Evaluation of the Maturity Method for Flexural Strength Estimation in Concrete Pavement

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Summary:

The knowledge of early strength gain in concrete pavement is critical for deciding when a pavement has sufficient strength to open to traffic without incurring the risk of early cracking, and in structural engineering for determining when formwork can be safely removed. The current practice of estimating in-place concrete strength by testing large numbers of beams and cylinders in the field has been found to be inefficient and difficult.

The maturity method is a completely non-destructive technique for estimating concrete strength in the field. The objective of the work presented in this report is to provide Caltrans with information regarding the accuracy and feasibility of the maturity method for the measurement of concrete flexural strength of pavement slabs. Information is also provided regarding use of the maturity method for measurement of compressive strength.

This report is available from the Pavement Research Center Website:

www.its.berkeley.edu/pavementresearch

The full report provides detailed information on the four mixes used in the study including composition, activation energy (*E*) and datum temperature (T_0), compressive and flexural strengths as a function of time and their correlations with *E* and T_0 . A step-by-step process for using the maturity method is presented in the recommendations in the report.

To fulfill this objective, it was necessary to answer the following questions:

- 1. Is the maturity method applicable to the estimation of flexural strength?
- Is the maturity method applicable to Caltrans concrete mixes with special cements and/or chemical admixtures, such as Fast-Setting Hydraulic Cement Concrete (FSHCC)?
- 3. What is the best approach for implementation of the maturity method to meet Caltrans requirements? In particular:
 - · Which method (Nurse-Saul or Arrhenius) should be used to calculate maturity?
 - Is it necessary to measure datum temperature or activation energy in the laboratory?
 - How should maturity be measured in the field?
 - Should some beams or cylinders still be tested in the field?

Tasks performed to answer these questions include:

- 1. Instrumentation of slabs with four different mixes at three concrete pavement construction projects in District 8 to measure maturity,
- 2. Laboratory testing of flexural and compressive strength to develop maturity versus strength curves for each of the four mixes at three different curing temperatures,
- 3. Measurement of maturity in field cast and cured beams and cylinders on each of the four field projects, and testing of strength at several time intervals to compare maturity development in the slab versus field specimens, and to compare strengths predicted from the laboratory maturity curves with beam and cylinder strengths measured in the field specimens.

- 4. Analysis of the results to determine the applicability of the maturity method for the measurement of flexural strength,
- Development of recommendations for implementation of the maturity method by Caltrans.

Four mix designs from three construction projects were included in the laboratory and field experiments. These include: 1) I-40 at Ludlow, Type II mix, April 2002; 2) SR-91 at Riverside, Type III mix, February 2003; 3) SR-91 at Riverside, Type II/V mix, February 2003; and 4) I-15 at Victorville, Type II/V mix, June 2003.

Specimens for each of these mix designs were mixed, cast, and cured in the laboratory at three curing temperatures (10, 23, and 40°C). Specimens cured at 23°C were maintained at 100 percent relative humidity, and specimens cured at 10°C and 40°C were immersed in lime-saturated water when demolded 24 hours after casting. A total of 36 beams and 36 cylinders were prepared and tested for each mix design in the laboratory.

Temperature histories were measured in the laboratory specimens, the field specimens, and the field slabs. Maturity was calculated using the Nurse-Saul and Arhennius equations.

Conclusions and recommendations can be summarized as follows:

- 1. Applicability of the maturity method for estimation of flexural strength.
 - a. Reasonable correlations have been established between maturity indexes (*TTF* and t_e) and flexural strength during laboratory calibration of maturity curves for all four mixes included in this study.
 - b. Flexural strengths measured in field beams and flexural strengths predicted from the laboratory maturity curves were similar at early ages for the two Type II mixes checked against field beams. For the Type III mix, the field beams had

3

lower strengths than were predicted using the laboratory calibrated maturity curve.

- c. Maturity curves calibrated using data that included later age laboratory beam strengths tended to predict beam strengths that were greater than those measured in the field cured beams in some cases. This may be partly due to the temperature ranges experienced by the field beams as they developed strength being at the extremes of the temperatures used in the calibration of the laboratory maturity curves. It may also be due to differences in moisture conditions between the field and laboratory curing conditions. Field curing under wet sand may produce less humid conditions than the laboratory condition, resulting in lower tensile strengths due to drying shrinkage. Moisture conditions in the slab may be more similar to the laboratory curing conditions.
- d. The use of laboratory established compressive strength versus maturity curves to estimate the flexural strength is not recommended because the relation between compressive strength and flexural strength is not consistent across different mixes, and for a given mix may vary considerably with age and other variables.
- e. The results indicate that the maturity method using laboratory flexural strengths can be implemented for estimating flexural strengths for pavement construction.
 However, additional work is required for successful implementation, especially for Type III and other high early strength mixes.
- 2. Applicability of the maturity method to Caltrans concrete mixes with special cements and/or chemical admixtures

4

- a. Good correlations were found between maturity indexes [Time-Temperature Factor (*TTF*) and Equivalent Age (t_e)] and compressive strength of concrete during laboratory calibration of the maturity curves.
- b. Compressive strengths measured in field cylinders and compressive strengths predicted from the laboratory maturity curve matched well for one of the Type II mixes and the Type III mixes. For the other Type II mix (Victorville), the maturity method underestimated the compressive strengths of the field cylinders (i.e., was conservative). These results indicate that the maturity method is probably applicable to Caltrans mixes with special cements and/or chemical admixtures.
- 3. Implementation recommendations:
 - a. To calculate maturity:
 - The Nurse-Saul (*TTF*) method provided similar results to the more complex Arrhenius (t_e) method.
 - For the mixes considered in this study, the calculation of maturity indexes based on typically assumed values of Activation Energy (*E*) and Datum Temperature (*T*₀) appeared satisfactory.
 - The experimental determination of *E* and *T*₀ is recommended for "exotic"/special mixes only.
 - b. Recommended calibration procedure:
 - Perform calibration at three temperatures spanning the range of potential field temperatures for which the laboratory calibration curve for that mix may be used. The temperatures of 10, 23 and 40°C span the approximate range of

temperatures encountered on the three instrumented field projects included in this study. This calibration is necessary to be certain that the maturity assumption is true for the given mix. After sufficient field experience is obtained, it may be possible to reduce the laboratory calibration work to one curing temperature.

- Use specimens cured in 100 percent relative humidity conditions.
- c. Recommended measurement of maturity:
 - In the slab, the maturity meter should be installed close to the shoulder (around 300 mm from the edge), inserted at 50 mm depth.
 - The basic requirement of any maturity meter is that it must provide complete temperature history, not just the calculated values of one or more maturity indexes at specific ages. With the complete temperature history, the engineer can verify the calculations, double-check the results, and even alter parameters, guaranteeing a greater control of the process.
 - Wireless sensors read with a PDA equipped with an antenna were found by the field researchers to be the most convenient for field use. Sensors that require wires coming from the slab had the wires cut by construction equipment or laborers tripping over them several times during the study.
 Several data collection devices left near the slab were damaged by construction equipment or stolen during this study.
- d. Continued use of field testing of beams and cylinders:
 - Because of the relatively few projects included in this study, and the high cost of failure of pavements or structures if the maturity method were to

6

underestimate concrete strength, it is recommended that a limited number of flexural beams continue to be tested for pavements and compressive cylinders for structures. Once sufficient experience is gained with the maturity method, it is likely that the number of specimens to be tested can be reduced considerably.

- Several specimens should be cast from the field mix, cured at 23°C in the laboratory, and tested at several time intervals to confirm that the mix used in the field has a similar maturity curve to the curve developed from materials submitted by the contractor prior to commencement of construction.
- Several specimens should be periodically cast and cured in the field. As a check, these specimens should be tested when the critical strength has been estimated to have been achieved in the concrete pavement or structure. Maturity should be measured in these specimens for comparison with the strength predicted from the laboratory curve at same maturity.

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