SIMPSON GUMPERTZ & HEGER

Engineering of Structures and Building Enclosures

The Assessment of Alkali-Silica Reactivity In Massachusetts Highway Structures, Now

The 90th Annual Meeting of the North East States Materials Engineers Association

Matthew R. Sherman, P.E

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Acknowledgements

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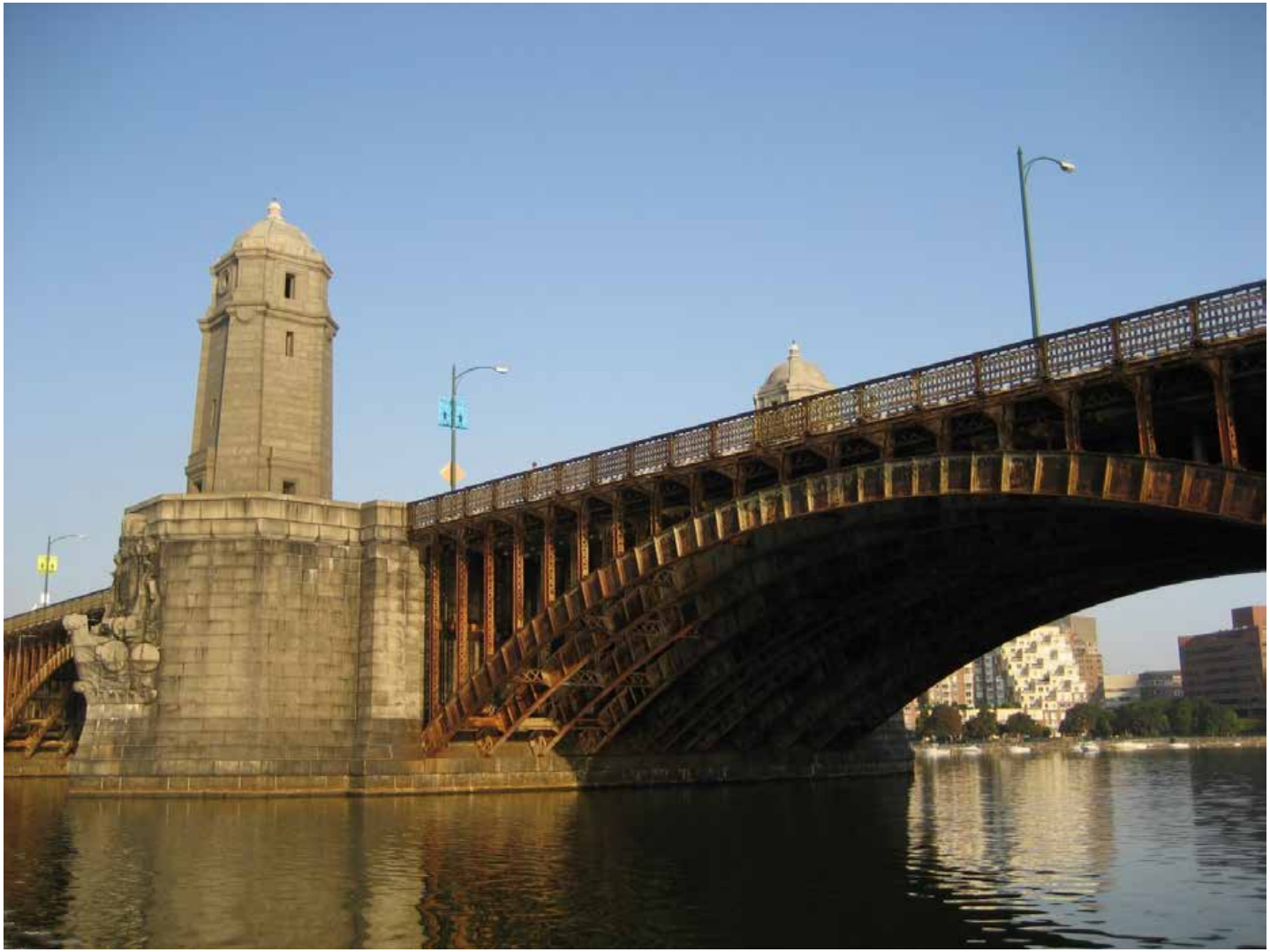
  - John Grieco, P.E., Director MassDOT Research and Materials
  - Walter Knox, MassDOT
  - Clem Fung, MassDOT

ASR Is Nothing New



ASR Is Nothing New

Objective and Outline

- Objectives:
  - Explain the evaluation and management plan protocols
  - Present “lessons learned”
  - Integrate with work to manage ASR in the future

- Outline
  - Background of ASR
  - Description of MassDOT ASR Testing and Evaluation Program
  - Review solutions to hurdles encountered
  - Conclusions

ASR Manifestations in New England

Avoidance of ASR

- ASR avoidance is pretty well understood…

- We test ongoing production…

Avoidance of ASR

- ASR avoidance is pretty well understood…
- We test ongoing production…
- We do long-term tests…

Avoidance of ASR

- ASR avoidance is pretty well understood…
- We test ongoing production…
- We do long-term tests…
- We mitigate where required…

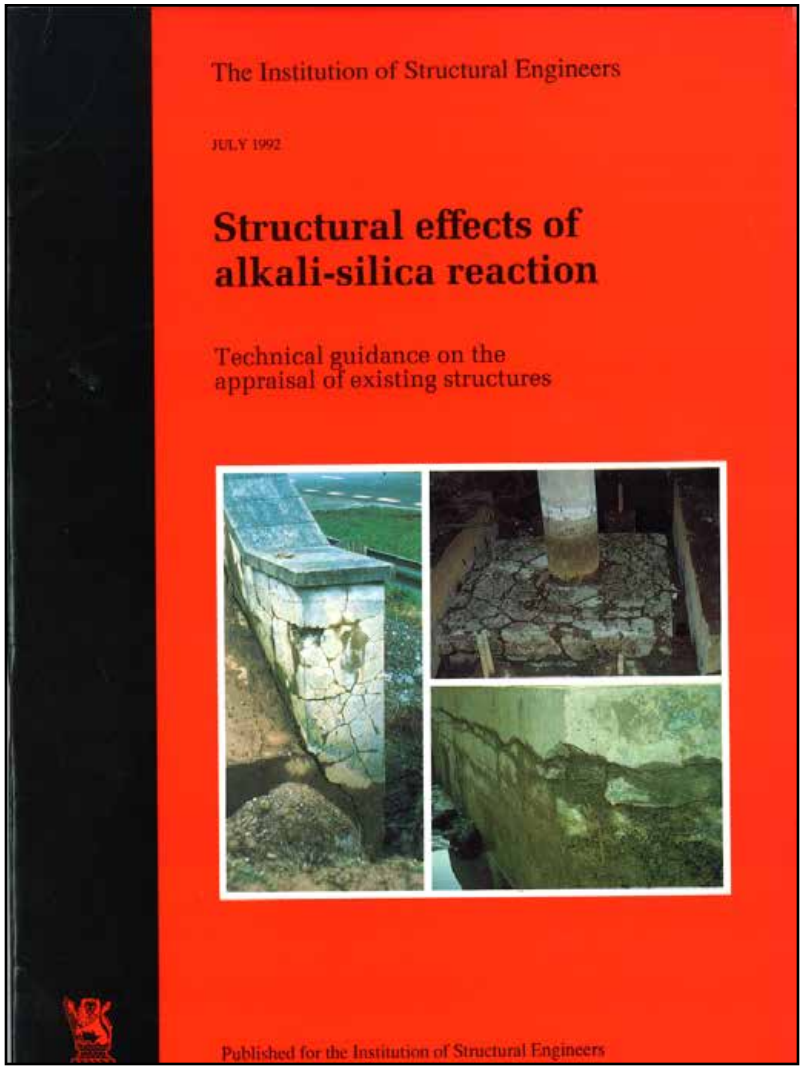
Management of ASR-Affected Structures

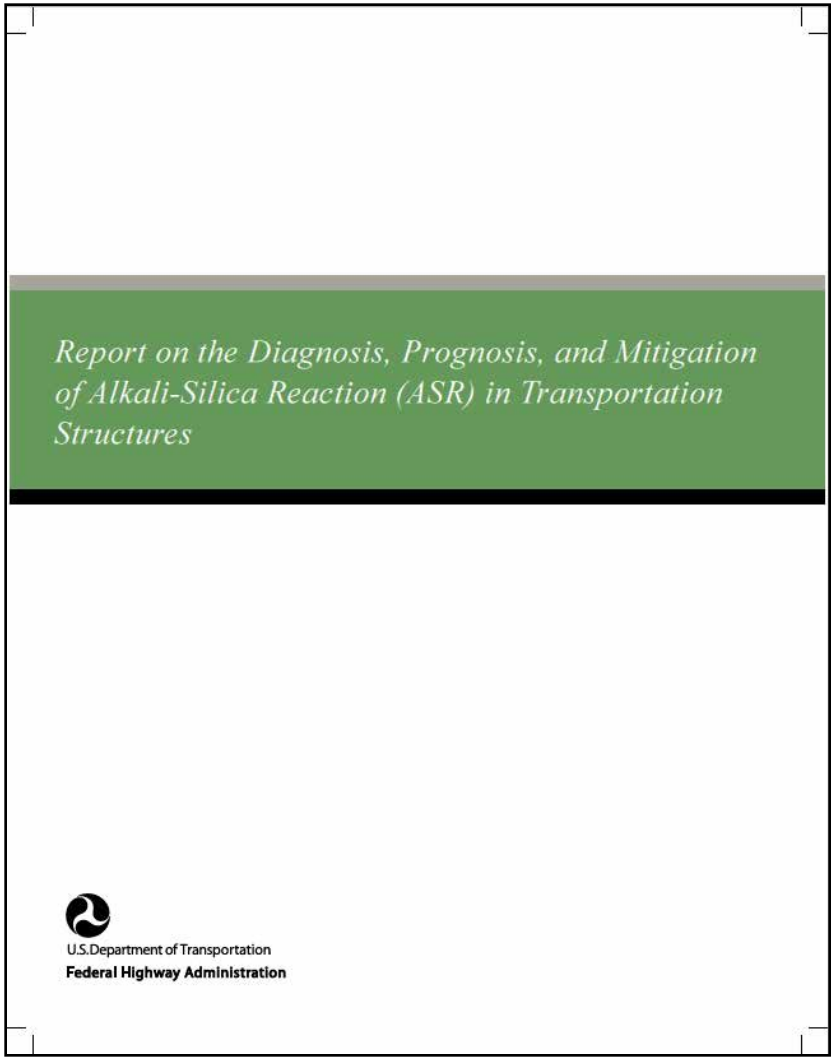
- Cannot be stopped – all constituents are present
  - Alkali (from cement)
  - Reactive silica (from aggregates)
  - Moisture (from rain or groundwater)

- It can be managed…
  - Long-term structural-health monitoring and evaluation
  - Structural retrofits
  - Protection against moisture

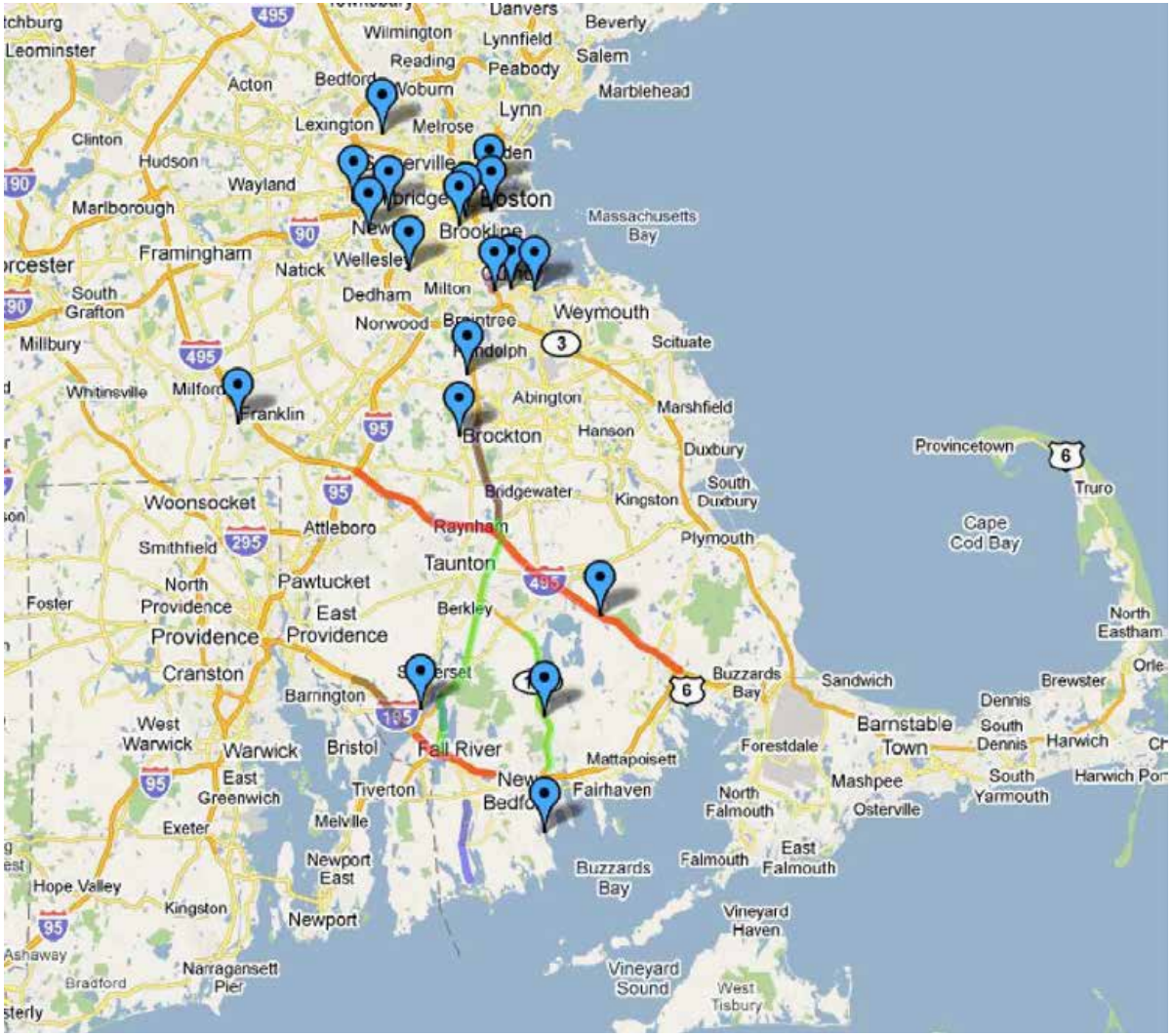
- However, protocols for managing ASR are not well-developed in the industry…

Management Guidelines…





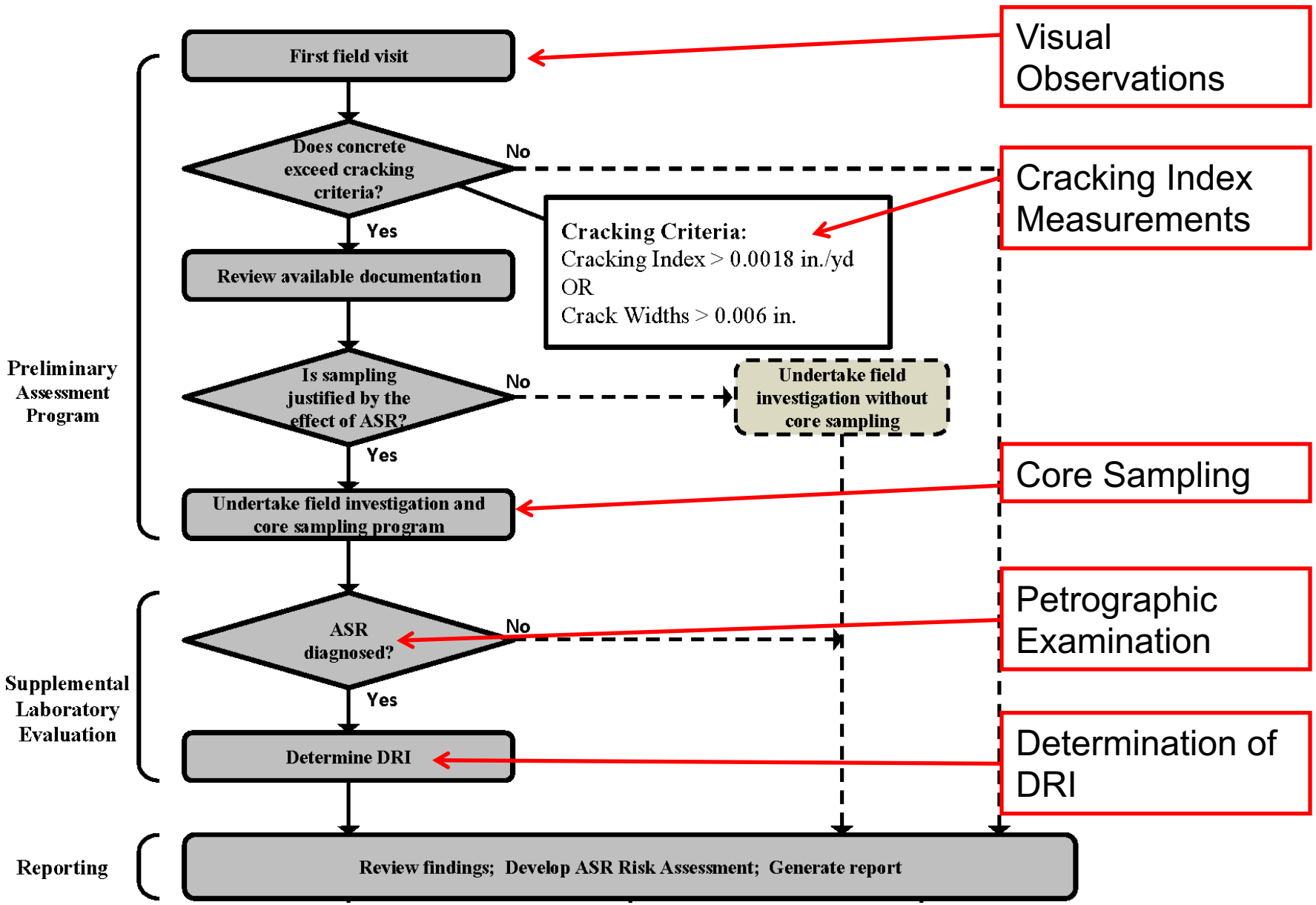
MassDOT ASR Testing and Evaluation Program



Project Description

- 40 structures identified with the potential for ASR due to the use of suspect reactive aggregates.
- Structures include elements of major and minor bridges, highway sign foundations, strain pole foundations, highway sound barrier foundations, sidewalks, etc.
- Project Objective
  - Establish an inspection procedure to diagnose ASR impact/potential in the structure
  - Determine the extent of damage caused by ASR
  - Evaluate potential concerns
  - Develop management plans for structure
  - Recommend actions for Districts

ASR Evaluation

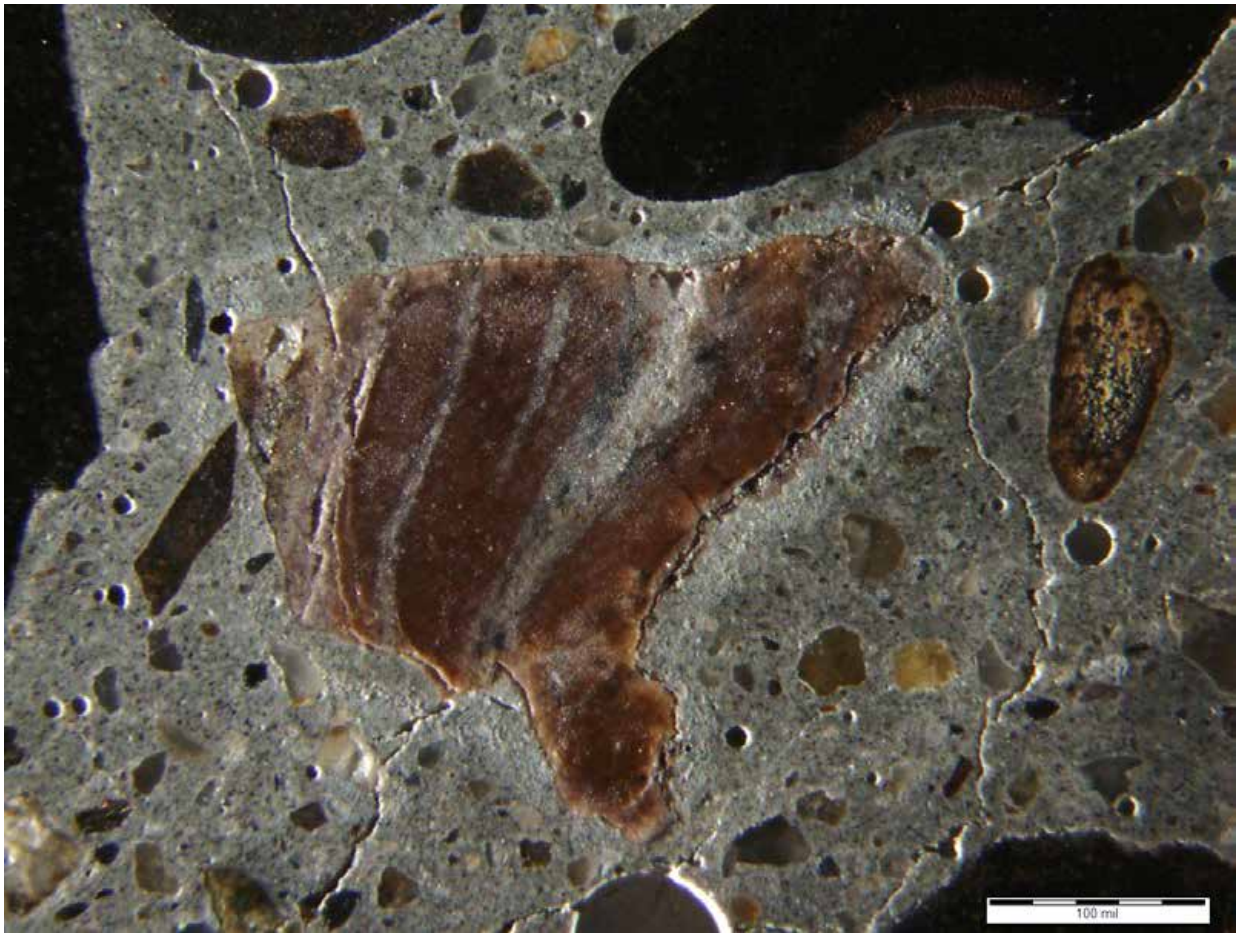


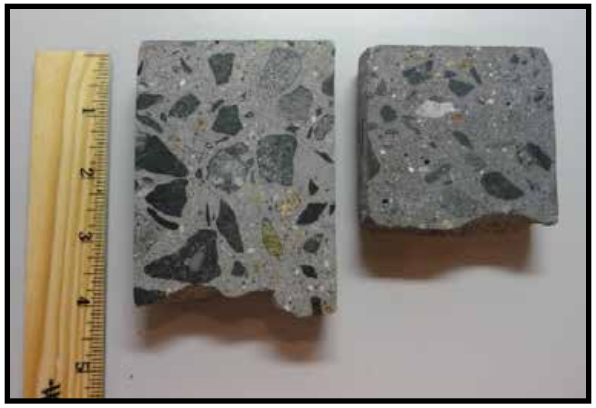
Visual Observations

- Global
  - Expansion, deformation, relative movement, and displacement.
- Cracking
  - Apparent pattern-cracking
  - Broad brownish zone
  - Damp appearance
  - Surface deposits – gel exudation
  - Pop-out of reactive aggregate

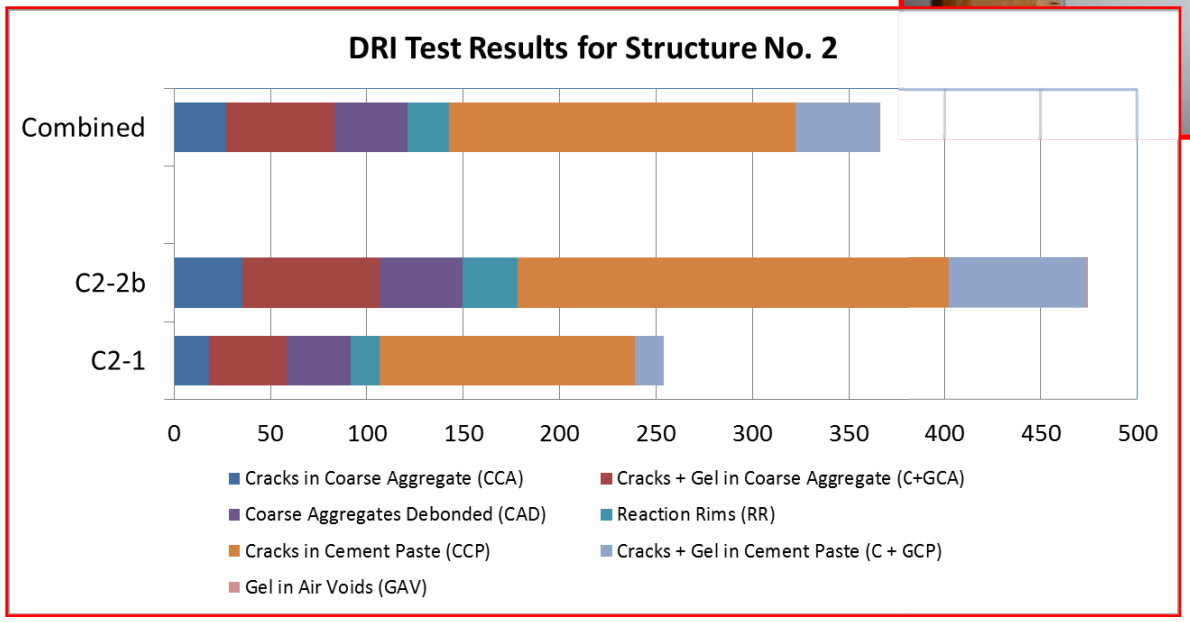
Crack Index (CI) Measurements

Petrographic Examination - Identifying ASR

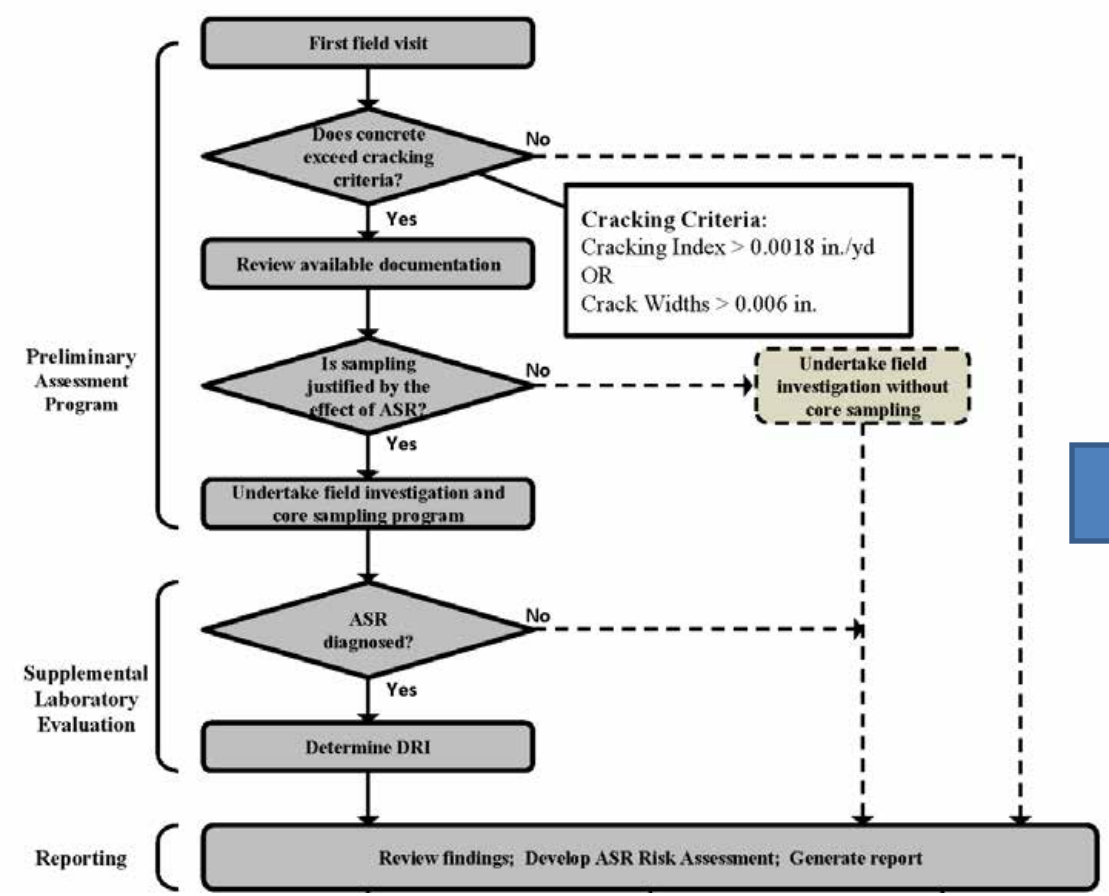


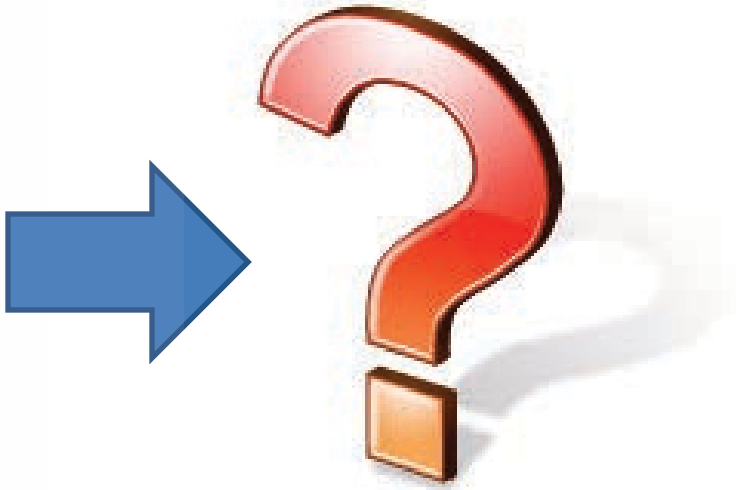


Damage Rating Index (DRI) Determination



ASR Evaluation – Then What?



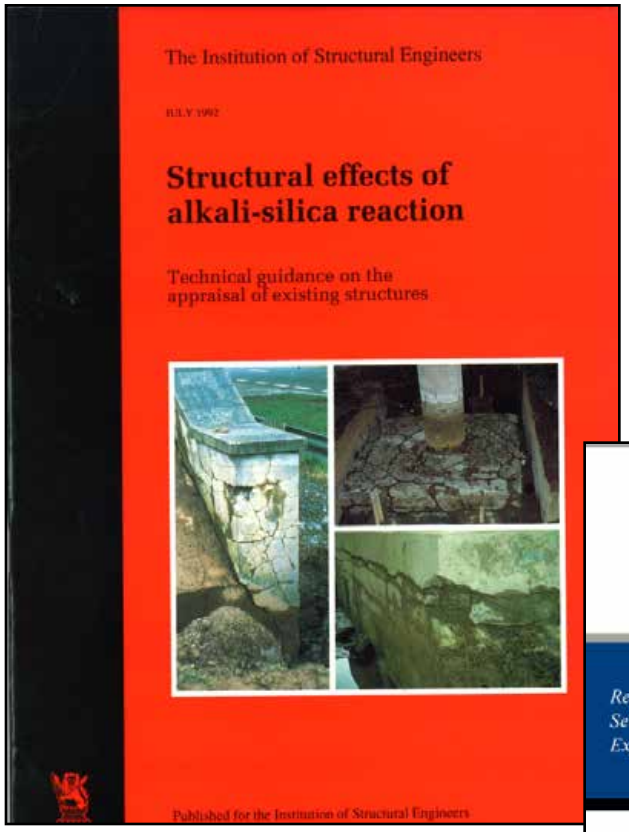


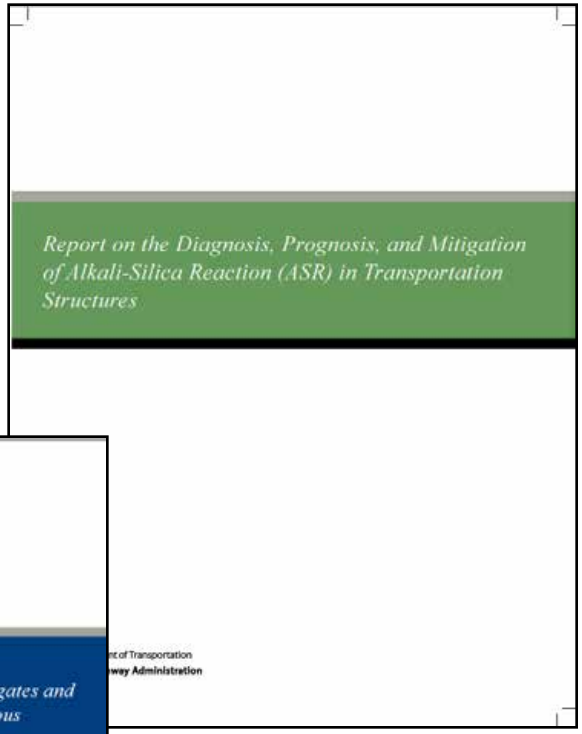
Assessment of ASR-Affected Elements/Structures

- Assessment – How do we use this information to help MassDOT at all levels?
  - Guidance is thin – most is about how to avoid it, not how to deal with it once you have it
  - ASR can be thought of as a chronic disease
    - Serviceability/appearance
    - Loss of bond
    - Spalling
    - Increased structural risk of unknown degree
- Our response is a hybrid of the available systems, customized for MassDOT

Management Guidelines…

How to Interpret…





SGH Recommended Measures for ASR-Affected Elements/Structures

- Uses Key Parameters/Characteristics
  - Effect of ASR on Function – Negligible, minor, significant
  - Exposure Condition – Dry, intermediate, wet
  - Expansion Index I through V
  - Reinforcement Detailing Class – Good, fair, poor
- Provides Ratings and Response/ Actions
  - 0 – Negligible
  - 1 – Minor
  - 2 – Moderate
  - 3 – Appreciable
  - 4 – Significant

Effect of ASR on Function

Negligible	• No structural implications or safety concerns beyond those of non-ASR-affected concrete (sidewalks, aprons, etc).
Minor (If all of these criteria apply)	• Only a limited portion of the element is affected by ASR. • ASR damage will causes no significant loss of performance. • ASR damage does not pose a risk of personal injury due to sudden failure. • Significant redundancy exists within a large structural element or element is redundant within the overall structure. • No or only gradual change in effect of ASR damage expected within the next 4 years.
Significant Property Value/ Personal Injury*	• "Ample warning" – Effect of ASR will occur with noticeable advance warning such as significant cracking, deflection or displacement. This will typically be the case for bridge decks, bridge piers, foundation walls, abutment walls, barrier rails etc) • "Sudden failure" – Effect of ASR will occur with no advance warning. This will typically be the case for pre-stressed elements and shear- and development-based modes, including anchorage, localized bearings, and shear-controlled bearings.

Rating	Effect of ASR on Function			
	Negligible	Minor	Significant Property Value/ Personal Injury	
			Ample Warning	Sudden Failure

Site Environment: Exposure Condition

Mild	Dry environment, internal RH < 75%
Intermediate	Internal RH between 75% ~ 85%; vertical surfaces w/o exposure to deicing salts; i.e. pier caps, sound walls, above-grade columns and piers
Severe	Wet environment, deicing salt exposure, horizontal surfaces; i.e. retaining walls, foundations, abutments, decks, barrier walls

Rating	Effect of ASR on Function			
	Negligible	Minor	Significant Property Value/ Personal Injury	
			Ample Warning	Sudden Failure
Site Environment: **Mild** (Dry environment, internal RH < 75%)				
Rating				
Site Environment: **Intermediate (**Internal RH between 75% ~ 85%; vertical surfaces w/o exposure to deicing salts; Ex. pier caps, sound walls, above-grade columns and piers**)**				
Rating				
Site Environment: **Severe** (Wet environment, deicing salt exposure, horizontal surfaces; ex. retaining walls, foundations, abutments, decks, barrier walls)				
Rating				

Expansion Index

I	< 0.5 mm/m (0.018 in./yd)
II	0.5 mm/m ~1.0 mm/m (0.018 in./yd~0.036 in./yd)
III	1.0 mm/m ~1.5 mm/m (0.036 in./yd~0.054 in./yd)
IV	1.5 mm/m ~2.5 mm/m (0.054 in./yd~0.090 in./yd)
V	> 2.5 mm/m (0.090 in./yd)

Rating		Effect of ASR on Function			
		Negligible	Minor	Significant Property Value/ Personal Injury	
				Ample Warning	Sudden Failure
Site Environment: Mild (Dry environment, internal RH < 75%)					
Expansion Index	I				
	II				
	III				
	IV				
	V				
Site Environment: Intermediate (Internal RH between 75% ~ 85%; vertical surfaces w/o exposure to deicing salts; Ex. pier caps, sound walls, above-grade columns and piers)					
Expansion Index	I				
	II				
	III				
	IV				
	V				
Site Environment: Severe (Wet environment, deicing salt exposure, horizontal surfaces; ex. retaining walls, foundations, abutments, decks, barrier walls)					
Expansion Index	I				
	II				
	III				
	IV				
	V				

Reinforcement Detailing Class*

Good	Stirrups, Hooked ends or welded laps
Fair	Conventional (corner lapped stirrups)
Poor	No through ties - No stirrups or side lapped stirrups, or unknown reinforcement condition

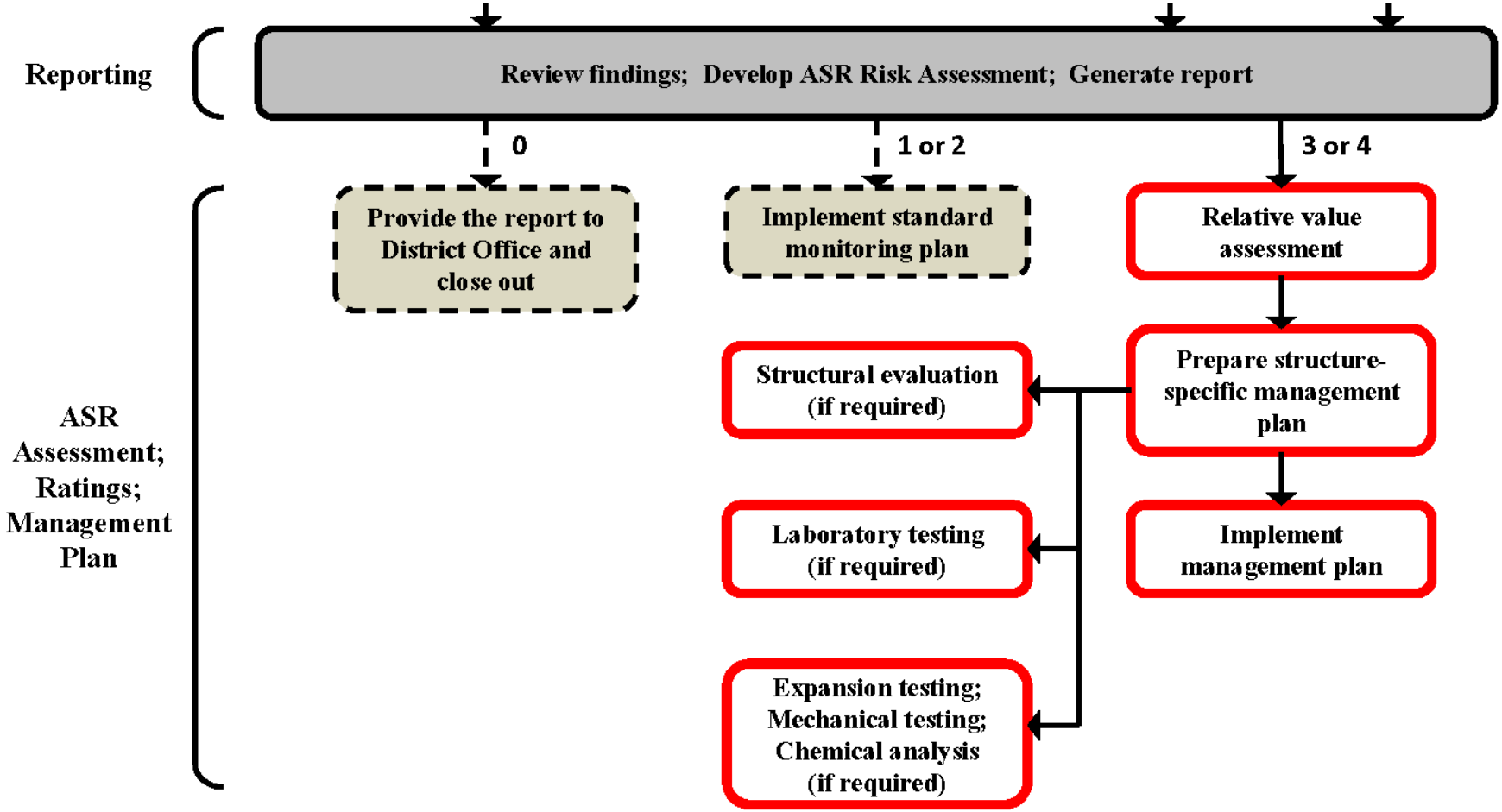
Rating		Effect of ASR on Function									
		Negligible	Minor			Significant Property Value/ Personal Injury					
						Ample Warning			Sudden Failure		
Reinforcing Detailing Class		-	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Site Environment: **Mild** (Dry environment, internal RH < 75%)											
Expansion Index	I										
	II										
	III										
	IV										
	V										
Site Environment: **Intermediate** (Internal RH between 75% ~ 85%; vertical surfaces w/o exposure to deicing salts; Ex. pier caps, sound walls, above-grade columns and piers)											
Expansion Index	I										
	II										
	III										
	IV										
	V										
Site Environment: **Severe** (Wet environment, deicing salt exposure, horizontal surfaces; ex. retaining walls, foundations, abutments, decks, barrier walls)											
Expansion Index	I										
	II										
	III										
	IV										
	V										

* For classification, assume typical reinforcement details were used if drawings are unavailable.

Management of ASR Affected Elements/Structures

Rating		Effect of ASR on Function									
		Negligible	Minor			Significant Property Value/ Personal Injury					
						Ample Warning			Sudden Failure		
Reinforcing Detailing Class		-	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Site Environment: Mild (Dry environment, internal RH < 75%)											
Expansion Index	I	0	0	0	0	0	0	0	0	0	0
	II	0	0	0	0	0	0	1	0	0	1
	III	0	0	0	0	0	1	1	0	1	1
	IV	0	0	1	1	1	1	1	1	1	2
	V	1	2	2	2	1	1	1	1	2	2
Site Environment: Intermediate (Internal RH between 75% ~ 85%; vertical surfaces w/o exposure to deicing salts; Ex. pier caps, sound walls, above-grade columns and piers)											
Expansion Index	I	0	0	0	0	1	1	1	1	1	1
	II	0	0	0	0	1	1	1	1	1	1
	III	0	0	1	1	1	1	2	1	2	2
	IV	0	0	1	1	1	2	3	2	2	4
	V	1	2	2	2	3	3	3	3	3	4
Site Environment: Severe (Wet environment, deicing salt exposure, horizontal surfaces; ex. retaining walls, foundations, abutments, decks, barrier walls)											
Expansion Index	I	0	0	0	0	1	1	1	1	1	1
	II	0	0	0	0	1	1	1	1	1	1
	III	0	0	1	1	2	2	2	2	2	4
	IV	0	1	1	1	2	2	4	4	4	4
	V	1	2	2	2	3	3	4	4	4	4

ASR Evaluation



Now the hurdles of turning a research project into a practical protocol…

Implementation Challenges

- ISE document:
  - Very frequent inspections
  - Detailed analysis
  - Large damage factors
- FHWA document:
  - Relies on long-term testing
  - Little guidance on evaluation
  - Conflicting interpretation of results
- Knowledge gap:
  - “Owners” of non-bridge elements
  - Inspectors
  - Designers
- Budget

Avoiding the "Hand Grenade"

- Recognize that they have a lot on their plate
- Giving them a problem with no solution dooms them to failure

- RESPONSES:
  - Educate
  - Provide examples, staff, expertise, and options
  - Always provide a "way out" – don't set them up to fail
  - Be prudent in demands

Coordinating with ongoing inspections

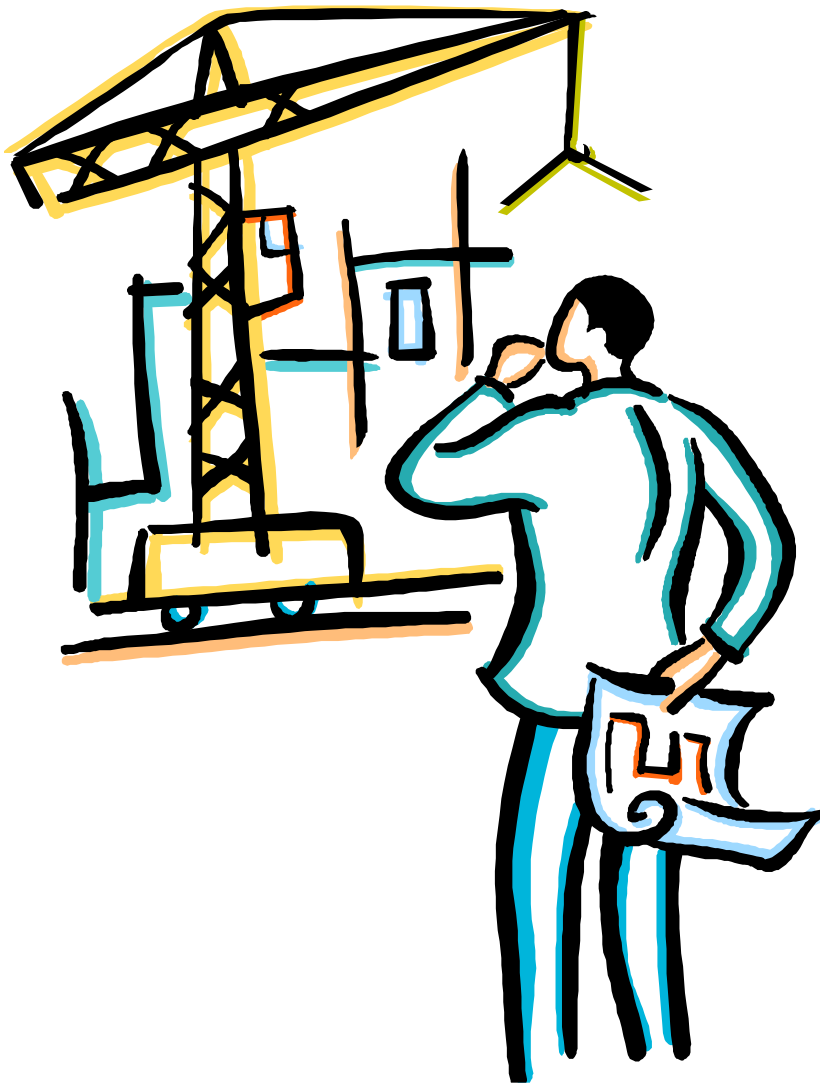
- Established protocol that is defined by others
- They have to “live by the form”

- RESPONSES:
  - Incorporate into their work
  - Provide clear direction
  - Minimize extra work (access, amount of measurement, number of measurements)
  - Lots of photographs and graphical information

- or -

Even the designers need help

- Engineers have a hard time dealing with ASR.
  - Real structural effects are not clearly defined
  - Detailing is unknown (splices, anchorage, etc.)
- RESPONSES:
  - Examples
  - Resources
  - Support



Budget – An "Umbrella" Challenge

- Know your customer
- Recognize that ASR is not the "be all, end all" and that it doesn't trump everything else
- Resources are limited and we have to optimize what we can do

- RESPONSES:
  - Balance risk/reward
  - Provide resources – examples, staff, expertise, options
  - Integrate into other work
  - Intelligently back off from ISE & FHWA researcher recommendations
  - But, don't dismiss real concerns – there are critical items

Ratings and Response/ Actions

Rating	Effect of ASR on Performance of Element or Structure	Management Plan
0	Negligible	• No ASR-specific response required. • Reassess only if warranted by new information or changes noted in course of other routine maintenance work.
1	Minor	• Visually inspect every two years for signs of large changes in condition (new spalling, staining, “alligator cracking” with cracks wider than 1/32 in.) • For bridge structures, add note to NBIS report to alert inspectors of potential ASR during future inspections. • If possible, minimize moisture intrusion to increase service life. • Repeat detailed ASR inspection and risk assessment during second MassDOT NBIS inspection cycle for bridges or after 4 years for structures not covered by routine inspections.
2	Moderate	• Visually inspect annually for signs of large changes in condition (new spalling, staining, “alligator cracking” with cracks wider than 1/32 in.). • If possible, minimize moisture intrusion to increase service life. • Perform detailed crack survey and CI measurements as part of NBIS inspections for bridges or with local staff for other structures every two years and repeat ASR risk assessment. If a new ASR rating is assigned, modify current management plan and act accordingly.

3	Appreciable	• Visually inspect and perform detailed crack survey and CI measurement every six months until implementation of a management and maintenance plan.
		• Prepare and implement a structure-specific management and maintenance plan. This may include one or more of the following options depending on factors such as the expected time to scheduled replacement, replacement value of the structure(s), relative cost analysis, and local monitoring capabilities.
		  • Structural analysis and evaluation and/or prediction of remaining service life using reduced concrete properties due to ASR distress. This option may require additional field investigation, non-destructive testing, and extensive laboratory testing to determine reduction of concrete properties and potential future ASR expansion.
		  • Formal monitoring with a scheduled frequency, if indicated by structural analysis and evaluation. This option may require using additional monitoring techniques, such as “tell-tale” markers or crack displacement gages.
		  • Permanent repair and/or strengthening.
		  • Replacement of the structure.

4	Significant	• Visually inspect and perform detailed crack survey and CI measurement every three months until implementation of a management and maintenance plan. • Prepare and implement a structure-specific management and maintenance plan, as described for “Rating 3” above.

Ratings and Response/ Actions

Rating	Effect of ASR on Perform-ance of Element or Structure	Management Plan
0	Negligible	• No ASR-specific response required. • Reassess only if warranted by new information or changes noted in course of other routine work.

Rating		Effect of ASR on Function									
		Negligible	Minor			Significant Property Value/ Personal Injury					
						Ample Warning			Sudden Failure		
Reinforcing Detailing Class		-	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Site Environment: Mild (Dry environment, internal RH < 75%)											
Expansion Index	I	0	0	0	0	0	0	0	0	0	0
	II	0	0	0	0	0	0	1	0	0	1
	III	0	0	0	0	0	1	1	0	1	1
	IV	0	0	1	1	1	1	1	1	1	2
	V	1	2	2	2	1	1	1	1	2	2
Site Environment: Intermediate (Internal RH between 75% ~ 85%; vertical surfaces w/o exposure to deicing salts; Ex. pier caps, sound walls, above-grade columns and piers)											
Expansion Index	I	0	0	0	0	1	1	1	1	1	1
	II	0	0	0	0	1	1	1	1	1	1
	III	0	0	1	1	1	1	2	1	2	2
	IV	0	0	1	1	1	2	3	2	3	4
	V	1	2	2	2	3	3	3	3	3	4
Site Environment: Severe (Wet environment, deicing salt exposure, horizontal surfaces; ex. retaining walls, foundations, abutments, decks, barrier walls)											
Expansion Index	I	0	0	0	0	1	1	1	1	1	1
	II	0	0	0	0	1	1	1	1	1	1
	III	0	0	1	1	2	2	2	2	2	4
	IV	0	1	1	1	2	2	4	4	4	4
	V	1	2	2	2	3	3	4	4	4	4

Rating 0 - Examples

Ratings and Response/ Actions

1	Minor	• Visually inspect <u>every two years</u> for signs of large changes in condition (new spalling, staining, “alligator cracking” with cracks wider than 1/32 in.) • For bridge structures, add note to NBIS report to alert inspectors of potential ASR during future inspections. • If possible, minimize moisture intrusion to increase service life. • Repeat detailed ASR inspection and risk assessment during second MassDOT NBIS inspection cycle for bridges or after 4 years for structures not covered by routine inspections.

Rating		Effect of ASR on Function									
		Negligible	Minor			Significant Property Value/ Personal Injury					
						Ample Warning			Sudden Failure		
Reinforcing Detailing Class		-	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Site Environment: Mild (Dry environment, internal RH < 75%)											
Expansion Index	I	0	0	0	0	0	0	0	0	0	0
	II	0	0	0	0	0	0	1	0	0	1
	III	0	0	0	0	0	1	1	0	1	1
	IV	0	0	1	1	1	1	1	1	1	2
	V	1	2	2	2	1	1	1	1	2	2
Site Environment: Intermediate (Internal RH between 75% ~ 85%; vertical surfaces w/o exposure to deicing salts; Ex. pier caps, sound walls, above-grade columns and piers)											
Expansion Index	I	0	0	0	0	1	1	1	1	1	1
	II	0	0	0	0	1	1	1	1	1	1
	III	0	0	1	1	1	1	2	1	2	2
	IV	0	0	1	1	1	2	3	2	2	4
	V	1	2	2	2	3	3	3	3	3	4
Site Environment: Severe (Wet environment, deicing salt exposure, horizontal surfaces; ex. retaining walls, foundations, abutments, decks, barrier walls)											
Expansion Index	I	0	0	0	0	1	1	1	1	1	1
	II	0	0	0	0	1	1	1	1	1	1
	III	0	0	1	1	2	2	2	2	2	4
	IV	0	1	1	1	2	2	4	4	4	4
	V	1	2	2	2	3	3	4	4	4	4

Rating 1 - Examples

Ratings and Response/ Actions

2	Moderate	• Visually inspect <u>annually</u> for signs of large changes in condition (new spalling, staining, “alligator cracking” with cracks wider than 1/32 in.). • If possible, minimize moisture intrusion to increase service life. • Perform detailed crack survey and CI measurements as part of NBIS inspections for bridges or with local staff for other structures <u>every two years</u> and repeat ASR risk assessment. If a new ASR rating is assigned, modify current management plan and act accordingly.

Rating		Effect of ASR on Function									
		Negligible	Minor			Significant Property Value/ Personal Injury					
						Ample Warning			Sudden Failure		
Reinforcing Detailing Class		-	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Site Environment: Mild (Dry environment, internal RH < 75%)											
Expansion Index	I	0	0	0	0	0	0	0	0	0	0
	II	0	0	0	0	0	0	1	0	0	1
	III	0	0	0	0	0	1	1	0	1	1
	IV	0	0	1	1	1	1	1	1	1	2
	V	1	2	2	2	1	1	1	1	2	2
Site Environment: Intermediate (Internal RH between 75% ~ 85%; vertical surfaces w/o exposure to deicing salts; Ex. pier caps, sound walls, above-grade columns and piers)											
Expansion Index	I	0	0	0	0	1	1	1	1	1	1
	II	0	0	0	0	1	1	1	1	1	1
	III	0	0	1	1	1	1	2	1	2	2
	IV	0	0	1	1	1	2	3	2	3	4
	V	1	2	2	2	3	3	3	3	3	4
Site Environment: Severe (Wet environment, deicing salt exposure, horizontal surfaces; ex. retaining walls, foundations, abutments, decks, barrier walls)											
Expansion Index	I	0	0	0	0	1	1	1	1	1	1
	II	0	0	0	0	1	1	1	1	1	1
	III	0	0	1	1	2	2	2	2	3	4
	IV	0	1	1	1	2	2	4	4	4	4
	V	1	2	2	2	3	3	4	4	4	4

Rating 2 - Examples

Ratings and Response/ Actions

3	Appreciable	• Visually inspect and perform detailed crack survey and CI measurement every six months until implementation of a management and maintenance plan.
		• Prepare and implement a structure-specific management and maintenance plan. This may include one or more of the following options depending on factors such as the expected time to scheduled replacement, replacement value of the structure(s), relative cost analysis, and local monitoring capabilities.
		  • Structural analysis and evaluation and/or prediction of remaining service life using reduced concrete properties due to ASR distress. This option may require additional field investigation, non-destructive testing, and extensive laboratory testing to determine reduction of concrete properties and potential future ASR expansion.
		  • Formal monitoring with a scheduled frequency, if indicated by structural analysis and evaluation. This option may require using additional monitoring techniques, such as “tell-tale” markers or crack displacement gages.
		  • Permanent repair and/or strengthening.
		  • Replacement of the structure.

Rating 3 - Examples

Ratings and Response/ Actions

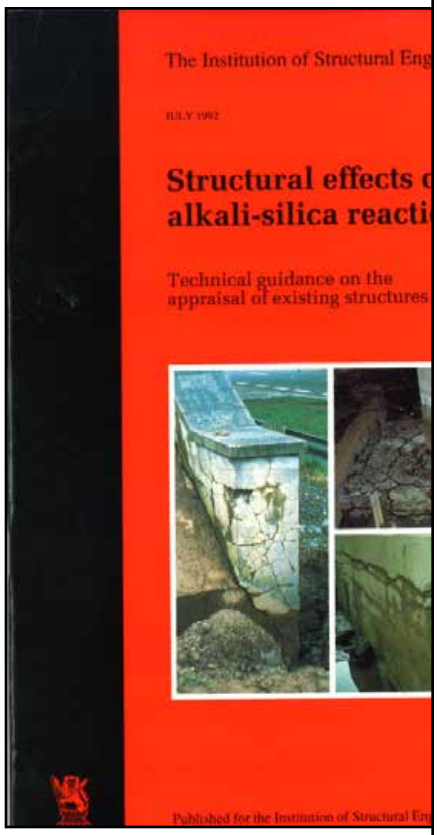
4	Significant	• Visually inspect and perform detailed crack survey and CI measurement <u>every three months</u> until implementation of a management and maintenance plan. • Prepare and implement a structure-specific management and maintenance plan, as described for “Rating 3” above.

Rating		Effect of ASR on Function									
		Negligible	Minor			Significant Property Value/ Personal Injury					
						Ample Warning			Sudden Failure		
Reinforcing Detailing Class		-	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
Site Environment: Mild (Dry environment, internal RH < 75%)											
Expansion Index	I	0	0	0	0	0	0	0	0	0	0
	II	0	0	0	0	0	0	1	0	0	1
	III	0	0	0	0	0	1	1	0	1	1
	IV	0	0	1	1	1	1	1	1	1	2
	V	1	2	2	2	1	1	1	1	2	2
Site Environment: Intermediate (Internal RH between 75% ~ 85%; vertical surfaces w/o exposure to deicing salts; Ex. pier caps, sound walls, above-grade columns and piers)											
Expansion Index	I	0	0	0	0	1	1	1	1	1	1
	II	0	0	0	0	1	1	1	1	1	1
	III	0	0	1	1	1	1	2	1	2	2
	IV	0	0	1	1	1	2	3	2	3	4
	V	1	2	2	2	3	3	3	3	3	4
Site Environment: Severe (Wet environment, deicing salt exposure, horizontal surfaces; ex. retaining walls, foundations, abutments, decks, barrier walls)											
Expansion Index	I	0	0	0	0	1	1	1	1	1	1
	II	0	0	0	0	1	1	1	1	1	1
	III	0	0	1	1	2	2	2	2	3	4
	IV	0	1	1	1	2	2	4	4	4	4
	V	1	2	2	2	3	3	4	4	4	4

Rating 4 - Examples

Rating 4 - Examples

How to Interpret…



ASR INSPECTION REPORT No. 35 – SUMMARY

No. 35 – Rte 24, Brockton-West Bridgewater, Concrete Substrate Repair

GENERAL INFORMATION

Structure Type:	Parapet walls and median barriers and repair patches on the concrete deck and abutment walls of highway bridge structures.
Location:	Oak Street bridge, Torrey Street bridge, and West Chestnut bridge, along Rte 24, Brockton, MA.
Contract # :	95045
Contractor:	Roads Corporation
Concrete Supplier:	McCabe Concrete-Taunton
Age of Structure:	About 16 years
Structure Exposure:	Exposed to weathering, moisture, and splash/spray of de-icing salts.

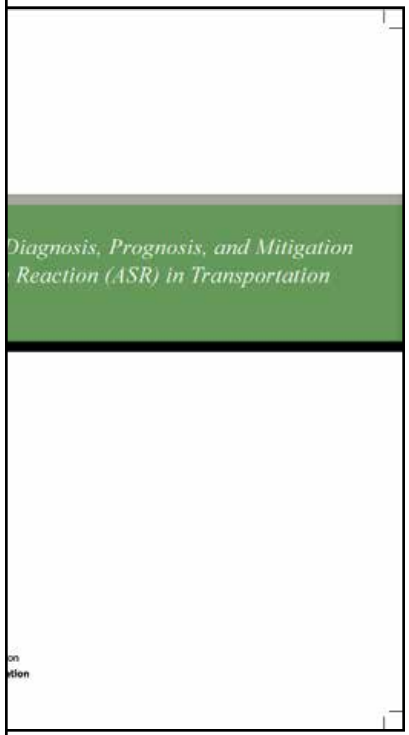
SCOPE OF WORK

Our work included the following sub-tasks. Individual reports for each completed sub-task are attached.

Sub-Task	Completed	Not available	Not applicable, by agreement	Not performed, recommended as follow-up
Visual Inspection	☒	☐	☐	☐
Review of Contract Document/Details	☐	☒	☐	☐
In-situ Cracking Index (CI) Measurements	☒	☐	☐	☐
Core Sampling	☒	☐	☐	☐
Petrographic Examination	☒	☐	☐	☐
Damage Rating Index (DRI)	☒	☐	☐	☐
Risk Assessment	☒	☐	☐	☐
Laboratory Expansion Testing	☐	☐	☒	☐
Detailed Structural Review	☐	☐	☒	☐

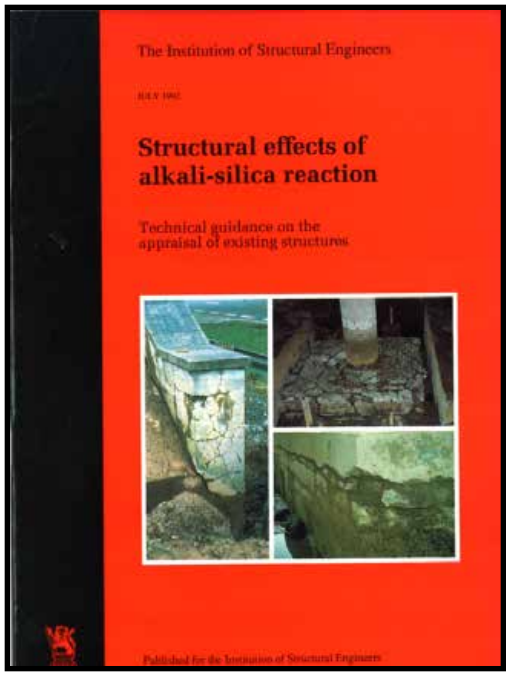
FIELD INVESTIGATION AND KEY FINDINGS

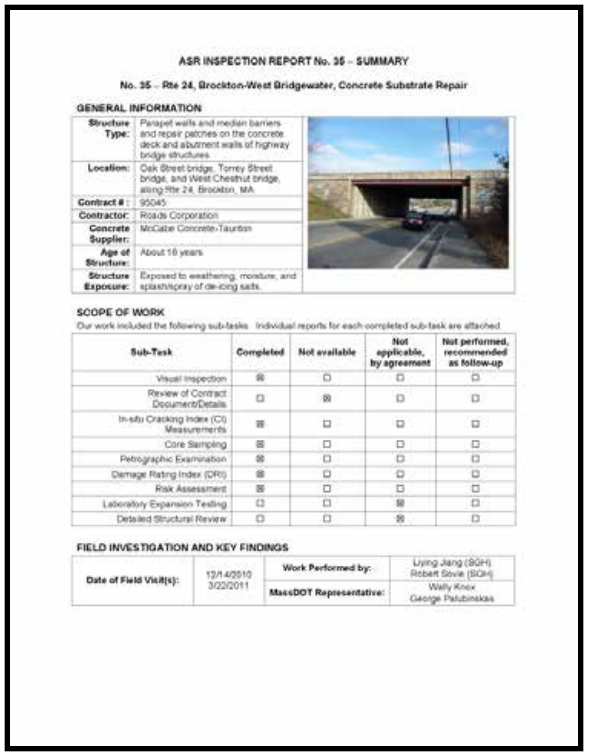
Date of Field Visit(s):	12/14/2010 3/22/2011	**Work Performed by:**	Liying Jiang (SGH) Robert Sovie (SGH)
		MassDOT Representative:	Wally Knox George Palubinskas



U.S.Department of Transportation
Federal Highway Administration

How to Interpret…





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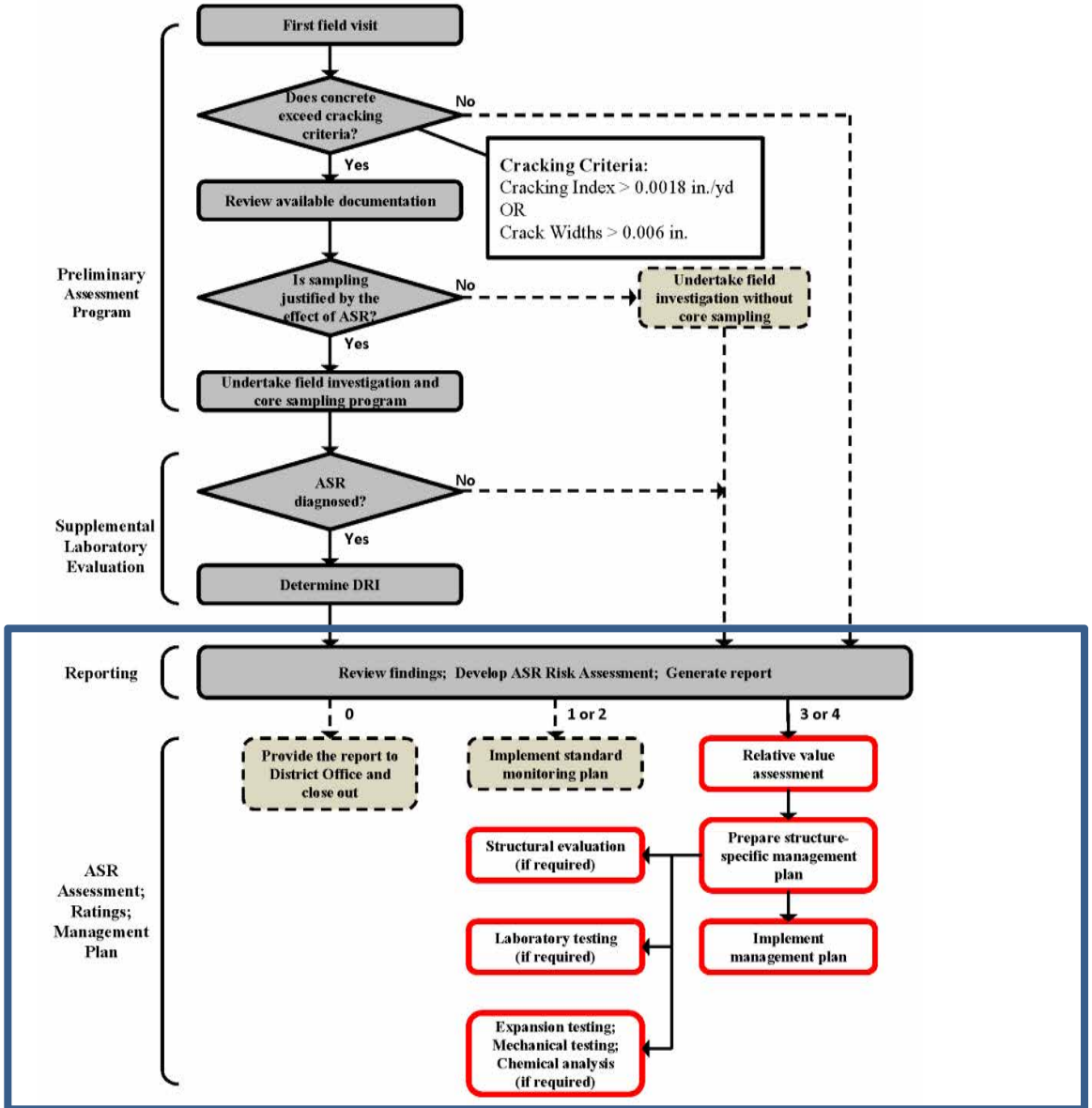
ASR Inspection and Evaluation Protocol



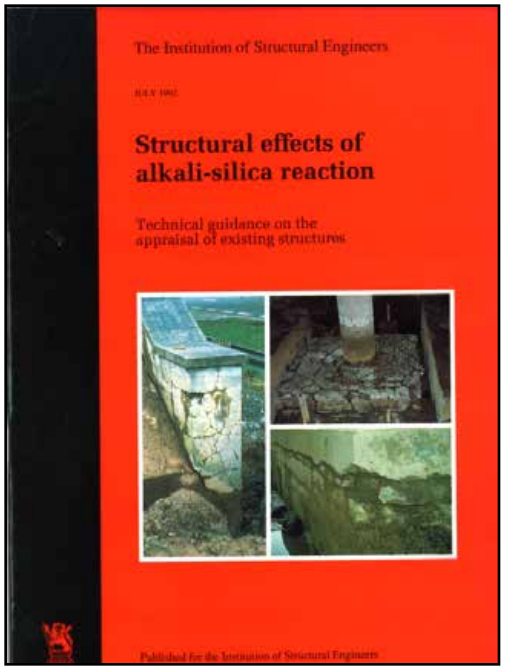
Findings

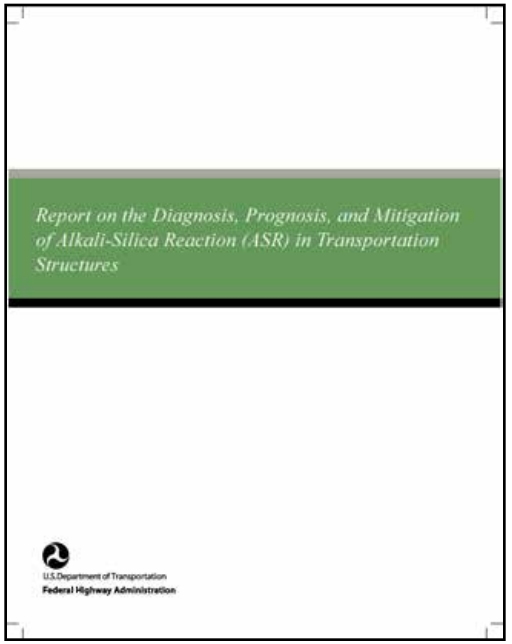
- ASR Assessment at 40 MassDOT structures completed:
  - ASR Rating 0: 19 Structures
  - ASR Rating 1: 12 Structures
  - ASR Rating 2: 1 Structure
  - ASR Rating 3: 4 Structures
  - ASR Rating 4: 4 Structures

Conclusions

- Although ASR cannot be easily treated or mitigated, concrete structures undergoing ASR can still serve their intended purpose provided that the effects of the ASR are understood, monitored, and managed.
- ASR-affected structures can be assessed throughout an ASR inspection and evaluation protocol.
  - Preliminary field assessment
  - Supplemental laboratory testing
  - ASR risk assessment and customized management strategies
- Effective support and coordination is required along the way.

How to Interpret…





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