# PRACTICAL APPLICATION OF MATURITY CONCEPT TO DETERMINE IN SITU STRENGTH OF CONCRETE

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Strength of field-cured concrete has been estimated by correlating the maturity to strength, the maturity being a function of age and curing temperature. Additional standard cylinders are cast, and the maturity of in-place concrete is determined from thermocouples cast into the concrete pour or maturity meters installed during placing of the concrete. Standard cylinder strength and field maturity are then correlated, and in-place strength is determined by using constants for the concrete used. To check the validity of this approach, a series of strength tests on 4-in. (10-cm) cubes at various maturities were conducted in the laboratory. These sets of cubes were cast from concrete obtained from various job sites in Toronto. Seven and 28-day cylinder strengths predicted from low-maturity cylinder strengths of the same set were evaluated. The constants of the strength-maturity equation were determined to suit the local normal concrete and to compare the results with those of Plowman. A satisfactory correlation was obtained. The method was used to predict the in situ strength of concrete slabs during construction of buildings at the University of Waterloo in 1971 and 1972. The contractor could then strip the forms early and determine if there were any inadequate curing conditions during winter construction. Tests were made during construction to check the actual strengths of the in situ concrete and to compare them with predicted theoretical values. The results were satisfactory. The strength gain of lightweight concrete floor slabs of a 37-storied tower recently completed in Toronto was monitored to determine the earliest time when posttensioning operation of the slabs could be carried out safely.

THE standard method of determining the potential strength of concrete by using 6 by 12-in. (15 by 30-cm) cylinders cured in a fog room at 73.4 F (23 C) does not necessarily indicate the strength of the same batch of concrete in a structure. A number of people (1, 2, 3, 4, 5), mainly Plowman (3), have suggested methods of relating strength to maturity, maturity being a function of age and curing temperature. This approach to estimation of strength of a field-cured concrete has been successfully used on several occasions.

In practice, the method adopted involves the casting of additional standard cylinders and determination of the maturity of the in-place concrete. The latter is normally done by using thermocouples cast into the concrete pour or maturity meters installed during placing of the concrete. The data (standard-cured cylinder strength and field maturity) are then correlated, and the in-place strength is determined by using constants in the correlation equation for the particular type of concrete being used. Once a correlation between cylinder strength and the corresponding maturity is established, the strength of the structural element can be estimated from the maturity of the in situ concrete alone.

## LABORATORY TESTS

To check the validity of this approach, limited test programs were carried out. The first involved the casting, each day, of a set of 4-in. (10-cm) cubes from one of the

sites on which routine testing was taking place. On each day, the site from which the samples were taken was chosen randomly; therefore, the specimens represented various suppliers and ingredients. A total of 22 sets of test specimens were cast. Out of each set of four cubes, two were cured at temperatures between 20 and 25 F (-6.67 and -3.89 C), and the others were cured in the standard fog room at 73.4 F (23 C). Individual cubes were tested at different ages to produce a range of maturities. The test results of individual cubes were then used to cross-predict the strengths of the other cubes in the same set but of different maturities by using Plowman's constants (3) for rapid-hardening cement. Constants derived from our observations based on the equation, percentage of strength of 28-day standard-cured concrete = A + B (log $M/10^3$), where constants A and B were used in the same way as Plowman's, and M is the maturity in deg F (C) hours.

The following values of the constants were used for calculating the percentage strength of 28-day standard-cured concrete at 65 F (18.33 C) in the case of Plowman's constants and 28 days at 73.4 F (23 C) in the case of constants derived from local tests:

| Cement | From Plowman's Rapid-Hardening Cement | From Locally Conducted Tests |
|---|---|---|
| A | 31.8 | 41.3 |
| B | 43.6 | 36.4 |

The evaluated data are shown in Figures 1, 2, and 3. One can see in Figures 1 and 2 that a good correlation exists between the predicted and actual strengths of cubes cured in the fog room. It was felt that, if the predicted strength based on the equation, percentage of strength of 28-day standard-cured concrete = A + B (log $M/10^3$), is within ±10 percent of the actual strength of the concrete, the method is acceptable. However, erratic results were obtained on the cubes cured at a low temperature [20 to 25 F (-6.67 to -3.89 C)] as can be seen in Figure 3. All the concrete tested was in the strength range of 3,500 to 5,000 psi (24 to 34 MPa) at 28 days.

Similar evaluations of 7 and 28-day, standard-cured, 6 by 12-in. (15 by 30-cm) cylinder strengths were carried out, and values were predicted from low-maturity cylinder strengths of the same set (generally 2 to 3-day, standard-cured cylinders). These data are shown in Figures 4, 5, 6, and 7.

Except for a few cases, the predicted strength is generally within ±10 percent of the actual strength of the cylinders and is generally the lower limit when it is outside the range. In other words, the strength predicted by the equation is lower than the actual strength, which, from a construction point of view, is safe and is a warrant for adequate precaution in matters such as proper curing condition, particularly during cold weather construction. Therefore, the relationship put forward by Plowman (3) is valid within reasonable limits for concrete used in the Toronto area provided the concrete is cured under normal conditions.

## FIELD OBSERVATIONS

A limited field study was carried out at the Students Services and Administrative Studies Buildings, University of Waterloo, during the construction period in 1971. The tests were made to check the actual strengths of the in situ concrete and compare them with predicted strengths.

At the test sections of the concrete slab, thermocouples were installed, and extra cylinders were cast. At the same time 4-in.-diameter (10-cm) cylindrical tubes were installed in the slab adjacent to thermocouple locations. These tubes were constructed so that the concrete cast into them could be withdrawn on the day that the corresponding standard cylinder strength tests were made. The predicted strength from the maturity

**Figure 1. Test results of 4-in. (10-cm) cubes based on Plowman's constants.**

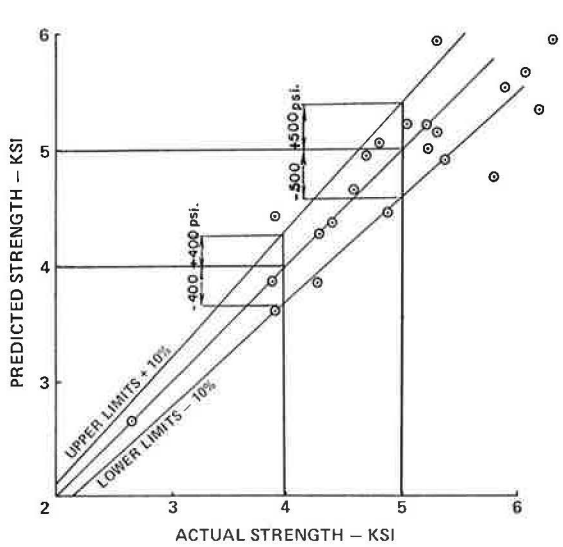



**Figure 2. Test results of 4-in. (10-cm) cubes based on constants derived from local tests.**

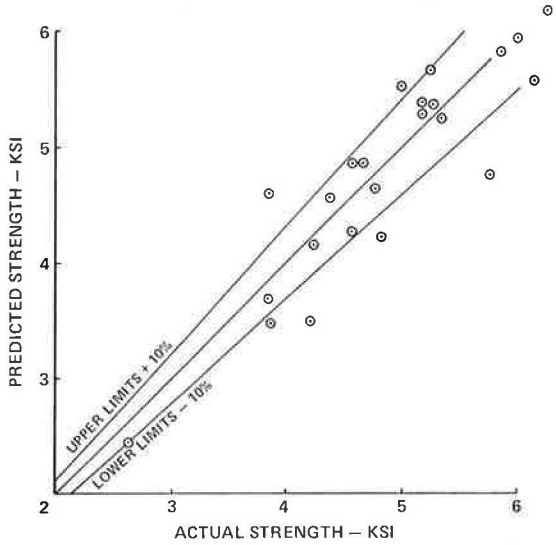


**Figure 3. Test results of 4-in. (10-cm) cubes cured in freezing condition.**

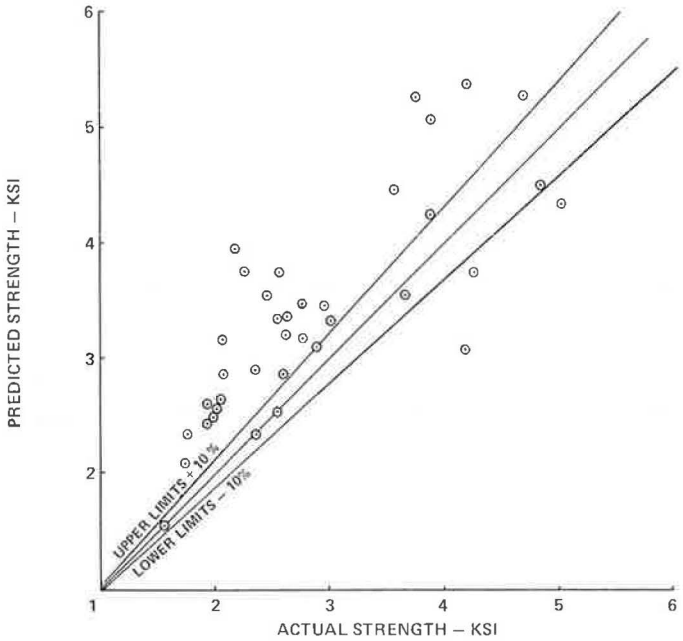



**Figure 4. Tests made on 6 by 12-in. (15 by 30-cm) cylinders from Students Services Building and based on Plowman's constants.**

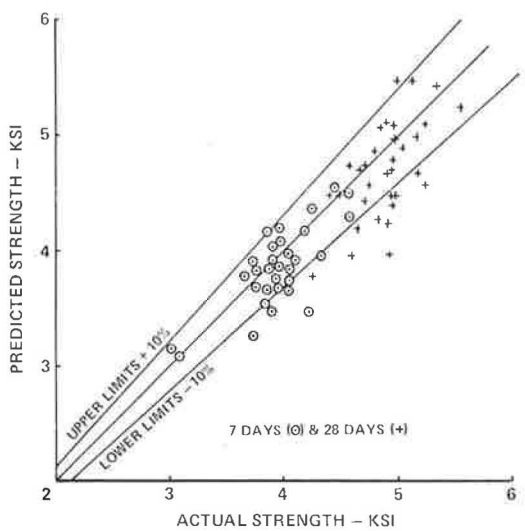



**Figure 5. Tests made on 6 by 12-in. (15 by 30-cm) cylinders from Students Services Building and based on constants derived from local tests.**

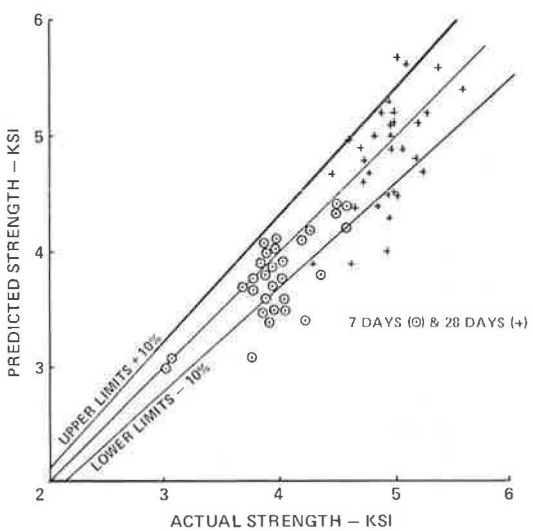


**Figure 6. Tests made on 6 by 12-in. (15 by 30-cm) cylinders from Administrative Studies Building and based on Plowman's constants.**

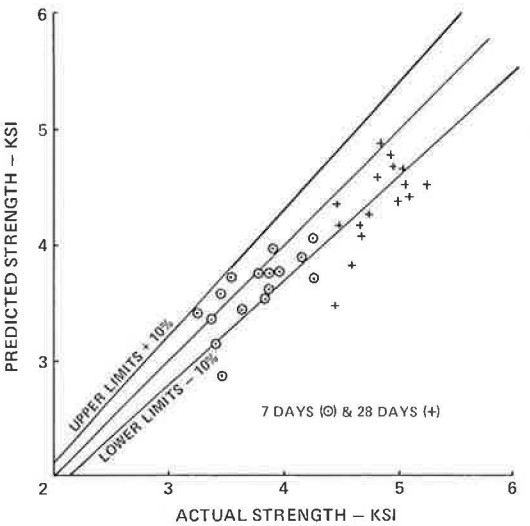



**Figure 7. Tests made on 6 by 12-in. (15 by 30-cm) cylinders from Administrative Studies Building and based on constants derived from local tests.**

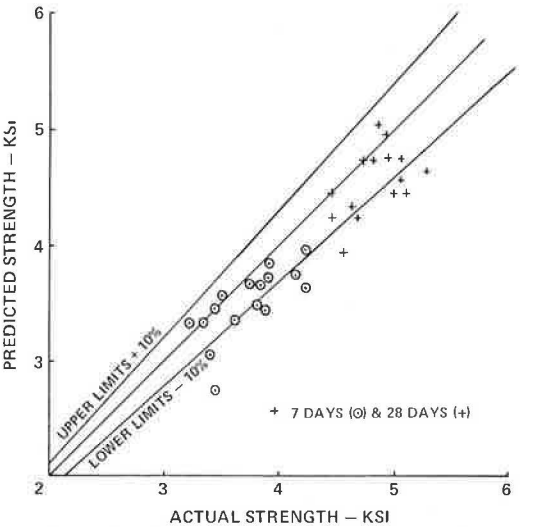
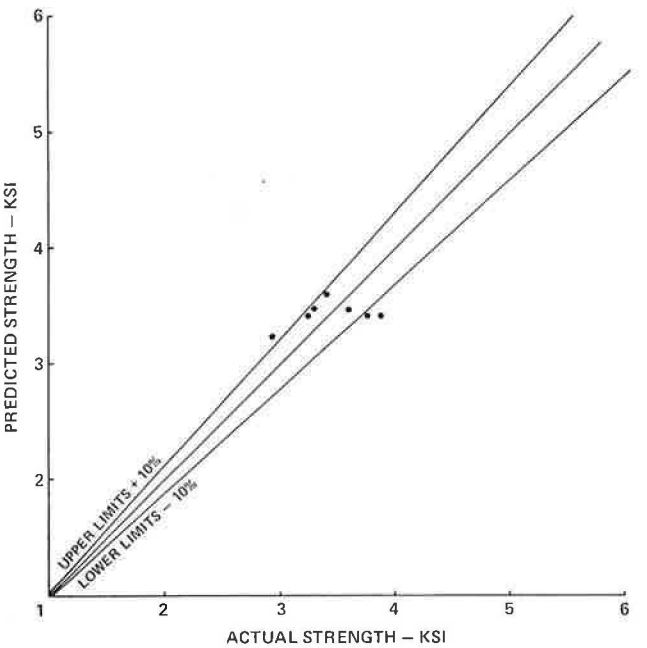



**Figure 8. Tests on 4-in. (10-cm) push-out cores.**



of the concrete and the actual strength of the push-out cylinder based on Plowman's equation are shown in Figure 8. In view of the small amount of test data and the small range of strength data, the correlation is not very clear. However, the predicted strengths of the push-out cylinders were close to the actual strengths.

This method indicates that the in situ strength of the concrete can be predicted with reasonable accuracy if the maturity of the field concrete and a relationship between the cylinder strength and the corresponding maturity are known. When the relationship between the maturity and the cylinder strength for a particular type of concrete is established, the monitoring of the field maturity alone could be repeatedly used on every floor of a building to help the contractor achieve early stripping of the forms or to indicate if there are any inadequate curing conditions during winter construction.

The strength gain of the lightweight concrete posttensioned floor slabs of the 37-storied tower recently completed by Direzione Lavori of Canada Limited in Toronto was monitored by maturity test. A requirement of a minimum concrete strength of 3,000 psi (20.7 MPa) was placed by the structural engineer before the posttensioning operation and the stripping of the form work could be carried out safely. The maturity of the concrete was checked every 24 hours, and immediate calculation of the in situ strength was made. This helped the contractor to achieve a faster rate of construction.

## CONCLUSIONS

Although a considerable amount of research in this field is needed to solve many unanswered questions, it is felt that this approach is a valuable means, from the economic as well as safety point of view, of estimating early strength gain of in situ concrete.

## REFERENCES

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