FHWA Workshop

Alkali-Aggregate Reaction

Session 06: AAR Specifications

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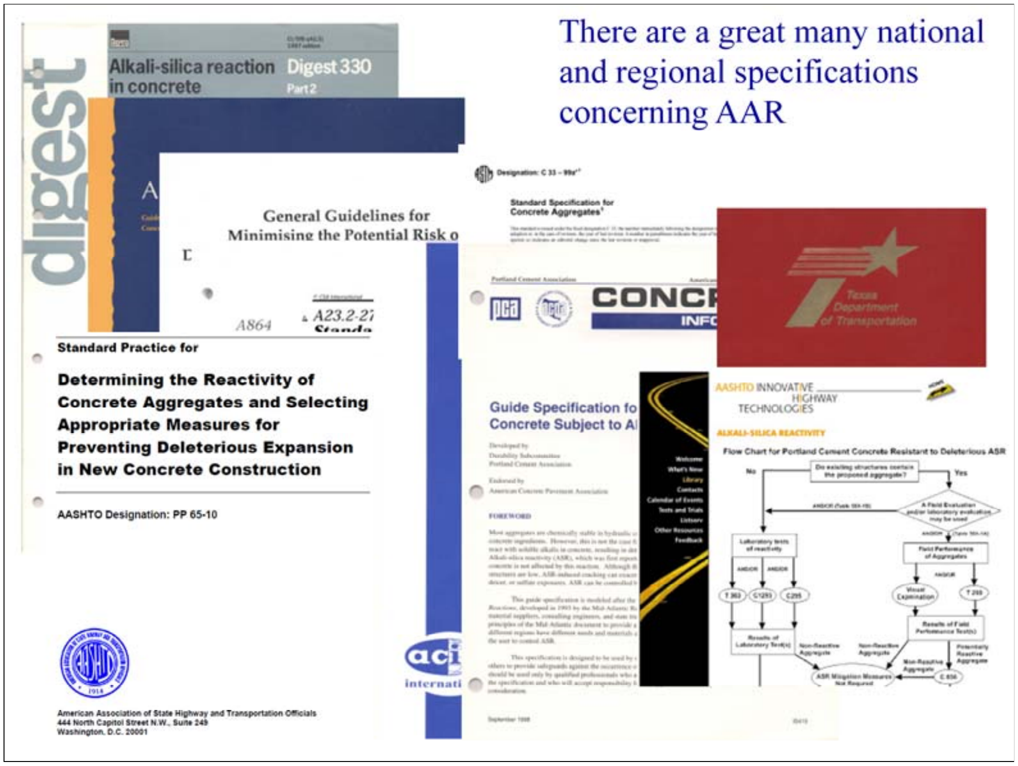
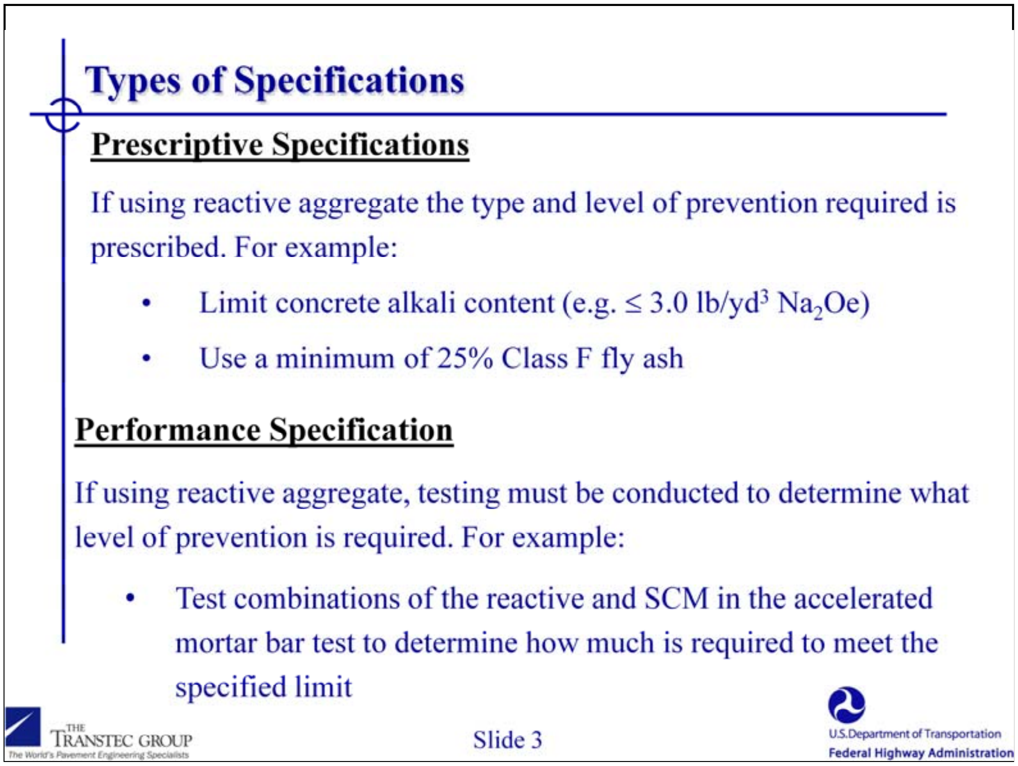


There are literally hundreds of specifications, recommendations and guidelines for avoiding ASR in new construction or managing it in existing structures. There are national specifications from many countries including the U.K. and many other European nations – Australia – Canada and the U.S.A. Within the United States there are guidelines from ACI, specifications from ASTM, guide specifications from PCA and then individual specs from state DOT’s, national highway authorities and many other government bodies.

This makes a general discussion about specifications very difficult – however …



… there are basically two approaches to a specification for preventing damaging expansion due to ASR – the spec maybe prescription based or performance based

In a prescriptive specification the method of mitigation is spelled out exactly for the contractor or producer – for example – either limit the alkali content of the concrete to a specific level (such as 3 pounds per cubic yard) or use a minimum level of certain SCMs (for example 25% Class F fly ash or 50% slag)

In a performance spec – the level of prevention is NOT specified but has to be tested to prove that it works – so, for exampl,e if the contractor or producer wants to use 40% slag with a reactive aggregate – that combination of materials has to be tested using a suitable test method to demonstrate that it does not produce an unacceptable level of expansion.

This presentation discusses the recently published AASHTO Standard Practice: PP 65-11

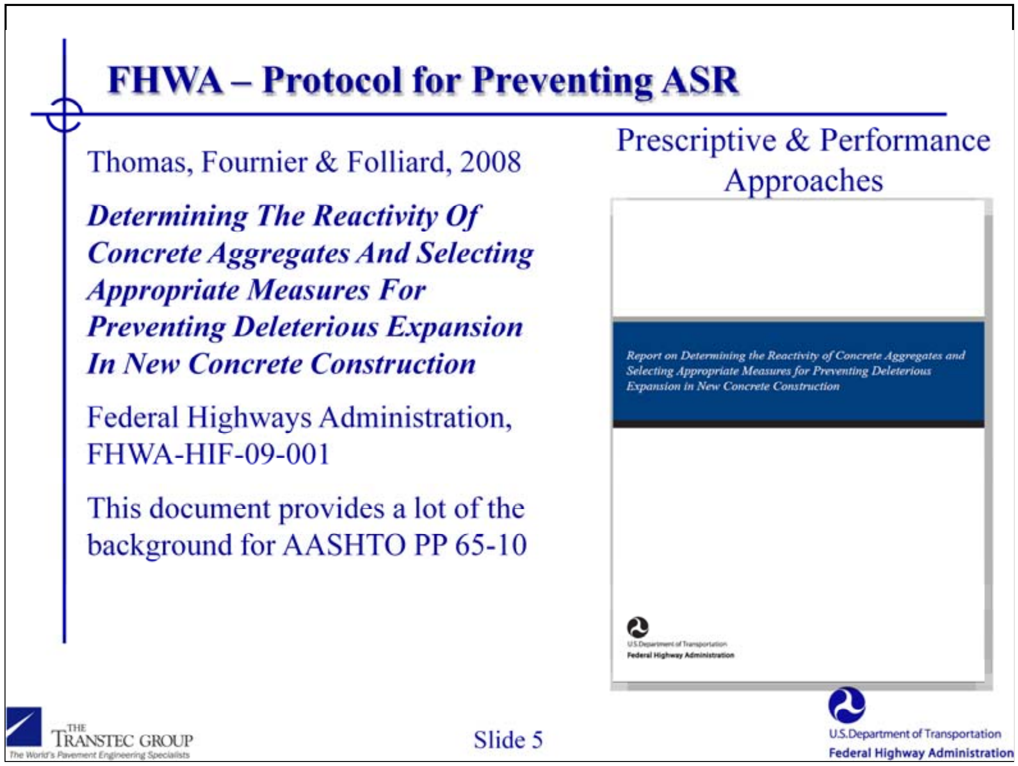
Standard Practice for

Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction

AASHTO Designation: PP 65-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

In this presentation we are going to focus on the recently developed AASHTO standard practice for determining the reactivity of aggregates and selecting preventive measures – AASHTO PP 65



The background to the development of this practice is document in a federal highway report that can be downloaded (for free) – just google the report number shown

AASHTO PP 65

- Deals with AAR – in other words ASR & ACR
- Prescriptive & performance alternatives
- Allows the use of (alkali-silica) reactive aggregates with the following preventive measures:
  - Limiting the alkali content of the concrete
  - Use of SCM including (ternary blends)
  - Use of lithium
- The actual level of prevention varies with "risk" as defined by:
  - Reactivity of the aggregate
  - Nature of the structure (design life & consequences of ASR)
  - Exposure condition

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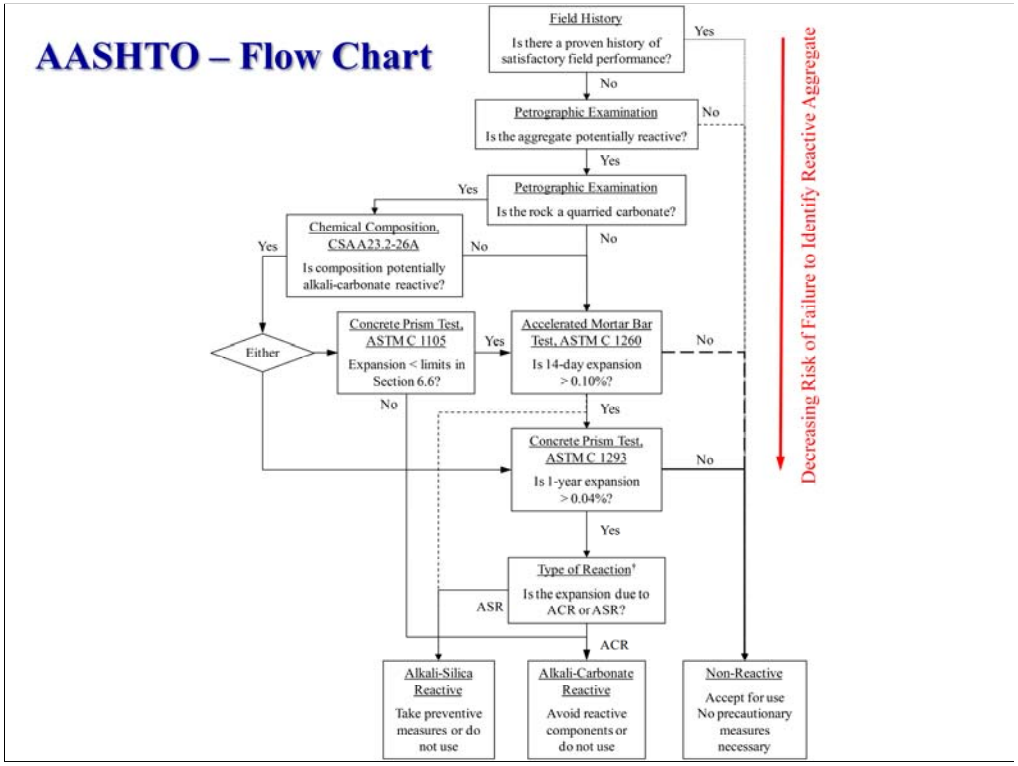


As the title suggests there are two steps in the practice

The first step is to determine if you have either an alkali-silica reactive or alkali-carbonate reactive aggregate.

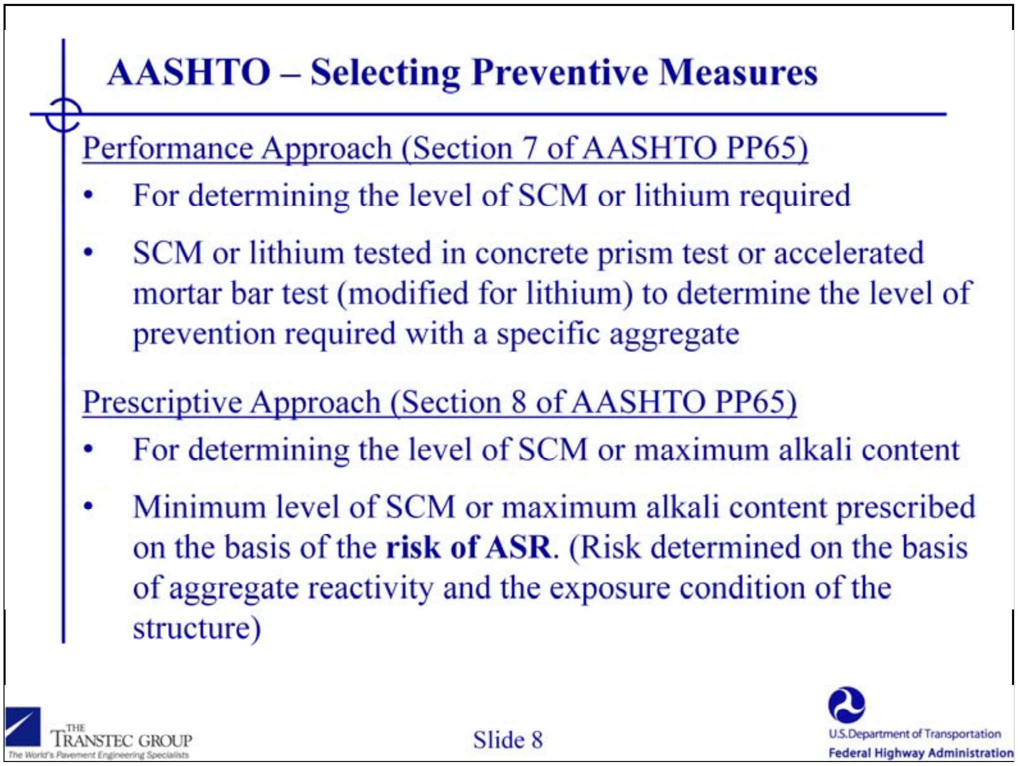
The second is to select preventive measures if after the first step you find you have an alkali-SILICA reactive aggregate.

The stages in the first step are shown in this flow chart. This approach was discussed in the presentation on test methods.

By considering field history, petrography and/or data from expansion testing – there are three possible outcomes – these are

1. The aggregate is non-reactive so no precautionary measures are required
2. The aggregate is potentially alkali-CARBONATE reactive and should be rejected for use in concrete OR
3. The aggregate is potentially alkali-SILICA reactive and may be used with appropriate preventive measures

The second step in the practice concerns the selection of preventive measures in the event of this third outcome. The second step is not required if the outcome is either “non-reactive” or “alkali-carbonate-reactive”



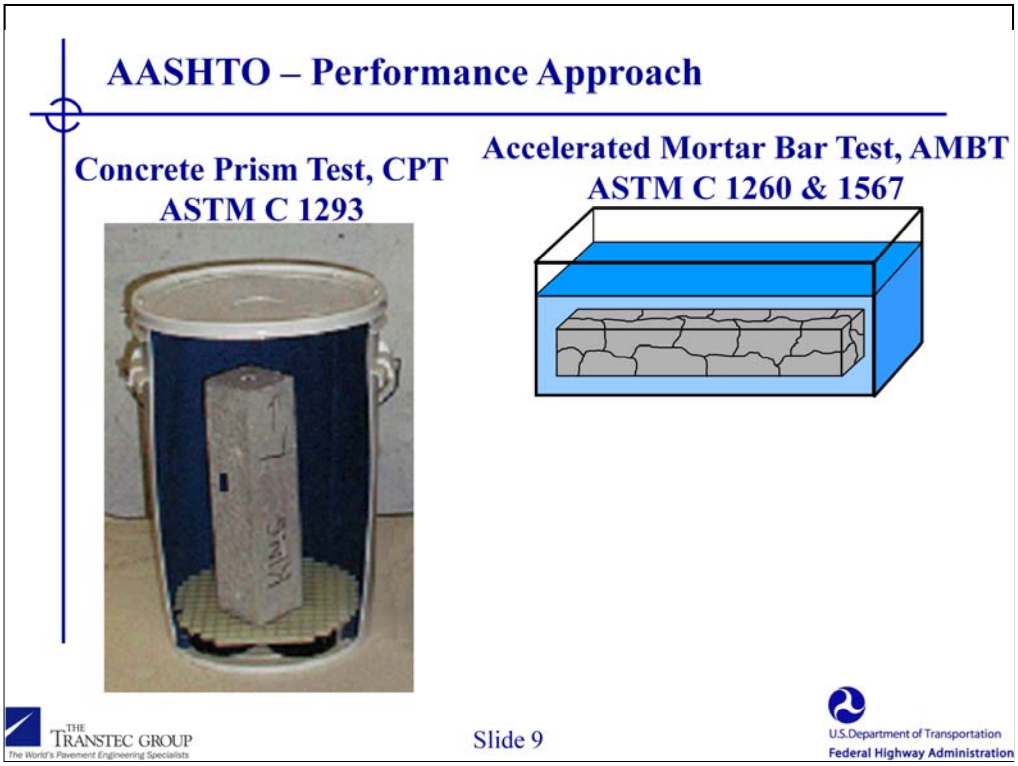
So having discussed the first step in the presentation on test methods – we will focus on the selection of preventive measures.

As mentioned earlier we have a choice of either prescription or performance testing.

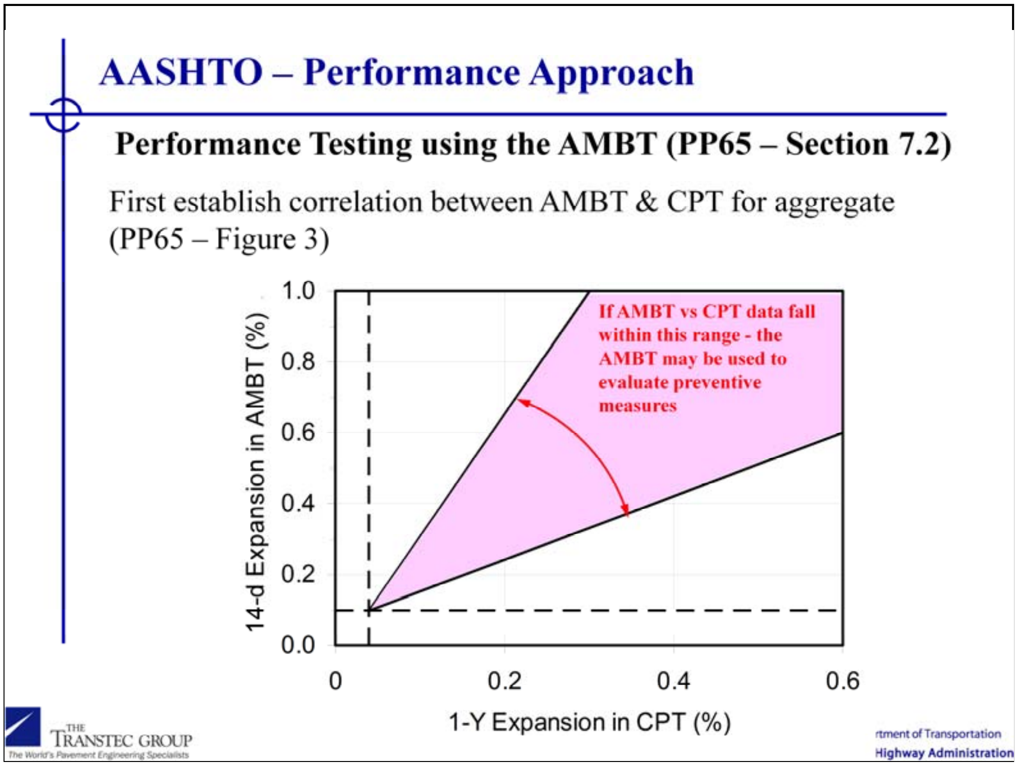
The minimum level of SCM can be determined by using either approach.

The dose of lithium has to be determined by performance testing because – as we have soon – the dose is strongly aggregate dependent and lithium doesn't work with some reactive aggregates.

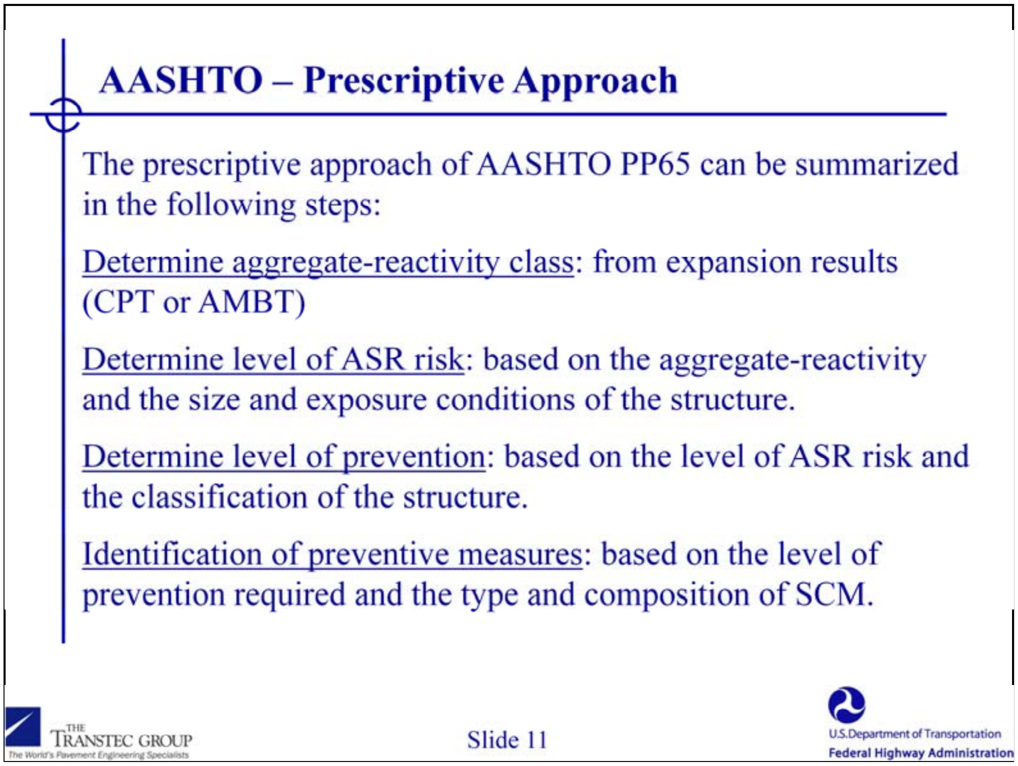
On the other hand – if we want to control ASR by limiting the alkali content of the concrete – we have to follow the prescriptive approach as there is no test method for determining the safe level of alkali.



The performance approach utilizes both the concrete prism test and the accelerated mortar bar test, and the use of these tests was covered by the presentation on test methods.



Just a reminder that the AASHTO practice recommends that the accelerated test be calibrated for the aggregate in question by comparing data from this test with results from the concrete prism test.



[No notes – summarize the text in the slide]

AASHTO – Prescriptive Approach

Step 1 – Determine Aggregate Reactivity (PP65: Section 8.2)

Table 1 Classification of Aggregate Reactivity

Aggregate-Reactivity Class	Description of aggregate reactivity	One-Year Expansion in CPT (%)	14-day Expansion in AMBT (%)
R0	Non-reactive	< 0.040	≤ 0.10
R1	Moderately reactive	0.040 – 0.120	0.10 – 0.30
R2	Highly reactive	0.120 – 0.240	0.30 – 0.45
R3	Very highly reactive	> 0.240	> 0.45

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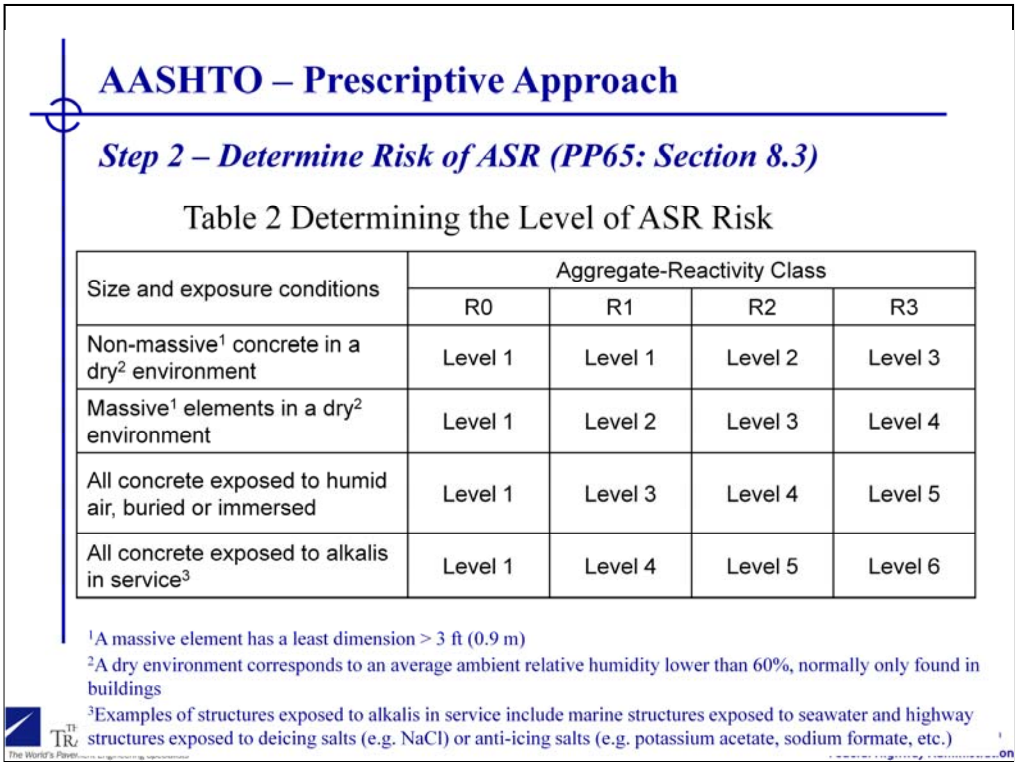
Aggregates are classes in one of four classes from R-zero for non-reactive to R-3 for very highly reactive. The classification is based on the expansion results from either the one-year prism test or the 14-day accelerated mortar bar test. If data are available from both tests – the results from the concrete prism test prevail.

If coarse and fine aggregates are classed differently – the most reactive classification is used.



AASHTO – Prescriptive Approach

Step 2 – Determine Risk of ASR (PP65: Section 8.3)

Table 2 Determining the Level of ASR Risk

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

[1]A massive element has a least dimension > 3 ft (0.9 m)

[2]A dry environment corresponds to an average ambient relative humidity lower than 60%, normally only found in buildings

[3]Examples of structures exposed to alkalis in service include marine structures exposed to seawater and highway structures exposed to deicing salts (e.g. NaCl) or anti-icing salts (e.g. potassium acetate, sodium formate, etc.)

The 2nd step is to determine the RISK of ASR. This is a function of the aggregate reactivity determined in the 1st step and the exposure condition of the structure.

The risk ranges from Level 1 – which essentially means “NO risk” – to level 6 – the highest risk.

There is “no risk” or level 1 when either the aggregate is classed as non-reactive – that is R-zero – or a moderately reactive, R-1, aggregate is used in concrete that is in a dry environment.

Level 6 is the worst case scenario – where a very-highly reactive aggregate is used in concrete exposed to moisture and alkalis in service.

The table shows how the risk varies between these two extremes.

AASHTO – Prescriptive Approach

Step 3 – Determine the Level of Prevention(PP65: Section 8.4)

Table 3 Determining the Level of Prevention

Level of ASR Risk (Table 4)	Classification of Structure (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 1) when the risk of ASR is level 6. Measures must be taken to reduce the level of risk in these circumstances.

Once the risk level is defined the next step is to use this information to determine the level of prevention required. But first we need some information of the Class of the Structure and we have to jump ahead to Table 4.

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OK – back to Table 3 – where we can see that the prevention level ranges from Level V – which means no prevention required to Level double-Z which means the strongest prevention possible.

Level V results when the risk of ASR occurring is low and the consequences should it occur are not too significant.

Level double-Z would result if there is a high risk of ASR occurring given the reactivity of the aggregate and the nature of the exposure, and the occurrence of ASR would have dire consequences for the structure

The table shows how the level varies between V and double-Z as the risk and consequences of ASR increase.

AASHTO – Prescriptive Approach

Step 4 – Classify Structure (PP65: Section 8.4)

Class	Consequences of ASR	Acceptability of ASR	Examples[††]
S1	Safety, economic or environmental consequences small or negligible	Some deterioration from ASR may be tolerated	▪ 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	▪ Sidewalks, curbs and gutters ▪ Service-life < 40 years
S3	Significant safety, economic or environmental consequences if minor damage	Minor risk of ASR acceptable	▪ 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	▪ Major bridges ▪ Tunnels ▪ Critical elements that are very difficult to inspect or repair ▪ Service life normally > 75 years

Note: Class of Structure to be determined by the owner

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The class of structure is determine by considering the consequences of ASR and the design life of the structure. In some cases, some level of risk may be tolerated – where the consequences are not really significant to the performance of the element and/or the service life of the element is relatively short. An example could be a sidewalk in some cases. In other case – no risk of ASR is acceptable because the consequences cannot be tolerated and may shorten the life of the structure – an example might be a major bridge with an extended service life.

Note: The "Class of Structure" should really be determined by the owner.

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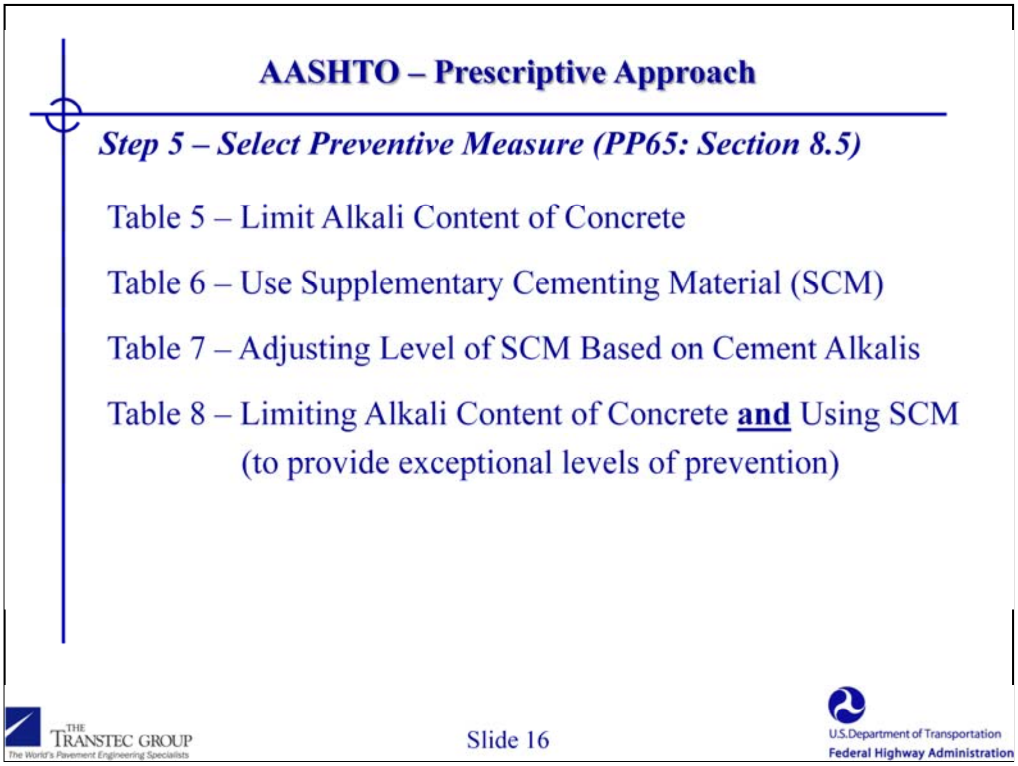

Now the level of prevention is known – the next step is to decide the type of prevention.

If we want to prevent by controlling the alkali content we use Table 5

If we want to use SCMs we use Table 6.

Table 7 allows us to modify the level of SCM based in the cement alkalis.

Table 8 covers the case where an exceptional level of prevention is required and where it may be necessary to limit alkalis AND use SCM

AASHTO – Prescriptive Approach

Step 5 – Select Preventive Measure (PP65: Section 8.5)

Table 5 Maximum Alkali Contents (from Portland Cement) to Provide Various Levels of Prevention

Prevention Level	Maximum alkali content of concrete (Na_2Oe)	
	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	Table 8	
ZZ		

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The maximum alkali content permitted ranges from 5 pounds per cubic yard for a low level of prevention – level W – to 3 pounds per cubic yard for a higher level of prevention – level Y.

For level Z or double-Z it is not permitted to prevent ASR merely by controlling the alkali content of the concrete and some SCM is required as will be seen later.

AASHTO – Prescriptive Approach

Step 5 – Select Preventive Measure (PP65: Section 8.5)

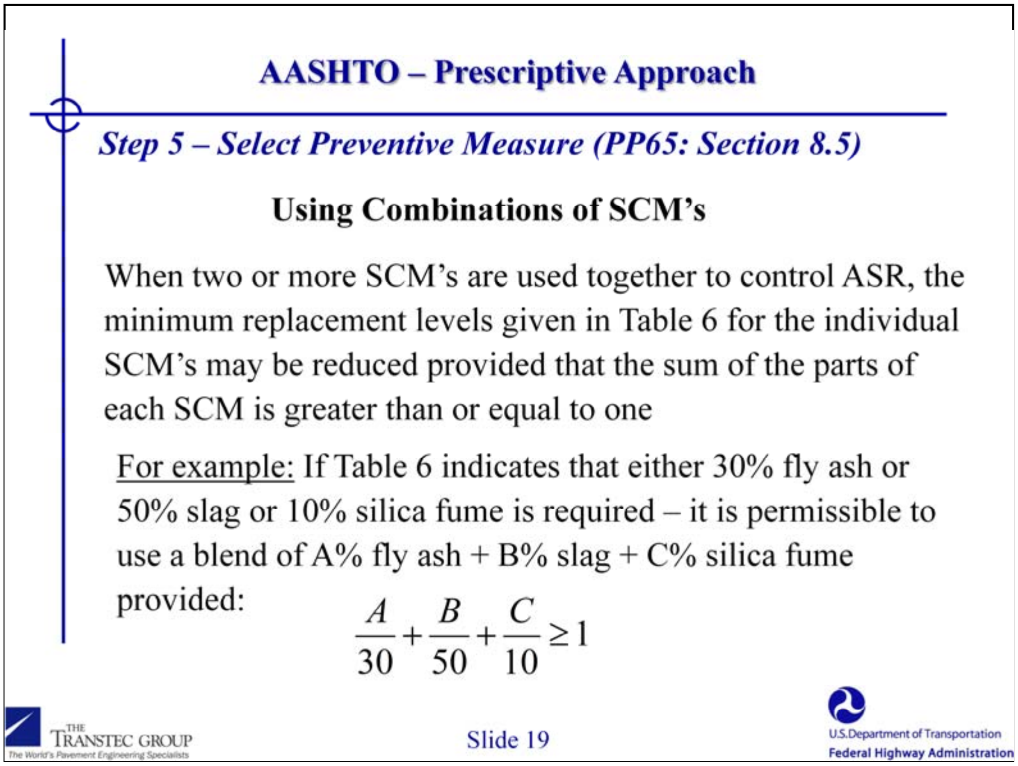
Table 6 Minimum Levels of SCM to Provide Various Levels of Prevention

Type of SCM	Alkali level of SCM (% Na_2Oe)	Minimum Replacement Level (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash (CaO ≤ 18%)	< 3.0	15	20	25	35	Table 8
	3.0 – 4.5	20	25	30	40	
Slag	< 1.0	25	35	50	65	
Silica Fume† (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	

† The minimum level of silica fume (as a percentage of cementing material) is calculated on the basis of the alkali (Na_2Oe) content of the concrete contributed by the portland cement and expressed in either units of lb/yd^3 (LBA in Table 6) or kg/m^3 (KGA in Table 6).

Table 6 shows how the minimum level of SCM varies across the different prevention levels and with the type of SCM. The amount of SCM increase with the level of prevention – obviously. For example, for slag, only 25% is required for Level W but 65% is required for Level Z.

For silica fume the level required is a function of the alkali content in the concrete contributed by the portland cement. So if you are in Level Z and you have 5 pounds of alkali – you will need 2.4 multiplied by 5 equals 12% silica fume.



[Note not required – read slide]

AASHTO – Prescriptive Approach

Step 5 – Select Preventive Measure (PP65: Section 8.5)

Table 7 Adjusting Minimum SCM Level Based on Cement Alkalis

Cement Alkalis (% Na_2Oe)	Level of SCM
< 0.70	Reduce the minimum amount of SCM given in Table 6 by one prevention level
0.70 to 1.00	Use minimum SCM levels in Table 6
> 1.00	Increase the minimum amount of SCM given in Table 6 by one prevention level
> 1.25	No guidance is given

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The SCM levels in Table 6 are deemed to be necessary with cements of moderate to high alkali content. If low-alkali cement is used it is possible to reduce the minimum amount of SCM by one prevention level. If, however, a high-alkali cement is used, the level of SCM should be increased.

AASHTO – Prescriptive Approach

Step 5 – Select Preventive Measure

Table 8 Using SCM and Limiting the Alkali Content of the Concrete to Provide Exceptional Levels of Prevention

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

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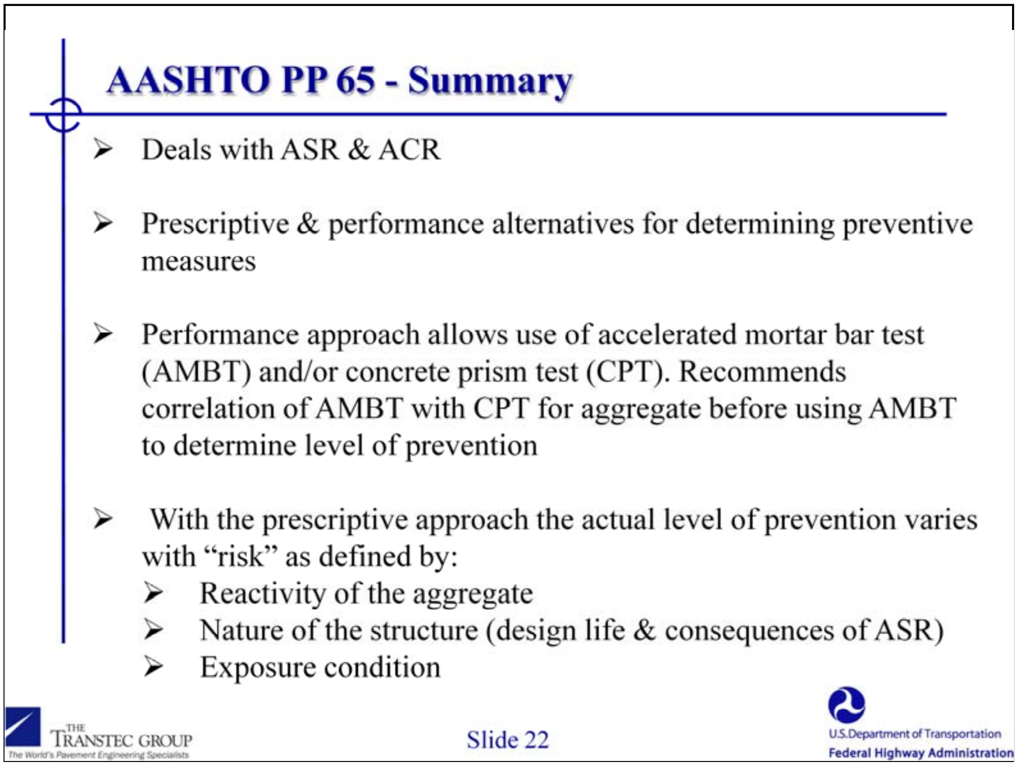
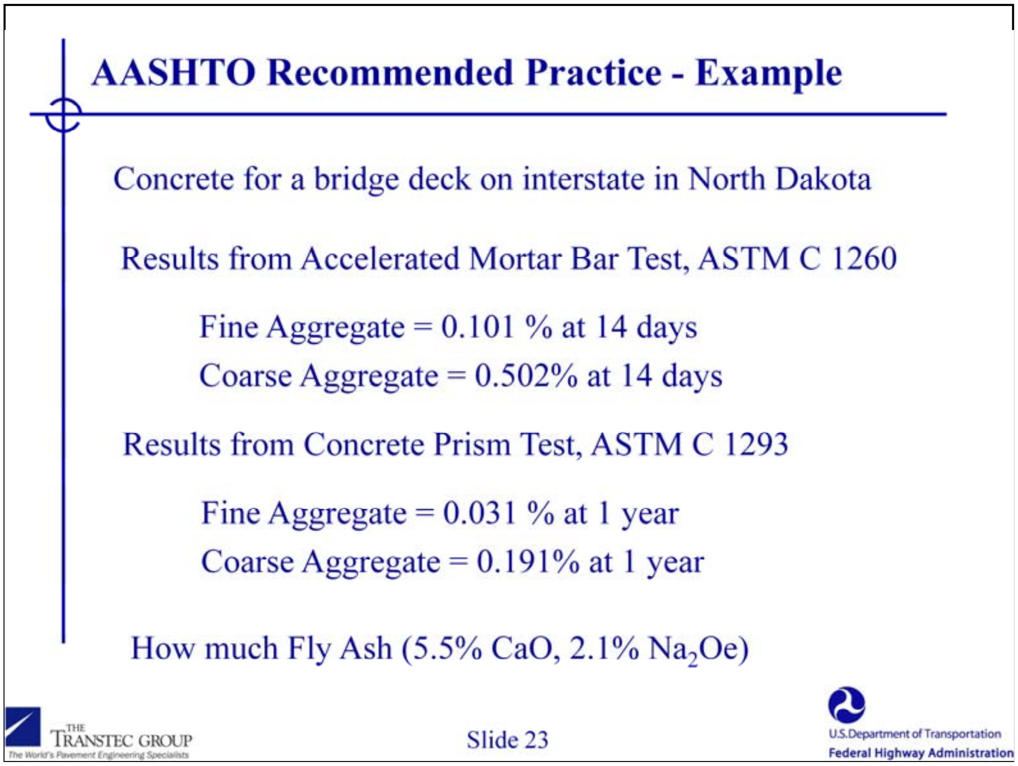
Table 8 deals with extreme levels of prevention – where combined strategies of controlling alkalis and using SCMs are required.

In Level z – there is an option to use either the amount of SCM shown for Level Z in Table 6 – or to reduce this level of SCM by one prevention level – in other words use the amount specified for Level Y BUT in this case the alkali content of the concrete (from the portland cement) but also be limited to 3 pounds per cubic yard.

For level double-Z … the minimum level of SCM must that prescribed for this level of prevention in Table 6 PLUS the alkalis MUST ALSO be controlled to be less than or equal to 3 pounds per cubic yard.



In summary [no notes required – read slide]



The remaining slides show a worked example for using the prescriptive approach [presenters notes are not required]

AASHTO Recommended Practice - Example

Step 1 – Determine Aggregate Reactivity

Table 1 Classification of Aggregate Reactivity

Aggregate-Reactivity Class	Description of aggregate reactivity	One-Year Expansion in CPT (%)	14-day Expansion in AMBT (%)	
R0	Non-reactive	< 0.040	≤ 0.10	
R1	Moderately reactive	0.040 – 0.120	> 0.10, ≤ 0.30	Fine
R2	Highly reactive	0.120 – 0.240	> 0.30, ≤ 0.45	
R3	Very highly reactive	> 0.240	> 0.45	Coarse

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AASHTO Recommended Practice - Example

Step 1 – Determine Aggregate Reactivity

Table 1 Classification of Aggregate Reactivity

Aggregate-Reactivity Class	Description of aggregate reactivity	One-Year Expansion in CPT (%)	14-day Expansion in AMBT (%)	
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R2	Highly reactive	0.120 – 0.240	> 0.30, ≤ 0.45	Coarse
R3	Very highly reactive	> 0.240	> 0.45	Coarse

Reactivity = R2

AASHTO Recommended Practice - Example

Step 2 – Determine Risk of ASR

Table 2 Determining the Level of ASR Risk

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

Risk of ASR = Level 5

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AASHTO Recommended Practice - Example

Step 3 – Classify Structure

Class	Consequences of ASR	Acceptability of ASR	Examples††
S1	Safety, economic or environmental consequences small or negligible	Some deterioration from ASR may be tolerated	▪ Non-load-bearing elements inside buildings ▪ Temporary structures (e.g. < 5 years)
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S4	Serious safety, economic or environmental consequences if minor damage	ASR cannot be tolerated	▪ Major bridges ▪ Tunnels ▪ Critical elements that are very difficult to inspect or repair ▪ Service life normally > 75 years

AASHTO Recommended Practice - Example

Step 4 – Determine the Level of Prevention

Table 3 Determining the Level of Prevention

Level of ASR Risk (Table 4)	Classification of Structure (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	††

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AASHTO Recommended Practice - Example

Step 5 – Select Preventive Measure

Table 5 – Limit Alkali Content of Concrete

Table 6 – Use Supplementary Cementing Material (SCM)

Table 7 – Adjusting Level of SCM Based on Cement Alkalis

Table 8 – Limiting Alkali Content of Concrete **and** Using SCM (to provide exceptional levels of prevention)

AASHTO Recommended Practice - Example

Step 5 – Select Preventive Measure

Table 5 Maximum Alkali Contents (from Portland Cement) to Provide Various Levels of Prevention

Prevention Level	Maximum alkali content of concrete (Na_2Oe)	
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Y	3.0	1.8
Z	Table 8	
ZZ		

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AASHTO Recommended Practice - Example

Step 5 – Select Preventive Measure

Table 6 Minimum Levels of SCM to Provide Various Levels of Prevention

Type of SCM	Alkali level of SCM (% Na_2Oe)	Minimum Replacement Level (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash (CaO ≤ 18%)	< 3.0	15	20	25	35	Table 8
	3.0 – 4.5	20	25	30	40	
Slag	< 1.0	25	35	50	65	
Silica Fume† (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	

† The minimum level of silica fume (as a percentage of cementing material) is calculated on the basis of the alkali (Na_2Oe) 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).

AASHTO Recommended Practice - Example

Step 5 – Select Preventive Measure

Table 8 Using SCM and Limiting the Alkali Content of the Concrete to Provide Exceptional Levels of Prevention

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**

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AASHTO Recommended Practice - Example

Step 5 – Select Preventive Measure

Table 6 Minimum Levels of SCM to Provide Various Levels of Prevention

Type of SCM	Alkali level of SCM (% Na_2Oe)	Minimum Replacement Level (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash (CaO ≤ 18%)	< 3.0	15	20	25	35	Table 8
	3.0 – 4.5	20	25	30	40	
Slag	< 1.0	25	35	50	65	
Silica Fume† (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	

† The minimum level of silica fume (as a percentage of cementing material) is calculated on the basis of the alkali (Na_2Oe) content of the concrete contributed by the portland cement and expressed in either units of lb/yd^3 (LBA in Table 6) or kg/m^3 (KGA in Table 6).

AASHTO Recommended Practice - Example

Prescriptive Solution

Use 35% Fly Ash

AND

Limit alkalis from portland cement to 3.0 lb/yd^3 (1.8 kg/m^3) Na_2Oe

Performance Solution

Run AMBT or CPT at range of fly ash replacement levels to determine how much is required to meet expansion limits

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