FINAL REPORT

TESTS FOR EARLY ACCEPTANCE OF CONCRETE

by

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and

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

A literature survey and limited study of laboratory concretes were conducted to evaluate various methods for predicting concrete strengths at 28 days based on procedures for accelerated strength development or measurement of strength of normally cured specimens at early ages. A review of the literature was also made to assess the usefulness of procedures for the direct determinations of water and cement contents in quality control of hydraulic cement concrete.

It is concluded that although general relationships exist as reported in the literature, none of the procedures are sufficiently precise for use in quality control or acceptance testing by the Virginia Department of Highways & Transportation. The amount of calibration testing for projects normally built by the Department would be prohibitive. Any application of reduced pay factors for strength in a statistical specification must be based on tests made at the age designated in the specification.

The literature survey shows that in their present state of development existing procedures for the direct determination of water and cement in plastic concrete are not sufficiently fast or precise to be useful for quality control of hydraulic cement concrete. It is recommended that further evaluation of such procedures by the Virginia Department of Highways and Transportation be deferred until results of studies now being made for the FHWA are available.

The results of 14-day and 28-day tests on the same field concretes reveal that the ratio of strengths at these two ages often varies significantly from the assumed value of 0.85. Thus, it is recommended that the practice of accepting concrete on the basis of 14-day strengths be discontinued unless the value at 14 days is equal to the required value at 28 days.

SI CONVERSION FACTORS

To Convert From	To	Multiply By
Length:		
in	cm	2.54
in	m	0.025 4
ft	m	0.304 8
yd	m	0.914 4
mi	km	1 . 609 344
Area:		
in^2	cm^2	6.451 600 E+00
ft^2	m^2	9.290 304 E-02
yd^2	m^2	8.361 274 E-01
mi^2	Hectares	2.589 988 E+02
acre (a)	Hectares	4.046 856 E-01
Volume:		
oz	m^3	2.957 353 E-05
pt	m^3	4.731 765 E-04
qt	m^3	9.463 529 E-04
gal	m^3	3.785 412 E-03
in^3	m^3	1.638 706 E-05
ft^3	m^3	2.831 685 E-02
yd^3	m^3	7.645 549 E-01

NOTE: $1m^3$ = 1,000 L

To Convert From	To	Multiply By
Volume per Unit Time:		
ft^3/min	m^3/sec	4.719 474 E-04
ft^3/s	m^3/sec	2.831 685 E-02
in^3/min	m^3/sec	2.731 177 E-07
yd^3/min	m^3/sec	1.274 258 E-02
gal/min	m^3/sec	6.309 020 E-05
Mass:		
oz	kg	2.834 952 E-02
dwt	kg	1.555 174 E-03
lb	kg	4.535 924 E-01
ton (2000 lb)	kg	9.071 847 E+02
Mass per Unit Volume:		
lb/yd^2	kg/m^2	4.394 185 E+01
lb/in^3	kg/m^3	2.767 990 E+04
lb/ft^3	kg/m^3	1.601 846 E+01
lb/yd^3	kg/m^3	5.932 764 E-01
Velocity: (Includes Speed)		
ft/s	m/s	3.048 000 E-01
mi/h	m/s	4.470 400 E-01
knot	m/s	5.144 444 E-01
mi/h	km/h	1.609 344 E+00
Force Per Unit Area:		
lbf/in^2	Pa	6.894 757 E+03
lbf/ft^2	Pa	4.788 026 E+01
Viscosity:		
cS_t	m^2/s	1.000 000 E-06
P	Pa·s	1.000 000 E-01

Temperature: °F-32)^5/9 = °C

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INTRODUCTION

In any highway or related construction, it is desirable that acceptance testing of the materials to be used be completed prior to use or as soon thereafter as practicable. This cannot be accomplished with concrete, since the presently used acceptance procedure is based on the strength at 28 days. Furthermore, the ultimate durability depends considerably upon how the concrete is consolidated and cured, which is not necessarily reflected in the standard strength tests. Because of the inherent delay in basing acceptance on the 28-day strength, there has been a considerable amount of research to develop predictive tests that could be performed on fresh and hardened concrete specimens to provide early assurance that the specified concrete ingredients were present and that the required strength at 28 days would be attained.

Such predictions for strength are important since they would provide information that would allow early corrective actions to be taken if needed, and thus preclude the likelihood that large amounts of questionable concrete would be placed in a job.

Early indications of adequate strengths are especially desirable when specifications based on statistical principles are used and penalties or incentives may affect the cost of the project or the profit for the contractor. Early recognition of a problem will permit adjustments that would eliminate or reduce potential pay reductions for noncomplying concrete.

In addition to the need for a method of making predictions of strength at later ages based on early tests, there is a need for an independent verification of the water-cement ratio in the mixture. Batch records prepared by the producer provide information on the composition of the concrete mixture sent to the job site, but there are uncertainties because of inherent limitations in the techniques used to make measurements at the batch plant. For example, aggregates containing some water are weighed during batching, and the difference between the water content of the total aggregate added to the mix and that determined on a small sample of the aggregate may be significant. There also is a possibility that the measuring equipment can malfunction. Thus, direct tests of the amounts of water and cement in the mixed plastic concrete are highly desirable. This report constitutes an evaluation of the usefulness of existing procedures in each of these areas to the Virginia Department of Highways and Transportation.

PREDICTIVE STRENGTH TESTS

Available Standard Procedures

The ASTM has adopted procedures for accelerated strength tests that are useful for making early decisions concerning the potential 28-day strength. ASTM Method C684, Standard Method for Making, Accelerated Curing and Testing of Concrete Compression Test Specimens, contains three procedures: warm water, boiling water, and autogeneous curing methods. A second ASTM Method, C918, Developing Early Age Compression Test Values and Projecting Later Age Strengths, uses the maturity concept and is based on projecting the strength at 28 days on the basis of calibration with laboratory mixtures. Utilization of the maturity concept in projecting the strengths of concrete prepared in the field is also under consideration by ASTM Committee C-9. All of these methods require calibration and correlation with mixtures of like materials if the results are to be related to expected later strengths. Since the proposed revision of specifications for hydraulic cement for Virginia roads and bridges is based on 28-day strengths and failure to reach specified levels can result in reductions in payments to the contractor, there is renewed interest in obtaining early assurance that the required strength will be reached. It is, therefore, of interest to determine if the relationships established in these tests are sufficiently precise to permit application of partial payments on the basis of early tests. Accordingly, a literature search was conducted to determine the degree of success others had had with the various procedures. Also, limited laboratory tests were made using the warm water and boiling water methods and the maturity concept. The autogenous method was not included because it is reported to be the least accurate when compared to the other ASTM C684 procedures, and also the strength gain as compared with normal 48-hr moist cured specimens is not high.

Characteristics of Concretes Used for Evaluation of Procedures

Laboratory concretes were prepared using the mixture proportions as summarized in Table 1. The first 4 batches had the same proportions of materials, then 3 batches were made with the same cement and aggregate content but with a lower water-cement ratio. Finally, 2 batches were made with lower cement contents and higher water-cement ratios. All of the batches were air-entrained. The characteristics of the freshly mixed concretes are summarized in Table 2.

Table 1

Mixture Proportions

Batch	Cement Content, lb	w/c	C.A., lb	F.A., lb
1,2,3,4	588	0.48	1.839	1,174
5,5A,5R	588	0.40	1,839	1,296
6,6A	470	0.55	1,839	1,333

Table 2

Characteristics of Freshly Mixed Concrete

Batch	Air, %	Slump, in	Unit wt, lb/ft^3
2	5.3	2.3	145.4
2	7.5	4.0	145.2
3	4.9	1.8	147.0
4	4.8	2.1	147.0
5	8.0	4.0	144.2
5A	6.9	4.1	144.4
5R	6.0	3.9	144.8
6	6.0	1.8	144.6
6A	7.6	2.9	140.8

Warm Water and Boiling Water Methods

In the warm water method specimens in plastic molds with caps were submerged in a water tank at 95° + 5°F and tested at 23½ hr ± 30 min. In the boiling water method the specimens were kept in the laboratory in plastic molds at about 72°F for 23 hr ± 15 min then stripped and boiled for 3½ hr ± 5 min and tested. Also, specimens were tested at 24 hr ± 30 min. The strength data for all three conditions and for 28 days are given in Table 3.

The data from all 9 batches were used to obtain a correlation equation. It represents a total of 27 sets of 4 x 8-in cylinders averaged from each batch for each method tested at an early age and at 28 days. The correlation equation, correlation coefficient, and standard error of estimate are summarized in Table 4. The results indicate that good correlations are established in all cases, with regular 24 hr and the boiling water tests exhibiting better correlations than the warm water tests. However, to apply this concept to field concrete, a different correlation equation would be needed for each mixture using different materials.

Table 3

Strength Data (Avg. of 3 Cylinders)

Batch	24-hr Avg.	Warm Water	Boiling Water	28-Day
1	1,880	2,090	2,000	5,040
2	1,550	1,250	2,130	4,730
3	1,950	2,300	2,230	5,180
4	2,270	2,300	2,110	5,360
5	3,050	3,060	3,400	5,820
5A	2,600	2,270	3,670	6,420
5R	2,160	2,580	3,120	5,160
6	1,280	1,220	1,460	3,950
6A	950	810	1,640	3,950

Table 4

Correlation Equation

Method	Equation	Corr. Coeff., %	Std. Error of Est., lbf/in^2
Regular 24 hr	y = 1.102 x + 2,894	0.921	342
Warm water	y = 0.964 x + 3,192	0.849	463
Boiling water	y = 0.963 x + 2,791	0.922	339

The ACI committee on the use of accelerated strength testing states that to estimate the 28-day strength from the accelerated strength data, the correlation equation must be established with a minimum of 30 sets of test data covering a wide strength range with no fewer than 3 ratios.(1) This amount of testing can be justified on very large projects but is too time consuming and costly for most of the work undertaken by the Department.

After this preliminary laboratory study and a review of the ASTM procedures for accelerated testing and those reported in use by other agencies, it appeared evident that for small jobs utilizing a number of different concrete producers and different ingredients in the concrete mix, none of the accelerated procedures would be particularly useful for adoption by the Department because of the special equipment involved with some of the methods and the extensive calibration testing required for all of them. The most promising procedure was to utilize the maturity concept for predicting strength at later ages from strength at early ages using standard curing procedures and temperatures. Accordingly, further efforts in this study were directed towards evaluating the usefulness of this concept as a means of predicting the acceptability of concrete strengths at 28 days based on early tests.

Tests Using the Maturity Concept

Principles Involved

The maturity concept has potential usefulness for predicting if the required strength at 28 days will be attained and for predicting when sufficient strength has been attained to permit form removal or construction loading. This concept provides a method for taking into account the combined effect of time and temperature on strength development by use of a single number termed "Maturity" by Saul.(2) According to the theory, samples of concrete with the same ingredients will have equal strengths at equal maturity, regardless of their actual time-temperature histories. The basic equation for maturity is

$$M = \int_{o}^{t} (T-T_o)\, dt, \qquad (1)$$

where

M is the maturity at age t,

T is the temperature to which the concrete is exposed, and

T_o is a datum temperature.

As discussed by Carino, this relationship was developed empirically and it has been shown that it does not hold for all conditions.(3) The curing temperature at early ages affects the subsequent strength-maturity relationship and there is evidence that T_o, the datum temperature, varies with curing conditions. Thus, when using the maturity concept for field concretes the determination of T_o may be needed and the procedure is included in the proposed ASTM method. However, when the standard curing conditions are employed, the elimination of temperature variation, except during the initial 24 hr, basically eliminates much of the cause of variability for the same concrete. Thus, if the initial curing period is at a temperature close to the standard curing temperature conditions, it would be expected that the strength relationship used in ASTM Method C918 would hold reasonably well. This relationship is

$$S_M = S_m + b\ (\log M - \log m), \qquad (2)$$

where

S_M is the predicted compressive strength at maturity M,

S_m is the measured compressive strength at maturity m,

b is the slope of the prediction line -- determined by calibration tests,

M is the degree-hours of maturity at 28 days under standard curing conditions (temperature is expressed in °F, and

m is the degree-hours of maturity of the test specimens at the time of the early test.

Although the datum temperature, T_o, shown in equation 1 does not appear in the calculation of maturity for the purposes of Method C918, it is noted that the use of the temperature in degrees Fahrenheit as the multiplier for the hours of curing is equivalent to assuming T_o to be 0°F, or -17.8°C. This is not greatly different from the -10°C^o(14°F) value reported by Carino and others as being the accepted value for T_o in North American practice.(3)

The key parameter in the use of the prediction curve is the slope of the line, b. This is the amount of strength increase for a unit increase in the logarithm of maturity which represents a 10-fold increase in maturity. It must be determined by laboratory calibration tests for any given mix design using the same ingredients. ASTM Method C918 requires that calibration tests be made at 1, 3, 7, 14, and 28 days. Two 6 x 12-in cylinders are tested at each of the earlier ages and 6 are tested at 28 days. The data obtained are plotted using strengths on the y-axis and the logarithms of maturity on the x-axis. The best fitting straight line is drawn through the plotted points making certain that the line passes through the point for the maturity at 28 days, since this is the more precisely determined point. If companion specimens are made for calibration, the slopes should be averaged to determine the calibration value.

Since in this procedure all specimens from any batch are cured at a constant temperature for a designated period of time, they will all have approximately the same maturity for any given time period. The major variation results from differences in ambient temperatures during the initial 24 hr. Differences in maturity for this period become a decreasing segment of the total, being negligible at 28 days and possibly earlier ages. It is also apparent that differences in strength levels for different batches of concrete used for calibration would not significantly affect the prediction of later age strengths, if the slope attained for each batch is essentially the same.

Evaluation of Maturity Concept

The maturity concept was evaluated using the procedure outlined in ASTM Method C918. For this purpose the concrete mixtures shown in Table 1 were tested at 1, 3, 7, 14, and 28 days. The reported value for 28 days is the average of 9 specimens. The reported values for other ages are the averages of 3 specimens. The strength values are summarized in Table 5 and the typical strength-log maturity curves are shown in Figure 1.

Table 5

Characteristics of Laboratory Concretes

Batch	Entrained Air, %	Water/ Cement Ratio	Cement Content, lb/yd^3	Avg. Compressive Strength - lbf/in^2 1 day	3 days	7 days	14 days	28 days	Slope
1	5.3	0.48	589	1,880	2,440	3,880	4,410	5,040	2,130
2	7.5	0.48	589	1,550	2,200	3,250	4,030	4,730	2,400
3	4.9	0.48	589	1,950	3,140	3,970	4,670	5,180	2,100
4	4.8	0.48	589	2,270	3,540	4,240	4,540	5,360	2,030
5	8.0	0.40	589	3,050	4,160	4,540	5,360	5,820	1,840
5A	6.9	0.40	589	2,600	3,790	4,780	5,760	6,420	2,700
5R	6.0	0.40	589	2,610	--	4,530	5,130	5,610	1,900
6	6.0	0.55	470	1,280	2,180	2,960	3,620	3,950	1,780
6A	7.6	0.55	470	950	1,640	2,510	3,330	3,950	2,100

The same cement and aggregates were used in all of these concretes but different water-cement ratios and different cement contents were used to assess the effects of such variations on the strength of the concrete and the slopes of the calibration curves. Except for variations in air content, mixes 1 through 4 were replicates. The average strength at 28 days was 5,080 lbf/in^2 with a standard deviation of 266 lbf/in^2, thus the results are generally within the laboratory repeatability for compressive strength determinations on different batches of the same mixture.

The slopes of the prediction curves computed from the data are shown in Table 5. Mixtures 5, 5A, and 5R were made to assess the effects of a low water-cement ratio in mixtures with and without a water-reducing admixture. Mixtures 6 and 6A were duplicates utilizing a high water-cement ratio and a low cement content. Although the slope of the strength-log maturity for batch 6 was relatively low, batch 6A had a slope that was not significantly different from the slopes obtained with the lower water-cement ratios and higher cement contents.

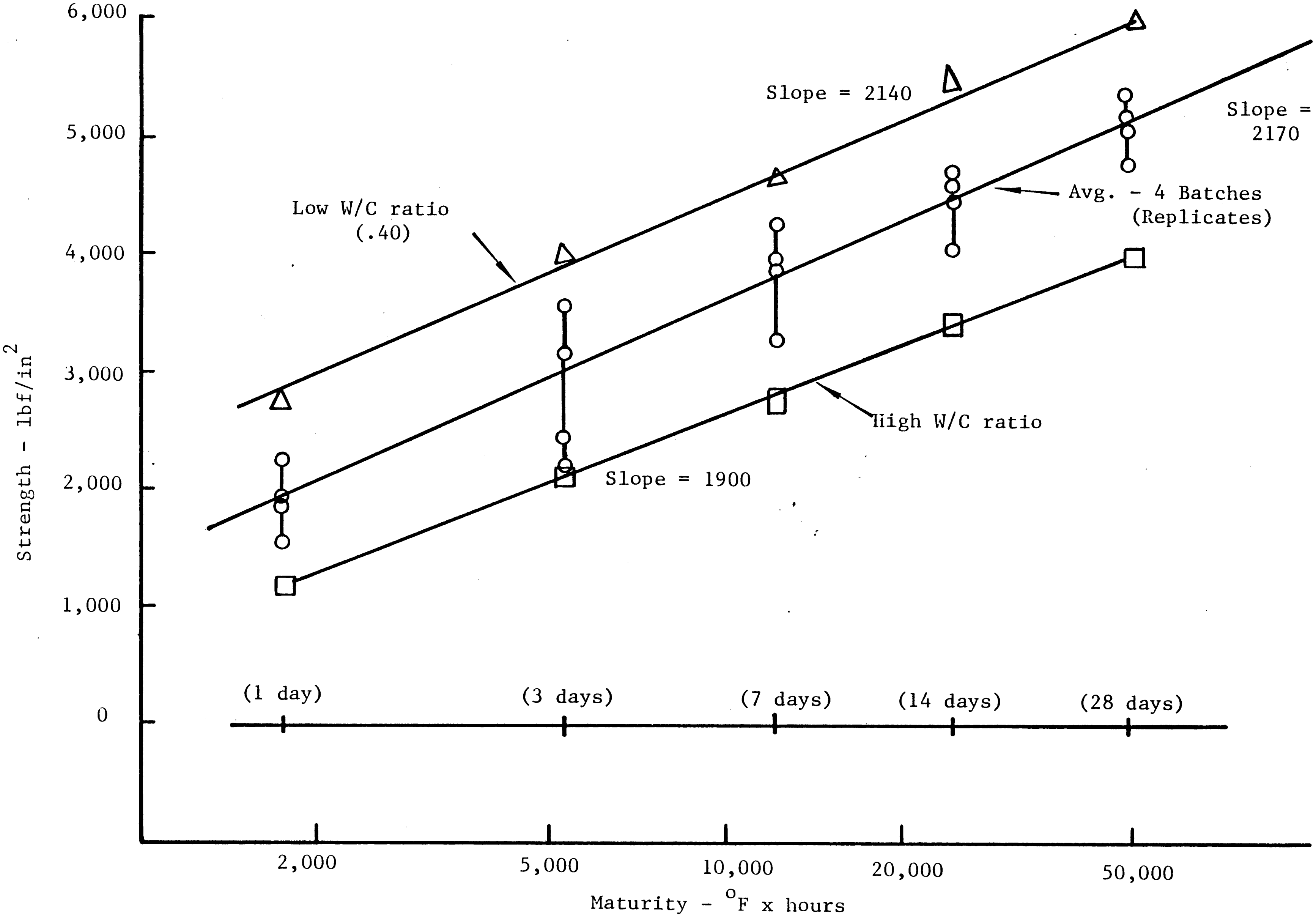

Figure 1. Strength-log maturity curves for laboratory concretes.

In general, the conclusion drawn from this series of tests was that even though the level of strength varied appreciably because of deliberate variations in the water-cement ratio and cement content, the slope of the strength-log maturity line was relatively constant. The average value for all batches with the same water-cement ratio and cement content was 2,170 with a standard deviation of 162. The average slope for the three batches with low water-cement ratios was 2,140 and the average of the two high water-cement ratios was 1,900. It is noted that the laboratory temperature for the first 24 hr in the molds for all these specimens was essentially constant and only a few degrees warmer than the standard curing conditions. Thus, in these tests the time of curing was essentially the only variable affecting strength development.

To determine the extent to which this relation was true for other mixtures, data were examined from a number of control mixtures used in another project measuring the effects of silica fume. These are plotted in Figure 2. These data show pronounced deviations from a straight line. The slopes are also significantly different from those depicted in Table 5. Further evaluations were made for strength data obtained in various laboratory and field studies where strengths were determined at three ages. It was found that although good straight-line relations were obtained in some cases, significant deviations from the straight line occurred in others, so that with only three points a good estimate of the applicable slope could not be made. Strength data for field concrete at 2, 7, and 28 days obtained from New Jersey were also examined, and it was found that the three available points did not all have a straight-line relation.

These results collectively indicate that the test variability and uncontrolled variability in materials are sufficiently large so that any estimate of the slope of the strength-log maturity line must be based on averages of strength at at least 5 ages as required in ASTM C918, and that for good estimates more than one test is needed at each age. Thus, the amount of "calibration" testing in using this concept for small jobs becomes prohibitive. In addition, it becomes questionable if a slope based on averages is sufficiently precise to permit its use in computing pay factors. While estimates based on minimum slopes might provide useful indications that strength levels would most likely be adequate, assessments of pay reductions on such a basis could unfairly penalize a concrete producer. Similarly, the use of a high slope may indicate satisfactory strength when such is not the case.

Accordingly, it is concluded that any application of reduced pay factors for concrete acceptance must be based on test results made at the designated age.

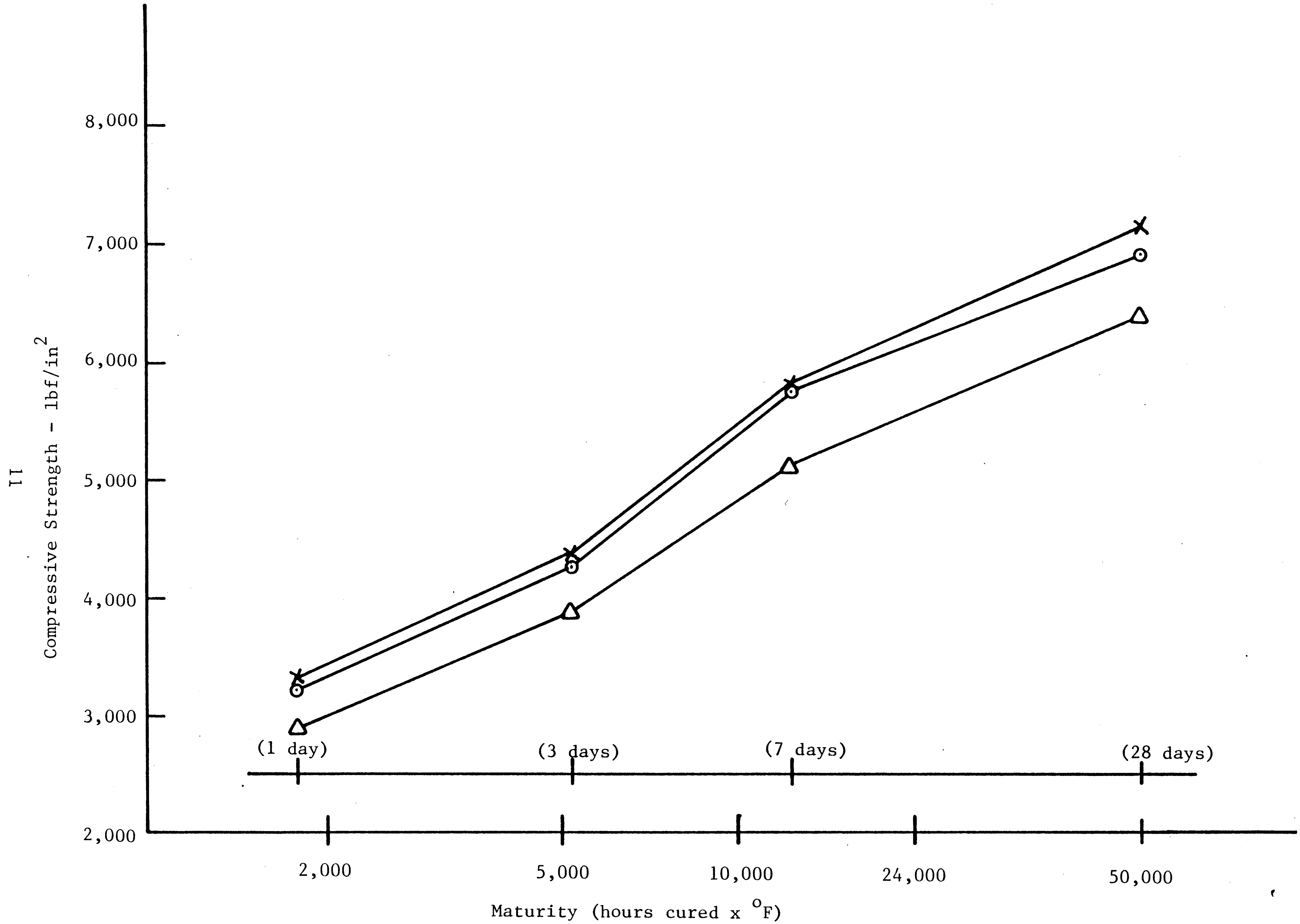

Figure 2. Strength vs. log maturity-control concretes, silica fume project.

DIRECT DETERMINATIONS OF CEMENT AND WATER

A 1980 report prepared by the West Virginia University for the Federal Highway Administration (FHWA) and the West Virginia Department of Highways discusses a number of methods for rapidly determining the cement and water contents of plastic concrete.(4) The abstract of this report states:

> It was concluded that cement and water contents of plastic concrete could be determined rapidly, accurately, and inexpensively with the aid of several devices/procedures (rapid analysis techniques) and that comprehensive plastic concrete quality assurance programs should include independent verification of mixture composition. An additional conclusion was that the CERL/K-V (Kelly-Vail) method is the most readily usable method of the existing rapid analysis techniques.

A review of the West Virginia report,(5) and favorable reports by the U. S. Corps of Engineers Construction Engineering Research Laboratory,(6) led to a full review of the literature, presented below, to assess the feasibility of using the Kelly-Vail procedure for acceptance testing of portland cement concrete being supplied to the Virginia Department of Highways and Transportation.

Literature Survey

Following publication of the West Virginia report, the FHWA sponsored evaluation studies by other states and a direct construction unit of the FHWA (Western Direct Federal Division, Region 17, Vancouver, Washington). Reports from Colorado, Illinois, Oklahoma, Oregon, and FHWA Region 17 were reviewed. These reports indicate that variable results were obtained by each of the agencies. Brief summaries of the scope of the work and the findings reported by the agencies are given under the following subheads.

Colorado Department of Highways

The Colorado study evaluated the microwave oven method and Kelly-Vail procedure for determining the water content of plastic concrete,(7) and the former was used in tests for cement content. Water/cement ratios arrived at by using the water content determined by the microwave oven and the weighed cement content were consistently lower than the values based on measured amounts of the water and cement added to the mix. Consistently high water/cement ratios were obtained when the water contents determined by the Kelly-Vail procedure were used. It was reported that it was difficult to obtain samples that were representative of the batch or production unit being tested, and that the difficulty increased as the size of the coarse aggregate increased. Some difficulty was encountered in obtaining sharp end points in the Kelly-Vail titration. The time required for the water determination in the microwave oven test was reported to be about 1 hr and the Kelly-Vail test required about 15 min. It was pointed out that adjustments based on the Kelly-Vail test could be made quickly before additional noncomplying concrete would be placed, but in an ongoing placement the 1-hr delay for the microwave oven results would permit a relatively large volume of concrete to be placed before a need for adjustments would be known.

It was concluded that either method provided satisfactory results for water content, and it was recommended that one or both of the procedures be adopted for use in testing plastic concrete. Proposed test methods are included in the report. Further work to improve the accuracy and decrease the time required for the tests is planned.

Illinois Department of Transportation

The Kelly-Vail system was used to determine both water and cement contents of plastic concrete in an Illinois study.(8) It was reported that both the cement and water contents could be determined with satisfactory accuracy and repeatability. Even though the magnitude of the error increased with increasing cement and water contents, the percentage error for each determination remained relatively constant at all levels. The method was not considered to be operator-sensitive. The report recommends use of the Kelly-Vail as a general indication of process uniformity, but indicates that it is not useful for tight process control. Additional work utilizing instrumental methods of analysis is recommended, and the opinion is expressed that newer electronic methods of analysis would likely prove to be more cost-effective. Difficulties in attaining a representative sample for test were reported.

Oklahoma Department of Transportation

The Oklahoma DOT evaluated the Kelly-Vail procedure for use in determining both water and cement contents and the use of a water/cement ratio determined as a predictor of compressive strength.(9)

Statistically designed experiments were used and the results were statistically analyzed. In general, it was concluded that there was no statistical relationship between the 28-day strengths of the concrete and the water-cement ratio determined by the Kelly-Vail procedure. Relatively large discrepancies were found between the measured quantities of both water and cement contents in separate batches of the same mix design. The poor correlations obtained with laboratory mixtures led to the conclusion that refinements to the procedure were needed before further field evaluations could be made, and the study was discontinued.

Oregon State Highway Division

The objective of the Oregon study was to place a CERL/Kelly-Vail testing unit and a microwave oven in the field for testing plastic concrete. The CERL/Kelly-Vail tests were to determine water and cement contents and to evaluate the water-cement ratio so determined as a method for predicting 28-day concrete strengths.(10)

Difficulty was encountered in obtaining a clear end point in the Kelly-Vail titration for cement content. The cause was investigated and "masking agents" were tested to provide a suitable end point. A suitable agent was found; however, it contains sodium cyanide so that it must always be added in the proper order to prevent the formation of deadly cyanide gas.

It was concluded from this study that acceptable accuracy could be obtained in determining water and cement contents, but that the water-cement ratio could not be used as a reliable predicter of 28-day compressive strengths because too many variables are present in field concrete. While the report recognizes that the Kelly-Vail procedure would "have its place" as a quality control tool, the need for specially trained operators and specialized equipment is cited. Also, the shelf life of reagents is limited.

The microwave oven in the "defrost mode" provided reliable results for total water content with a minimum of equipment and training, but advance testing to determine absorbed moisture in the aggregate is needed to provide for a proper determination of the free-water available for mixing.

Federal Highway Administration, Region 17

The FHWA prepared an executive summary of information concerning the usefulness of various procedures for quality control based on tests on a federal construction project and from published reports.(11) The evaluation included the rapid analysis machine (RAM), the Kelly-Vail equipment, and the microwave oven for water.

It was concluded that the calibration for determinations of the cement content with the RAM equipment is time consuming and must be checked regularly. Backup equipment is needed in case of problems with the equipment being used. The high cost of the equipment and poor availability of service are major drawbacks. Special training is needed, and the same person should run and calibrate the tests. There are also problems with nonuniformity of samples.

The Kelly-Vail tests were also reported as being too time consuming to be useful in quality control. A large amount of concrete would be placed before results become available. The short shelf life of reagents also leads to reliability problems.

The microwave oven test for water is easy to perform, but the 1-hr time required is too long for control testing, and correction for absorbed moisture is needed for many aggregates.

Conclusions from Literature Survey

Even though some early reports indicate that satisfactory determinations of water and cement contents can be obtained using the Kelly-Vail system,(4,5,6,7) the experience of the various highway agencies in evaluating the application of the system indicates that the system is not readily adaptable for use in either quality control or acceptance testing. The water-cement ratio determined often varies significantly from the ratio determined by weight (mass) of added material with corrections for water in the aggregate. Representative samples could not be consistently obtained. A reliable relationship between 28-day strengths and determined water-cement ratios was not obtained by any state agency testing field concrete, most likely because special training of personnel is needed. Similar problems are encountered with the RAM test procedure. Accordingly, it is concluded that laboratory or field evaluations of either the RAM equipment or the Kelly-Vail procedure by the Virginia Department of Highways and Transportation is not warranted at this time.

It is known that an ongoing NCHRP project is making a critical examination and evaluation of some of the variables that affect the results of existing rapid analysis procedures. In addition, the FHWA is directly sponsoring research for the development of methods for the instantaneous determination of water-cement ratios in fresh concrete. Thus, any further efforts by the Virginia Department of Highways and Transportation related to the problem of determining water and cement contents in plastic concrete should be deferred until after reports of these efforts have been received.

RELATION OF 14- TO 28-DAY STRENGTHS

Based on the observed relationship between 14-day and 28-day strengths over a number of years, the Virginia Department of Highways and Transportation has often accepted concrete when the strength at 14 days was equal to or greater than 85% of the required strength at 28 days. However, pilot studies of a proposed revision of the concrete specification to include statistical evaluation of test results as a part of the acceptance procedure have revealed that most concretes now being supplied to the Department have ratios of 14 to 28 day strengths greater than 0.85. At first glance, a high ratio of strength at 14 days to strength at 28 days may appear advantageous. However, when such high ratios exist, false indications of adequate strength at 28 days may be obtained, because the increase in strength between 14 and 28 days is not as great as it was assumed to be on the basis of the 0.85 ratio. In the comparisons of 14- and 28-day strengths for A4 concretes included in the pilot study it was shown that a number of concretes had 14-day strengths equal to or greater than 85% of the 28-day requirement, but did not reach the specified limit because of the slower than expected gain between 14 and 28 days.(12) Strengths at 28 days for A3 concretes generally were satisfactory, because for this class of concrete strength levels generally significantly exceed the requirements. In most cases, the full 28-day requirement was attained in 14 days.

While both the strength ratio and the maturity concepts are empirical relationships, it is noted that the two concepts are not mathematically consistent. In the ratio concept, which assumes a constant percentage change, the increase in strength from 14 to 28 days varies with the level of strength measured, while in the maturity concept the increase is assumed to be a constant amount depending on the slope of the log maturity vs. strength curve. For example, A3 concrete at 3,000 lbf/in^2 is expected to have 2,550 lbf/in^2 at 14 days, a difference of 450 lbf/in^2 between 14 and 28 days. However, A4 concrete at 4,500 lbf/in^2 at 28 days is expected to have 3,825 lbf/in^2 at 14 days -- a difference of 675 lbf/in^2. Conversely, if the slope determined under the maturity concept would be shown to indicate an increase of 600 lbf/in^2 from 14 to 28 days, the ratio of strengths for 3,000 lbf/in^2 is 0.80 but at 4,500 lbf/in^2 this amount of increase results in a ratio of 0.87.

An examination of field data where 14-day and 28-day strengths were available for the same batches of concrete showed inconsistent results with either concept -- both the ratio of strengths and the increment of increase were erratic. Thus, at present there is no basis for concluding that one procedure is better than another and, as previously stated, reliable predictions cannot be made with either concept on the basis of a few tests.

RECOMMENDATIONS

On the basis of the findings in this study the following recommendations are made.

1. Study by the Research Council on the use of accelerated strength testing and the direct determination of water and cement in a concrete mixture should be discontinued until after completion of present efforts in this area being sponsored by the FHWA. Additional study should be made only to evaluate any possible recommendation by the FHWA.

2. The practice of accepting concrete on the basis of 85% or greater of the 28-day requirement at 14 days should be discontinued. Until additional data are obtained, concrete should be accepted at 14 days only if the 14-day strength is equal to or greater than the required 28-day class design minimum.

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