

A PRESCRIPTIVE SPECIFICATION FOR THE SELECTION OF MEASURES FOR PREVENTING ALKALI-SILICA REACTION

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Abstract

This paper presents a prescriptive approach for the selection of measures for the prevention of deleterious alkali-silica reaction (ASR) in concrete. The level of prevention required is based on the reactivity of the aggregate, the exposure conditions, the type of structure, and the available alkalis in the concrete. The preventive measures include controlling the alkali content of the concrete, the use of supplementary cementing materials (SCM) and combinations of these two strategies. The approach was recently adopted as a provisional practice by the American Association of State Highways and Transportation Officials (AASHTO).

Keywords: specification, preventive measures, supplementary cementing materials

1 INTRODUCTION

In 2011 AASHTO published PP65-11 “Standard Practice for Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction”. As the title suggests, these guidelines can be broken down into two steps as follows: (i) evaluating aggregate reactivity (for alkali-silica and alkali-carbonate reactive aggregates) and (ii) selecting preventive measures (for alkali-silica reactive aggregates only). Aggregate reactivity is evaluated by considering one or more of: (i) field performance history, (ii) petrographic assessment, (iii) chemical composition (for quarried carbonates), (iv) data from accelerated mortar bar tests (ASTM C 1260), and (v) data from concrete prism tests (ASTM C 1293). A detailed description and explanation of the approach used in AASHTO PP65-11 for evaluating aggregates is provided in FHWA-HIF-09-001 [1]. AASHTO PP65-11 provides two approaches for selecting preventive measures; these being: (i) a performance approach based on laboratory testing and (ii) a prescriptive approach based on a consideration of the reactivity of the aggregate, type and size of structure, exposure conditions and the composition of cementitious materials being used. The two test methods used for the performance-based approach are the accelerated mortar bar test for evaluating combinations of cementing materials and aggregates (ASTM C 1567) and the concrete prism test (ASTM C 1293); with preference given to the latter test. The rationale behind the use of these two tests and the preference for the concrete test is presented elsewhere [1,2].

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The options for preventive measures included in the prescriptive approach of AASHTO PP65-11 (from this point forward referred to as PP65) are to (i) control the alkali content of the concrete to a maximum allowable level, (ii) use a minimum level of supplementary cementing material (SCM) or a combination of SCMs, or (iii) use a combination of these two options (that is controlling the alkali content of the concrete and using SCM). The precise level of alkali permitted or SCM required depends on a number of factors including the aggregate reactivity, type and size of structure, exposure conditions and even the composition of the cement and SCM being used. The approach is described in FHWA-HIF-09-001 [1] and is similar to that developed in Canada (CSA A23.2-27A) and in Europe (RILEM TC191-ARP: AAR-7). This paper provides an overview of the prescriptive approach.

2 OUTLINE OF THE AASHTO PP65 PRESCRIPTIVE APPROACH

The prescriptive approach of AASHTO PP65 can be summarized in the following steps:

- Step 1. Determine aggregate reactivity class: the aggregate is tested in either the accelerated mortar bar test (AMBT), ASTM C 1260 (or equivalent AASHTO T 303), or, preferably, the concrete prism test (CPT), ASTM C 1293. The criteria in Table 1 are used to classify the aggregate reactivity, which can range from “R0 – non-reactive” through to “R3 – very highly reactive”.
- Step 2. Determine level of ASR risk: based on the aggregate-reactivity class determined in Step 1 (Table 1) and the size and exposure conditions of the concrete under construction, the level of ASR risk is determined using the criteria in Table 2. The risk may range from Level 1 (lowest or negligible risk) through to Level 6 (highest risk).
- Step 3. Determine level of prevention: based on the level of ASR risk determined in Step 2 (Table 2) and the classification of the structure (see Table 4), the level of prevention required is determined using Table 3. The level of prevention required may range from Level V (no measures necessary) to Level ZZ (extreme preventive measures necessary).
- Step 4. Identification of preventive measures: based on the level of prevention required that was determined in Step 3 (Table 3), a number of options are presented as acceptable measures for preventing ASR; these are:
 - Option 1 – limiting the alkali content of the concrete (Table 5)
 - Option 2 – using supplementary cementing materials, SCM¹ (Tables 6 and 7)
 - Option 3 – limiting the alkali content of the concrete and using SCM (Table 8)

Although the performance approach allows the option for using lithium compounds as a preventive measure, the prescriptive approach does not. Research has shown that the efficacy of lithium compounds in controlling expansion due to ASR is highly influenced by the nature of the reactive aggregate [3]. Currently, it is not possible to prescribe the required lithium dose based on aggregate reactivity or mineralogy and, consequently, lithium compounds must be tested using the prescriptive approach to determine the minimum dose required with a specific aggregate.

3 ASSUMPTIONS

A number of assumptions were made in developing the overall framework of the prescriptive approach used in AASHTO PP65; these were:

¹ Note that for Option 2 the minimum amount of SCM determined from Table 6 may be adjusted based on the alkali level of the Portland cement using Table 7.

- The level of ASR risk increases as the reactivity of the aggregate, the size of the structure, or the availability of moisture in service increases and if the structure is exposed to alkalis during service.
- Some concrete structures can tolerate a higher level of risk than other structures, either because the consequences of ASR are less severe or because the required service life is less (or both). In such cases, a lower level of prevention is warranted.
- Deleterious ASR can be prevented solely by limiting the alkali content of the concrete in some cases.
- The maximum alkali content that can be tolerated without the occurrence of deleterious ASR will depend mainly on the reactivity of the aggregate and whether the concrete is exposed to alkali compounds in service.
- Deleterious ASR can be prevented by using supplementary cementing material, SCM.
- The amount of SCM required to prevent deleterious ASR depends upon a number of factors including (but not limited to) the following:
 - The reactivity of the aggregate
 - The composition of the SCM (particularly CaO, SiO₂ and Na₂Oe)
 - The alkali provided to the system by the Portland cement
 - The presence of alkali compounds in service

The paper discusses these assumptions and provides reference to evidence supporting the selection of limits for maximum alkali contents and minimum SCM replacement levels.

4 RISK OF ASR

In the prescriptive approach the risk of ASR is determined by the degree of aggregate reactivity, the exposure conditions of the structure and the size of the element.

4.1 Effect of Aggregate Reactivity

Clearly, for a given set of cementitious materials, mixture proportions and exposure conditions, the risk of deleterious reaction would be expected to increase as the reactivity of the aggregate increases. Intuitively, it is reasonable to anticipate that the preventive measures required to suppress expansion become more onerous as the aggregate reactivity increases. Indeed, the main reason for classifying aggregate reactivity in the context of the prescriptive approach is because it has been generally observed that aggregates of higher reactivity require greater preventive measures. The question that remains is how to measure “reactivity.” The reactivity of an aggregate depends on its mineralogy; however, it is difficult to classify aggregate reactivity based solely on mineralogical observations as aggregates may contain various types of reactive minerals in different quantities, and the extent to which reactive minerals cause damage in concrete depends on other factors such as particle size.

In AASHTO PP65 the reactivity of aggregates is classified on the basis of either the 1-year expansion in the concrete prism test or the 14-day expansion in the accelerated mortar bar test (see Table 1). The guidelines published by the Federal Highways Administration, report FHWA-HIF-09-001 [1] which was the precursor to PP65, recommended that only the concrete prism test be used to classify the reactivity of aggregates as it was generally considered that the accelerated test was too aggressive and insensitive to differences in aggregate reactivity. For the concrete prism test an expansion value of 0.04% at 1 year was selected to separate non-reactive from reactive aggregates. This is consistent with other specifications such as CSA A23.2-27A and with the recommendations in Appendix X1 of ASTM C 33 “Standard Specification for Concrete Aggregates”. In the PP65 prescriptive approach the risk of ASR is considered to be negligible if the aggregate is classified as non-reactive and no preventive measures are required. An expansion value of 0.12% was selected to delineate between moderately-reactive and highly-reactive aggregate to be consistent with CSA A23.2-27A. This value was chosen by CSA as it separates the expansion behaviour of two aggregates

Spratt limestone and Sudbury gravel that have been widely used by researchers in Canada and results from tests on these aggregates form much of the database that was used to develop the CSA standard practice. A number of studies in North America have indicated that there are many aggregates that produce significantly greater expansion than the Spratt aggregate and thus present a greater risk of ASR (and require a greater level of prevention). Consequently, a fourth category of “very highly reactive” aggregate was included in FHWA-HIF-09-001 and AASHTO PP65 to represent aggregates that produce 1-year expansions in excess of 0.24%.

Although FHWA-HIF-09-001 [1] recommends that aggregate reactivity only be classified using the concrete prism test, AASHTO PP65 also included criteria based on the accelerated test (see Table 1) because it was considered that in many cases in practice only data from the accelerated test may be available. The criteria used to delineate between aggregate classes based on the accelerated test were based on a comparison of data from this test with data from the concrete prism test for the same aggregates, although it is recognized that there is a poor correlation between the two tests.

It should be noted that the magnitude of expansion is not the only means for classifying aggregate reactivity. For example, in the UK, guidelines for preventing ASR (Building Research Establishment, 1997) infer aggregate reactivity based on the threshold alkali content in concrete that is required to initiate expansion with that particular aggregate. For the purpose of selecting preventive measures, this concept has more technical merit than using the magnitude of expansion but, given the wide range of aggregate types available in North America and the complexity of establishing the alkali threshold (not to mention the lack of an established test for determining the threshold), it is impractical to adopt this approach at this time.

4.2 Effect of Exposure Conditions and Size of Element

ASR reaction can only proceed if there is a sufficient level of moisture present in the concrete. Internal moisture is required to transport the alkali ions to the location of the reactive silica, to enable the dissolution of silica and formation of alkali-silica gel, and to sustain the swelling of the gel (which occurs due to the imbibition of water). Laboratory testing has shown that ASR expansion ceases if the relative humidity within the concrete falls below 80% [4]. In non-massive concrete elements (least dimension $\leq 0.9\text{m}$, 3ft) exposed to a dry environment (e.g. internal components of a building) the internal relative humidity will decrease with time and eventually fall below that necessary to sustain ASR before significant expansion can occur, unless a highly reactive aggregate is used. Consequently, the level of ASR risk is considered to be negligible (Level 1) if non-reactive or moderately-reactive aggregate (RO or R1) are used, but the level increases with increased aggregate reactivity. Massive concrete elements (least dimension $> 0.9\text{m}$, 3ft) exposed to a dry environment are likely to retain sufficient moisture to sustain ASR for an extended period of time and, consequently, there is a risk of ASR if the aggregates are reactive, the risk increasing with the reactivity of the aggregate. For concrete exposed to moisture during service the internal humidity will remain sufficiently high to promote ASR regardless of the size of the element. In this type of exposure there is a risk of ASR with all reactive aggregates, although the risk still increases with aggregate reactivity. It should be noted that the rate at which ASR proceeds will be a function of the degree of moisture exposure and elements directly exposed to water will deteriorate more rapidly than sheltered elements exposed only to humid air (e.g. girders under a bridge deck). This is not taken into account in the prescriptive approach. In AASHTO PP65 concrete elements that are exposed to alkalis in service (e.g. seawater or deicing salts containing sodium or potassium) are considered to be at a greater risk of ASR. The role of external alkalis is equivocal. For example, the effect of sodium chloride (NaCl) on expansion due to ASR is influenced by a number of factors including, among other things, the concentration of the salt, the composition of the cement (particularly C_3A and alkali), the mineralogy of the aggregate and the permeability of the concrete [5]. Alkali salts of formic and acetic acid (e.g. potassium acetate, sodium acetate, potassium formate and sodium

formate) now commonly used as anti-icing and de-icing chemicals on airfield pavements have been found to exacerbate ASR damage in laboratory tests on concrete containing reactive aggregates [6] but the extent to which damage occurs in the field, where the depth of penetration is limited, has not been established. In view of the potential for external sources of alkali to aggravate ASR it was considered prudent to increase the risk of ASR by one level for concretes exposed to alkalis in service compared with concretes exposed to moisture only. The increased level of risk only applies to concrete containing reactive aggregates (R1, R2 or R3). Noticeably absent from the exposure conditions considered in AASHTO PP65 is the role of ambient temperature. It is well established that ASR, like most chemical reactions, is accelerated by an increase in temperature. Thus, for concrete of similar composition, the rate of reaction and the time to cracking will be faster in warm compared to cold climates. It can be argued that temperature does not influence whether ASR occurs or not (unless the concrete remains permanently frozen) just when it occurs; in other words, the “risk of ASR” is not affected by temperature. However, a counterargument would be that temperature does have an impact on the risk of ASR occurring within the service life of a structure. For example, neglecting the role of other deterioration mechanisms such as freeze-thaw, a concrete structure constructed with a reactive aggregate is more likely to suffer ASR damage during a 25-year service life in a warm environment than a similar structure constructed with the same materials in a cold climate. It is possible that future versions of AASHTO PP65 will take the temperature of the environment into consideration.

5 CLASSIFICATION OF STRUCTURE

The approach to classifying structures on the basis of “the consequences if ASR should occur” (see Table 4) was adopted from that used in RILEM TC 191-ARP Alkali-Reactivity and Prevention – Assessment, Specification, and Diagnosis of Alkali-Reactivity. The approach presumes that a higher level of risk of ASR can be accepted in some types of structures. This approach provides a greater level of flexibility for the owner when selecting preventive measures. For example, when constructing a major bridge with a 100-year service life, ASR cannot be tolerated because ASR will likely jeopardize the service life and lead to premature rehabilitation. In such a case, if a reactive aggregate is used, it will be necessary to use a high amount of SCM and possibly even control the alkali content of the concrete. This could impact the constructability and cost of construction but it is necessary to ensure durability. If the same aggregate was used in a sidewalk, a reduced level of SCM with no control of the alkali content may produce an acceptable level of risk because the consequences of ASR are less severe and are likely not to impact the service life of the concrete element. Although examples are given in Table 4 of the type of structures that might fall into the different classes, it is probable that owners will reclassify structural types based on their own experiences dealing with the consequences of ASR.

6 PREVENTIVE MEASURES

6.1 Limiting the Alkali Content of the Concrete

A number of specifications have employed a maximum concrete alkali content as an option to control expansion in concrete containing reactive aggregates. Nixon and Sims [7] reported that maximum permissible alkali contents between 2.5 and 4.5 kg/m³ (4.2 to 7.5 lb/yd³) Na₂O_e have been specified by various countries and agencies, with the allowable alkali content sometimes varying depending on aggregate reactivity. In 2000, the alkali limit used as a preventive measure in CSA A23.2-27A was modified from the single value of 3.0 kg/m³ (5 lb/yd³) Na₂O_e specified in the 1994 edition to a sliding scale from 1.8 to 3.0 kg/m³ (3 to 5 lb/yd³) Na₂O_e. As the data available from laboratory tests at the time was considered unreliable for the purpose of establishing threshold alkali values, the maximum alkali content limits were based on published data from structures and field experience. Thomas [8] had previously reported damaging ASR in concrete dams in the

U.K. and Canada where the estimated alkali content was in the range of 2.0 to 2.4 kg/m³ (3.3 to 4.0 lb/yd³) Na₂Oe. Rogers et al [9] reported results from a study of 8-year-old concrete blocks (0.6 x 0.6 x 2 m, 2 x 2 x 6.6 ft) stored on an exposure site in Ontario, Canada. Specimens produced with high-alkali cement showed very significant expansion and cracking after 8 years. Specimens with low-alkali cement (0.46% Na₂Oe) and a calculated alkali content of 1.91 kg/m³ (3.18 lb/yd³) Na₂Oe showed significantly less expansion; however, the expansion did exceed 0.04% at 8 years and small cracks were evident. Based on the information available, a maximum alkali limit of 1.8 kg/m³ (3.0 lb/yd³) Na₂Oe was selected for Prevention Level Y (e.g. concrete with highly reactive aggregate, exposed to moisture with a service life up to 75 years) and it was decided to require the same limit plus incorporate minimum levels of SCM for Level Z. This was supported by anecdotal evidence available to the committee preparing the CSA guidelines, there being no known case of ASR in concrete structures with lower alkali contents. Higher limits of 2.4 and 3.0 kg/m³ (4.0 and 5.0 lb/yd³) Na₂Oe are required for Prevention levels X and W, respectively. In the absence of any other data, the same alkali limits were adopted in AASHTO PP65 for prevention levels W, X, Y and Z. Prevention Level ZZ requires the same maximum alkali content as Level Z but a higher level of SCM.

6.2 Using Supplementary Cementing Materials (SCM)

A comprehensive review of the use of SCM to control expansion due to ASR was recently published by Thomas [10]. Since the first investigations more than 70 years ago, studies on the use of SCMs to control ASR expansion proliferated and there are now literally hundreds of publications on the subject. Although there remains conflicting views regarding how SCMs control ASR and their precise efficacy in this role, there is a general consensus that most, if not all, SCMs can control deleterious expansion due to ASR provided they are present in sufficient quantity. The question that remains is how much SCM is sufficient? The amount required varies widely depending on, among other things, the following [10]:

- The nature of the SCM (especially mineralogical and chemical composition)
- The nature of the reactive aggregate (generally, the more reactive the aggregate, the higher the level of SCM required)
- The availability of alkali within the concrete (i.e. from the Portland cement and other sources)
- The exposure conditions of the concrete (i.e. concrete exposed to external sources of alkali may require higher levels of SCM).

Generally, the amount of SCM required decreases as the reactive silica content of the SCM increases or as the calcium or alkali content of the SCM decreases. In other words, an SCM with high silica and low amounts of calcium and alkali, such as silica fume, tends to be effective at low levels of replacement. Slag, on the other hand, is much less efficient due to its lower silica and higher calcium contents, and has to be used at much higher levels of replacement to control expansion. There are numerous publications that indicate that a replacement level of 25% low-calcium fly ash or 50% slag is sufficient to control expansion with a highly reactive aggregate and high-alkali cement and these levels were adopted as the minimum levels for the “general case” which is considered to correspond to Prevention Level Y. For silica fume, the level of replacement required is strongly influenced by the amount of alkalis available and, based on a synthesis of published data [11], the value used for the general case is $SF = 3.0 \times AL$ where SF is the minimum level of silica fume (% by mass of cementitious material) and AL is the alkali content contributed by the portland cement (kg/m³ Na₂Oe). As stated above, higher replacement levels may be necessary in critical structures with an extended service life or where the aggregate reactivity or cement alkali levels are exceptionally high, or the concrete is exposed to alkalis in service. Conversely, lower replacement levels may be expected in structures with a relatively short service life or where moderately reactive aggregates or moderate alkali cements are used. This variation is taken into account in Table 6 with further adjustment based on cement

alkalis being controlled by Table 7. Combinations of SCM are allowed providing the following condition is satisfied: $fa/FA + sg/SG + sf/SF \geq 1$ where fa , sg and sf are the replacement levels of fly ash, slag and silica fume, respectively, that are to be used in combination and FA , SG and SF are the minimum amounts of fly ash, slag and silica fume, respectively, required according to Table 6 when these materials are used on their own.

When the risk of level is high and the concrete has an extended service life, extreme measures are required to prevent damaging ASR. In such cases, it may be necessary to both control the alkali content of the concrete and to use a minimum level of SCM. AASHTO PP65 includes this option in Table 8. For prevention level Z, there is an option to either use the minimum levels of SCM for level Z given in Table 6, without limiting the alkali content of the concrete, or to limit the alkali content of the concrete with a reduced level of SCM. For prevention level ZZ, both the maximum alkali content and minimum SCM level must be met.

6 REFERENCES

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Aggregate-Reactivity Class	Description of Aggregate Reactivity	One-Year Expansion in CPT (%)	14-Day Expansion in AMBT (%)
R0	Non-reactive	≤ 0.04	≤ 0.10
R1	Moderately reactive	$> 0.04, \leq 0.12$	$> 0.10, \leq 0.30$
R2	Highly reactive	$> 0.12, \leq 0.24$	$> 0.30, \leq 0.45$
R3	Very highly reactive	> 0.24	> 0.45

Size and exposure conditions	Aggregate-Reactivity Class			
	R0	R1	R2	R3
Non-massive ¹ concrete in a dry ² environment	Level 1	Level 1	Level 2	Level 3
Massive ¹ elements in a dry ² environment	Level 1	Level 2	Level 3	Level 4
All concrete exposed to humid air, buried or immersed	Level 1	Level 3	Level 4	Level 5
All concrete exposed to alkalis in service ³	Level 1	Level 4	Level 5	Level 6

¹A massive element has a least dimension > 3 ft (0.9 m).
²Corresponds to an average ambient relative humidity lower than 60%, normally only found in buildings.
³Examples include marine structures exposed to seawater and highway structures exposed to deicing salts (e.g. NaCl) or anti-icing salts (e.g. potassium acetate, potassium formate, sodium acetate, sodium formate, etc.).

Level of ASR Risk (from Table 2)	Classification of Structure (see Table 4)			
	S1	S2	S3	S4
Risk Level 1	V	V	V	V
Risk Level 2	V	V	W	X
Risk Level 3	V	W	X	Y
Risk Level 4	W	X	Y	Z
Risk Level 5	X	Y	Z	ZZ
Risk Level 6	Y	Z	ZZ	††

††It is not permitted to construct a Class S4 structure (see Table 4) when the risk of ASR is Level 6. Measures must be taken to reduce the level of risk in these circumstances. The level of prevention V, W, X, Y, Z or ZZ is used in Tables 5 to 8.

Class	Consequences of ASR	Acceptability of ASR	Examples ²
S1	Safety, economic or environmental consequences small or negligible	Some deterioration from ASR may be tolerated	<ul style="list-style-type: none"> ▪ Non-load-bearing elements inside buildings ▪ Temporary structures (e.g. < 5 years)
S2	Some safety, economic or environmental consequences if major deterioration	Moderate risk of ASR is acceptable	<ul style="list-style-type: none"> ▪ Sidewalks, curbs and gutters ▪ Service-life < 40 years
S3	Significant safety, economic or environmental consequences if minor damage	Minor risk of ASR acceptable	<ul style="list-style-type: none"> ▪ Pavements ▪ Culverts ▪ Highway barriers ▪ Rural, low-volume bridges ▪ Large numbers of precast elements where economic costs of replacement are severe ▪ Service life normally 40 to 75 years
S4	Serious safety, economic or environmental consequences if minor damage	ASR cannot be tolerated	<ul style="list-style-type: none"> ▪ Major bridges ▪ Tunnels ▪ Critical elements that are very difficult to inspect or repair ▪ Service life normally > 75 years

¹This table does not consider the consequences of damage due to ACR. This practice does not permit the use of alkali-carbonate aggregates.

²The types of structures listed under each Class are meant to serve as examples. Some owners may decide to use their own classification system. For example, sidewalks or curbs and gutters may be placed in the Class S3.

Prevention Level	Maximum Alkali Content of Concrete (Na ₂ Oe)	
	lb/yd ³	kg/m ³
V	No limit	
W	5.0	3.0
X	4.0	2.4
Y	3.0	1.8
Z ¹	Table 8	
ZZ ¹		

¹SCMs must be used in Prevention levels Z and ZZ.

Type of SCM ¹	Alkali level of SCM (% Na ₂ Oe)	Minimum Replacement Level ³ (% by mass of cementitious material)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash (CaO ≤ 18%)	≤ 3.0	15	20	25	35	Table 7
	> 3.0, ≤ 4.5	20	25	30	40	
Slag	≤ 1.0	25	35	50	65	
Silica Fume ² (SiO ₂ ≥ 85%)	≤ 1.0	1.2 x LBA or 2.0 x KGA	1.5 x LBA or 2.5 x KGA	1.8 x LBA or 3.0 x KGA	2.4 x LBA or 4.0 x KGA	

¹The SCM may added directly to the concrete mixer or it may be a component of a blended cement.

²The minimum level of silica fume (as a percentage of cementitious material) is calculated on the basis of the alkali (Na₂Oe) content of the concrete contributed by the portland cement and expressed in either units of lb/yd³ (LBA in Table 6) or kg/m³ (KGA in Table 6). For example, for a concrete containing 300 kg/m³ of cement with an alkali content of 0.91% Na₂Oe the value of KGA = 300 x 0.91/100 = 2.73 kg/m³. For this concrete, the minimum replacement level of silica fume for Level X is 2.5 x 2.73 = 6.8%. Regardless of the calculated value, the minimum level of silica fume shall not be less than 7% when it is the only method of prevention.

³The use of high levels of SCM in concrete may increase the risk of problems due to deicer salt scaling if the concrete is not properly proportioned, finished and cured.

Cement Alkalis (% Na ₂ Oe)	Level of SCM
≤ 0.70	Reduce the minimum amount of SCM given in Table 6 by one prevention level ¹
> 0.70, ≤ 1.00	Use the minimum levels of SCM given in Table 6
> 1.00, ≤ 1.25	Increase the minimum amount of SCM given in Table 6 by one prevention level
> 1.25	No guidance is given

¹The replacement levels should not be below those given in Table 6 for prevention level W, regardless of the alkali content of the portland cement.

Prevention Level	SCM as Sole Prevention	Limiting Concrete Alkali Content Plus SCM	
	Minimum SCM Level	Maximum Alkali Content, lb/yd ³ (kg/m ³)	Minimum SCM Level
Z	SCM level shown for Level Z in Table 6	3.0 (1.8)	SCM level shown for Level Y in Table 6
ZZ	Not permitted	3.0 (1.8)	SCM level shown for Level Z in Table 6