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ANALYSES OF COMPRESSIVE STRENGTHS AFTER ACCELERATED AND NORMAL CURING OF CONCRETE ON THE CHURCHILL FALLS PROJECT

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SUMMARY OF RESULTS

The consultants for the hydro-electric development at Churchill Falls, Labrador, Acres-Canadian Bechtel of Churchill Falls (ACB), have adopted the accelerated test developed at the Mines Branch for routine strength determination of concrete at the project site. Analyses at the Mines Branch of preliminary laboratory data, compiled by the ACB, indicate that the test can be used to predict the 28-day compressive strength of standard-cured concrete cylinders with an accuracy of ± 10 per cent. Furthermore, the accuracy of predicted 28-day compressive strengths based on accelerated curing approximates that based on the 7-day strength of standard-cured specimens.

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INTRODUCTION

Since 1963, the Construction Materials Section of the Mineral Processing Division has been engaged in the development of an accelerated method of estimating the 28-day compressive strength of concrete. The findings of this research work have been reported (1-3).

Briefly, the accelerated method consists of standard moist curing of test specimens for 24 hours, followed by boiling in water for 3 1/2 hours and testing for compression one hour later.

ACB have adopted this method as one of the routine methods of estimating strength of concrete at the Churchill Falls, power project. Mr. P.K. Smith, Senior Concrete Engineer with ACB requested an analysis of preliminary test data obtained from the use of the standard and accelerated method and this was submitted on March 6, 1969.

TEST PROCEDURE AND RESULTS

All test data were obtained by ACB laboratory personnel.

Coarse and fine aggregate consisted of crushed granite gneiss and Sona lake outwash sand. The maximum size of coarse aggregate was 1 1/2 inch. The gradings of both coarse and fine aggregates are given in Table 1. Normal portland cement (ASTM Type I) used in the concrete mixes was obtained from North Star Cement Limited, Corner Brook, Nfld. The physical and chemical properties of the cement are given in Table 2. The admixture used was an air-entraining agent, obtained commercially.

The properties of the fresh concrete are summarized in Table 3, and the compressive strengths of accelerated- and standard-cured test specimens are given in Table 4.

A total of 23 sets of compressive strengths were submitted by ACB for analysis. The compressive strengths had been determined on sets of six 6 x 12-inch cylinders; of each set, one pair had been cured for 28 1/2 hours which included the accelerated test, one pair had been cured for 7 days, and the third pair had been cured for 28 days. Thus the total number of cylinders tested to obtain the data was 138.

TABLE 1

Grading of Typical Samples of Aggregates Used

Coarse Aggregate			Fine Aggregate	
Sieve Size	Per cent Passing		Sieve Size	Per cent Passing
2-in.	100.0		3/8-in.	100.0
1 1/2-in.	87.5		No. 4	97.0
1-in.	38.0	100.0	No. 8	92.5
3/4-in.	8.0	95.0	No. 16	78.0
3/8-in.	2.0	37.0	No. 30	42.0
No. 4	0.0	6.5	No. 50	13.0
			No. 100	4.5

TABLE 2

Physical Properties and Chemical Analyses of Normal Portland Cement*

Description of Test		
Physical Tests - General		
Time of Set (Vicat Needle):	Initial	2 hr: 15 min
	Final	2 hr: 45 min
Specific Surface - Blaine		3650 cm^2/g
Soundness - Autoclave		+0.40 %
Physical Tests - Mortar Strength (2-in. cubes)		
Compressive Strength:	3-day	2450 psi
	7-day	3150 psi
	28-day	4100 psi
Chemical Analysis		
Insoluble Residue		0.02 %
Silicon Dioxide (SiO_2)		20.80 %
Aluminum Oxide (Al_2O_3)		4.90 %
Ferric Oxide (Fe_2O_3)		3.15 %
Calcium Oxide (CaO)		61.80 %
Magnesium Oxide (MgO)		4.00 %
Sulphur Trioxide (SO_3)		2.90 %
Loss on Ignition		1.50 %
Others		0.75 %
Total		100.00 %

* Test Data on Cement Supplied by North Star Cement Limited

TABLE 3

Summary of Properties of Fresh Concrete

Mix No.	W/C*	Properties of Fresh Concrete			
		Temp, °F	Slump, in.	Unit Weight, lb/cu ft	Air Content, %
1	0.80	Temperature not Taken	2.00	148.6	4.7
2	0.70		2.00	147.7	5.4
3	0.60		3.00	149.1	5.0
4	0.50		2.75	150.4	4.4
5	0.50		3.25	149.7	5.5
6	0.40		3.00	148.2	5.7
7	0.35		1.00	152.4	3.6
8	0.35		2.00	150.7	5.3
9	0.80		3.50	144.8	7.2
10	0.80		3.25	146.6	6.0
11	0.70		3.50	147.3	5.7
12	0.60		3.50	147.6	5.9
13	0.50		3.50	149.7	5.7
14	0.40		3.25	153.4	3.6
15	0.40		3.00	151.2	4.7
16	0.35		2.00	152.6	4.8
17	0.35		2.00	151.8	5.1
18	0.35		3.00	153.5	3.7
19	0.35		4.50	144.3	8.8
20	0.55		2.25	154.0	2.4
21	0.55		2.50	149.2	5.8
22	0.55		2.50	149.6	5.2
23	0.55		2.50	149.2	5.9

* Water/Cement ratio by weight.

TABLE 4

Summary of Compressive Strength Tests

Mix No.	W/C*	Strength** of 28½-hr Accelerated-Cured Specimens,** psi	Strength** of Standard-Cured Test Specimens,** psi	
			7-day	28-day
1	0.80	735	1420	2315
2	0.70	885	1690	2900
3	0.60	1245	2405	3880
4	0.50	1980	3630	4925
5	0.50	1525	2615	4075
6	0.40	1855	3685	4595
7	0.35	3135	5140	6720
8	0.35	2650	4735	5750
9	0.80	565	860	1505
10	0.80	600	975	1785
11	0.70	875	1540	2485
12	0.60	1095	1950	2960
13	0.50	1705	2865	4120
14	0.40	2600	4605	5575
15	0.40	2370	4320	5445
16	0.35	3020	4975	5750
17	0.35	2685	4000	5605
18	0.35	2820	4620	5885
19	0.35	2115	3630	4980
20	0.55	1690	3115	4410
21	0.55	1370	2350	3695
22	0.55	1290	2305	3420
23	0.55	1245	2165	3200

* Water/cement ratio by weight.
** Average of two tests only.

ANALYSES OF TEST DATA

The analyses have been confined to comparing the compressive strengths of concrete after accelerated and 7-day curing with that after 28-day curing. In analyzing the data, a hyperbolic curve and a linear regression line were fitted to the relationship between accelerated and 28-day strengths, and between the 7-day and 28-day strengths respectively. A summary of the analyses is shown in Table 5; the within-batch coefficients of variation for the test data are shown in Table 6. Plots of the relationships together with the lines of best fit are shown in Figures 1 and 2.

TABLE 5

Summary of Compressive-Strength Relationships

Compressive Strength Relationship	Equation*	Standard Deviation, psi	Refer to Figure No.
Accelerated vs 7-day strength	$Y = 187 + 1.63X$	210	1
Accelerated vs 28-day strength	$Y_1 = \frac{X}{0.000052X + 0.307}$	271	2

* X = Accelerated strength
X_1 = 7-day strength
Y = 28-day strength

TABLE 6

Within-Batch Coefficients of Variation

No. of Test Results	Within-Batch Coefficient of Variation, per cent		
	28 1/2-hr accelerated strength	7-day standard-cured strength	28-day standard-cured strength
23	1.53	3.60	2.21
ACI Recommended values for excellent laboratory control < 3.0			

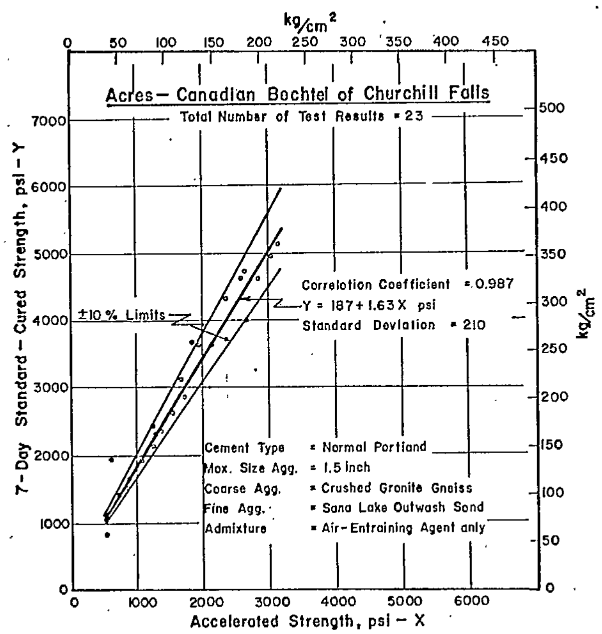

Figure 1. Relationship Between Accelerated and 7-Day Standard-Cured Strengths.

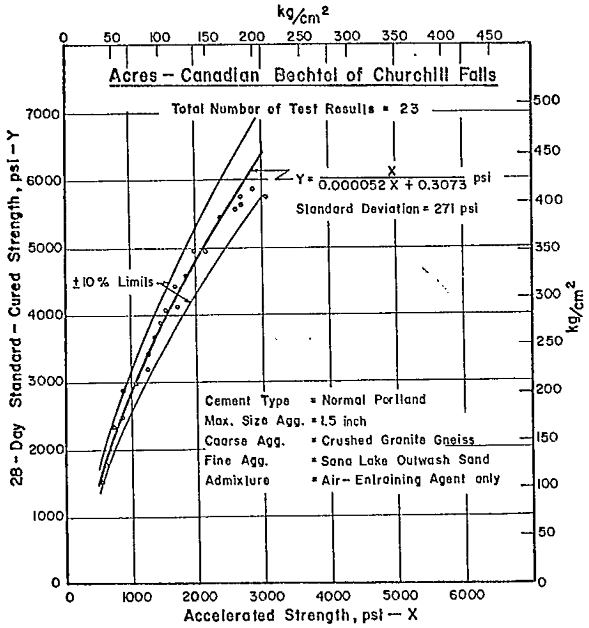

Figure 2. Relationship Between Accelerated- and 28-Day Standard-Cured Strengths.

DISCUSSION OF RESULTS

The compressive strengths of accelerated- and 7-day standard-cured test cylinders are in a straight-line relationship with a correlation coefficient of 0.987 (Figure 1). Figure 2 indicates that the compressive strengths of accelerated-cured test cylinders relate hyperbolically to those of 28-day standard-cured test cylinders. The standard deviations about the regression lines (Figure 1,2), which reflect the accuracy of estimates, indicate that the accuracy of prediction of 7- and 28-day compressive strengths based on accelerated strengths is satisfactory.

It should be noted that each strength test result was the average of tests on two 6 x 12-in cylinders. Increasing the number of cylinders from 2 to 3 at each of the above ages could increase the accuracy of prediction.

The within-batch variation for tests at various ages varies from 1.53 per cent for accelerated strengths to 3.61 per cent for 7-day strengths. The nature of the data supplied by ACB did not permit the calculation of between-batch variations.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the analysis of the data supplied by ACB the following conclusions and recommendations may be made:

The strength test after accelerated curing predicts the 28-day compressive strength of normally cured concrete with an accuracy of ±10 per cent. This accuracy of prediction of 28-day strength is at least as high as that based on 7-day strength test after normal curing.

When concrete structures are designed on the basis that concrete will reach a specified strength at either 91 days or one year, the strength test after accelerated curing can be used with advantage to predict the quality of concrete, and should replace strength predictions based on conventional 3-, 7-, or 28-day normal curing. If the accelerated-curing strength test is adopted for routine prediction of 28-day strngth, it is advisable to test one specimen at 7 or 14 days to ensure that a satisfactory rate of gain of concrete strength is being achieved. This should be checked further by regular testing of samples of cement being used on the job.

To use the accelerated strength test effectively, a minumum of two accelerated-curing tanks should be installed in a field laboratory so that testing will not be interrupted, should one tank cease to operate.

After the test has been in use for some time and more strength values have been plotted (Figure 2) the equation expressing strength relationship should be revised as necessary.

REFERENCES

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3. V.M. Malhotra and N.G. Zoldners, "Some Field Experience in the Use of an Accelerated Method of Estimating 28-Day Strength of Concrete" Mines Branch Internal Report MPI 68-42. August, 1968.

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