The Influence of the Alkali-Silicate Reaction on Structures in the Vicinity of Sudbury, Ontario

E.R. Magni and C.A. Rogers

Engineering Materials Office
Ministry of Transportation and Communications
Toronto, Ontario, Canada

P.E. Grattan-Bellew

Institute for Research in Construction
National Research Council
Ottawa, Ontario, Canada

ABSTRACT

Argillites, greywackes and quartz arenites (quartzitic sandstones) of the Huronian Supergroup are alkali-reactive in Portland cement concrete. These metamorphosed sedimentary rocks are found in Northern Ontario from Blind River through Sudbury to New Liskeard. The percentage of the reactive rock types in the gravels of the Sudbury area is between 65 and 90 percent. Alkali reaction with these aggregates has resulted in the expansion and cracking of numerous concrete structures in the vicinity of Sudbury. Twenty six bridge structures in the Sudbury area are affected and many sections of sidewalk, and curb and gutter show pattern cracking. Many of the structures require or will eventually require extensive repairs. A general relationship exists between age of concrete and severity of distress.

GENERAL GEOLOGY

The reactive rocks are argillites, greywackes and quartz arenites (or quartzitic sandstones) of the flat-lying Huronian Supergroup which is of Middle Precambrian Age (>2160 million years). The distribution of the Huronian Supergroup is shown on Figure 1.

Glacial movement during the Pleistocene was generally in a northeast to southwest direction and glacio-fluvial gravels containing the reactive Huronian Supergroup rocks were deposited in a corresponding northeast/south-west trending zone incorporating Sudbury. The reactive particle content of the gravels ranges from about 15 percent near Englehart to 65 to 90 percent in the Sudbury area.

FIELD AND LABORATORY STUDIES

The problem of alkali-silicate reactivity was studied by field surveys of concrete structures as well as laboratory examination and testing of concrete containing the reactive aggregate.

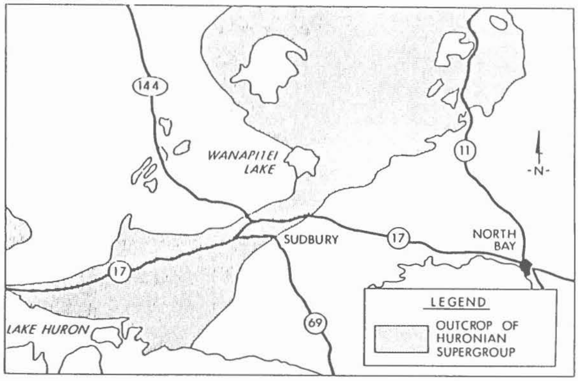

FIGURE 1: Outcrop of rocks of the Huronian Supergroup

a) Laboratory Studies on Sudbury Gravels

i) Prisms containing selected rock types

Grattan-Bellew conducted concrete expansion tests on prisms containing selected rock types (1978, 81). The greatest expansion was measured in prisms containing exclusively argillite. At 38°C, 100 percent humidity and 1.08 percent Na_2O equivalents, these prisms expanded 0.22 percent at 300 days. Prisms containing greywackes expanded on average 0.11 percent, while quartz arenites were the least expansive of the reactive rock types with expansions averaging 0.07 percent. Grattan-Bellew (1978) noted a relationship between porosity, microcrystalline content and expansivity of the various rock types. He observed that the microcrystalline material consisted mainly of illite and a mixture of microcrystalline quartz similar in appearance to chert. It was also noted that the composition and microstructure of the microcrystalline material in the argillite was almost identical to that of the greywackes and arenites, confirming the petrographic continuity of the suite. The occurrence of alkali-silica gel in all the prisms containing the different reactive rocks suggests the reaction mechanism probably involves microcrystalline quartz.

ii) Prisms containing gravels from the Sudbury area

Grattan-Bellew (1978, 81) conducted concrete prism expansion tests using gravels from the Airport pits located to the northeast of Sudbury. The expansion tests were carried out on prisms made with cement containing 0.68 and 1.08 percent Na_2O equivalent alkalies and 300 kg cement per cubic metre. A plot of expansion versus time for prisms containing the Airport gravel is shown in Figure 2. Expansions of 0.07 percent at 365 days for the gravel appears to confirm the severity of the problem observed in the field. The prisms were examined petrographically by MTC. Evidence of an alkali-aggregate reaction includes moderate to distinctive reaction rims, alkali-silica gel, and cracking of aggregates and cement paste. The gravels contain from 70 to 80 percent reactive material.

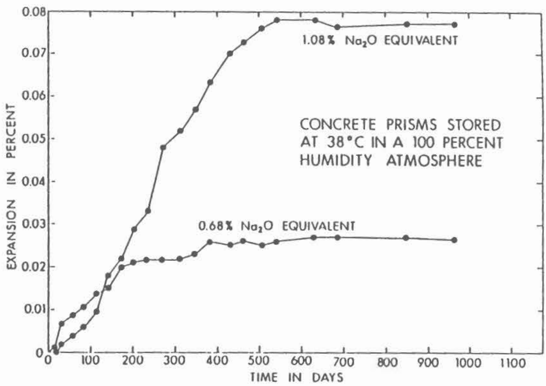

FIGURE 2: Expansion data for concrete prisms containing Sudbury Airport gravels

b) <u>Bridge Examinations</u>

Twenty-six bridges in the vicinity of Sudbury are affected by an alkali-silicate reaction. These ranged in age from four to forty-six years old (see Figures 3 & 4), and all show pattern cracking to various degrees in all elements exposed to moisture and de-icing salt (NaCl). Concrete samples from ten of these structures were studied in the laboratory. The results of this work is presented in Table 1. Rating systems to describe the severity of the reaction and petrographic observations are shown on the table. The concrete in these bridges contained from 67 to 90 percent reactive aggregates which appeared petrographically identical to the gravels from the Airport area. The severity of the reaction appears to be related to age. The bridges constructed in 1938 and 1940 have been replaced. The CPR structure on Regional Road 55 constructed in 1955 has been extensively rehabilitated and petrographic studies of this concrete confirm a severe reaction including moderate to abundant gel and moderate to extensive cracking. Many other structures require or will require rehabilitation. More recent bridges show progressively less field and laboratory evidence of an alkali aggregate reaction.

c) <u>Structures in the Municipality of Sudbury</u>

A large number of concrete structures in Sudbury were examined. These included bridges, retaining walls, sidewalks, and curb and gutter. The concrete was rated according to the severity of the reaction in the field. Much of the concrete in Sudbury placed before 1975 shows pattern cracking. Structures constructed before 1965 show moderate to severe reaction and have generally required considerable maintenance. Most curb and gutter construction between 1969 and 1975 shows minor to moderate reaction.

d) <u>Other Structures containing Huronian Supergroup materials</u>

A number of other concrete structures containing rock of the Huronian Supergroup further from Sudbury were also studied. Concrete examined in the New Liskeard area to the northeast of the study area contains from 40 to 55 percent alkali-silicate reactive aggregate. Assigning damage exclusively to the presence of the alkali-silicate reactive aggregate is complicated by the presence of Palaeozoic chert in the fine aggregate which is undergoing a conventional alkali-silica reaction.

Lady Evelyn Lake Dam west of New Liskeard was constructed in 1925 and replaced in 1972. The concrete contained about 80 percent alkali-silicate reactive aggregate and was severely cracked and displaced at the time of its replacement (Dolar-Mantuani, 1969). This concrete also contained a trace of Palaeozoic chert in the fine aggregate. The Maskinonge Dam north of Sudbury was built in 1926 and is still in service. It contains about 85 percent alkali- silicate reactive aggregate and shows evidence of severe reaction.

The Serpent River Bridge (Fig. 4), east of Blind River and to the southwest of Sudbury is severely cracked and has required extensive maintenance over the years. The deterioration of this structure has been compounded by freeze-thaw damage and corrosion of reinforcing steel.

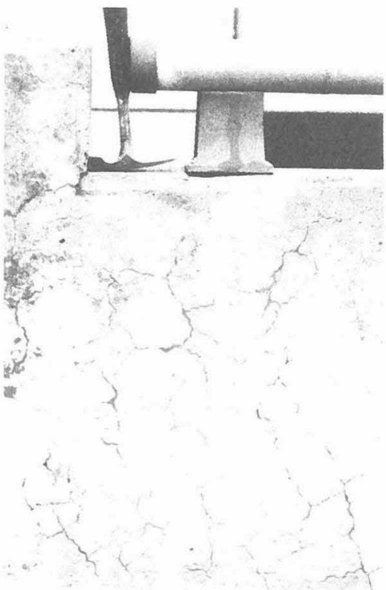

FIGURE 3: Bridge Structure constructed in 1980. Moderate reaction after 4 years.

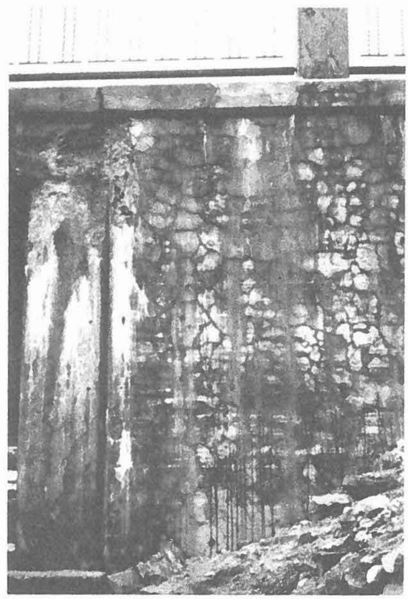

FIGURE 4: Bridge Structure constructed in 1938. Severe reaction after 47 years.

CONCLUSIONS

1. A large number of concrete structures in Sudbury and vicinity were studied in the field. Most show signs of an alkali-aggregate reaction including pattern cracking and expansion. At least five structures have been replaced and many have required extensive maintenance. Petrographic examination of concrete from many of these structures showed evidence of reaction rims, alkali-silica gel and cracking on a microscopic scale. It is concluded that gravels of the Sudbury area that contain rocks of the Huronian Supergroup are potentially alkali-reactive and can cause deterioration of concrete. Argillites give rise to greater expansion than greywackes in the concrete prism expansion test. These in turn cause more expansion than quartz-arenites.

2. There is no evidence that concrete fine aggregates produced from the Sudbury gravels are reactive.

3. Many of the structures affected by the alkali-silicate reaction have also experienced freeze-thaw damage and corrosion of reinforcing steel. It is concluded that initial cracking resulting from the alkali-aggregate reaction accelerated these other destructive mechanisms.

4. Acknowledging the fact that the structures examined vary significantly in construction method and material content, a definite relationship between age of concrete and extent of deterioration was recognized. Pattern cracking can generally be observed between 5 and 10 years after construction, significant maintenance is usually necessary after 25 years, and a number of structures have been replaced at 40 years.

5. Selection of concrete aggregates in the region is currently based on petrographic examination. A maximum of 15 percent argillites, greywackes, quartz arenites and arkoses of the Huronian Supergroup is allowed in concrete coarse aggregate. The most promising test is the concrete prism expansion test at 38°C and 100 percent humidity. A reliable maximum expansion value to separate deleterious from satisfactory aggregates has not yet been determined. Preliminary work suggests an expansion of 0.04 percent or greater at 1 year would rate aggregate as deleterious.

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TABLE 1

RESULTS OF FIELD SURVEY AND PETROGRAPHIC EXAMINATION OF CONCRETE FROM BRIDGE STRUCTURES IN THE VICINITY OF SUDBURY

SITE	STRUCTURE	YEAR	FIELD OBSERVATIONS		PETROGRAPHIC EXAMINATION	
			SEVERITY OF REACTION	COMMENTS	% REACTIVE AGGREGATE	PETROGRAPHIC OBSERVATIONS
1	Veuve River Br., Hwy. 17	1938	Severe	Bridge replaced in 1970	76	Moderate reaction rims; moderate gel; minor cracks
2	Wanapitae River Br., (Old Bridge), Hwy. 17	1940	Severe	Bridge replaced in 1974	90	Moderate reaction rims; abundant gel; moderate cracks
3	CPR Br., RR 55	1955	Severe	50% of deck replaced in 1984	72	Distinctive reaction rims; abundant gel; extensive cracks
4	Wanapitae River Br., Hwy. 69	1956	Minor	-	81	Moderate reaction rims; minor gel; moderate, continuous cracks
5	Vermillion River Br., Hwy. 144	1959	Minor	-	83	Minor reaction rims; minor gel; one crack
6	Witson River Br., RR 15	1967	Moderate	-	67	Moderate reaction rims; minor gel; moderate cracks
7	Bailey Creek Br., Hwy. 144	1967	Moderate	-	68	Moderate reaction rims; minor gel; minor cracks
8	Junction Creek Br., Sudbury S.W. Bypass	1973	Moderate	-	72	Moderate reaction rims; minor gel; minor cracks
9	Wanapitae River Br., (New Bridge), Hwy. 17	1974	None	-	70	Minor reaction rims; no gel; minor cracks
10	RR 55, Hwy. 17	1980	Moderate	East bound structure	72	Minor reaction rims; minor gel; minor cracks

LEGEND: Evidence of Reaction in Field

None - No pattern cracking observed at time of field visit.
Minor - Pattern cracking observed but judged not likely to increase maintenance costs or reduce life.
Moderate - Pattern cracking observed and judged likely to eventually result in increased maintenance costs or reduce life.
Severe - Pattern cracking observed and currently causing or has caused need for maintenance and reduced life.

Petrographic Observations

Cracking - extensive (most particles)
- moderate (half particles)
- minor (1-5% particles cracked)

Gel - abundant (filling most voids)
- moderate (filling half voids)
- minor (filling 1 to 2% of voids)