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

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The C. N. Tower will be the highest free-standing structure in the world. The foundations contain 10,000 yd^3 (7646 m^3) of low-heat cement concrete, and accelerated testing was used throughout the concreting period. The slip-formed concrete superstructure is 1,464 ft (450 m) high and contains 40,000 yd^3 (30 580 m^3) of concrete. The accelerated test used during slip forming was the 48-hour autogenous test devised by Smith and Tiede. The last 3 months of slip forming were carried out from December 1973 to February 1974, the coldest period of the Canadian winter. Ambient conditions as low as 1 F (-17 C) were experienced, and wind-chill factors at heights above 1,000 ft (305 m) significantly increased the low-temperature effects. Maturity testing was done to check that, as the slip form rose, the concrete exposed to winter conditions achieved adequate strength. Thermocouples inserted during every shift were monitored at intervals throughout each 24-hour period, and in-place strengths were calculated. Monitoring continued until acceptable strengths had been achieved at each level. Evaluation was based on cores drilled from the structure and cylinder tests.

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COLD WEATHER PROBLEMS

Problems presented by cold weather are threefold. First, the steady rise of the slip form depends on the setting of the concrete proceeding normally during the few hours the concrete is in the form. Second, the concrete is only in the form for a few hours before it is exposed to the weather. Third, should the concrete on emerging into the cold ambient conditions be cooled before it has achieved adequate strength, the continued rise of the slip form could result in a significant height of the C. N. Tower above

a weak layer or layers of concrete.

The initial setting of the concrete for the C. N. Tower in Canada was fairly simply controlled by the use of heated concrete and radiant heaters directed at the slip form at the finishing level.

DESIGN OF PROTECTION

Protection of the concrete in the C. N. Tower after it had emerged from the form was a little more complex. Three-dimensional calculations showed that without protection the concrete would cool rapidly to ambient temperatures before it had gained adequate strength (Figure 1). Two to 3 days of protection with 1 in. (25.4 mm) of polystyrene would however give adequate strength. At a planned maximum rise of 12 ft/day (3.65 m), this meant that about 36 ft (10.97 m) of protection would hang below the slip form. However, the temperature gradients resulting as the concrete emerged into the cold air could crack the concrete (Figure 2). The final configuration of the protection was therefore 20 ft (6.09 m) of 1-in. (25.4-mm) polystyrene, 9 ft (2.74 m) of ½-in. (12.7-mm)polystyrene, and 8 ft (2.43 m) of ¼-in. (6.4-mm) plywood. This combination provided adequate protection for initial strength gain. It also allowed the concrete to cool sufficiently before it was exposed to the atmosphere to avoid temperature gradients severe enough to cause cracking (Figure 3).

STANDARD AND ACCELERATED TESTING

Throughout the concreting program, sets of five test cylinders were cast for each 75 yd^3 (57 m^3) of concrete.

Two cylinders were subjected to accelerated testing after 48 hours by use of the autogenous method developed by Smith and Tiede. The remaining cylinders were given standard laboratory fog-room curing. One was tested at 7 days, two were tested at 28 days, and one was tested at 90 days. Analysis of all standard cylinder tests gave the following results [the superstructure is 620 lb (280 kg) of varying proportions of types 1 and 4 cement per cubic yard (cubic meter) (1 psi = 6.9 kPa)]:

Age at Test (Days)	Mean Strength (psi)	Standard Deviation (psi)	Coefficient of Variation
7	5,190	432	8.3
28	6,900	432	6.1

Typical data devised from regression analysis for the relationships of accelerated tests to standard 28-day cylinder tests were as follows (1 psi = 6.9 kPa):

Cement Type	No. of Tests	y = mx + b	Sy·x (psi)	Correlation Coefficient	95 Percent Level of Signif-icance
1	43	y(28-day) = +1.3027 Ra(48-hour) + 1,392	341	0.8227	Yes
4	147	y(28-day) = 0.9162 Ra(48-hour) + 3,611	356	0.7173	Yes

Figure 1. Temperature curves for walls; no protection below finishing platform.

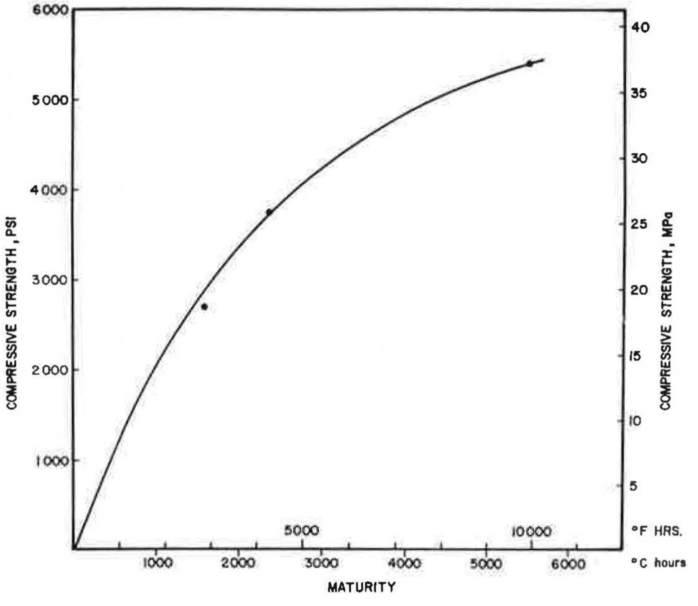


Figure 2. Temperature curves for walls; 36 ft (10.97 m) of 1-in. (25.4-mm) polystyrene below finishing platform.

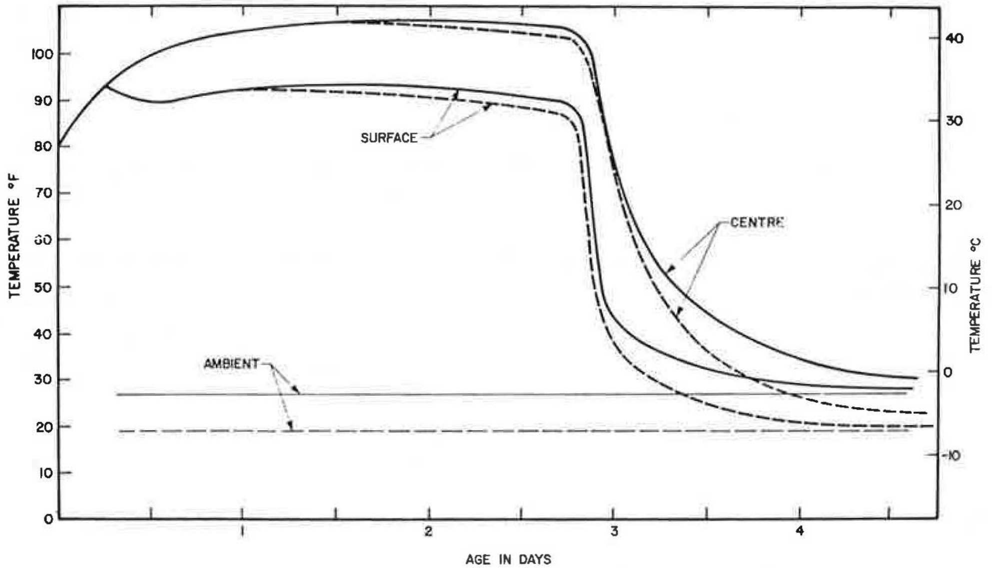


Figure 3. Temperature curves for walls; 20 ft (6.09 m) of 1-in. (25.4-mm) polystyrene, 9 ft (2.74 m) of ½-in. (12.7-mm) polystyrene, and 8 ft (2.43 m) of ¼-in. (6.4 mm) plywood below finishing platform.

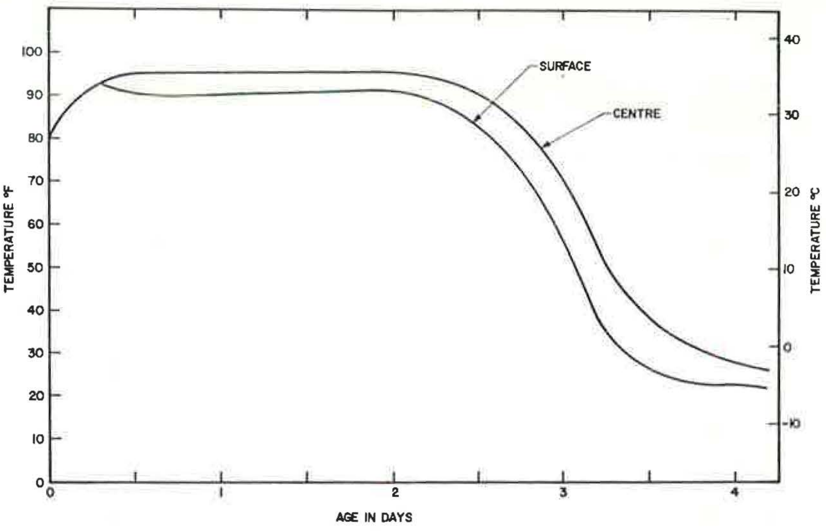


Figure 4. Strength-maturity plots for three thermocouples.

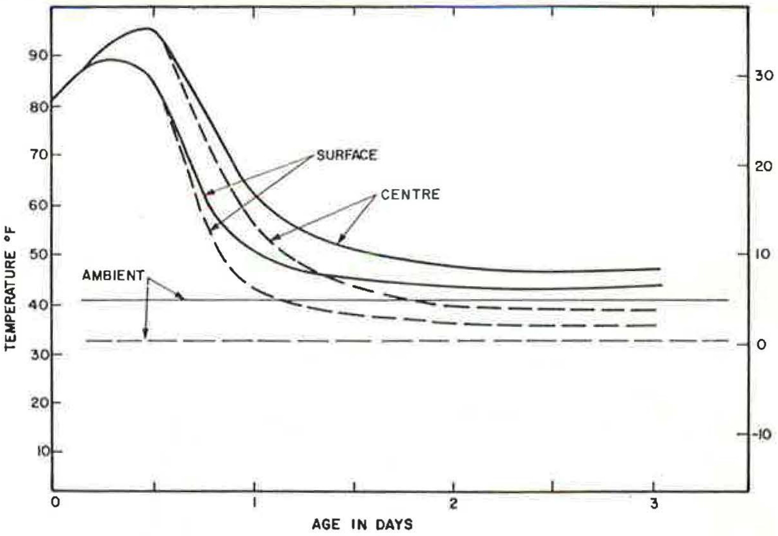
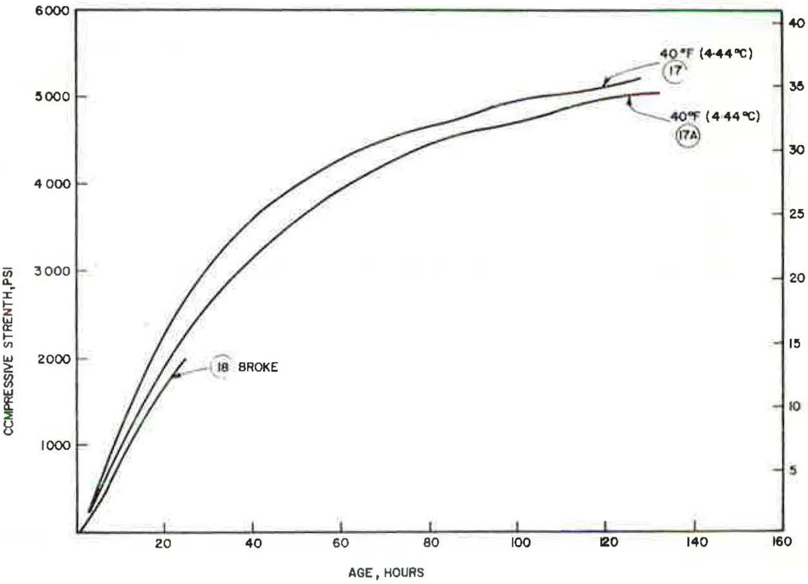


Figure 5. Strength-maturity curves for concrete mix used.



The concrete was uniform, and correlation coefficients for prediction of the 28-day strength from accelerated tests were good.

MATURITY TESTING

Before continual maturity testing was started on the C. N. Tower, some preliminary tests were made. Two cores drilled from the section of the structure chosen for the experiment were both tested at 4,710 psi (32.5 MPa) and at 7 days. Corrected to allow for the effect of overnight laboratory storage, these cores indicated in-place strength of 4,400 psi (30.3 MPa). In-place strength predicted from thermocouple readings of the same concrete was 4,250 psi (29.3 MPa).

After it was determined what strengths could be achieved, field checks were necessary to ensure they were consistently achieved. During each shift, a number of thermocouples were installed in the walls. Each thermocouple was on a free-turning reel fixed to the formwork to support the framework. As the form rose, the thermocouple wire unwound into the rising concrete. Readings were taken a number of times a day and were plotted on a standard form (Figure 4). Strength values were based on a strength-maturity curve previously established for the mix in use (Figure 5). The in-place strength of each shift of concrete was therefore known each day as it developed.

CONCLUSIONS

By the use of accelerated testing and in-place strength determinations, the adequacy of the concrete and thus the safety of the structure were continuously monitored. The results of the potential and actual strengths were available during the first 3 days after the concrete was placed. The concrete in the C. N. Tower was therefore known to be strong enough before it emerged from its protection.

Developments of this combination of advanced testing techniques offer great potential to the industry for safety and economy.