ALKALI-AGGREGATE REACTION IN WESTERN CANADA: REVIEW OF CURRENT TRENDS

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Abstract

This paper presents an update of information on Alkali-Aggregate Reaction in the western provinces and northern territories of Canada. Previous papers on this topic were published for the 11th ICAAR in Quebec Canada. Considerable additional data has been developed throughout western Canada over the past ten years, and this data has been compiled herein to enable a more comprehensive perspective of this issue in concrete engineering and the geology of aggregates..

The survey presented herein utilizes aggregate testing data from numerous sources, including aggregate producers, concrete suppliers, project data files, mine developments, highway construction projects, and other civil engineering projects. In addition, information on new cases of AAR identified in concrete structures from sites within western Canada is given.

KEYWORDS: AAR, concrete aggregates, cement, concrete, western Canada.

1 INTRODUCTION

With a total land area of approximately 6.3 million km^2, the western provinces and territories of Canada represent over two-thirds of the total land area of the country (Figure 1). Within this area, there are about 10.2 million residents. The diversity of landforms, climate and geology within western Canada provides for a variety of circumstances, as natural resources are utilized as aggregates in the construction of buildings, highways, infrastructure and civil works, dams, mines and the manufacture of products.

This paper examines the trends and data available for aggregates that are or have been used in western Canada, as they pertain to the potential for Alkali-Aggregate Reaction (AAR) in concrete. In addition, we review new information concerning cases of AAR within the region. These data are intended to provide an update of previous papers, most notably Roy and Morrison (2000) and Shrimer (2000).

2 BACKGROUND

2.1 Geology, landforms and aggregate supplies

Throughout western Canada, aggregates are produced from various types of sources, depending upon the geological setting, the nature of the requirements for aggregates, and the market for the products. Numerous sources of aggregate, for example, have been developed for use in specific projects, such as dams or mines. In addition, Provincial and Territorial governments commonly hold title to aggregate sources on Crown (i.e., government-owned) lands, typically held in reserve for use by the Provincial Highways/Transportation Ministry. The remainder of aggregate sources are developed on a commercial basis, for use within a regional or local market. These may be privately-owned, or may be developed on Crown Lands.

A few sources – some of them significant, large-size supplies – have been developed specifically or largely for shipment to distant markets, rather than for use in local/regional markets. These sites are located in coastal British Columbia, from which aggregates are shipped to US markets in California, Hawaii, Oregon and Washington. Minor cross-border shipping of aggregates occurs in other locations along the international border, with shipments from Canada going to US states, and vice-versa.

Aggregate supplies in western Canada are dominated by sources of natural, glaciofluvial or fluvial granular materials, namely, sand and gravel deposits. Quarried supplies of aggregates, i.e., blasted and crushed bedrock formation sources, tend to be the exception rather than the rule, in most western Provinces and the Territories. Exceptions to this supply scenario do exist, however, in south coastal British Columbia, where quarried supplies are increasing, and in the Winnipeg, Manitoba area, where several carbonate rock quarries produce aggregates. In both these areas, quarried aggregates are used in concrete production, although the current proportion of their use is low to moderate.

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Total aggregates consumption within the western Canada region is estimated to be on the order of 175 – 200 million tonnes per annum.

2.2 Concrete materials: aggregates, cements, supplementary cementing materials

Aggregates

As noted above, aggregates are sourced from both quarried bedrock supplies as well as from sand & gravel pits. Aggregates that are used for production of concrete are required to comply with specifications developed by the Canadian Standards Association (CSA), including specific criteria for the avoidance of deleterious AAR in concrete. Most commercial supplies of aggregate are capable of complying with the physical durability requirements set out in CSA, but there is considerable variability in the characteristics of aggregates in terms of their AAR potential.

Cements

In western Canada, cements are mainly sourced from British Columbia, Alberta and Ontario. Alberta cement production is from Inland Cement in Edmonton and Lafarge in Exshaw, Alberta. Cement plants in BC are operated by Lafarge in Kamloops and Vancouver, and by Lehigh Cement, also in Vancouver. Two plants in Winnipeg Manitoba which formerly produced cement were closed by the early 1990s; these now operate as distribution facilities only. In the past as now, Ontario cement plants have also supplied cement to some locales in western Canada.

With such a variety of cements, there are variable alkali contents, with Ontario-produced cements generally reporting higher Na_2O-equivalents (e.g., 0.6 – 1.0%), while western-produced cements tend to have alkali contents that range from 0.35% to 0.65%.

The use of blended cements in western Canada is uncommon, as these products are not typically produced in western Canada cement plants. Some imported cements, produced in Ontario, incorporate a ground granulated blast furnace slag blend.

Fly Ash

Power plants located in Alberta, Saskatchewan, and US border states supply various fly ashes for markets in western Canada. Fly ash sources in common use include: Centralia (Washington), Sundance (Alberta), Genesee (Alberta), Forestburg (Alberta), Boundary Dam and Shand (Saskatchewan), with other sources in Montana, Wyoming and North Dakota providing some material as well.

Silica Fume

This material is typically imported from US suppliers. Its use in certain applications (bridge decks, shotcrete, etc.) is relatively common.

Other SCMs

Other sources of SCMs within the region include the recent development of a metakaolin deposit in Saskatchewan (Whitemud Resources). Other kaolinite supplies are imported from the US.

Ground granulated blast furnace slag (GGBFS) is not typically in use in western Canada.

The use of lithium products is not common, although lithium has been used in some applications. This material is available from US admixture firms.

2.3 Methods for the assessment of AAR potential

General

Typically, assessment of the potential for AAR of aggregates intended for use in concrete begins with Petrographic Examination, per CSA A23.2-15A, to identify the rock and mineral types that comprise fine and coarse aggregates. This information is then used to identify whether the material may have a potential for alkali-silica reaction (ASR) or for alkali-carbonate reaction (ACR). Petrographic Examination may require in-depth analyses including thin-section/polarized microscopy, Scanning Electron Microscopy (SEM), X-Ray Analysis (XRA), X-Ray Fluorescence (XRF) and other techniques.

Secondly, length-change-based tests that involve the preparation of bars of mortar or larger concrete prisms made using the aggregates under evaluation are frequently conducted to assist in assessment of AAR potential. Consisting of the Accelerated Mortar Bar Test (AMBT) (CSA A23.2-25A) and the Concrete Prism Test (CPT) (CSA A23.2-14A), these are most commonly used for assessing ASR potential. Although ACR may also be measured using the Concrete Prism Test (CPT), assessment for ACR is typically undertaken using a chemical analysis test (CSA A23.2-26A). This may be supplemented by the "Rock Cylinder" method given in ASTM C 586.

Thusfar, no cases of ACR-prone carbonate aggregates have been reported in western Canada, although carbonate resources that may be utilized as aggregate exist throughout the region and have been and continue to be in production in western Canada as sources of aggregate.

Two predictive analysis methods are provided in CSA A23.2-04 ("Concrete materials and methods of concrete construction/Methods of test and standard practices for concrete") to assist in predictive assessments of AAR. These consist of CSA A23.2-27A, *"Standard practice to identify degree of alkali-reactivity of aggregates and to identify measures to avoid deleterious expansion in concrete"*, and CSA A23.2-28A, *"Standard practice for laboratory testing to demonstrate the effectiveness of supplementary cementing materials and lithium-based admixtures to prevent alkali-silica reaction in concrete"*.

3 AGGREGATE TESTING DATA FOR AAR

Manitoba

In Manitoba, AAR data has been collected from several regions, including Winnipeg, Stonewall, Brandon, Steinbach, Churchill, Flin Flon, The Pas, Dauphin, Beausejour and Thompson. The data indicate that, overall, AAR potential within the province is relatively low, both for natural sand and gravel deposits as well as for most quarry sites (see Tables 1 and 2).

The plentiful carbonate rock deposits at Stonewall are composed of primarily of dolomite, but testing to-date has indicated that these formations possess no potential for either the ACR or the ASR forms of the reaction. Typical chemistry data, given in Bannatyne (1988), indicate that compositions are not consistent with those of potentially reactive carbonate rocks, as encountered in eastern Ontario and Quebec. The non-reactive nature of these rocks has been confirmed in testing of various Stonewall-area carbonate quarries, using the CSA A23.2-26A test procedure.

Saskatchewan

Aggregate resources in Saskatchewan are dominantly sand and gravel, with some quarried rock mined in central-eastern and northern parts of the province.

AAR data for Saskatchewan aggregates is not extensive, and the results indicate variable potential for AAR, ranging from aggregates with low AAR potential to aggregates of moderate AAR potential. Roy (2000) reported the presence of reactive aggregates at the Gardiner Dam project site in southern Saskatchewan as well as in the Cypress Hills region.

Alberta

There is a relatively extensive dataset for AAR testing from Alberta. Previous documentation was published in Morgan & Empey (1989), Fournier, Bilodeau and Malhotra (1997) and in Roy & Morrison (2000). The updated data confirms the previous work, and continues to show that reaction potential for Alberta aggregates can range from "low" to "high".

Most aggregates in central Alberta and the Edmonton area tend to exhibit moderate to high AAR potential, based on testing of the aggregates in the Concrete Prism test. Selected data are illustrated in Figure 9. Reactive rock types in Edmonton-area aggregates include quartz-rich sandstones, quartzites, and chert.

AAR data for Calgary and southern Alberta are illustrated in Figures 8 and 9. Reactive rocks in this region include volcanic rock, sandstone, chert and quartzite.

Northern Alberta requires significant aggregate supplies to meet the demand of the developing energy projects and related infrastructure growth at and near Fort McMurray. The aggregate supplies in the Fort McMurray region tend to exhibit low to no potential for AAR, based upon the results obtained in Accelerated Mortar Bar tests (AMBTs) (Table 1 & 2).

British Columbia

Potential AAR levels for aggregates in British Columbia have been described previously in Shrimer (2000a). Additional test data included in this survey confirm the previous outlook, and shed further light on sites for which data had not been developed.

Aggregates on Vancouver Island tend to exhibit expansions in the AMBT which exceed the CSA 14-day limit of 0.15% expansion slightly, but do not expand above the one-year expansion limit of 0.04% in the CPT (see Table 1 & 2, Figs. 8-9). A few Vancouver Island supplies have been identified that give higher expansions in the AMBT. Rock types are dominantly mafic volcanic rocks.

South coastal BC/Fraser Valley aggregates can be characterized on the basis of their general mode of origin and location: (a) granitic rocks that comprise the Coastal Mountain Range; (b) Fraser River/Cascade glacial/fluvial aggregates (c) Garibaldi-volcanic derived sediments.

Many of the aggregates of Coast Mountain provenance tend to have no or low AAR reactivity potential, while Fraser/Cascadian sediments often have reactivity levels that classify them as 'moderately' to 'highly' reactive. These materials contain reactive rock types including quartzite, volcanic rocks, chert and sandstone, with mixed metamorphic and granitic rocks.

Glaciofluvial sediments that contain volcanic rock derived from the Garibaldi-Whistler region can be classified as "highly reactive", with measured length-change expansions as high as 1.20% at 14 days in the AMBT (Table 1). Initial studies have shown that these materials consist of felsic to intermediate volcanic rocks, some containing abundant glass. In addition, opal has been identified in concrete made with these aggregates.

The Interior region of BC includes highly varied aggregate geology and modes of occurrence, with aggregates running the range from sedimentary to metamorphic, plutonic and volcanic igneous rocks. There is a growing body of AAR testing data for Interior aggregates, and the general trends are illustrated in Figures 8 & 9. Review of these graphs shows that a large proportion of these aggregates tend to exceed the AMBT 14-day expansion limit, but that a lower percentage exceed the one-year CPT expansion limit (Table 2).

Thus, the AMBT limits tend to be exceeded frequently with many BC aggregates, and as a result, it is generally recommended that concrete aggregates be evaluated using the one-year CPT. The AMBT can be used as a rapid quality control tool, in cases when it is important to develop AAR data in a short timeframe, or to "calibrate" the AAR characteristics of production aggregates on a periodic basis. However, its data cannot be relied upon as strict and reliable indication of potential for AAR, without undertaking additional assessment by means of the CPT.

Taken in context, BC aggregates in general may exhibit expansions in the CPT when AMBT expansions are higher than approximately 0.30%. Usually, BC aggregates with AMBT expansions below 0.20-0.25% do not exhibit CPT expansions above 0.04%.

Yukon Territory

No data has been collected for commercial aggregate sources in the Yukon.

Northwest Territories (NWT)

Potential for AAR in the Inuvik region was determined to be 'moderate' to 'high', where aggregates contained cherty limestone and shaley dolomite components, and has also been determined for sources of aggregate evaluated for use in developing minesites. In these cases, AAR potential was measured for kimberlite and granitic rock types, with measured expansions of 0.11% or less in the AMBT.

AAR testing data for commercial aggregate supplies have not been obtained.

Nunavut Territory

In Nunavut, data obtained in AMBT evaluation of materials proposed for use in minesite development has given expansions which averaged 0.1%. The aggregates consisted of mixed-lithology igneous rock types and metamorphic rocks. Work by Swenson and Gillott (1973) identified reactive greywacke and chert in aggregates on Ellesmere Island.

4 CASES OF AAR IN CONCRETE

Manitoba

Cases of AAR in concrete in Manitoba are few. A well-documented case of deleterious AAR is the Pointe du Bois Generating Station east of Winnipeg (Figure 2). The facilities were constructed over a number of years, with the earliest phase of construction being 1909-1911, using cements that were imported, likely from Ontario or Quebec (Robinson, pers. comm., 2008). Later construction phases were accomplished using local cement, produced in Manitoba. These cements had different characteristics, and none of the concrete at Pointe du Bois made using these later cements have exhibited significant deterioration due to ASR. The aggregates used at the project were locally-sourced granitic deposits.

Langdon & McPhail (1994) provide a detailed discussion of AAR at the Pointe du Bois GS.

Saskatchewan

No new cases of AAR have been reported in Saskatchewan. In Saskatchewan, cements manufactured in Alberta are typically used.

Alberta

Our survey did not identify new cases of AAR in Alberta. This may be in part due to the cooler and drier climate in Alberta.

The current data indicates that the most significant AAR identified in the province occurs in southern Alberta, and affected water control structures – dams and spillways. Incidental cases of AAR in a few bridges have been reported in Calgary and Edmonton regions, and in central Alberta.

British Columbia

AAR has affected over 100 structures throughout the province, including bridges, dams, tunnels, waterfront structures, retaining walls, industrial facilities and buildings. Notable sites include dams in southwestern BC; a number of dams in the Okanagan Valley; bridges on Hwys 1, 3 and 5; tunnels along Hwy 1 and 99; bridges in North Vancouver, Lytton, Merritt, and various locations throughout the Interior; reservoirs in the South Coast/Fraser Valley region; Stanley Park in Vancouver; port facilities in Vancouver; industrial and transportation facilities in Prince Rupert and Terrace;

In many of these cases, reactive aggregates – as determined by Petrographic examination of concrete samples – were found to include various volcanic rock types, chert, quartzite, sandstone, occasional granitic rocks, and some metamorphic rocks. Reaction-caused distress in the concrete was typically not noted until the concretes had achieved an age of a few decades. This suggests that, even though aggregates classified as "reactive" had been used, the reaction was slowed, likely due to the use of low-alkali cements.

In many cases, the effects of AAR are observed to be 'masked' in the structure by distress caused by freeze-thaw activity and/or reinforcing steel corrosion. Use of Petrographic-based methods such as the Damage Rating Index (DRI) have been found to be useful in distinguishing between the effects of AAR and those caused by corrosion or freeze-thaw cycles.

Figures 3 to 5 illustrate some examples of AAR in British Columbia. Examples of DRI evaluation samples are shown in Figures 6 to 7. Reaction rims on reacted aggregate particles, ASR gel in cracks, air voids and on fracture surfaces, and cracks in aggregate and through paste are observed in these photos.

Yukon, Northwest Territories, Nunavut

Only a few cases of AAR have been reported for sites within the northern territories of Canada. Petrographic examination of concrete from a series of bridges on the Alaska Highway between Whitehorse, Yukon and Alaska identified minor to moderate ASR in the concrete. The overall damage in the concrete was not significant, however. Cold temperatures and low relative humidity are thought to minimize the development of AAR within these regions of Canada.

In older concretes, though, slow-late progression of AAR in the North may be identified in investigations of concrete deterioration. It is likely that the effects of AAR would be accompanied by the effects of reinforcing steel corrosion and of freeze-thaw activity.

5 DISCUSSION

5.1 General

In overview, AAR is not as widespread or significant a problem in western Canada, when compared to the extent and severity of the reaction in eastern and central Canada. This is thought to be due to two primary causes: (1) use of overall lower-alkali cements in the West, and (2) cooler temperatures and drier climates in most of western Canada, particularly in the prairie region and the North. Additional factors may include: (3) smaller population, and therefore less built infrastructure and concrete construction and (4) the relatively later manifestation of AAR in concrete due to (1) and (2), such that AAR, if present, is either not diagnosed properly and is ascribed to some other deterioration mechanism, or that it is not recognized as such.

5.2 Aggregate reactivity

In either case, it is evident that some regions in western Canada contain aggregates that are "potentially reactive", based upon (1) cases of AAR identified in these regions and (2) the results of a growing database of lab testing data of aggregates. Some regions, such as Calgary-Edmonton in Alberta, the Fraser Valley-Caribou, Squamish-Whistler-Lillooet and other Interior regions of British Columbia contain aggregate supplies that are demonstrably "potentially reactive". Use of aggregates in concrete that may be susceptible to deleterious ASR should be done only after assessments have been completed that show that the aggregates in question may be "safely used" in concrete without potential for deleterious expansion.

One aggregate supply with a particularly high level of expansion formerly provided aggregate materials to the Vancouver region, during the 1950s to 1970s. The aggregate source is a glaciofluvial outwash deposit, located on the flanks of Howe Sound, a fjord north of Vancouver. Provenance for the sediments that comprise the deposit is to the north, towards Garibaldi Mountain (a quaternary volcano of the Cascade Range), and the deposit therefore contains much volcanic material, some of it glassy. Measured AMBT expansions for this deposit range from 0.73% at 14-days for the gravel fraction to over 1.20% for the fine aggregate fraction. Since the deposit is no longer actively mined as a concrete aggregate supply, the material is no longer used for concrete production. Where its use can be traced for in-service concrete in the Vancouver area, past experience indicates that deleterious levels of AAR may occur (Shrimer 2000b).

This deposit exemplifies the need to evaluate individual aggregate supplies on a separate basis, since the pit in question is located – on a regional basis – among several other supplies that have overall low reaction potential. The reactivity of individual sources is governed by the geology of each deposit, and for this reason, geological assessment is a fundamental first step in understanding the potential reactivity of aggregates.

Use of the Standard Practices given in CSA A23.2-27A and CSA A23.2-28A is recommended when a known or suspected "potentially-reactive" aggregate is considered for use in construction that may be susceptible to AAR development, due to exposure conditions in the service environment, alkali levels within the concrete and design service life. The nature of the construction is also a consideration, i.e., whether the structure is considered "critical", for example, a dam, a bridge, water structure, etc. Where replacement or repair would be difficult or expensive, concrete to be supplied to the project should be evaluated for longevity expectations with specific reference to AAR.

In some cases, where potentially reactive aggregates are being considered for use, it may be possible to safely use the aggregates provided that certain mitigative measures are used. Such measures may include the use of an effective amount of SCMs (e.g., fly ash, silica fume) or of kaolin/metakaolin, or the use of lithium admixtures. Provisions for the evaluation of various SCMs or admixtures are provided in CSA A23.2-28A.

Since these evaluations in some cases require up to two years to produce data, it is important that aggregate supplies be assessed in a timely fashion. Commercial aggregate supplies are required per CSA A23.1-04 requirements to be evaluated not less than annually; therefore, most commercial supplies should have relevant test data available for review by project teams for specific projects.

On the basis of numerous testing programs, it is apparent that many western Canadian aggregate sources exhibit differential expansions for fine and coarse aggregates, wherein the fine aggregates exhibit expansion levels that are usually higher than those of the accompanying coarse aggregate fractions. This is depicted in Figure 10.

However, the opposite is also observed in some cases with some Alberta aggregates, where coarse aggregates have reaction levels higher than the accompanying fine aggregates. In a few cases, we observe that the combined aggregates produce a lower net expansion in the CPT than either the fine or the coarse aggregates separately tested.

5.3 AAR identification in concrete

Transportation/Highways departments have not conducted surveys in recent years specifically for AAR, although their routine inspection programs should be capable of effectively identifying AAR deterioration if personnel who conduct the surveys are appropriately trained.

Beyond various levels of government responsible for management of their concrete structures, AAR evaluations of concrete construction are generally only carried out on a case-by-case basis. Typically, Owners of power generation and water management structures retain engineering consultants to carry out such specialized work. Cases reported by Morgan (pers. comm.) and Shrimer (2003) in British Columbia highlight the need for careful diagnosis of AAR. In the former example, concrete thought to be affected by AAR was assessed in detail and found to be deteriorated due to freeze-thaw attack.

In the second instance, suspected ASR was confirmed in a dam suffering from jamming of the radial gate, but only after foundation/geotechnical assessments were carried out to verify that settlement had not affected the operation of the radial gates. Progressive/cumulative expansion of concrete elements in the dam had not been noticed until the structure was some 30 years old, at which time, modification of the radial gate to operating condition had to be undertaken roughly every five years, thereby providing an indication of the rate of expansion.

In both these cases, the evaluation studies were led by investigators experienced in diagnosis of AAR, and were supported by appropriate laboratory investigations, including Petrographic examination, thin-section and/or Damage Rating Index analyses.

6 SPECIFICATIONS FOR THE CONTROL OF AAR

CSA specifications for concrete aggregates, contained in CSA A23.1-04/A23.2-04, tend to form the basis for most specifications used throughout western Canada. Typical Building Codes call for compliance with CSA, as do many project documents.

Provincial and Territorial government Ministries, such as the Transportation, Highways and Infrastructure regulators may develop their own requirements, but these generally are consistent with the provisions of CSA. Typical specification requirements may include wording that (1) limits the alkali contents of the cement; (2) requires the use of an SCM in a proportion demonstrated to be effective; (3) requires the use of approved sources of aggregate; (4) limits the alkali content of concrete mixes to some threshold amount.

The increase of Private-Public Partnership ('P3') projects in western Canada can lead to uneven application of specifications, as Owner/Contractor/Engineer responsibilities sometimes become blurred. Still, with P3 design documents that reference the Provincial-Territorial or CSA Standard Specifications, ultimately the intent of avoiding deleterious AAR expansions in new concrete construction should be achieved.

7 CONCLUSIONS

While AAR is not an extensive problem within western Canada, awareness that the reaction is possible in some regions is important, both for new construction as well as for the development of appropriate strategies for repair of structures that may be affected by AAR. With the increased move towards development of new sources, due to depletion of current supplies, and the increasing requirements for structures to provide extended service lives, selection of aggregates and cementing materials that will achieve durable concrete requires additional effort.

Continuing work throughout western Canada in the field of AAR assessment should enable diligent and appropriate use of available resources, as ongoing demand for construction and development in the Provinces and Territories within the region progresses.

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Table 1: Selected results of Accelerated Mortar Bar tests (CSA A23.2-25A) of western Canadian aggregates (% length change at 14 days)					
Location	Fine	Coarse	Location	Fine	Coarse
Vancouver Island	0.19	0.17	Southern Alberta	0.19	0.31
South Coast BC	0.25	0.19	Calgary Alberta	0.29	0.35
Squamish BC	0.89	0.73	Central Alberta	0.37	0.33
Fraser Valley 1 BC	0.52	0.42	Edmonton Alberta	0.30	0.34
Fraser Valley 2 BC	0.35	0.32	Fort McMurray AB	0.07	0.09
Fraser-Thompson	0.50	0.42	Saskatchewan	0.28	0.22
South Interior 1 BC	0.27	0.30	Winnipeg 1	0.03	0.02
South Interior 2 BC	0.53	0.47	Winnipeg 2	0.044	0.028
NE BC	0.36	0.27	Stonewall Manitoba	--	0.012

Table 2: Selected results of Concrete Prism Expansion tests (CSA A23.2-14A) of western Canadian aggregates (% length change at 52 weeks)					
Location	Fine	Coarse	Location	Fine	Coarse
Vancouver Island	0.023	0.016	Southern Alberta	0.102	0.048
South Coast BC	0.019	0.015	Calgary Alberta	0.134	0.056
Squamish BC	0.315	0.023	Central Alberta	0.096	0.050
Fraser Valley 1 BC	0.25	0.07	Edmonton Alberta	0.168	0.092
Fraser Valley 2 BC	0.025	0.022	Fort McMurray AB	--	--
Fraser-Thompson	0.132	0.072	Saskatchewan	0.072	0.034
South Interior 1 BC	0.068	0.055	Winnipeg 1	--	--
South Interior 2 BC	0.078	0.060	Winnipeg 2	--	--
NE BC	0.011	0.064	Stonewall Manitoba	--	--

Figure 1: Map of Canada

Figure 2: Concrete core, Pointe du Bois GS, showing ASR gel deposits associated with granite aggregate

Figure 3: Massey Tunnel walls, Hwy 99, Delta-Richmond BC

Figure 4: Saddle Rock tunnel, Hwy 1 north of Yale BC

Figure 5: Radial gate wall of a dam in southern BC exhibiting ASR distress

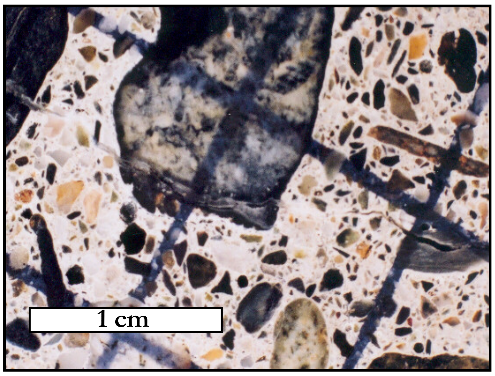

Figure 6: Damage Rating Index sample of polished concrete, showing ASR-gel-filled crack and reaction rims on aggregate.

Figure 7: ASR gel, reaction rims on aggregates on sample of concrete from dam, Southern BC.

Figure 8 -- Western Canada Percent 14-day AMBT Results

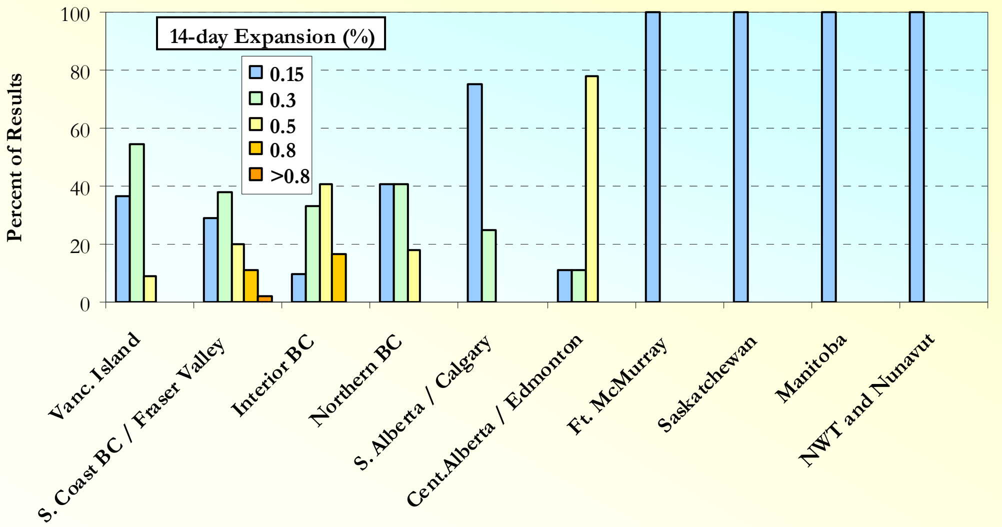

Figure 9 -- Western Canada 52-week CPT Results

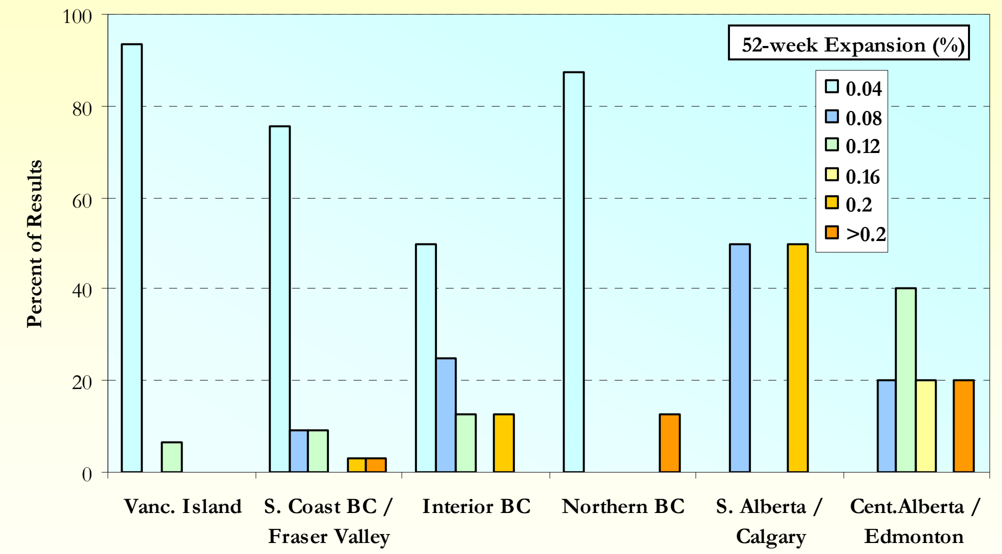

Figure 10 -- Typical CPT Expansion: Coarse, Fine and Mitigated Tests

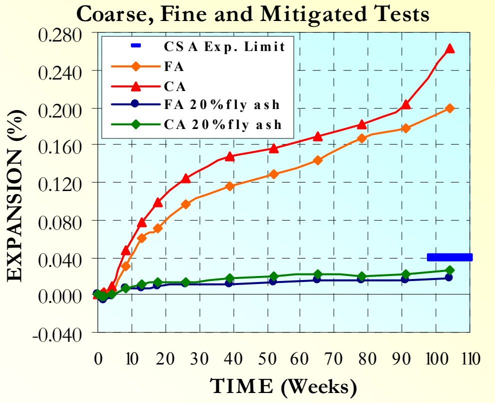

Figure 11 -- AAR Expansion via AMBT and CPT