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SOME FIELD EXPERIENCE IN THE USE OF AN ACCELERATED METHOD OF ESTIMATING 28-DAY STRENGTH OF CONCRETE

V. M. MALHOTRA AND N. G. ZOLDNERS

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Some Field Experience in the Use of an Accelerated Method of Estimating 28-day Strength of Concrete

By V. M. MALHOTRA and N. G. ZOLDNERS

Statistically analyzes field strength data supplied by various organizations using the accelerated method of estimating 28-day strength of concrete. Briefly, the accelerated method consists of initial standard moist-curing of test specimens for 24 hr, followed by boiling for 3½ hr, and testing in compression 1 hr later. The analyses of the test data indicate that the accelerated test method under discussion is an excellent means for rapid strength determination of concrete, and its use by the concrete industry is recommended.

Keywords: **accelerated tests; compressive strength; concretes; quality control; tests.**

■ THE RIGID QUALITY CONTROL specifications and the much faster pace of current concrete construction have all pointed towards the need for an accelerated test for the determination of the compressive strength of concrete. In recent years a considerable number of papers on accelerated strength testing of concrete have been published.[1-10]

Since 1963 the Canadian Mines Branch has been engaged in the development of an accelerated test for estimating the 28-day compressive strength of concrete. The findings of this research work were presented first at the 17th ACI Fall meeting at Miami, Fla., in Nov. 1964, and have been published elsewhere.[6,7] The method, known as the modified boiling method, was selected by the ASTM as one of the three most promising methods for an international cooperative testing program.

Since the introduction of the above method, several ready-mixed concrete producers in Newfoundland, Quebec, and Ontario, testing companies in Quebec and British Columbia, and provincial and municipal authorities in Quebec have installed suitable equipment. They have used this test, with and without modifications, as one of their routine control tests when job conditions required. One federal agency has subjected the method to further laboratory testing.

This paper presents and analyzes the data obtained by these organizations using the above accelerated testing method.

DETAILS OF TEST METHOD

The salient features of the test method are:

1. Prepare three 6 x 12 in. (15 x 30 cm) test cylinders in steel molds, using standard molding methods. The delay between mixing of concrete and preparation of test specimens should not exceed 30 min.

2. Immediately after molding, close tightly all molds with steel cover plates and place them in a moist-curing room or box maintained at 73.4 ± 3 F (23 ± 1.7 C) temperature and 100 percent relative humidity. If suitable moist-curing facilities are not available, cover the molds with moist burlap, and keep wet, for 24 hr.

3. At the end of this curing period, remove the cylinders from the curing room and place them, complete with their molds and covers, in boiling water. Keep the temperature of the water just below the boiling point, 212 F (100 C), to avoid excessive evaporation.

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ACI member **N. G. Zoldners** is head, Construction Materials Section, Mineral Processing Division, Department of Energy, Mines and Resources, Ottawa, Canada. He obtained his engineering degree from the University of Latvia, Riga, in 1940. After more than 20 years of field work in concrete construction in Europe Mr. Zoldners was for about 10 years in charge of the quality control of a major ready-mixed concrete company operating in Montreal and Ottawa areas in Canada. He is the author of several papers dealing with the heat effects on properties of concrete and concrete aggregates. Currently, Mr. Zoldners is a member of ACI Committees 201, Durability of Concrete; 216, Fire Resistance and Fire Protection of Structures; and 437, Strength Evaluation of Existing Concrete Structures.

4. After 3½ hr of boiling, remove the cylinders from the boiling water, strip the molds and allow the specimens to cool for 45 min. By the end of this cooling period the cylinders reach a temperature of about 135 F (57 C).

5. Weigh the test cylinders, cap them, and test in compression 15 min later.

The total elapsed time between molding and testing of cylinders is 28½ hr.

ORGANIZATIONS AND COMPANIES USING TEST METHOD

The names and locations of organizations in Canada using the described method are given in the full-length paper.

An accelerated-curing tank at the control and research laboratory of the Public Works Department, City of Montreal, is shown in Fig. 1. Three of these curing tanks can accommodate 160 6 x 12-in. cylinders at one time.

TEST RESULTS AND THEIR ANALYSIS

Number of tests

A total of 396 batches of concrete were sampled and 1807 cylinders were tested by the various organizations.

Analysis of test results

Method—The analyses have been confined to the relationship between the compressive strengths obtained by the accelerated method and at 28 days for concrete made with portland and sulfate resistant cements. For concrete made with low heat portland cement, the relationship

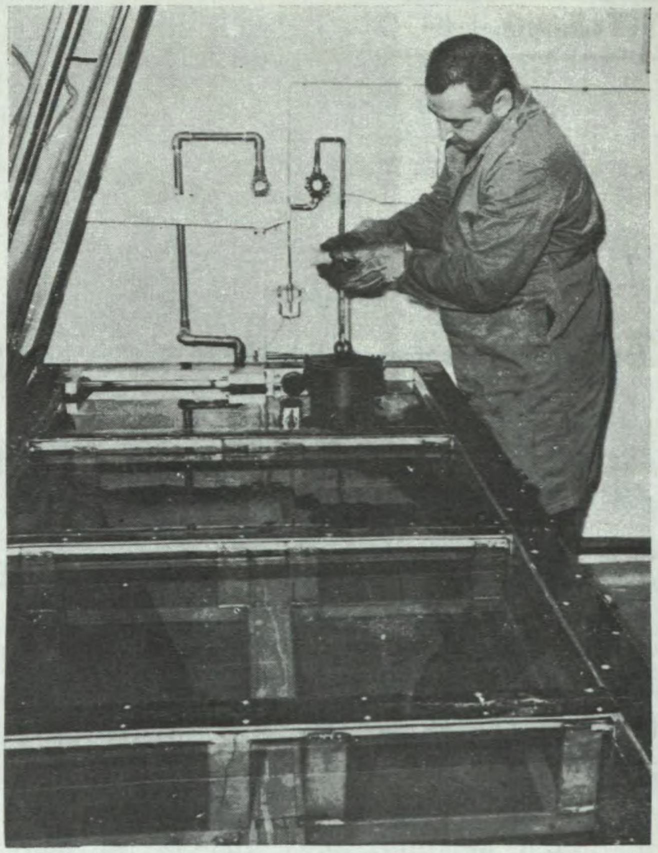

Fig. 1 — Accelerated-curing tank at the control and research laboratory (Public Works Department, City of Montreal)

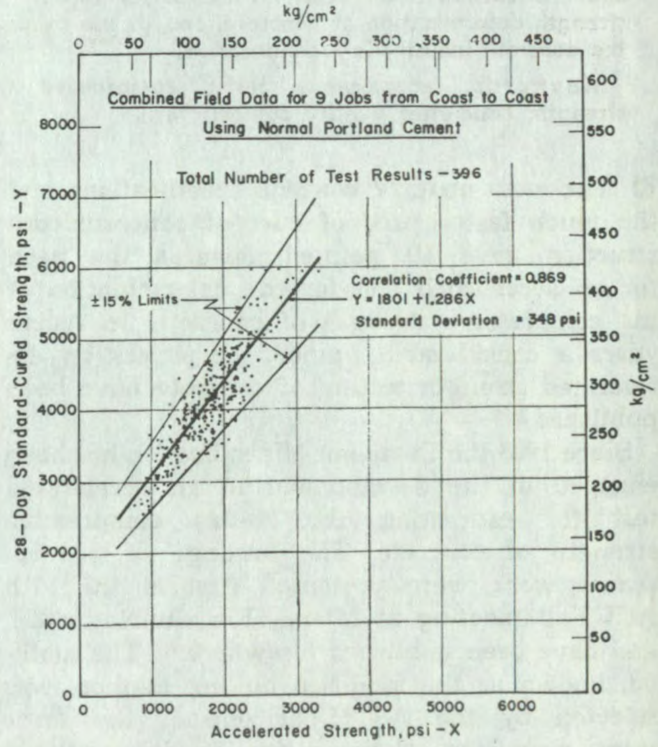

Fig. 2 — Relationship of accelerated to 28-day strength; combined field data from nine jobs across Canada.

TABLE 1 — WITHIN-BATCH COEFFICIENTS OF VARIATION

Name of organization	No. of test results	Coefficients of variation,* percent: 28 ½ hr accelerated curing	Coefficients of variation,* percent: 28 days standard curing
City of Montreal			
Sidewalk concrete	46	2.9	4.2
Pavement concrete	56	3.0	3.7
A Canadian government agency			
Normal portland cement concrete	10	1.8	2.5

ACI 214-65[11] values for excellent field control is less than 3.0.

*Coefficients of variation are based on the results of three 6x12-in. (15x30 cm) cylinders.

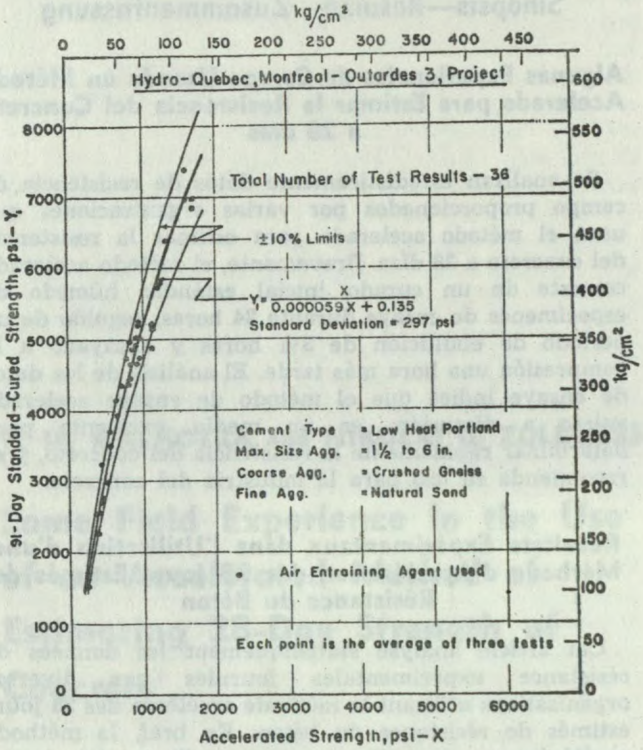

Fig. 3 — Relationship of accelerated to 91-day strength (Hydro-Quebec, Outardes 3 Project)

between the compressive strengths obtained by the accelerated method and at 91 days have also been investigated. In analyzing the data, regression lines of the following types were used:

$$Y = A + BX \quad (1)$$

and hyperbolic curves of the type:

$$Y \text{ or } Y_1 = \frac{X}{A + BX} \quad (2)$$

where

X = accelerated strength, psi

Y = 28-day strength of standard-cured cylinders, psi

Y_1 = 91-day strength of standard-cured cylinders, psi

A, B = constants

The curves have been fitted to plots using statistical techniques.

Fig. 2 shows the combined data for all jobs across Canada where normal portland cements were used. Data for low heat cement are shown in Fig. 3.

To evaluate the laboratory testing and casting techniques, the within-batch coefficient of variation for the 28½-hr (accelerated cured) and 28-day strengths have been determined for those jobs where sufficiently detailed data were submitted for analyses. This analysis is shown in Table 1. Also shown, for comparison, is the maximum value for within-batch variation recommended by ACI 214-65.[11]

SOME COMMENTS ON THE TEST METHOD AND ANALYSES OF THE TEST RESULTS

The relative simplicity of the test method has led to its acceptance in Canada. On a large project, where there are a number of small batch plants scattered over a large area, the test cylinders can be collected after about 22 hr and brought to a control laboratory where they can be subjected to accelerated curing. The same is true if the method is to be used by a large ready-mixed concrete producer in a metropolitan city. This is a distinct advantage over other accelerated-curing methods where individual hot or boiling water tanks have to be installed at each individual batch plant or construction site.

Owing to the rather promising nature of this test method, ASTM Committee C-9 has selected this method, for inclusion in a tentative standard under preparation; two other methods are also being included in this standard.

For the combined data throughout Canada (Fig. 2), when various brands of normal portland cements, various types of aggregates and a number of different kinds of admixtures have been used, the 28-day compressive strength of standard-cured cylinders can be predicted with an accuracy of ± 15 percent.

CONCLUDING REMARKS

The modified boiling method is recommended for routine control of quality concrete. At the start of concreting operations, the relationship shown in Fig. 2 may be used for estimating the 28-day compressive strength of concrete and for making necessary changes in the mix proportioning. However, each testing and control agency using the method is strongly advised to develop its own relationships for predicting the 28-day strengths.

When sufficient field data have been collected these should be submitted to appropriate code and standardization committees for further evaluation so that consideration could be given to replacing the 28-day compressive strength test with an accelerated strength test.

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Sinopsis—Résumé—Zusammenfassung

Algunas Experiencias de Campo Usando un Método Acelerado para Estimar la Resistencia del Concreto a 28 dias

Se analizan estadísticamente datos de resistencia de campo proporcionados por varias organizaciones que usan el método acelerado para estimar la resistencia del concreto a 28 días. Brevemente, el método acelerado consiste de un curado inicial estándar húmedo de especímenes de ensaye durante 24 horas, seguido de un período de ebullición de 3½ horas y ensayado a la compresión una hora más tarde. El análisis de los datos de ensaye indica que el método de ensaye acelerado sujeto a discusión, es un medio excelente para determinar rápidamente la resistencia del concreto, y se recomienda su uso para la industria del concreto.

Résultats Expérimentaux dans l'Utilisation d'une Méthode d'Accélération des 28 Jours Estimés de Résistance du Béton

Cet article analyse statistiquement les données de résistance expérimentales fournies par diverses organisations utilisant la méthode accélérée des 28 jours estimés de résistance du béton. En bref, la méthode accélérée consiste d'un ressuage d'humidité initial standard de 24 heures des spécimens essayés, suive d'un chauffage de 3½ heure et d'essai en compression 1 heure plus tard. L'analyse des résultats d'essai indique que la méthode d'essai accélérée qui est ici discutée est un excéllent moyen pour déterminer rapidement la résistance du béton et son utilisation par l'industrie du béton est recommandée.

Erfahrungen auf der Baustelle mit einer beschleunigten Methode zur Bestimmung der 28-Tage Festigkeit von Beton

Ergebnisse von Versuchen mit Hilfe einer beschleunigten Methode zur Abschätzung der 28-Tage Festigkeit von Beton, die von verschiedenen Organisationen durchgeführt wurden, werden statistisch ausgewertet. In der beschleunigten Methode werden die Proben über einen Zeitraum von 24 Stunden feucht gelagert, dann über einen Zeitraum von 3½ Stunden gekocht und eine Stunde später auf ihre Druckfestigkeit geprüft. Die Analyse der Versuchsergebnisse zeigt, daβ die hier diskutierte beschleunigte Methode vorzüglich dazu geeignet ist, die Festigkeit von Beton rasch abzuschätzen. Der Gebrauch dieser Methode in der Betonindustrie wird empfohlen.

Disc. 66-76

V. M. MALHOTRA and NIKOLAI G. ZOLDNERS

Some Field Experience in the Use of an Accelerated Method of Estimating 28-Day Strength of Concrete[†]

DISCUSSION BY: EDWARD A. ABDUN-NUR, JOHN A. BICKLEY, E. L. HOWARD, RIMANTAS LAPINAS, ALEJANDRO G. LOPEZ and SERGIO Z. BARRERA, J. NEIL MUSTARD, LLOYD E. RODWAY, WALTER G. J. RYAN, PETER K. SMITH, GORDON W. SPRATT, and AUTHORS

By EDWARD A. ABDUN-NUR[‡]

This paper makes a most interesting presentation of how accelerated strength tests may be useful in estimating the 28-day strength of concrete.

The authors conclude that the "method is recommended for routine control of quality of concrete." The use of an accelerated method for such control is excellent, and has served that purpose for several years. Such control, however, has nothing to do with the predicting of 28-days strengths, as such control is usually based on the accelerated strength. The test itself, has many advantages which have been pointed out in the paper, but it also has some serious shortcomings that make one wonder whether it is the test best adapted to the accelerated control of the quality of concrete.

Length of cycle

The test requires a 28½-hr cycle, which will mean overtime work for any specimens made in the afternoon of a normal 8-hr working day. This overtime work is both costly and inconvenient in most organizations, except in the rare case of around-the-clock operation.

Effect of altitude

One must also consider that the boiling point is far from being 212 F everywhere in the world. In such places as Denver, Mexico City, and other high altitude locations, this variation can amount to 12 to 15 F or even more. It is doubtful that such a variation will permit an acceptable accuracy for a method that if adopted would have to be standardized. Current curing methods require the control of the curing temperatures to be maintained within ±3 F (ASTM C 192-69). An alternative is the use of a pressure vessel at the higher altitudes, which makes for complicated equipment that is most inconvenient to handle.

Safety

There is the danger, from the standpoint of safety, in handling cylinder molds at boiling temperatures, and the possible facial burns of operators from the steam emanating from a curing tank when it is first opened. These two serious safety factors have been ex-

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perienced by an organization that has tried this method very extensively.

These three weaknesses could be compensated for by special design of the equipment and by expending the necessary cost for overtime, if this were the only accelerated test method available that could be used for early control of the quality of concrete.

However, this method should be weighed at least against the two other accelerated curing methods that are also included in the ASTM tentative standard under preparation, referred to by the authors. In one of the methods, the cylinders are cured in a tank at a temperature of 95 F (35 C). This is very close to body temperature, so that there is no danger whatsoever from either handling hot objects or of having steam blow in an operator's face. This temperature is easily maintained by a thermostat. Thermostats are both reliable and relatively inexpensive. The use of thermostats, to maintain this 95 F temperature, does away with changes in temperature for different altitudes, as this relatively low temperature can easily be maintained anywhere. This low temperature method uses molds with machined top and bottom plates that permit the curing in a horizontal position (after having been cast in the standard vertical manner), thus, obviating the need for capping. It uses a 24-hr cycle, so that there is no overtime except on holidays or nonwork days. Its disadvantage is that one must have a testing machine at the curing point, so that it is not practical for the very small projects which require only a few cylinders. This limits its practical usefulness to plant control or to the larger projects where a control laboratory can be justified at the site—these situations are, anyway, where the major volume of the work is.

Another available method is one that utilizes insulated containers that provide autogenous curing from the heat generated by the hydration of the cement in the concrete cylinder. The insulated container forms a useful and protective shipping device. The cycle for this method is 48 hr, which permits cylinders to be shipped to a central laboratory for testing, and is therefore useful for the small projects that cannot afford a laboratory at the site. It also involves no handling of hot material, and overtime is needed only on holidays or nonwork days.

The authors further conclude that Fig. 2 may be used to forecast 28-day strengths at the beginning of a job before more definitive data are available. This chart permits the prediction to be made within roughly ±15 percent of the expected value. Tables in ACI 613-54 and in its currently recommended revision and other tables and charts in the U. S. Bureau of Reclamation Concrete Manual, and in publications of the Portland Cement Association, provide tools that permit this close an estimate of the expected 28-day strength, without testing cylinders under accelerated conditions. These methods make it possible to move directly to the field adjustments of a mix that the authors recommend to supplement their method.

Another conclusion in the paper is that the control agency should develop its own relationship for predicting the 28-day strength for each particular project—this is really the crux of the matter. But with the development of such a relationship for each particular project, one eliminates the need for charts similar to those presented in the paper.

Finally, one must question the validity of the development of statistical parameters for data about which little is known except numbers presented as universes from various projects. Such a question arises because the paper does not provide any assurance that the data from the various universes pooled together can be statistically considered to be a single universe, or failing this, that the distribution of the universes can be considered normal. It has been the experience of the writer from detailed field examinations of several hundred projects, that no two sets of data are strictly the same for the purpose of statistical treatment. One has to know exactly how a set of data has been obtained and its possible limitations, to be able to validly analyze it statistically, otherwise the analysis becomes simply an exercise in statistical mathematics, and comparisons with other parameters become invalid.

The statistical treatment of data shown in the paper does, however, furnish a good example of how to go about developing a relationship to predict 28-day strength from accelerated tests. But one wonders why it is so important to go to so much trouble to predict 28-day strengths. Even the authors, in their last recommendation, point out the desirability of doing away with the 28-day strength as a basis for acceptance and using the accelerated strength instead. This is an excellent suggestion and one must concur with it most heartily. Actually, there does not seem to be any justification, except habit, to base everything on 28-day strengths, as it has been shown in the studies of the various accelerated curing tests, that the 28-day strengths provide the most variability when compared to the strengths at either earlier or later ages.

Yes, accelerated curing of test specimens for the control of quality is a "must" today, as the faster building schedules make results at 28 days of no practical usefulness. At such late age, so much concrete has usually been placed on top of a pour that may turn out to be unacceptable at 28 days, that it becomes impracticable to do anything about removing it. The only recourse, then, is to costly methods of strengthening the unacceptable material. Early diagnosis through accelerated tests would have permitted adjustments and corrections that would have eliminated the problem. But with two other accelerated curing methods available, both of which have the advantages of the proposed method and none of its shortcomings, the writer cannot agree that the proposed method is necessarily *the* method to be used advantageously for such accelerated control.

By JOHN A. BICKLEY*

The writer has used this test method since 1958 and considers it a very useful construction tool.

It gives early confirmation of satisfactory strength and early warning of possible trouble. In the former case construction can proceed without doubts as to the concrete quality. This can be especially helpful in high strength slipforming. In the latter case the cause of trouble can be diagnosed and corrected at an early stage and one can avoid placing good concrete on top of suspect concrete.

On two recent contracts we obtained the following results.

	Contract 1	Contract 2
Average strength psi	3890	5450
Coefficient of variation, percent	9.8	9.9
In-test variation, percent	2.0	2.1
Number of accelerated tests	12	4
Error in prediction:		
Average psi	124	162
Average, percent	3.2	3.0
Maximum, psi	285	260
Maximum, percent	6.9	3.9

*General Manager, Construction Testing Services Limited, Weston, Ontario, Canada.

By E. L. HOWARD*

The strength test results of ready-mixed concrete concerns the producer to the point that he quite often catches the disease known as "strength jitters." His product is highly perishable and passes from his control in less than 100 min. A month passes before the product is accepted by the customer. By this time it may be quite inaccessible, having been covered and surrounded by other construction.

The authors are contributing to a worthy cause in their search for early knowledge of concrete strengths. Our own work in this area is small by comparison, but confirms in some respects with the authors' findings.

The concretes we have tested are typical of the materials used in Northern California. They include cements from four mills and aggregates from five sources. Cement contents vary from 5 to 6½ sacks (470 to 611 lb) per cu yd. Standard 6 x 12 in. cylinders have been cast from 84 samplings. The cylinders are brought to the laboratory the day following casting and divided into two curing procedures. A pair of cylinders go into the fog room for 28 days, and the others are placed in boiling water for 3½ hr, cooled to room temperature, capped, and broken. The age at breaking is 24 to 30 hr.

On a single job, as might be expected, variation between tests was one-half that of the whole project variations (see Table A). We were searching for some easy, simple cure for the ready-mixed concrete operator's "strength jitters." We concluded that he could add 2400 psi to the 1-day accelerated strength and know the approximate 28-day compressive strength. This is not a sophisticated formula but quite practical and accurate enough to assure or alert the producer to the quality of the concrete as it might be a month from now.

TABLE A — INCREASE IN COMPRESSIVE STRENGTH, ONE DAY ACCELERATED STRENGTH COMPARED WITH 28-DAY STANDARD CURE STRENGTH

Average strength increase, psi	2400
Standard deviation, psi	420
Coefficient of variation, percent	17.5
Number of tests	84
A single job average, psi	2500
Standard deviation, psi	200
Coefficient of variation, percent	8
Number of tests	20

By RIMANTAS LAPINAS†

The authors are to be commended on their continuing efforts in development of accelerated methods for estimating the 28-day strength of concrete. There is little doubt that the 28-day strength concept is being rapidly outmoded by increasingly faster pace of concrete construction as well as the need for quicker results in concrete research work. The situation today is such that concrete producer as well as the structural engineer, in most cases, has to make a decision on potential strength of the concrete on the basis of 7-day strengths, the 28-day strength results that follow are more of interest from a legal standpoint to prove if concrete did or did not meet the specified quality since action would be taken on a 7-day strength basis if a critical situation resulted.

It appears from the test data presented, that the accelerated test can predict the 28-day strength probably as accurately as the standard 7-day test. If indeed, in practice, we are forced to rely on 7-day strengths, it is obvious that even greater benefits would be derived from obtaining results within 28½ hr. The writer is in complete agreement with the authors that serious consideration should be given not only in accepting the accelerated strength test for predicting 28-day strengths, but in actually replacing the 28-day strength concept of measuring potential quality of concrete. Indeed, the full benefits in adopting accelerated testing could be only realized if, at the same time, the whole significance of concrete strength and time at which it should be measured for the purpose of evaluating potential quality of the concrete are reconsidered.

The experience of the writer in carrying out over 220 accelerated tests using the method proposed by the authors indicated that this method is simple and practical to use. The equipment does not require any sophisticated controls and can be easily made locally and procedures are such, that they can be easily followed by any concrete technician.

The writer questions, however, two points in the test method. Firstly, the requirement that delay between mixing of concrete and preparation of test specimens should not exceed 30 min does not seem very practical since, in the case of ready-mixed concrete in a large city, most of the concrete exceeds 30 min in delivery time alone. Perhaps the authors could explain the significance of having this time limit. Secondly, the writer does not see the point in the requirement that specimens be kept at 100 percent relative humidity for the first 24 hr when they are cast in steel molds and covered with tightly fitting steel cover plates.

Since no data is given by the authors on lightweight concrete it may be of interest to note that the writer had on two occasions to rely on modified boiling method to predict the 28-day strengths of lightweight concrete. The relationship developed for normal weight concrete was used due to lack of data on accelerated tests with lightweight concrete. The predicted 28-day strength was only 2 percent higher than the actual 28-day strength in one case and 7 percent lower in the second.

By ALEJANDRO G. LOPEZ‡ and SERGIO Z. BARRERA§

The method proposed by the authors was experimentally tried in Mexico City at the laboratory of one of the largest ready-mixed concrete companies.

The accelerated tests of 28½ hr are very important for a quality control laboratory especially since there is a chance to correct the concrete proportions if this is needed. In this experiment the exact procedure of the proposed method in Reference 7 of the discussed paper could not be strictly followed. Reference 12 describes the main differences. All of the differences were due to the fact it was necessary to sample the concrete on the jobs.

One difference was that the temperature could not be controlled in the first 24 hr, and another difference,

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TABLE B — SUMMARY COEFFICIENTS OF TOTAL VARIATION

f_c' of the project, kg/cm²	Age, days	No. of test	Accelerated strength, 28 days			
			$\bar{x}$	V, percent	$\bar{x}$	V, percent
140	14	15	62	16	139	17
	28	—	—	—	—	—
175	14	13	79	15	173	13
	28	7	109	24	212	15
210	14	53	103	20	218	16
	28	42	114	18	236	13

was the time of removing the molds was between 22 and 25 hr instead of 24 hr.

With regard to materials and fresh concrete characteristics, the results obtained in the writers' experience were more uniform since the cement and the aggregates used were the same.

The following statistical differences were observed between the writers' tests and the authors' paper:

(a) Better correlation coefficients (0.96 or more) were obtained.

(b) High correlation coefficients were based on logarithmic functions.

(c) The hyperbolic functions used were:

$$y = \frac{x - c}{Ax}$$

The analysis started from:

$$Axy + By + C = x$$

although the By term was found less significant.

Fig. A shows the results obtained from the five series of tests as well as the final expressions for a confidence range of 80 percent. Tests for the high and low resistance are now being carried out so that a better expression for these zones can be obtained.

The writers obtained coefficients of variation for the accelerated tests (see Table B) which do not agree with the authors' results. However, this could be attributed to the different laboratory conditions.

It is important that further tests be conducted with this system.

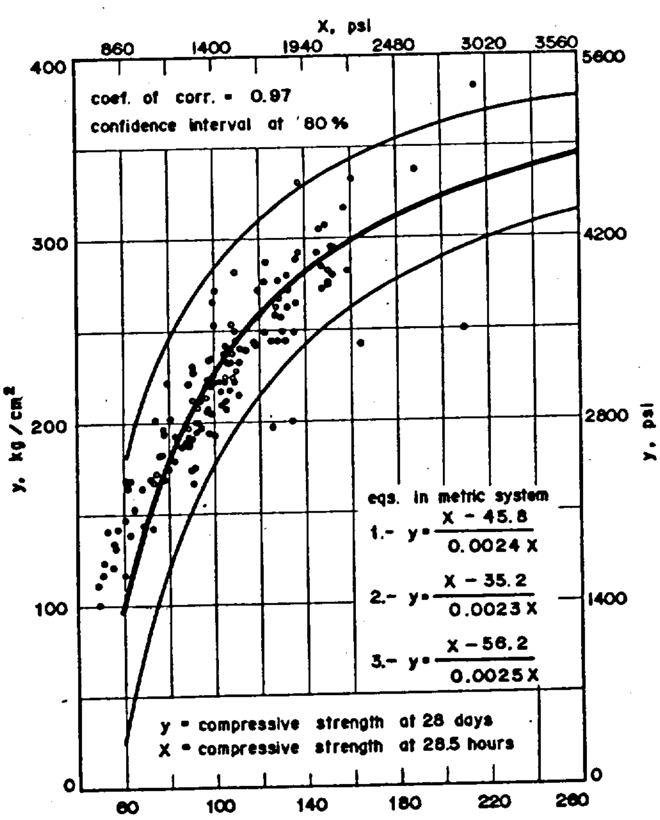

Fig. A — Strength results of five series of tests

REFERENCE

12. Lopez, Alejandro G., and Barrera, Sergio Z., "Evaluation of Acceleration Strength Tests in Quality Control of Concrete," *Revista IMCYC* (Mexico City) V. 70, No. 40, Sept.-Oct. 1969, pp. 41-56.

By J. NEIL MUSTARD*

The paper is timely and I would like to outline the steps being taken by the Candian Standards Association Committee A-23, "Concrete Materials and Methods of Concrete Construction" for the incorporation of several accelerated strength test methods in its standard. In 1967 a proposal[13] was submitted to the above committee for the adoption of the modified boiling method as a standard test. This proposal was considered by the committee at its meeting in Ottawa in December 1967. After considerable discussion the proposal was referred to its subcommittee on strength. The recommendations of this subcommittee that reference be made to three accelerated test methods in the next revision of CSA Standard A23.1 - 1967 were accepted by the main committee at its annual meeting in October 1968 and steps are being taken to implement these recommendations. Several other methods were considered and rejected. The three methods which have been recommended are:

1. Modified boiling method

The original curing cycle as outlined in the paper has been slightly modified and is as follows:

Commencement of curing	:	23 hr after mixing
Duration of curing in boiling water	:	3½ hr
Commencement of testing	:	2 hr after completion of boiling
Total curing cycle	:	28½ hr

2. Autogenous curing method
3. Fixed-set accelerated curing procedure.

Methods 2 and 3 are described in detail in reference 9 of the paper under discussion.

In the initial stages it is planned to include the methods in the Standard as "information" only. If the methods receive good acceptance by the industry and the test data obtained by field personnel are both reliable and reproducible, then the committee would

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consider incorporating one or all of these methods in the main body of the Standard, but this is still several years away.

I earnestly hope that field personnel will try out these methods and would forward their comments and observations to appropriate standardization organizations in the United States and Canada for evaluation and action.

REFERENCE

13. Malhotra, V. M., "A Proposal for the Incorporation of an Accelerated Curing Method for Strength Determination of Concrete in the CSA Standard A-23," *Mines Branch Internal Report* MPI 67-65, Canada, Dec. 1967.

By LLOYD E. RODWAY*

The authors are to be commended for their continued work in this field. The receipt of valid results in 28½ hr as opposed to 28 days allows for quality control action to be undertaken at an early stage in a concrete project, with resultant economies in construction. At present, the compilation of concrete statistical data and charts is largely of academic interest in terms of a specific project as a record of fait accompli.

The writer has plotted results from the calorimeter method developed by Smith and Tiede[1] on a field project. The results of 14 comparative tests plot as a linear regression with a correlation coefficient of 0.90. While this is considered satisfactory, practical difficulties mitigate against its use for concrete control of a number of separate projects from a central point, as is the normal case with a commercial laboratory located in an expanding city. The principal difficulty of the method under these conditions being the excessive number of thermatically sealed containers needed and the space required for same.

Grant[2] who also studied the problem recommends, as a prerequisite for an accelerated curing test, that standard methods be used as much as possible, including initial curing and that the test be as simple as possible using simple equipment. The writer finds it difficult to fault this general concept. The authors' method requires nonstandard molds and nonstandard moist curing during the initial 24 hr period after casting. In fact, this may be essential to produce reliable, reproduceable results.

However, in an effort to adapt the concept to practical concrete control under conditions as outlined, the writer is presently engaged in compiling data based on existing methods such as use of standard light gage sheet-metal molds and existing standard curing conditions of 60-80 F for the initial 20-24 hr period. Subsequent steps are identical with the authors' modified boiling method.

To date, 740 cylinders have been cast under existing standard initial curing conditions as above. Half of of these have then been submitted to accelerated cure by boiling, as per the authors, with the other half processed normally for 28-day standard compressive strength results. A wide range of variables is involved necessitating computer use to process the data. This program continues and it is considered premature to present all data until the statistical analysis is complete.

Nevertheless, in general terms it appears the somewhat looser method of initial control described above yields a lower coefficient of correlation than the more rigorous methods of the authors. However, testing continues and it is intended to publish this work in a few months but in the meantime the present renewed interest in accelerated testing should be encouraging to all concerned with quality control of concrete.

REFERENCES

1. Smith, P., and Tiede, H., "Earlier Determination of Strength Potential" *Highway Research Record* 210, Highway Research Board, 1967, pp. 29-61; discussion, pp. 61-66.

2. Grant, N. T., "The Use of an Accelerated Testing Method in the Quality Control of Ready-Mixed Concrete," Cement and Concrete Association, London, Nov. 1964, pp. 172-180.

By WALTER G. J. RYAN†

Arising from early association with the author while in Australia the concept of an accelerated testing procedure has been pursued here by the writer. It has therefore been most interesting to read of the author's continued work in this field of concrete technology and the data obtained.

Commencing from early in 1966 in Adelaide and then progressively throughout the operations of this large ready-mixed concrete company in Australia (which company produces several million cubic yards per annum), accelerated testing procedures have been used as a basic tool in the quality control of that concrete. The technique used is based on that reported by Grant[4] but using Australian standard 6 in. diameter x 12 in. high cylindrical specimens cast in sealable molds instead of the British standard cubes.

Initially using similar statistical techniques to those of the author relationships of the type he quotes were obtained. For example, on one group of 119 tests from six plants in one city using one cement gave an equation:

$$y = 1.72x - 42$$

with a correlation coefficient of 0.83.

At this stage within-batch coefficients of variation for accelerated and standard cured groups of specimens were checked and it was considered they had negligible differences being typically 2 ±0.3 percent for specimens prepared using both curing regimes over a period of several months in different locations. From this point only single cylinders have been used for the accelerated test.

With the increasing volume of data being produced in each operating area, computer programs were developed in Perth to speed up the derivation of these correlation equations. As finally implemented the program in use is a backstepping multiple regression handling up to 9999 sets of observations, each observation set in turn having up to 40 variables. Any particular variable of the 40 may be regressed against any number (or combination) of the others. In addition, transformations such as powers, logs, products, etc. of any of the variables may be specified.

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TABLE C — REGRESSION EQUATIONS

Region	Regression equation to predict 28-day strength	R value	A value
1.	$750 + 0.818 B_1 + 0.0359 B_2 \times B_4 - 109 B_3 + 0.956 B_5$	0.78	0.59
2.	$3050 + 0.633 B_1 + 1.57 B_2 \times B_3 - 0.0109 B_2 \times B_4 - 977 B_3$	0.88	0.77
3.	$420 + 1.23 B_1 + 0.0189 B_2 \times B_4 + 235 B_6$	0.90	0.80
4.	$-1420 + 0.778 B_1 + 8.19 B_2$	0.92	0.84
5.	$60 + 0.875 B_1 + 4 B_2 - 170 B_3$	0.94	0.87

B_1 = accelerated strength, psi
B_2 = cement content, lb per cu yd
B_3 = slump, in.
B_4 = temperature concrete, F
B_5 = time interval between initial mixing of concrete and placing cylinders in accelerated curing tank, min
B_6 = type of concrete

Admixture 1: $B_6 = 1$
Admixture 2: $B_6 = 2$
No admixture: $B_6 = 0$

The use of this program has expedited the processing of the accelerated test data, and by inclusion of more variables has provided generally more accurate predictions. The correlation equations in each operating area for each cement are being constantly updated typically once every two months or when approximately 50 results are available. Using these techniques regression equations in use in different operating areas in this country at one point in time recently are shown in Table C.

From equations such as these, each slightly different for each location, for each cement, it is possible to predict 28-day strengths.

However, the differences in relationships found here and those reported by the author and others working in this field highlight the difficulties to be overcome before achieving the goal of replacing the 28-day compressive strength test with an accelerated strength test in codes and standards. There can be no doubt that such a goal would represent a major step forward in the utilization of concrete but so long as these accelerated tests do produce correlations with 28-day results which vary with cements for example, the difficulties confronting standardization committees in drafting acceptance criteria based on accelerated test data appear almost insurmountable. Also the danger of the possible premature application of two-stage acceptance criteria, viz., say at 24 hr and also at 28 days, cannot be overlooked when considering the pressures in some areas for the introduction of a "standard" accelerated test. In the light of current knowledge this could in many cases be an impossible imposition unless comprehensive preliminary work was done on the mixes to be used before the criteria were drafted. Even this could prove misleading if subsequent to this preliminary work being carried out there was a change in performance characteristics of one of the mix constituents for example a marked change in chemical composition or fineness of the cement being used.

The foregoing is not intended to be a damnation of accelerated testing. There can be no doubt that any one of the several procedures now in use in various parts of the world have a very real application in the quality control of concrete. On particular job sites using fixed combinations of aggregates, cement, and admixtures, or from ready-mixed concrete plants, in each case where a correlation has been established and proven and is progressively updated an accelerated test can prove most reassuring to all concerned and could conceivably expedite construction in many situations. The ready-mixed concrete industry has made extensive use of such accelerated procedures for their day by day control of strength uniformity in several countries for some years now. Let us be beware, however, as yet of the use of such procedures to derive data on which the ultimate acceptance or rejection of concrete in place will be based.

By PETER K. SMITH*

The modified boiling method of accelerated curing was adopted for use at the Churchill Falls Power Project in December of 1968. The method used is the same as the one described by the authors.

The required test equipment was purchased from a laboratory equipment supply company. To date the equipment has been used to test concrete for preliminary laboratory studies and to check field concrete on eight contracts within a 25-mile radius of the townsite of Churchill Falls.

Since June of 1969, each set of test specimens has consisted of five 6 x 12 in. cylinders, which are tested as follows: two accelerated, one at 7 days, and two at 28 days. To date, in excess of 270 sets or 1350 test specimens of field concrete have been tested. The 28-day strength as predicted from the accelerated test has been accurate to within ±10 percent of the actual 28-day strength test even though the concretes tested have been produced and transported in a variety of manners, aggregate supply has been from three different sources using a variety of processing techniques, and maximum sized aggregate has ranged from ¾ to 3½ in. (see Fig. B).

Typical applications of the accelerated curing test at Churchill Falls are as follows:

1. As a tool in the early development of the water-cement ratio versus strength curves for use in concrete mix design. The laboratory relationship between the accelerated cured and the 28-day strength test result used during the period of preliminary mix design is shown in Fig. C.

2. To aid in the choice of concrete admixture or supplier of concrete admixture, where the cost per psi per standard dosage of admixture was determined.

3. The early determination of the 28 day compressive strength enabled early change in mix proportions, thus reducing the instance of higher than necessary cement factors in areas where strength was the prime requisite of concrete quality.

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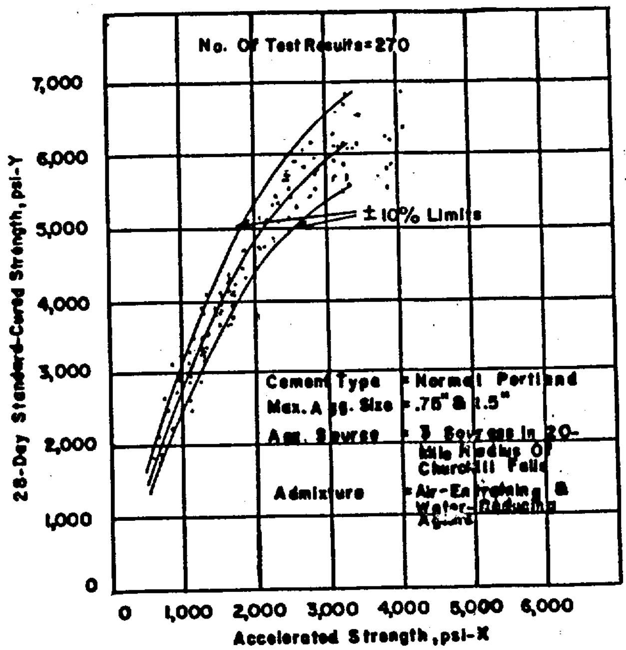

Fig. B — Relationship of accelerated to 28-day strengths

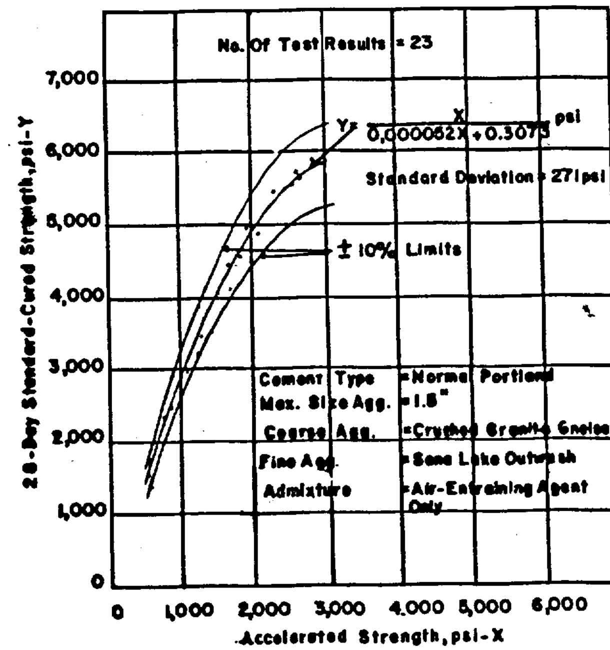

Fig. C — Relationship between accelerated and 28-day standard cured tests

TABLE D — CONCRETE LIFT REPORT

Start: Date Jan. 30, 1970 Time: 01:15

Finish: Date Jan. 30, 1970 Time: 11:15

Elapsed Time: 10 hrs.

Temperatures: Air 41 °F to 44 °F

Concrete 58 °F to 64 °F

Placing Equipment: 3-8 c.y. Agitators

2-3" vibrators, 1-100 Ton crane;

2-4 c.y. buckets

100 % Inspection by: Losier

Mix No.	Total Batched	Total Cement	Plastic Concrete			Compressive Strength					
			Slump	Air	Unit Weight	Req'd	28½ Hr.	7-Day	28-Day	28-Day	Series No.
P-2 Grout	4	3,200									
P-2	392	156,800	3"	5.0%	148.7	3,450	3620				2-2P-100
			2 3/4"	5.4%	148.3	3,450	3510				
Total	396	160,000									

COMMENTS: Seepage water at upstream end diverted with a box drain

TABLE E—MONTHLY STATISTICAL ANALYSIS AND CONCRETE MIX PROPORTIONING SUMMARY SHEET

MIX DESIGNATION		STANDARD CURING						ACCELERATED CURING					
		3-1		3-1a *		3-2		3-1		3-1a *		3-2	
PERIOD IN USE	FROM:	21-7-69		4-8-69		20-8-69		21-7-69		4-8-69		20-8-69	
	TO:	4-8-69		20-8-69		Present		4-8-69		20-8-69		Present	
Design Requirements:	Strength (p.s.i.)	5000		5000		5000							
	W/C	0.40		0.40		0.41							
	Slump ± ½"	2		2		2							
	Air ± 1%	5.0		5.0		5.0							
	Sand % of total Agg. by volume	36		38		41							
Mix Design Proportions	Cement	607		618		625							
	Water	243		253		258							
	Sand	1150		1230		1280							
	3/4"	830		815		750							
	1½"	1240		1220		1120							
	3½"	-		-		-							
	A.E.A. (oz.)	3.0		5.0		4.5							
	W.R.A. (oz.)	20.8		14.1		14.3							
Statistical Analysis		Month	To Date	Month	To Date	Month	To Date	Month	To Date	Month	To Date	Month	To Date
No. of Samples - n		2	7	16	16	5	5	2	6	16	16	5	5
Average Strength - X̄		6360	5785	5575	5575	5820	5820	6280	6280	5940	5940	6100	6100
Standard Deviation - S		-	-	615	615					390	390	-	-
Coefficient of Variation: Overall - V		-	-	11.03	11.03					6.57	6.57	-	-
Within Test - v				3.07	3.07					1.46	1.46		

REMARKS: * Mix changed to increase yield

STANDARDS OF CONCRETE CONTROL

Variation	Excellent	Good	Fair	Poor
V	Below 10.0	10.0 to 15.0	15.0 20.0	Above 20.0
v	Below 4.0	4.0 to 5.0	5.0 to 6.0	Above 6.0

4. Changes in compressive strength caused by seasonal changes or changes caused by variations in the source of materials were detected early and rectified.

5. The entire procedure of reporting was speeded up. It is possible to circulate a report on an individual placing operation, complete with an accurate prediction of the 28-day strength result, within 36 hr of the completion of the operation (see Table D). A comparative statistical analysis of the 28-day versus the 28½-hr strength results is circulated each month for each class of concrete batched (see Table E), and keeps all parties aware of close relationship between the two results.

Because of the immense size of the Churchill Falls Project, and the impractability of establishing numerous field laboratories, it is often necessary to transport test specimens for distances of up to 25 miles to a central laboratory. Therefore, it was necessary to determine the earliest possible time that specimens could be moved in order to be in the laboratory within the required time limit, i.e., 24 hr from the time the specimens were molded. A series of tests were conducted where specimens were transported under actual field conditions at various ages of curing. From the study it was concluded that if the specimens were 8 hr of age or older at the time of transportation there would be no significant variation in strength over control specimens which were not transported.

In conclusion, experience at the Churchill Falls Power Project has shown that the modified boiling method can be used very successfully on large scale construction projects, and that serious consideration should be given to replacing the 28-day compressive strength test with an accelerated strength test.

By GORDON W. SPRATT*

Our firm has been using the modified boiling method since 1967 on a routine basis. More than 700 sets of cylinders have been treated by this accelerated method and, in summary, we are totally satisfied with the method and the results obtained.

As testing engineers on projects whose concrete volume has exceeded 3 million cu yd since 1964, we have naturally compiled a great deal of data on concrete strength. Approximately 18 months ago we installed an IBM 360 RAX Computer to store, print out and analyze all compression test results. Accordingly, we have been able to make quick assessment concerning the ability of this accelerated test procedure.

More than 95 percent of our data has been obtained on concrete containing two local brands of cement. There is enough difference between the behaviors of the two cements to warrant separate curves for each source. Recently with a local cement strike in progress, several other brands of cement were tested by the accelerated method and the accelerated test was performed. The results have now been analyzed using the mean curve of the two local cements and we have found excellent reliability using this procedure. In other words, the "foreign" cements have behaved not unlike the average of our two local cements when subjected to the boiling test.

A growing percentage of concrete is pumped by small line pumps in the Vancouver area and with higher cementitious contents (including pozzolan or diatomite) and with lowered stone factors, we were pleased to find out that no special curve was required in these instances. However, when calcium chloride at 2 percent

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by weight of cement is used, we find that the indicated 28-day strength is 5 to 8 percent too high. Corrections are therefore made to these results.

Water reducing agents and/or air contents in excess of 8 percent have not unduly affected the accuracy of the accelerated test procedures.

Cubes (2 in.) of masonry mortar and 3 x 6 in. cylinders of grout and mortar cannot be tested by the standard sequence, because misleading results have been observed. Similarly, standard 2 in. cement test cubes cannot be reliably evaluated by the accelerated test method, according to our research.

With as many as 70 project sites underway on a given day it has been impossible for us to use steel molds exclusively. However, we have found no drop in reliability when using a premium grade paraffin coated paper mold.

It has been necessary to install insulated cylinder boxes at all project sites so that test cylinders will not drop below 60 to 65 F during the first 22 to 24 hr curing at the project site. We do not have excessively hot weather in the Vancouver area and cannot therefore comment on any effects of higher than 80 F curing during the first 24 hr.

Because Friday is the busiest day in concrete construction in the Vancouver area, the greatest number of test cylinders are made on this date. Most project sites are locked up on Saturday so it is impossible to conduct the boiling test on Friday's cylinders. Working in conjunction with the Department of Energy, Mines & Resources in Ottawa, we have arrived at a procedure that appears to satisfy our clients needs. Friday's cylinders are picked up first thing Monday morning, and are capped in time for breaking at 75½ hr. The test result is then multiplied by 0.93 and the value thus obtained is used in conjunction with the appropriate curve which relates standard 28-day strength with accelerated strength. This procedure was arrived at after attempts to establish a special curve for boiling cylinders at age 72 hr followed by breaking at age 75½ hr. There was no need to go through the extra effort of boiling the 72 hr old cylinders.

On a large out of town shotcrete project the accelerated test was used on more than 40 sets of specimens. A shotcrete test slab was cast by the operator approximately 2 in. thick and 16 in. square. After 24 hr curing at 60 to 80 F the slab was sawn into 2 in. cubes, of which two were subjected to the boil test for testing at age of 28½ hr. Excellent correlation occurred as a result of this technique, although a special curve was developed for this project in advance of actual construction.

AUTHORS' CLOSURE

The authors wish to express their appreciation to the discussers. The many discussions show that there is a universal concern about the need for a more rapid control and acceptance test for concrete than the present standard 7- or 28-day compression strength tests.

The points brought out by the discussers can be summarized as follows:

1. Accelerated strength tests are being used increasingly, in the control of quality of concrete in several countries, with satisfactory results.

2. There is a general dissatisfaction with the existing acceptance criterion based on the results of 28-day strength tests.

3. Standardization committees are facing a difficult problem in standardizing the different methods for accelerated strength tests, and in incorporating these in standards.

Some of the discussers, notably Messrs. Abdun-Nur and Lapinas, have raised some specific questions which should be answered.

Mr. Abdun-Nur has mentioned the overtime problem when using the modified boiling method. Yes, overtime work is needed for any specimens made in the afternoon of a normal 8-hr working day. But this is so also in the other two methods mentioned by Mr. Abdun-Nur. In the hot-water method (95 F), if the test is to be standardized, the test specimens must be capped and, according to ASTM C192, caps shall not be less than 1 hr old at time of test. This, together with the time required for transportation of the specimens to a cental laboratory, creates need for overtime work for all test specimens cast in the afternoons. In the other method mentioned by Mr. Abdun-Nur, overtime is a much more serious problem indeed. Because of the 48-hr cycle any specimens cast on Thursdays and Fridays, must be tested on Saturday and Sunday.

The writers did not mention in their paper that the modified boiling method was the best method, because they feel that satisfactory results can be achieved with a number of other existing methods. However, they do feel that, from a practical viewpoint, the modified boiling method is far superior to a number of other available methods and especially the two methods referred to by Mr. Abdun-Nur. Some of the disadvantages of these two methods are as follows:

Hot-water method (95 F)

1. The curing temperature of 95 F is too low to sufficiently increase the strength of accelerated-cured test specimens as compared to the standard-cured specimens. This is especially true when low-heat cement is being used.

2. If the hot-water method had to be standardized, it would involve setting up of small field laboratories at points of curing for the purposes of capping and testing. This is most inconvenient and undesirable as pointed out by Mr. Abdun-Nur himself. The transportation of test specimens to a central laboratory mould involves excessive overtime because all transportation must be done after the first 24 hr. In the ASTM tentative standard under preparation, the full cycle being considered for this method is 26 hr and not 24 hr as Mr. Abdun-Nur claims.

Because of the above and many other deficiencies in this test method, the Canadian Standards Association Committee A.23 has not included this method in the list of three methods which are being considered for incorporation in its Standard.

Autogeneous curing method

1. The curing cycle of 46 hr is rather too long. If accelerated strength testing is to be an acceptable proposition, then the curing cycle must be less than 30 hr and preferably less than 1 day. A longer curing cycle creates the need for a large number of insulating countainers, and hence additional expense will be involved.

2. As curing is carried out inside an insulated container by heat generated during the hydration of cement, the test results obtained by this method are greatly affected by the initial temperature of concrete at the time of casting test cylinders. It is not uncommon to have concrete temperature of 60 F. in winter and up to 90 F in summer.

3. Very little or no strength gain, as compared to the strength of standard-cured specimens after 46 hr, will result when specimens made with low-heat cement concrete are being tested.

4. The results of accelerated strength tests are greatly affected if large doses of set-retarders are used, or if errors are made in the batching of set-retarders as is sometimes the case.

5. Overtime is very expensive, as pointed out earlier.

Because of some of the above reasons, one of the discussers, Mr. Rodway, has discontinued the use of the above method in the Calgary area.

Mr. Abdun-Nur questions the pooling of data from various sources without subjecting these to significance tests. In their full-length paper, the authors have given in detail the strength relationships for each different job. The data in Fig. 2 of the digest paper were deliberately pooled to show that in spite of the various universes, one can still get a reasonable correlation between the accelerated and 28-day strength tests. This is one of those cases where statistical theory has given in to practical reality.

Mr. Abdun-Nur mentions about safety when using the modified boiling method. This is really surprising because none of the other discussers have raised this point. Yes, there was one case in Canada in which a laboratory did run into the problem of excessive steam from the curing tanks. But this was due to the lack of proper design of accelerated-curing tanks; very large tanks were placed in a very confined area without proper thermostatic control. To avoid excessive steam even in a small tank, the writers have recommended in their original paper[7] that temperature in the tank be maintained at just below boiling point, i.e., 210 F.

Mr. Abdun-Nur's point regarding the effect of altitude on the boiling point of water is well taken. In any standard test, allowance has to be made for exceptional circumstances: Mexico City and Denver are exceptional cases and would have to be treated as such. Messrs. Lopez and Barreva from Mexico City are successfully using the method by maintaining a temperature of 196 F in their accelerated curing tanks. This is just a shade lower than the boiling point of water in Mexico City. In Mexico, the test should be standardized at this temperature. Similar modifications can overcome the problem in Denver. It is agreed with Mr. Abdun-Nur that the use of pressure vessels should be avoided at higher altitudes. To maintain the same maturity of test specimens at higher altitude as at sea level, the specimens should be cured at 196 F or 200 F depending on the altitude of the place, but the boiling duration could be increased to 3¾ hr or 3 hr and 40 min, respectively. The writers hope to provide some data in this regard in the future.

Mr. Lapinas questions the significance of the 30-min time limit between mixing and moulding of test specimens. This requirement was included to standardize the moulding procedure, and to emphasize that test specimens should be moulded at the very first opportunity to avoid loss of moisture from concrete in hot weather. The other requirement of keeping the specimen at 100 percent relative humidity was incorporated again to standardize the procedure and to emphasize that the test specimens should not be left out in direct sunshine or in very dry air as often happens in heated buildings. Both of the above requirements are "desirable" but not a "must" and can be somewhat changed to suit different job conditions.

Since the publication of the original data the authors have carried out an experimental program to obtain data on accelerated strength test using lightweight aggregate.[9]

Two types of graded lightweight aggregates were used, both of which were expanded shale produced by the rotary kiln method. Aggregate A, known as Aggrite was classified as "coated" and aggregate B, Haydite, as "crushed."

The relations between the accelerated and standard-cured strengths are shown in Fig. D and E.

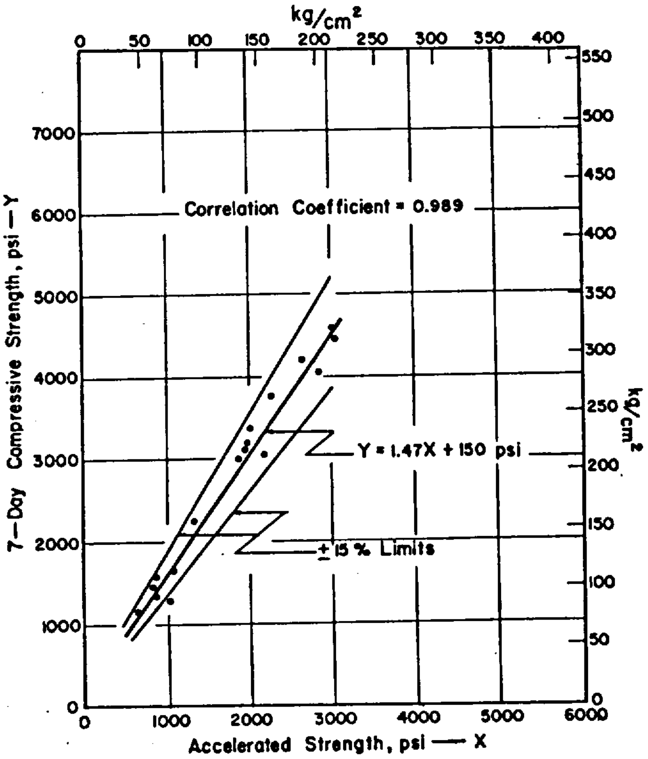

Fig. D — Relationship of accelerated to 7-day strength

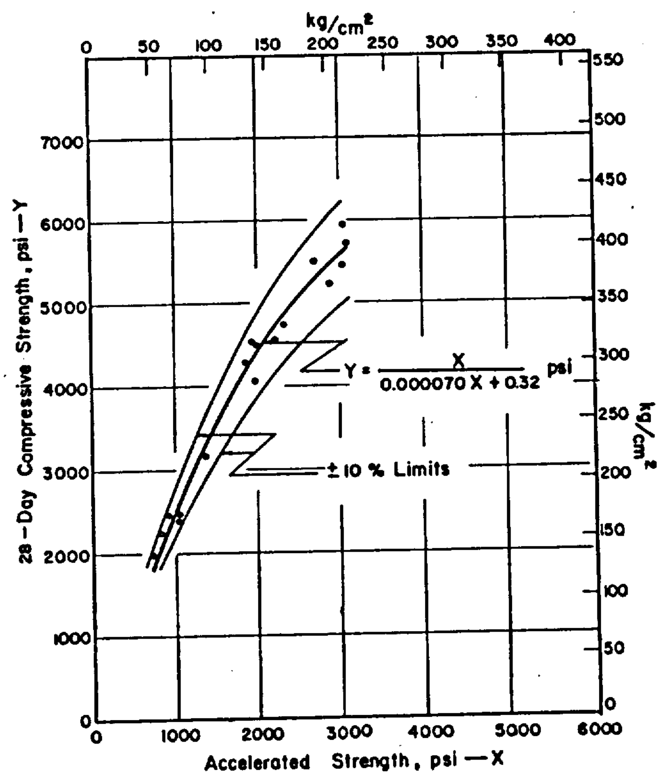

Fig. E — Relationship of accelerated to 28-day strength

In the accelerated curing procedure, though the elapsed time between moulding and testing was 28½ hr, the initial moist-curing period was reduced to 23 hr while the waiting period, between removal of the test specimens from the boiling water and testing, was increased to 2 hr.

The test data indicated that the modified boiling method was satisfactory for determining the strength development of lightweight aggregate concrete and for prediction of 7- and 28-day strengths at 28½ hr. If the same cement and the same accelerated curing cycle were used for both lightweight and normal weight concretes, the relationships between accelerated, and 7-, and 28-day strengths might be more nearly identical for the two types of concrete.[9]

We very much appreciate the actual field data submitted by Mr. Smith. The work at the billion-dollar Churchill Falls hydroelectric project emphasizes a number of ways in which accelerated strength testing can be used to design and control concrete mixes both in the laboratory and field.

Mr. Spratt's experience in the routine use of accelerated strength testing in Vancouver area is very interesting. It shows the enterprise of a testing organization to modify methods to suit its own needs. The writers have always insisted on the use of steel molds for accelerated strength testing, but Mr. Spratt's experience indicates no drop in reliability of test results when using a premium grade paraffin coated cardboard mold. Perhaps this is one field where more research work is needed. In the authors' original investigation, serveral admixtures were incorporated in concrete but no attempt had been made to isolate the effects of individual admixtures because the scatter in the results of the 28-day strength tests was within acceptable limits. Mr. Spratt's experience, that the addition of calcium chloride (2 percent by weight of cement) gives somewhat higher 28-day strength results than does plain concrete, is revealing and should be further explored.

The limited field data provided by Messrs. Howard and Bickley for jobs in Northern California and Toronto once more confirm the usefulness of the accelerated strength testing. We earnestly hope that Messrs. Howard and Bickley will publish their test results when they have accumulated sufficient data. The authors also await with interest the publication of data by Mr. Rodway.

Mr. Ryan reports wide use of an accelerated strength test by a ready-mixed concrete organization in Australia. Based on the analyses of a large number of test results, Mr. Ryan now uses only single cylinders for accelerated strength test. The writers would like to add a word of caution here for those who are just starting to use accelerated strength testing. Unless the user has proven to his satisfaction that, on his job, the reliability based on the accelerated testing of one test cylinder is of the same order as that based on testing two or more cylinders, he must use at least a set of two test cylinders for an accelerated strength test.

Mr. Ryan raises very valid points regarding the standardization of accelerated strength tests.

The authors feel that on the basis of the available test data the best standardization approach is that outlined by Mr. Mustard's discussion. The standardization committees should at least recognize the fact that accelerated strength tests are being widely used for quality control purposes and should standardize the test procedures without establishing any acceptance criterion. This would result in more test data being generated in the field on standardized test procedures.

The writers sympathize with Mr. Ryan's predicament regarding the premature acceptance of the two-stage acceptance criterion, i.e., at 24 hr and also at 28 days. The writers are, in principle, against such an acceptance criterion, but unfortunately the industry may have to go through this stage before finally abolishing the 28-day strength test. If the acceptance criterion were solely based on the accelerated strength test, then perhaps some cement manufacturer would come up with a cement blend which might give very high accelerated concrete strength, but might not give sufficiently high concrete strength at say 28 days or at 1 year. Thus it appears that, at this stage of our knowledge, if the accelerated strength test is to be used as an acceptance test, we will have to make sure that concrete will attain required strength at later ages. This can only be achieved by specifying a later-age strength for either cement or concrete.