15 YEARS OF LIVING AT KINGSTON WITH A REACTIVE CARBONATE ROCK

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Shortly after a number of highway bridges had been built near Kingston, Ontario, in 1956 and 1957, alkali-carbonate rock reaction was identified as being a cause of concrete deterioration observed in the area. Shortly afterward adjacent concrete structures and pavements were built of concrete aggregate from the same dolomitic limestone formations but selected as being innocuous on the basis of short-term concrete prism expansion tests (expansion using job materials not to exceed 0.02 percent after 84 days' storage at 100 percent relative humidity). Comparing the field performance of concrete in both groups of structures for up to 15 years with the results of short-term, long-term, and accelerated laboratory tests shows that selective quarrying was a successful countermeasure. Whereas the earlier structures now show severe pattern cracking in moisture-prone exposures, those built later are free of blemish.

•IN 1972, Swenson summarized studies over the last 15 or so years into concrete deterioration attributable to the reaction of certain active minerals in concrete aggregates used in Canada with alkali components in portland cement (1). The first of these studies concerned concrete deterioration at Kingston, Ontario, where a dolomitic limestone concrete aggregate was quarried from certain lithologies in the Gull River (formerly known as Black River) formation of the Middle Ordovician system. In 1957, Swenson showed that, in this case, the observed disruptive expansion of concrete in service was the result of an alkali-carbonate rock reaction (2).

Just prior to Swenson's 1957 report, the Ministry of Transportation and Communications (then Department of Highways, Ontario) had started a major highway construction program in the Kingston area. Unwittingly, therefore, potentially reactive aggregates were incorporated in the first concrete structures built on the new highway. However, as already reported (3), both short- and long-term countermeasures were rapidly developed for the bulk of the work remaining, which involved about 250,000 yd^3 (191 139 m^3) of concrete in pavement and bridges.

Selective quarrying was employed to obtain from the same formation concrete aggregates that did not cause excessive expansion in concrete prisms made with the job materials and stored in the laboratory at 73.4 F (23 C) and 100 percent relative humidity. Originally the limit on tolerable expansion under these conditions with the then-available cement, which had a total alkali content in the order of 1.1 percent, was set not to exceed 0.05 percent at 84 days. As soon as some experience was available from the first screening tests, the limiting expansion criterion was reduced to 0.02 percent at 84 days, and the test method was standardized. From then on, expansions were measured of 3 × 4 × 16-in. (76.2 × 101.6 × 406.4-mm) concrete prisms, made with a standard coarse aggregate grading having $^3/_4$-in. (19.05-mm) nominal maximum size, a fixed cement factor of 525 lb/yd^3 (311.43 kg/m^3) using a cement of normal, for Ontario, alkali content (0.8 to 1.0 percent). The concrete was non-air-entrained, with a 3-in. (76.2-mm) slump.

Publication of this paper sponsored by Committee on Performance of Concrete—Chemical Aspects.

Laboratory testing in this investigation was mainly confined to measuring the length change of concrete prisms, but other exploratory tests, such as the petrographic examination of rock textures in thin sections, expansion of rock prisms, and the powder cell test, were also tried. The applicability of these other test methods to the "Kingston" type of alkali-rock reaction is adequately covered by Swenson (1) and the references cited therein. Accordingly, this paper is confined to revisiting the Kingston scene 15 years later to report on the field performance of both the concrete containing the reactive rock and that containing rock from the same quarries selected on the basis of the early-expansion criteria established for concrete prisms made and tested in the laboratory, and to relate this performance to the long-term behavior of concrete prisms under standard laboratory moist-curing.

PERFORMANCE OF CONCRETE IN BRIDGES AND PAVEMENTS

Figures 1, 2, and 3 are typical of distress to be seen in concrete containing a high-alkali cement and reactive aggregate after 15 years in service.

In no case has any of the concrete had to be replaced. The importance of the nature of the exposure of the affected concrete and the availability of moisture is obvious when making field inspections of the structures. In two circumstances pattern cracking and general deterioration is always worse: where water is channeled over the face of the concrete, as at joints, due to deficiencies in design, construction, or maintenance, or where the concrete stands with a readily available source of water at its base or back that can transpire from an exposed face.

Careful examination of structures of similar type and age on the same highway, within a few miles and with similar exposure conditions, that were built with high-alkali cement from the same mill but for which the concrete aggregate was selectively quarried, shows no sign of pattern cracking or distress whatsoever. Similarly, concrete pavements constructed with selected aggregates are free of distress. It should be noted that this particular exposure condition was considered to be potentially a very severe one, since sodium chloride used for deicing in winter could regenerate alkali in the pavement concrete if alkali-carbonate reaction occurred (3).

LONG-TERM EXPANSION OF LABORATORY SPECIMENS

The data originally reported (3) carried the expansion of concrete prisms containing aggregate from the Pittsburgh quarry at Kingston (the source of aggregate in most of the structures showing distress) to one year. The investigation of possible alkali-carbonate rock reaction involving other quarries in Ontario working the Gull River formation of the Middle Ordovician system led to the resampling and testing of the Pittsburgh quarry 0 to 24-ft (0 to 7.32-m) lift (containing the most reactive rock) in order to provide a comparative expansion yardstick (4, 5).

Expansion data are now available to the age of almost 7 years for 3 × 4 × 16-in. concrete prisms made with this reference aggregate and with low-alkali (0.45 percent) cement, with normal-alkali (0.8 to 1.0 percent) cement and with normal-alkali cement fortified by the addition of sodium hydroxide to the mix water to provide the equivalent total alkali (expressed as Na_2O) of 3 percent by weight of cement. Corresponding expansion measurements on rock prisms were also made. However, the rock prisms were made with flat rather than conical ends (ASTM C 586), and therefore it will be left to the report of the companion investigation (5) to provide a comparison between rock prism and concrete prism expansions, because, for the other quarries involved, conical-ended rock prisms (which are now standard) were measured.

Figure 4 shows the expansion of the concrete prisms to 2,300 days. In addition, because of the particular interest in establishing limiting expansions at an early age so that the test method can be of practical value for selecting "non-reactive" rock for concrete aggregate, the values up to 168 days are tabulated.

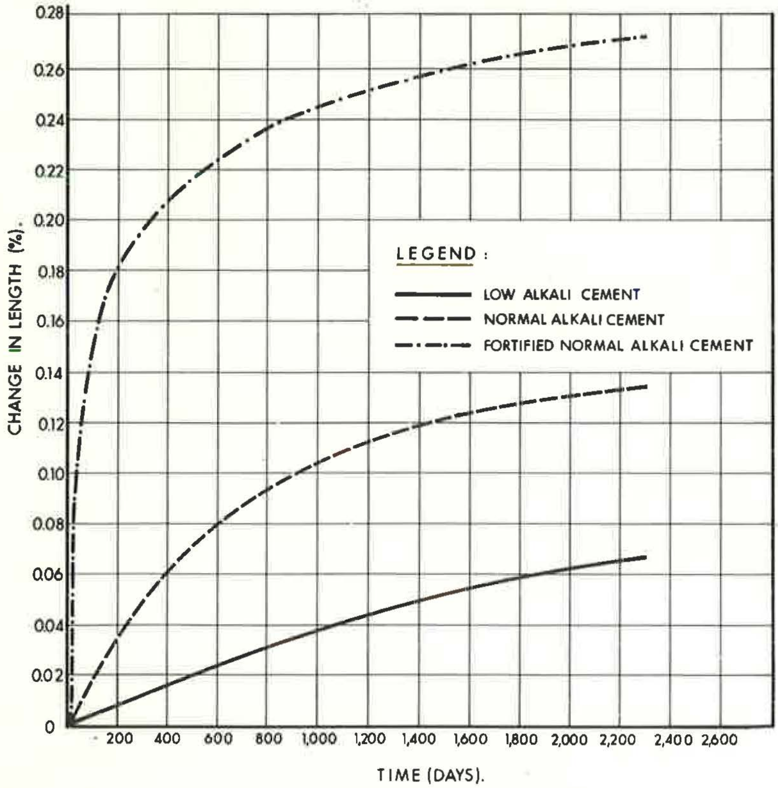
It will be noted that, with the low-alkali cement, and to a lesser extent with the normal-alkali cement, expansion at early ages is a somewhat erratic indicator of what might be expected later on. However, with the fortified-alkali (3 percent) cement the expansion is immediate, dramatic, and consistent.

Figure 1. In-water pier, Cataraqui Bridge, Hwy. 401, Kingston, after 15 years.

Figure 2. Abutment haunch, Sydenham Road Bridge, Hwy. 401, Kingston, after 15 years.

Figure 3. Wing wall, CPR Bridge, Hwy. 401, Kingston, after 15 years.

Figure 4. Long-term length change of conctete prisms containing reactive alkali-carbonate rock from Pittsburgh quarry, Kingston.



LENGTH CHANGE AT EARLY AGES

AGE IN DAYS *

	14	28	56	84	112	140	168
L	+0.0025	-0.0025	-0.0025	-0.0013	-0.0013	+0.0063	+0.0064
N	+0.0038	+0.0152	+0.0165	+0.0228	+0.0266	+0.0354	+0.0392
FN	+0.0089	+0.0444	+0.0964	+0.1350	+0.1549	+0.1730	+0.1800

** Age shown is the total time period in the moist room after making & demoulding prisms. Initial zero base measurement at 7 days.*

As noted in the earlier report (3), very obvious cracking is to be seen in concrete prisms when the expansion reaches between 0.10 and 0.12 percent, and minor cracking may be observed under magnification at about 0.05 percent expansion. The corresponding pattern cracking and distress that will follow within 15 years if structures are built with cement-aggregate combinations that produce expansions of this order during laboratory tests are vividly shown in Figures 1, 2, and 3.

CONCLUDING REMARKS

The investigation of alkali-carbonate reactivity of certain dolomitic limestone aggregates quarried at Kingston, Ontario, has now extended over a 15-year period.

Examination of the field performance of concrete structures incorporating reactive rock as coarse aggregate compared with that of structures incorporating rock from the same quarry that had been selectively quarried shows that rock selection has been a successful (and economical) countermeasure.

The basis established for selection of "non-reactive" rock—that is, the expansion of concrete prisms stored at 73.4 F (23 C) and 100 percent relative humidity for 84 days is not to exceed 0.02 percent—appears to be amply confirmed by the long-term performance of both concrete pavement and structures in the area. The acceleration of this test method by fortifying the normal-alkali "job" cement to 3 percent alkali is one of considerable promise. At 84 days, expansion is in the order of 6 times that occurring with the "job" materials. By no later than 21 days, a clear indication of unacceptable expansion is evident.

This investigation and its companion (5) have shown the clear benefit of involving geologists and petrographers from the beginning in the inspection and sampling of quarries and in the identification of suspect lithology by textural classification and length change of rock prisms. However, in all cases, the final engineering judgment as to the acceptability of a concrete aggregate must be based on the expansion of concrete prisms not exceeding a limit established by long-term in-service and laboratory performance.

ACKNOWLEDGMENT

This report is part of a long-term study of alkali-carbonate rock reactions in concrete in Ontario undertaken by the Engineering Research and Development Branch and the Materials and Testing Office, Construction Branch, Ministry of Transportation and Communications, Ontario.

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