4.94	-.006	-0.41	1.3
27-80	P	15	565	.435	.412					-.023	-1.56	5.3
		45			.415					-.020	-1.35	4.6
	W/20%	90			.416		.414	.0021	0.51	-.019	-1.29	4.4
	Fly Ash	15				.418				-.017	-1.15	3.9
		45				.425				-.010	0.68	2.3
		90				.451	.431	.0174	4.04	.016	1.08	3.7
27-80	P	15	565	.422	.419					-.003	-0.20	0.7
		45			.405					-.017	-1.15	4.0
	W/15%	90			.412		.412	.0070	1.70	-.010	-0.68	2.4
	Fly Ash	15				.412				-.010	-0.68	2.4
		45				.434				.012	0.81	2.8
		90				.424	.423	.0110	2.60	.002	0.14	0.5
31-80	A	15	565	.493	.504					.011	0.75	2.2
		45			.496					.003	0.20	0.6
		90			.514		.505	.0090	1.78	.021	1.42	4.3
		15				.452				-.041	-2.78	8.3
		45				.460				-.033	-2.24	6.7
		90				.484	.465	.0167	3.58	-.009	-0.61	1.8
31-80	B	15	565	.483	.536					.053	3.59	11.0
		45			.483					.000	0.00	0.0
		90			.499		.506	.0272	5.37	.016	1.08	3.3
		15				.479				.004	0.27	0.8
		45				.461				-.022	-1.49	4.8
		90				.499	.463	.0146	3.16	.016	1.08	3.3

Appendix B

Kelly-Vail and Microwave Oven Test Results and Statistical Summary

Concrete No.	Concrete Class	Aging Period	Cement lb/cu.yd.	W-C Ratio As Mixed	K-V W-C Ratio	Microwave W-C Ratio	Average $\bar{X}$	Std. Dev. σ	Coeff. of Var.	Difference W-C A.M. - W-C K-V&M	Difference in gallons per cu.yd.	% Error
31-80	D	15	660	.431	.449					.018	1.42	4.2
		45			.440					.009	0.71	2.1
		90			.446		.445	.0046	1.03	.015	1.19	3.5
		15				.406				-.025	1.98	5.8
		45				.394				-.037	-2.93	9.0
		90				.406	.402	.0069	1.72	-.025	-1.98	5.8
25-80	D	15	675	.409	.437					.028	2.27	6.8
		45			.440					.031	2.51	7.6
		90			.422		.433	.0096	2.22	.013	1.05	3.2
		15				.393				-.016	-1.29	3.9
		45				.396				-.013	-1.05	3.2
		90				.399	.396	.0030	0.76	-.010	0.81	2.4
11-80	DT	15	700	.411	.427					.016	1.34	3.9
		45			.437					.026	2.18	6.3
		90			.427		.430	.0058	1.34	.016	1.34	3.9
		15				.396				-.015	-1.26	3.6
		45				.387				-.024	-2.01	5.8
		90				.404	.396	.0085	2.15	-.007	-0.59	1.7
37-80	B	15	565	.484	.523					.039	2.64	8.1
		45			.532					.048	3.25	9.9
		90			.503		.519	.0148	2.86	.019	1.29	3.9
		15				.461				-.023	-1.56	4.8
		45				.453				-.031	-2.10	6.4
		90				.452	.455	.0049	1.08	-.032	2.17	6.6
37-80	D	15	660	.425	.435					.010	0.79	2.4
		45			.436					.011	0.87	2.6
		90			.449		.440	.0078	1.78	.024	1.90	5.6
		15				.418				-.007	-0.55	1.6
		45				.410				-.015	-1.19	3.5
		90				.413	.414	.0040	0.96	-.012	0.95	2.8

Appendix B

Kelly-Vail and Microwave Oven Test Results and Statistical Summary

Concrete No.	Concrete Class	Aging Period	Cement lb/cu.yd.	W-C Ratio As Mixed	K-V W-C Ratio	Microwave W-C Ratio	Average $\overline{X}$	Std. Dev. σ	Coeff. of Var.	Difference W-C Actual - W-C Tested	Difference in gallons per cu.yd.	% Error
37-80	B	15	565	.491	.512					.021	1.42	4.3
		45			.492					.001	0.07	0.2
	W/Fly Ash	90			.498		.501	.0103	2.05	.007	0.47	1.4
		15				.469				-.022	-1.49	4.5
		45				.459				-.032	-2.17	6.5
		90				.462	.463	.0051	1.11	-.029	-1.96	5.9
38-80	Lean Concrete	15	225	1.333	Not Run	1.340				.007	0.19	0.5
	Base	45				1.308	1.324	.0226	1.71	-.025	-0.68	1.9
31-80	A	15	565	.481	.458					-.023	-1.56	4.8
		45			.483					.002	0.14	0.4
	W/Fly Ash	90			.466		.469	.0128	2.72	-.015	-1.02	3.1
		15				.469				-.012	-0.81	2.5
		45				.478				-.003	-0.20	0.6
		90				.464	.470	.0071	1.51	-.017	-1.15	3.5
31-80	B	15	565	.489	.487					-.002	-0.14	0.4
		45			.490					.001	0.07	0.2
	W/Fly Ash	90			.471		.483	.0102	2.12	-.018	-1.22	3.7
		15				.487				-.002	-0.14	0.4
		45				.475				-.014	-0.95	2.9
		90				.471	.478	.0083	1.74	-.018	-1.22	3.7
40-80	A	15	565	.461	.430					-.031	-2.10	6.7
		45			.425					-.036	-2.43	7.8
		90			.429		.428	.0026	0.62	-.032	-2.17	6.9
		15				.451				-.010	-0.68	2.2
		45				.423				-.038	-2.57	8.2
		90				.461	.445	.0197	4.43	0.0	0.0	0.0

Appendix B

Kelly-Vail and Microwave Oven Test Results and Statistical Summary

Concrete No.	Concrete Class	Aging Period	Cement lb/cu.yd	W-C Ratio As Mixed	K-V W-C Ratio	Microwave W-C Ratio	Average X̄	Std. Dev. σ	Coeff. of Var.	Difference W-C Actual - W-C Tested	Difference in gallons per cu.yd.	% Error
40-80	B	15	565	.485	.497					.012	0.81	2.5
		45			.538					.053	3.59	10.9
		90			.525		.520	.0210	4.03	.040	2.71	8.2
		15				.444				-.041	-2.78	8.5
		45				.450				-.035	-2.37	7.2
		90				.455	.450	.0055	1.22	-.030	-2.03	6.2
40-80	D	15	660	.426	.433					.007	0.55	1.6
		45			.413					-.013	-1.03	3.1
		90			.392		.413	.0205	4.97	-.034	-2.69	8.0
		15				.399				-.027	-2.14	6.3
		45				.401				-.025	-1.98	5.9
		90				.388	.396	.0070	1.77	-.038	-3.00	8.9
40-80	A	15	565	.454	.415					-.039	-2.64	8.6
		45			.443					-.011	-0.75	2.4
	W/Fly Ash	90			.425		.428	.0142	3.32	-.029	-1.96	6.4
		15				.452				-.002	-0.14	0.4
		45				.445				-.009	-0.61	2.0
		90				.430	.442	.0112	2.54	-.024	-1.63	5.3
40-80	B	15	565	.475	.467					-.008	-0.54	1.7
		45			.467					-.008	-0.54	1.7
	W/Fly Ash	90			.443		.459	.0139	3.02	-.032	-2.17	6.7
		15				.428				-.047	-3.18	9.9
		45				.457				.018	-1.22	3.8
		90				.461	.449	.0180	4.01	-.014	-0.95	2.9
52-80	B	15	565	.469	.499					.030	2.03	6.4
		45			.490					.021	1.42	4.5
		90			.479		.489	.0100	2.05	.010	0.68	2.1
		15				.456				-.013	0.88	2.8
		45				.441				-.028	1.90	6.0
		90				.448	.448	.0075	1.67	-.021	-1.42	4.5

Appendix B

Kelly-Vail and Microwave Oven Test Results and Statistical Summary

Concrete No.	Concrete Class	Aging Period	Cement lb/cu.yd	W-C Ratio As Mixed	K-V W-C Ratio	Microwave W-C Ratio	Average $\overline{X}$	Std. Dev. σ	Coeff. of Var.	Difference $W\text{-}C_{Actual} - W\text{-}C_{Tested}$	Difference in gallons per cu. yd	% Error
52-80	D	15	660	.398	.408					.010	0.79	2.5
		45			.376					-.022	-1.74	5.5
		90			.385		.390	.0165	4.24	-.013	-1.03	3.3
		15				.414				.016	1.27	4.0
		45				.405				.007	0.55	1.8
		90				.394	.404	.0100	2.48	-.004	-0.32	1.0
54-80	DT	15	700	.440	.426					-.014	-1.18	3.2
		45			.407					-.033	-2.77	7.5
		90			.404		.412	.0119	2.89	-.036	-3.02	8.2
		15				.409				-.031	-2.60	7.0
		45				.408				-.032	-2.69	7.3
		90				.411	.409	.0015	0.37	-.029	-2.43	6.6
35-80R	B	15	565	.478	.503					.025	1.69	5.2
		45			.502					.024	1.63	5.0
		90			.475		.493	.0159	3.22	-.003	-0.20	0.6
		15				.467				-.011	-0.75	2.3
		45				.460				-.018	-1.21	3.8
		90				.464	.464	.0035	0.76	-.014	-0.95	2.9
35-80R	D	15	660	.436	.438					.002	0.16	0.5
		45			.436					0.0	0.0	0.0
		90			.417		.430	.0116	2.69	-.019	-1.50	4.4
		15				.372				-.064	-5.06	14.7
		45				.387				-.049	-3.88	11.2
		90				.401	.387	.0145	3.75	-.035	-2.77	8.0
6-80	D	15	660	.424	.448					.024	1.90	5.7
		45			.440					.016	1.27	3.8
		90			.434		.441	.0070	1.59	.010	0.79	2.4
		15				.371				-.053	-4.19	12.5
		45				.373				-.051	-4.03	12.0
		90				.388	.377	.0093	2.46	-.036	-2.85	8.5

Appendix B

Kelly-Vail and Microwave Oven Test Results and Statistical Summary

Concrete No.	Concrete Class	Aging Period	Cement lb/cu.yd	W-C Ratio As Mixed	K-V W-C Ratio	Microwave W-C Ratio	Average $\bar{X}$	Std. Dev. σ	Coeff. of Var.	Difference W-C Actual - W-C Tested	Difference in gallons per cu. yd	% Error
59-80	D	15	660	.376	.320					-.056	-4.43	14.9
		45			.338					-.038	-3.01	10.1
		90			.338		.332	.0104	3.13	-.038	-3.01	10.1
		15				.332				-.044	-3.48	11.7
		45				.337				-.039	-3.09	10.4
		90				.342	.337	.0050	1.48	-.034	-2.69	9.0

Field Tests

Project	Concrete Class	Test No.	Cement lb/cu.yd.	Design W-C Ratio	W-C Ratio by Kelly-Vail	W-C Ratio by Microwave	Average $\bar{X}$	Std. Dev. σ	Coeff. of Var.	Maximum Allowable W-C ratio
IR 70-4(80)	DT	1	700	.417	.449	.453				
		2			.401	.459				
		3			.429	.426	Kelly-Vail	K-V	K-V	.443
		4			.406	.432	.431	.0207	4.80	
		5			.413	.409				
		6			.451	.453				
		7			.435	.460				
		8			.465	.469	Microwave	Micro.	Micro.	
		9			.422	.437	.443	.0186	4.19	
		10			.436	.434				
I 76-1(53)	D	1	660	.400	.391	.364	.396 (K-V)	.0064	1.61	
		2			.400	.373	.369(Micro)	.0064	1.73	.443
	P	1	565	.406	.437	.485	N/A	N/A	N/A	
		2	565	.442	.419	.479	N/A	N/A	N/A	

Appendix B

Kelly-Vail and Microwave Oven Statistical Summary

	Design Water-Cement Ratio					
	.417		.469		.478	
	Kelly-Vail W/C Ratio	Microwave W/C Ratio	Kelly-Vail W/C Ratio	Microwave W/C Ratio	Kelly-Vail W/C Ratio	Microwave W/C Ratio
	.449	.406	.504	.452	.536	.479
	.440	.394	.496	.460	.483	.461
	.446	.406	.514	.484	.499	.499
	.437	.393	.458	.469	.523	.461
	.440	.396	.483	.478	.532	.453
	.422	.399	.466	.464	.503	.452
	.427	.396	.499	.456	.487	.487
	.437	.387	.490	.441	.490	.475
	.427	.404	.479	.448	.471	.471
	.435	.418			.497	.444
	.436	.410			.538	.450
	.449	.413			.525	.455
	.426	.409				
	.407	.408				
	.404	.411				
	.438	.372				
	.436	.387				
	.417	.401				
	.448	.371				
	.440	.373				
	.434	.388				
Average $\bar{X}$	.433	.397	.488	.461	.507	.466
Standard Dev. σ	.0125	.0137	.0181	.0140	.0229	.0167
Coeff. of Var. V	2.90	3.44	3.70	3.03	4.51	3.59

APPENDIX C

COLORADO PROCEDURE 64-81

FOR MEASURING THE MOISTURE CONTENT OF PLASTIC CONCRETE USING MICROWAVE OVENS

Scope

1.1 This method describes the procedure for determining the moisture content of plastic concrete. The moisture content determined can then be used to calculate the theoretical water-cement ratio of the sample of plastic concrete tested.

Apparatus

2.1 Microwave oven with variable power settings.
2.2 Balance, having sufficient capacity and sensitive to 0.1 gram.
2.3 Microwave compatible Pyrex or ceramic drying dishes of sufficient capacity.
2.4 Putty knife, 1½" blade.
2.5 Hand scoop, cast aluminum

Procedure

3.1 Obtain a sample of plastic concrete in accordance with AASHTO T 141.
3.2 Place the specimen into the tared Pyrex or ceramic drying dish and weigh to the nearest 0.1 g.

TABLE I
SIZE OF TEST SPECIMEN

Concrete Class	Approximate Minimum Weight of Specimen, grams
A, P or Lean Concrete Base	1400
B, D	1200
DT	1000

3.3 Dry the specimen in the microwave oven. The specimen is dry when further heating causes less than a 0.1 percent additional loss in weight.

Note 1: The specimen should be stirred after drying for approximately 15 minutes to break down any large particles of concrete. Breaking the specimen up into smaller particles accelerates the drying process and facilitates the cleaning of the drying dish. Care should be exercised to avoid the loss of any material while stirring.

3.4 Weigh the dry specimen and drying dish and record.

CALCULATIONS

4.1 Determine the moisture content of the plastic concrete as follows:

$$\text{Moisture content, grams} = A - B$$

where: A = weight of test specimen, wet, grams
B = weight of dry specimen, grams.

4.2 Determine the cement content of the specimen as follows:

$$\text{Cement content, grams} = \frac{C}{D\text{x}27} \text{ x } A$$

where: C = cement content lb. per cu. yd.
D = unit rodded weight
and A = weight of test specimen, wet, grams.

4.3 Determine the moisture absorbed in the aggregate as follows:

$$\text{Absorbed moisture content, grams} = A - E - F \text{ x } \frac{\text{Per cent absorbtion}}{100}$$

where: A = weight of test specimen, wet, grams
E - moisture content, grams
F = cement content, grams

4.4 Determine the water-cement ratio as follows:

$$\text{Water-cement ratio} = \frac{\text{moisture content, grams - absorbed moisture content}}{\text{cement content, grams}}$$

Report the results to the closest one hundredth (.01)

Note 2: Precise methods for determining moisture absorbed in aggregate:

$$A - E - F \text{ x } \frac{\text{\% Fine Aggregate}}{100} \text{ x } \frac{\text{\% Fine Aggregate Absorption}}{100}$$

$$\text{Plus } A - E - F \text{ x } \frac{\text{\% Coarse Aggregate}}{100} \text{ x } \frac{\text{\% Coarse Aggregate Absorption}}{100}$$

State of Colorado
Department of Highways
Division of Highways
DOH Form

MOISTURE CONTENT OF PLASTIC CONCRETE

(MICROWAVE OVEN)

PROJECT ____________

MIX DESIGN NO. ________

Test Number									
Tare Pan									
Wt. of Plastic Concrete and Pan									
Wt. of Plastic Concrete									
Wt. of Dry Sample and Pan									
Wt. of Dry Sample									
Moisture Lost									
Moisture in Aggregate									
Net Moisture Evaporated									
Cement Content									
Water-Cement Ratio									
Corresponding Cylinder Number									
Date									

APPENDIX C

COLORADO PROCEDURE 65-81

FOR MEASURING THE MOISTURE CONTENT OF PLASTIC CONCRETE USING THE KELLY-VAIL TITRATION

Scope

1.1 This method describes the procedure for determining the moisture content of plastic concrete by chemical methods. The moisture content determined can then be used to calculate the water-cement ratio of the sample of plastic concrete.

Apparatus

2.1 Balance, having sufficient capacity and sensitive to 0.1 gram.

2.2 Hand scoop, cast aluminum.

2.3 Wide Mouth Jar. ½ gallon polyethylene wide-mouth with screw closure and lid.

2.4 Mixer, end-over-end mixer, driven at 40 to 60 rpm, capacity to hold and turn end over end, two ½ gallon wide mouth jars containing 2.5 kg. of material. Mixer equipped with a 0 to 15 minute timer and switch.

2.5 Conical beakers, 2 narrow mouth conical beakers, 500 ml. capacity.

2.6 Pipette, 25 ml. volumetric pipette, glass, Class A or B, 25 ml. capacity.

2.7 Automatic Buret, 25 ml. automatic pipette with Teflon plug, glass. Two required.

2.8 Amber Reagent Bottles, narrow mouth amber bottles, Boston rounds from amber polypropolene, 32 oz. capacity, two required. Equipped with a No. 6 rubber stopper, one with two holes, and one with three. Glass tubing, siphon lines, 7 mm OD. Two for one stopper and one for the other. Ten feet of ¼ inch ID amber rubber latex tubing required to connect the glass siphon lines to the 25 ml. automatic pipettes.

2.9 Automatic Pipette, 10 ml. automatic pipette with Teflon plug, glass, 10 ml. capacity.

2.10 Burette, 100 ml., acrylic body Teflon plug, Class B accuracy 100 ml. capacity.

2.11 Volumetric Flask, polyethylene, volumetric flask 500 ml. capacity, two required.

2.12 Carboys, rectangular aspirator carboys with spigot, 2 gallon capacity, linear polyethylene.

2.13 Burette clamps, double burette holder clamp, one required. Utility clamp, three pronged grip, vinylized jaws, one required.

2.14 Fixed volume dispensers, one 2 ml. and two 5 ml. dispensers required.

Reagents

3.1 Distilled Water

3.2 Ferric Alum Indicator Solution: Dissolve 50 g of ferric ammonium sulphate |$FeNH_4(SO_4)_2 \cdot 12\ H_2O$| in 100 ml. of distilled water and add 5 drops of nitric acid solution.

3.3 Nitric Acid Solution: Carefully add one volume of concentrated nitric acid (HNO_3, sp gr 1.42) to one volume of distilled water.

3.4 Nitro Benzene (sp gr 1.30)($C_6H_5NO_2$).

3.5 Potassium Thiocyanate Solution (0.05 N), dissolve 24.3± 2g of dry potassium thiocyanate (KSCN) in distilled water and dilute to five liters.

3.6 Silver Nitrate Solution (0.5 N), dissolve 255.0± 2g of dry silver nitrate ($AgNO_3$) in distilled water and dilute to three liters.

3.7 Sodium Chloride Solution (0.5 N), dissolve 292.2 ± 3g of dry NaCl in distilled water and dilute to 10 liters.

Note 1: All solutions are available through the Staff Materials Branch.

Safety Precautions

4.1 Nitrobenzene is extremely toxic and is rapidly absorbed through the skin. Contact with skin or clothing and inhalation of fumes and vapors should be avoided. Caution should be used when using this material and the other reagents used in this procedure.

Procedure

5.1 Calibration Curves: Weigh 100 ± 0.1 g. of distilled water in a tared, clean, wide mouth jar. Add 500 ml. of 0.5N NaCl solution to this jar using a volumetric flask. Tighten the lid and mix in the mixer for 3 minutes. Withdraw a 25 ml. sample of the intermixed solution, using volumetric pipette and place this sample in a conical beaker. Using an automatic pipette, add 25 ml. of 0.5 N $AgNO_3$ (silver nitrate) to the beaker and with the fixed volume dispensers, add 10 ml. of 50 percent HNO_3 (nitric acid), 5 ml. of ferric alum and 2 ml. of nitrobenzene. Shake well. Titrate this intermixed solution with 0.5N KSCN (potassium thiocyanate) solution, using the 100 ml. burette. Swirl the contents of the beaker during titration. Stop titration when the first <u>permanent</u> reddish brown color appears. This is the end point of the titration. This is the volume of KSCN required for a concrete specimen containing a hundred grams of water. Repeat this procedure, using 50 ± 0.1 g and 75 ± 0.1 g of distilled water, when 1 - kg concrete specimens are being tested and 150 ± 1.1 g, if 2 - kg concrete specimens are to be tested. Plot the results of water content (grams vs. total KSCN ml.) Draw a smooth curve through the various calibration points.

5.2 Blank Equivalent Constant: Using an automatic pipette, place 10 ml. of 0.5 $AgNO_3$ (silver nitrate) solution in a conical beaker. Add to the beaker using fixed volume dispensers, 10 ml. of 50 percent HNO_3 (nitric acid), 5 ml. of ferric alum and 2 ml. of nitrobenzene. Shake well for a few seconds. Titrate this intermixed solution with the 0.05N KSCM (potassium thiocyanate) using the 100 ml. burette. Swirl the contents of the beaker during the titration. The end point of the titration is reached when the first permanent reddish brown color appears. Record the volume of KSCN required to reach the end point.

Note 2: These calibrations procedures are required each time new reagents are used.

TABLE I

SIZE OF TEST SPECIMEN

Nominal Maximum Sieve Size	Weight of Specimen grams
1 inch or less	1000 ± 0.1
1 inch to 1½ inch	2000 ± 0.1

5.3 Obtain a sample of plastic concrete in accordance with AASHTO T 141. This sample shall be representative of the entire batch.

5.4 Weigh out two properly sized specimens into clean wide mouth jars. Add 500 ml. at 0.5 N NaCl to one jar, the sample, and 500 ml. of distilled water to the other jar, the blank. Secure the lids and mix each in the mixer for three minutes.

5.5 Remove the jars from the mixer, loosen the lids and allow the contents to settle. After settling between three and five minutes, withdraw 25 ml. of clear sample and blank solutions and place in separate conical beakers. Add 25 ml. of 0.5 N $AgNO_3$ solution to the sample and 10 ml. of 0.5 N $AgNO_3$ solution to the blank, using automatic pipettes. Add to each beaker, with fixed volume dispensers, 10 ml. of 50 percent HNO_3, 5 ml. of ferric alum, and 2 ml. of nitrobenzene. Shake the beakers to thoroughly mix the solutions.

5.6 Titrate both the sample and the blank with the 0.05 N KSCN solution. Swirl the beakers during titration. Stop the titrations when the first permanent reddish brown color appears. Record the volumes of KSCN solution needed to reach the end points of the sample and the blank.

Note 3: If the concrete being tested does not contain chlorides, (the end point of the blank equals the blank equivalent constant,) use of the blank may be discontinued after one trial.

Calculations

6.1 Determine the total volume of KSCN as follows:

Total Volume KSCN, ml = A + (B - C)

where: A = end point of the sample, ml KSCN
B = blank equivalent constant, ml KSCN
C = end point of the blank, ml KSCN

6.2 Water content is determined using the calibration curve for the size specimen being tested. The water content is in grams.

6.3 Determine the cement content of the sample as follows:

$$\text{Cement content, grams} = D \times \frac{E}{F \times 27}$$

where: D = weight of specimen in grams
E = cement content in lbs. per cu. yd.
F = unit rodded weight lb. per cu. ft.

6.4 Determine the water-cement ratio as follows:

$$\text{Water-cement ratio} = \frac{\text{Water content, g}}{\text{Cement content, g}}$$

State of Colorado
Department of Highways
Division of Highways
DOH Form

MOISTURE CONTENT OF PLASTIC CONCRETE

(KELLY-VAIL TITRATION)

PROJECT ____________

MIX DESIGN NO. __________

CALIBRATION

Date	Blank Equivalent Constant (ml)	Calibration End Points					Operator
		50 g	75g	100g	150g	200g	

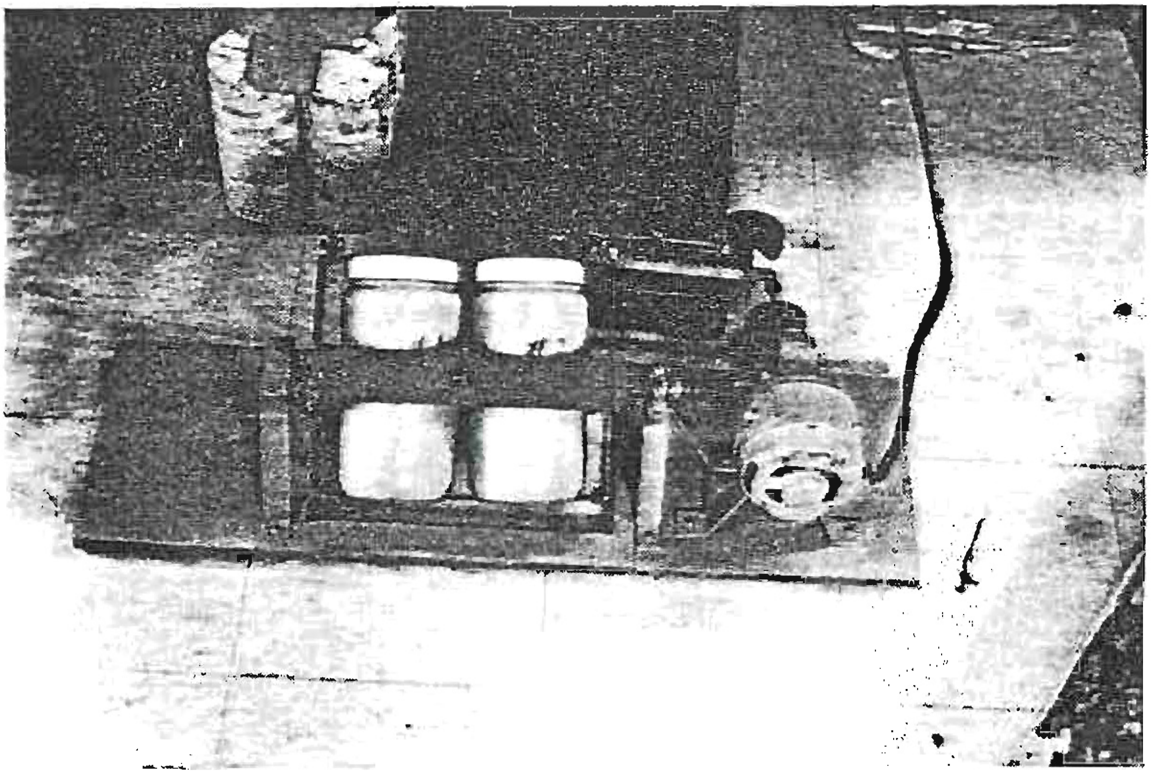
TESTS

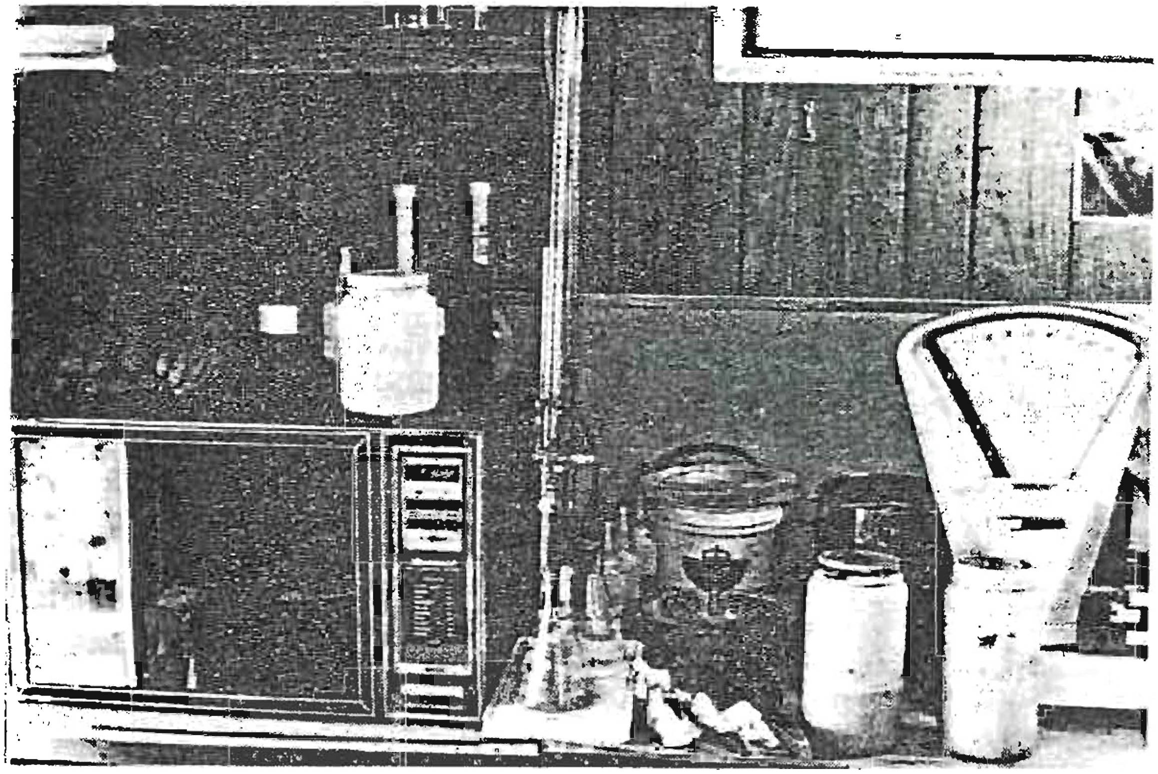
Date	End Point of the Blank	Y	Sample End Point	Total Volume of KSCN	Water in Sample (g)	Cement Content of Sample (g)	Water-Cement Ratio	Corresponding Cylinder No.

Note: Y= Blank Equivalent Constant- the Endpoint of the Blank

Appendix D

PHOTOGRAPHS OF THE MIXER FOR THE KELLY-VAIL PROCEDURE AND THE APPARATUS AS SET UP FOR FIELD TESTING





APPENDIX E

The classes of concrete listed in the table are used as follows:

Class A, AX, and B are general purpose concrete mixes and are placed in curb and gutter, sidewalks, slope paving, and in highway bridges up to the superstructure,

Class AZ - is a high strength Class A used for pier caps and other specialized applications,

Class BX - is used for exposed aggregate concrete mixes,

Class D - is used in the superstructures of highway bridges,

Class P - is for Portland cement concrete paving,

Class S - is used in the prestressed members of concrete structures and is normally designed by the supplier.

CONCRETE CLASS	LABORATORY DESIGN MINIMUM (a) COMPRESSIVE STRENGTH 28 DAYS (45 days for Type V Cement) Lbs. per Sq. In.	CEMENT CONTENT (Cement Factor) Range (b)		WATER/CEMENT RATIO (Lbs. H^2O per Lbs. of Cement) Field Maximum (c)	% ENTRAINED & ENTRAPPED AIR (Total) Range	CONSISTENCY AASHTO DESIGNATION T 119 (d) Range in Inches	COARSE AGGREGATE AASHTO DESIGNATION M 80 (e) Size Number	FINE AGGREGATE AASHTO DESIGNATION M 6 (e) Percent Total Aggregate Range
		MIN. Lbs. per Cu. Yd.	MAX. Lbs. per Cu. Yd.					
A	3750	550	600	0.500	4-7	2-4	467	34-39
AX	3750	600	700	0.500	5-8	1-3	(f)	(f)
AZ	5000	600	700	0.450	4-7	2-4	467	34-39
B	3750	550	600	0.530	5-8	1-4	67	37-44
(g) BX	3750	550	600	0.530	5-8	1-4	6	34-36
							67	34-39
(h) D	5625	635	800	0.443	5-7	1-2½ (r)	67	36-42
(k) P	3750	550	600	0.480	4-7	1-3	467	34-39
							357	33-38
(m) S	(n)	635	800	(p)	(q)	-	-	-

NOTE: Concrete mixtures that do not conform to the above table, but are required for special uses will be designed for the purpose intended. These include light weight concrete, colored concrete, lean concrete, grouting mixtures, patching mixtures and concretes that require special cements, pozzolans or aggregates not covered in the Standard Specifications.

(Continued)

NOTES (continued)

(a) Not a field specification requirement. These laboratory strengths are required to obtain the desired ultimate strengths.

(b) Laboratory mix design will require at least 15 to 20 lbs. more cement than the minimum amount shown. This will allow for field adjustments of entrained air and water as necessary for controlling consistency and still remain within the limits of the table.

(c) The water/cement ratio reported in the laboratory mix design will be sufficiently below that shown to permit the addition of water during field mixing in the amount allowed by the Specifications.

(d) The point of acceptance for Consistency requirements will be at the mixer discharge for transit mixed concrete except when concrete pumps are used for movement of the concrete after mixer discharge. In this case the point of acceptance will be as nearly as practical at the pump discharge. The Contractor shall provide a safe working area for the inspector at that point. In the event that sampling at the pump discharge is determined to be impractical, the concrete shall be sampled at the mixer discharge and an appropriate correction factor applied to simulate pump discharge. The Contractor shall provide adequate means for the inspector to select a sufficient number of samples to establish a valid correlation between samples selected at the two sampling points.

(e) See table preceding Subsection 703.01.

(f) See gradation in Subsection 601.03.

(g) Class "BX" will be used for exposed aggregate concrete.

(h) An approved water reducer will be required for this class.

(k) Class "P" is to be used for pavement. The Contractor may choose the coarse aggregate size number based on the most economical size combination available. When small quantities are involved (1000 sq. yds. or less) Class "A", "AX" or "B" may be used in lieu of Class "P".

(m) Whenever Class "S" is designated, the field compressive strength and the mix design shall be the Contractor's responsibility.

(n) The Contractor's laboratory design minimum compressive strength for concrete Class "S" should be approximately 125% of the field compressive strength specified on the plans. The field compressive strength shall be determined in accordance with AASHTO T 23.

(p) A maximum of 0.443 when Class "S" is used in deck concrete.

(q) 5 to 7 when Class "S" is used in deck concrete.

(r) Design Limits. The Design Slump will be between 1 and 2-1/2 inches and will be shown on the Division's mix design sheet for the combination of materials to be used. The field slump shall be within 3/4" of the Design Slump.

In subsection 601.03, delete the first sentence following the subsection listing of Materials in the first paragraph and replace with the following:

In order to permit the greatest possible use of local aggregate sources, the plans may permit the use of Class "AX" concrete in lieu of Class "A", Class "B", or Class "P". Class "B" concrete may be used in lieu of Class "A".

In subsection 601.11(f), add the following paragraph after the item; 4. Straightedge testing and surface correction:

5. Movable bridge for the inspectors.

A movable bridge or platform shall be provided by the Contractor and moved as directed to allow the inspectors to work directly over the freshly placed concrete.

APPENDIX F

FLY ASH CHEMICAL COMPOSITION

Source	Comanche	Jim Bridger
Moisture (%)	0.03	0.07
Loss on Ignition (%)	0.26	0.94
Silicon Dioxide, SiO_2 (%)	32.1	62.2
$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	55.1	84.0
Calcium Oxide, CaO, (%)	29.4	5.7
Magnesium Oxide, MgO (%)	1.7	2.1
Sulfur Trioxide, SO_3 (%)	2.5	0.6
325 Sieve (% Retained)	13.5	24.2
Sodium Oxide, (NaO), (%)	-	2.7
Potassium Oxide, (K_2O), (%)	-	1.3