ALKALI SILICA REACTIVITY

Lead State Team

TRANSITION PLAN FOR AASHTO

May 2000

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THE PAST

Introduction

This transition plan is a summary of alkali-silica reactivity (ASR) related activities of many individuals from a multitude of public and private agencies. The contributions of these people and their various organizations have advanced the knowledge, awareness, and state-of-the-practice of addressing ASR through administration and technical support, financial and personnel contributions, and laboratory and field research. The network of ASR related communication and coordination has broadened over the years with key champions stepping forward when needed to spearhead initiatives and propel their efforts to new levels.

Even though the ASR program has evolved through several major transitions, there has been a thread of continuity in each effort due to interested and active participation and support of ASR experts in both public and private agencies. Now with the ASR program once again being handed to new participants, the ASR Lead State Team desires to continue this cooperation, and to continue critical efforts. To do so, the past, present, and future are presented, with the Team's ideas of recommended future activities.

Previous Efforts

SHRP

The Strategic Highway Research Program (SHRP) was established by Congress in 1987 as a five year, $150 million research program to improve the performance and durability of our nation’s roads and to make those roads safer for both motorists and highway workers. Targeting those products with perceived high pay off, state transportation agencies played a key role in guiding this research performed under the National Academy of Sciences.

At the time SHRP concluded in 1993, it had developed 130 products in support of its mission. Five of these products addressed the problems of detecting, identifying, mitigating, and avoiding ASR in concrete structures and roadways. There were three publications:

- *ASR: An Overview of Research, SHRP-C-342, SHRP Product 2011,*
- *Eliminating or Minimizing ASR, SHRP-C-343, SHRP Product 2011, and*
- *Handbook for the Identification of ASR in Highway Structures, SHRP-C-315, SHRP Product 2010.*

Two rapid test procedures were also developed to detect ASR, and to screen aggregates in the laboratory for potential reactivity:

- *Rapid Identification of ASR Products in Concrete, AASHTO T 299, SHRP Product 2013, and*
- *Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to ASR, AASHTO T 303, SHRP Product 2009.*

AASHTO

In recognition that the SHRP program would create an unprecedented need for the rapid development and acceptance of new standards, AASHTO took two complimentary actions. AASHTO hired Dr. A. Haleem Tahir to facilitate and provide support to the various contributors to SHRP research implementation, particularly the Subcommittee on Materials. The Subcommittee created a new class of standards, labeled Provisional Standards. These were intended to be dynamic standards for immediate use by the states with the understanding they would likely be revised or updated more frequently than the mature standards. Ultimately, when these standards matured, they would be balloted as full standards. Some have already reached that point and have been established as such.

This is exactly what occurred with the *Rapid Identification of ASR Products in Concrete*, originally a provisional standard, it is now known as AASHTO T 299. Similarly, the *Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to ASR*, was originally identified as AASHTO TP 214, and is now a full standard as AASHTO T 303. The AASHTO staff person has been critical to the facilitation and management of the process in support of the Subcommittee on Materials.

At the completion of the SHRP research phase, AASHTO recognized the benefits that implementation of the SHRP products would provide its member Departments. Thus, AASHTO established a Task Force on SHRP Implementation. It was composed of executive level managers of member Departments from each of the AASHTO Regions. The Task Force on SHRP Implementation mission was to develop plans and proposals furthering the implementation of SHRP research, working as needed with the committees of AASHTO, the member Departments, the Federal Highway Administration and private sector organizations. Further, it was to propose, as necessary, to the Executive Committee and the Board of Directors of AASHTO such actions as it believed would further the implementation of SHRP, including proposals for securing necessary resources, for their consideration and appropriate action.

FHWA - SHRP Implementation

When the SHRP studies concluded, Congress directed the FHWA to establish an implementation program for the SHRP findings. As a result, the FHWA established the ASR Implementation effort under the Concrete and Structures Program.

With an ASR Expert Task Group to provide guidance and assistance, the four-part program consisted of conducting ASR Showcases in all nine AASHTO regions and one in Canada, providing technical assistance to AASHTO states, an equipment loan program for the ultraviolet light kits used to detect ASR, and a SHRP verification program where a round-robin inter-laboratory study was conducted. At the end of six years, the FHWA concluded its implementation efforts, and handed the ASR program to the AASHTO ASR Lead State Team.

The Lead State Program

In 1996, the AASHTO Task Force on SHRP Implementation established the Lead State Program and invited more than 30 states to join lead state teams in seven technology groups; ASR being one of them. A Lead State was defined as a transportation agency that had used a SHRP technology on a sufficient scale to gain expertise on that technology and its procedures. The Lead State then volunteered to share its expertise, on a formal basis, to help those states that wanted help and to serve as examples for all the states.

In September of 1996, the first Lead State Conference was held in St. Louis, Missouri. The ASR Lead State Team included Pennsylvania, Virginia, North Carolina, South Dakota, and New Mexico. The ASR Lead State Team included members beyond employees of the named states. The FHWA, the Department of Energy, the lithium and concrete production industries, and academia were also represented. The inclusion and participation of all these stakeholders was considered critical to the success of the program.

The mission of the ASR Lead States Team, developed at the conference, was: *To provide a clearinghouse to share and deliver information and technical assistance in identification, prevention, and rehabilitation of alkali silica reactivity to the public, private, and academic sectors of transportation.*

The initial objectives of the ASR Lead State Team were modified twice over the years as meetings were held, yet the focus of the Team remained true to its mission. Appendix A lists the Team's initial objectives and membership. Appendix B shows the next year's revisions, and Appendix C documents the Team's final objectives and membership.

Lead State Program Transition

As with the SHRP studies and the FHWA-SHRP implementation, the Lead State Program was to have a beginning and an end. In establishing the program, AASHTO agreed that at some reasonable point in time, national implementation should have matured to a level where a Lead State Program was no longer necessary. It was thus decided that the Lead State Program would conclude in the year 2000.

It is the purpose of this paper to describe and recommend, if necessary, the institutional framework and support systems necessary to advance the technology absent the Lead State Program.

THE PRESENT

Successful Accomplishments

The ASR Lead State Team takes credit for accomplishing several key elements of their objectives. These include conducting a national survey on ASR; developing and maintaining an internet web site; updating the SHRP-C-315 publication; drafting a guide specification on ASR-Resistant Concrete for AASHTO (these last two items were posted on the ASR web site); and incorporating many of the state-of-the-art practices of ASR mitigation into their own states' specifications and policies. Each of these items is discussed below.

ASR Survey

State highway agencies were surveyed to assess the extent of ASR in the nation. The full text and results of the survey are included in Appendix D. A separate Microsoft Excel file (Appendix D ASR-Survey.xls) is included that shows the actual survey results, with embedded comments. Conclusions drawn from the responses showed an increased awareness of ASR both in detecting it and confirming its presence. The original SHRP studies found ASR generally evident in 35 states. This survey found that of the 38 responding agencies (including 3 Canadian provinces) 8 reported widespread ASR, 13 thought their ASR was localized, 11 felt it was not applicable, 2 did not know, and 4 did not respond to the question.

Web Site

The ASR Lead State Team provided information to AASHTO to include on the Internet web site of http://leadstates.tamu.edu/asr and kept it updated and current. The information available to the public included an updated version of the SHRP-C-315 publication, the AASHTO Guide Specification on ASR-Resistant Concrete, a publications list of ASR related documents, a questions and answer forum, the ASR Lead State contacts, ASR related terminology, a bibliography of ASR-related research; online training materials; databases on aggregates; a list of resources, equipment, and sources of funding for ASR-related projects; and a bulletin board for obtaining technical assistance from Lead States team members.

Updated SHRP-C-315

Published under SHRP, the *Handbook for the Identification of ASR in Highway Structures* was perhaps the most popular ASR product with simple text and plenty of photographs. Without modifying any of the original text, the ASR Lead State team elaborated on the detection technique. This updated text (but not photographs) of the publication is included in Appendix E. A separate Adobe Acrobat file (Appendix E ASR-C315.pdf) is included that shows the actual web pages with modified text and photographs.

ASR Guide Specification

The ASR Lead State team produced an ASR guide specification for AASHTO to incorporate the current state-of-the-art practices in producing ASR-resistant concrete. The Team included information from the Mid-Atlantic Regional Technical Committee, SHRP recommendations, practices from the Canadian Standards Agency, the Portland Cement Association, and individual states' experiences. This ASR guide specification for *Portland Cement Concrete Resistant to Excessive Expansion Caused by Alkali-Silica Reaction* is included in Appendix F. It was designed to help highway agencies and others draft their own specifications for mitigating ASR, and was submitted to the AASHTO Subcommittee on Construction for balloting and approval.

Technical Assistance and Research

Team members have provided technical assistance to highway agencies in California, Delaware, Maryland, Minnesota, Nevada, New Jersey, and New England and electric companies in New Mexico, Utah, and Wyoming. The team also participated in ASR-related research projects, including:

- Tests on in-service pavements in Pennsylvania, New Mexico and South Dakota of concrete mixes and additives that prevent ASR-related damage.
- Tests in South Dakota, New Mexico, North Carolina, and Maryland of ways to slow or stop ASR-related damage in existing pavements.
- Development of a new, environmentally safe test for ASR.
- A study on preventing the reoccurrence of ASR when using recycled aggregate from ASR-affected concrete.
- Laboratory tests of improved methods of determining the effectiveness of ASR mitigation techniques.

State Highway Agency Specifications and Policies

All of the state agencies represented on the ASR Lead State Team modified their specifications to include parts of their own recommendations. Descriptions of these are listed below for each of the five states of New Mexico, North Carolina, Pennsylvania, South Dakota, and Virginia.

<u>New Mexico Department of Transportation</u>

New Mexico implemented performance based ASR mitigation requirements in January 1999, over a year ago. Since that time, all of the suppliers in the state have been required to determine if their aggregates are reactive, and if so, how they will mitigate the potential reactions.

<u>North Carolina Department of Transportation</u>

The following is a brief summary of NCDOT implementation for prevention of ASR for new construction, as included in the specifications as the Standard Special Provision effective June 1977.

There are six aggregates in the state that are identified as highly or moderately reactive.
1) For these six aggregates, use cement alkali content equal to or less than 0.4%.
2) For other aggregates use cement alkali content, equal to or less than 0.6%.
3) Alternatively, use class F fly ash or other pozzolans (e.g., silica fume, and GGBFS) of specified amounts.

Pennsylvania Department of Transportation

Policy Concerning Use of Portland Cement Concrete Aggregates With the Potential to Cause Alkali-Silica Reactivity

The Pennsylvania Department of Transportation has had a specification in effect since August of 1992 which addresses the use in Portland cement concrete of aggregates which have the potential to cause alkali-silica reactivity (ASR). This specification has been revised twice since it was first written. At first, the specification concerning the use of aggregates with ASR potential was published as a special provision for all contract work, which required the use or Portland cement concrete. With the printing of Form 408/2000, "Specifications", the ASR special provision was incorporated into Section 704, "Cement Concrete", as Section 704.1(h), Mix Designs Using Potentially Reactive Aggregate.

The Pennsylvania Department of Transportation, Materials Testing Division has tested all Department-approved Portland cement concrete aggregates for the potential to cause ASR. The results of this testing are published in Bulletin #14, "Aggregate Producers". If the mortar bar expansion resulting from testing an aggregate by AASHTO TP 14 (now AASHTO T 303) is greater than 0.10% linear expansion, then any concrete mix utilizing this aggregate must be mitigated for ASR. The methods accepted for mitigation are as follows:

a) Use of a Portland cement meeting the optional requirement in AASHTO M 85 for a maximum alkali content of 0.60%.
b) Use of a blended hydraulic cement, Type IS or IP, ASTM C 595, from a manufacturer listed in Bulletin 15, "Approved Construction Materials".
c) Substitution of Class F fly ash, meeting the optional chemical requirement in AASHTO M 295 for a maximum alkali content of 1.5%, in an amount constituting between 15% and 25% of the total cementitious material by mass. If the AASHTO TP 14 mortar bar expansion of both coarse and fine aggregates proposed for use in a fly ash mix are greater than 0.10%, but less than 0.41%, then the minimum amount of fly ash may be used. If the AASHTO TP 14 mortar bar expansions or either or both aggregates proposed for use in the mix are 0.41% or greater, then the fly ash must constitute a minimum of 20% of the total cementitious material by mass.
d) Substitution of ground granulated blast furnace slag in an amount between 25% and 50% of the total cementitious mass. When the TP 14 mortar bar expansions of both aggregates proposed for use in the mix are greater than 0.10%, and less than 0.41%, the minimum substitution level may be used. If the TP 14 mortar bar expansion of either aggregate proposed for use in the mix is 0.41% or greater, then the ground granulated blast furnace slag must constitute a minimum of 40%, by mass, of the total cementitious material.
e) Substitution of between 5% and 10%, by mass, of the total cementitious material by silica fume.

South Dakota Department of Transportation
ASR Specifications

South Dakota DOT has specified the use of Type II LA (Low Alkali) cement for concrete since 1983 as a means of mitigating ASR. We also currently specify the use of Modified Class F fly ash on all paving projects excluding isolated small volume pours at a 1.25 replacement rate for a 15% reduction in cement content. This equates to a fly ash content of 18.75%. The reason for this blanket specification is the significant incidence of reactive fine aggregate throughout the state and the fact that one of our three quarried coarse aggregate (the only three used) is also ASR-reactive. A Modified Class F fly ash meets all the general AASHTO M295 requirements except as modified by the following:

Loss on ignition..2.0% Maximum
Moisture content..2.0% Maximum
Sum of Oxides ($SiO_2 + Al_2O_3 + Fe_2O_3$ ....66.0% Minimum
SiO_2 content...40.0% Minimum

ASTM C1260 is used to screen fine aggregate sources and monitor possible changes in reactivity over time for a given source. If the 14 day expansion value from the test is > 0.250%, the cement used on the project employing this source is altered from a Type II LA to a Type V LA cement to further insure a substantial reduction in reactivity. The State is also in the process of reviewing the incorporation of lithium nitrate into new concrete containing reactive aggregate in conjunction with Modified Class F fly ash as additional insurance against potential reactivity. A series of test sections containing various lithium admixtures with fly ash were constructed in 1996 and are being evaluated.

Virginia Department of Transportation
ASR Implementation

In the early 1980's, prior to the start of SHRP, the Virginia Department of Transportation (VDOT) began to notice durability problems involving extensive cracking of some Portland cement concrete pavements and structures. Alkali-silica reaction (ASR) was identified as a primary cause of distress in these cases and they were included in the SHRP ASR project.

In 1990 the Virginia Transportation Research Council (VTRC) began a project determine the extent of the ASR problem confronting VDOT and assess strategies to avoid this durability problem. During the course of this research project, it became clear that a number of aggregate sources were potentially reactive and that the most suitable screening test for aggregates (now standardized as AASHTO T 303 and ASTM C 1260) was not sufficiently effective in discriminating between non-reactive and deleteriously reactive aggregates.

Consequently, to avoid future durability problems, VDOT changed its specification for concrete in December 1991. This change required the use of 20% (by mass of cementitious material) Class F fly ash (low-lime content), 30-50% ground slag, or 7% silica fume when the alkali content of the Portland cement to be used exceeded 0.40% Na_2O equivalent (Lane, 1993a). This change was also supported by the knowledge that these mineral admixtures would produce concretes with low permeability that were thus more resistant to the other major concrete durability problem confronted by most DOTs, chloride-induced corrosion of reinforcing steel. In the Virginia market and many others, the use of Class F fly ash or ground slag offer economical alternatives to producing concrete with Portland cement as the sole cementitious material.

In 1992, VIRC initiated a study to (1) evaluate the effectiveness of particular mineral admixtures in combination with Portland cements of varying alkali content and (2) to establish the minimum amount of mineral admixture necessary to control a given cement alkali level. The findings of this study were published (Lane & Ozyildirim, 1995 and 1999a). Based on these findings, the VDOT concrete specification was revised in 1997 to require that the cementitious materials used in concrete mixtures limit the expansion of ASTM C 441, mortar (with Pyrex glass aggregate) to 0.1% at an age of 56 days. Compliance with the specification could also be met by using materials that conformed to requirements listed in Table 1.

Recognizing that these specification requirements were based on the testing of mortars made with Pyrex glass, VTRC initiated a new project to evaluate the performance of these cementitious materials in concretes produced with construction aggregates. This project encompassed a broader approach by evaluating important concrete properties such as strength and permeability as well as resistance to freezing and thawing, deicer scaling and ASR. The ASR testing was performed using a modified ASTM C 1293 test with reactive Virginia aggregates. The findings were published (Lane & Ozyildirim, 1999b) and clearly indicate that lower amounts of Class F fly ash (15-20%) or slag (35% min.) than currently specified should control the reactivity of Virginia aggregates with cements having alkali contents of 1.0% Na_20eq or less. This suggested that an expansion limit of 0.15% at 56 days might be more appropriate for evaluating cementitious materials in C 441 intended for use with aggregates of similar reactive potential to those found in Virginia. The findings of this study support the continued use of mineral admixtures to produce concretes resistant to ASR and chloride-induced corrosion thus providing the durable concrete needed for an economical transportation system. Various aspects of VTRC's research efforts in ASR can also be found in Lane & Ozyildirim, 1999c; Lane, 1999a; Lane, 1999b; Lane, 1996; and Lane, 1993b.

Table 1. Material combinations accepted as conforming to the 1997 VDOT concrete specification without testing.

Material	Maximum Portland cement alkali content, % Na_20eq
Portland cement only	0.45
Cement with min. 15% Class F fly ash	0.60
Cement with min. 20% Class F fly ash	0.68
Cement with min. 25% Class F fly ash	0.75
Cement with min. 30% Class F fly ash	0.83
Cement with min. 25% ground slag	0.60
Cement with min. 35% ground slag	0.90
Cement with min. 50% ground slag	1.00
Cement with min. 3% silica fume	0.60
Cement with min. 7% silica fume	0.90
Cement with min. 10% silica fume	1.00

In 1997, VTRC initiated a laboratory investigation to evaluate the effectiveness of lithium compounds in minimizing ASR-related expansion. This study should be completed in the near future. Preliminary findings indicate that lithium-bearing admixtures appear more effective with rapidly reactive materials than they do with the more slowly reactive aggregates found in Virginia presumably because a certain portion of the lithium is consumed during the hydration of the cementitious material. This suggests that the determination of lithium admixture dosage should be evaluated using longer-term tests following C 1293 with the construction aggregates, rather than in rapid tests such as C 441.

VDOT began permitting the use of fly ash or ground slag as cementitious materials in concrete in the mid-1980. Consequently there are now structures and pavements in place with up to 15 years service. VTRC has recently initiated a project to evaluate the performance of concretes containing fly ash or ground slag relative to the performance of Portland cement concretes. This study will provide the information necessary to assess the durability of these materials under field conditions and guidance for further specification development.

Management of pavements and structures affected by ASR has not differed significantly from the approach used with other deterioration mechanisms VDOT has experienced the largest maintenance problems with pavements, likely because of the repeated, active loading they receive. The section of I-64 at Charlottesville serves as the best example. This section of continuously reinforced concrete pavement (CRCP) was constructed in the early 1970's. By the late '70's extensive map cracking with a predominant longitudinal trend was noticed and the cause was determined to be ASR, primarily involving the coarse aggregate. This pavement also suffered from CRCP punch-outs at closely spaced (0.3-1.0 m) transverse cracks. Spalling began at the transverse cracks, and where punch-outs were repaired with full-depth patches, the rate of spalling increased on either side of the patch. By 1987, the worst stretch had become such a continual maintenance problem, that a decision was made to remove and reconstruct the section. The new CRCP was produced using the same aggregate sources, the same Portland cement source (having an alkali content of ~0.60% Na_2Oeq), but including ground slag as 20% by mass of the cementitious material. Today, approaching 13 years in service, this section of pavement is performing quite well.

As maintenance problems mounted on the remaining sections of the 1970's CRCP at Charlottesville, a decision was reached in the early 1990's to quickly proceed with full-depth repairs of punch-outs and associated delaminated sections, installation of edge drains, followed by an asphalt overlay. This approach also appears to be working well, presumably because the overlay isolates the cracked concrete from the constant traffic loading that would otherwise lead to its breakup. From this experience it would appear that when spalling at edges and joints or transverse cracks becomes common, it signals the beginning of a rapid decline in pavement condition requiring increasingly frequent repairs. Consequently, the onset of spalling is the point at which rehabilitation such as overlays or removal and replacement should be considered to avoid an excessive, burdensome, and eventually futile series of repairs.

Structures in Virginia have presented fewer problems, presumably because most elements are not dynamically loaded by traffic. Decks, which are dynamically loaded, usually are not cracked as extensively as the associated concrete because they lack a continual source of moisture. Routine repair and maintenance of joints, as well as providing for good drainage away from concrete elements should be emphasized to extend service-life of ASR-affected structures.

VDOT has not conducted any field trials using the topical application of lithium solutions to reduce the expansion of ASR-affected concrete. At this point in time this approach seems problematic. Much research is needed to ascertain not only if, and under what conditions, such treatment might be beneficial; but also to develop the methodologies needed to accurately assess the concrete condition to make such an assessment. Published findings of field trials conducted in other states will be of interest.

References for the Virginia Department of Transportation:

D. S. Lane, 1999a. Comparison of Results from C 441 and C 1293 with Implications for Establishing Criteria for ASR-Resistant Concrete, *Cement, Concrete and Aggregates*, V21(2), pp. 149-156.

D. S. Lane, 1999b. Virginia's Approach to Evaluation of Concrete Resistant to Alkali Silica Reactions, *Transportation Research Record No. 1668*, pp. 42-47.

D. S. Lane and C. Ozyildirim, 1999a. Evaluation of the Effect of Portland Cement Alkali Content, Fly Ash, Ground Slag, and Silica Fume on Alkali-Silica Reactivity, *Cement, Concrete and Aggregates*, V21(2), pp. 126-140.

D. S. Lane and H. C. Ozyildirim, 1999b. Final Report: Combinations of Pozzolans and Ground, Granulated, Blast-Furnace Slag for Durable Hydraulic Cement concrete, VTRC 00-RI.

D. S. Lane and H. C. Ozyildirim, 1999c. Preventive measures for alkali-silica reactions (binary and ternary blends), *Cement and Concrete Research*, V29(8), pp. 1281-1288.

D. S. Lane, 1996. Final Report: Use of the Rapid Immersion Test to Evaluate the Efficacy of Admixtures to Mitigate Alkali-Silica Reactivity. VTRC 96-R22.

D. S. Lane and C. Ozyildirim, 1995. Final Report: Use of Fly Ash, Slag, and Silica Fume to Inhibit Alkali-Silica Reactivity. VTRC 95-R21.

D. S. Lane, 1993 a. Final Report: Alkali-Silica Reactivity in Virginia. VTRC 94-RI7.

D. S. Lane, 1993b. Experience with ASTM P214 in Testing Virginia Aggregates for Alkali-Silica Reactivity, *TRR No. 1418*, Transportation Research Board, Washington, D.C., 1993, p. 8-11.

Ongoing Research

While the ASR Lead State Team is directly sponsoring no research work, several ongoing research efforts are being monitored. Under SHRP, the first ASR mitigation field test site ever installed in the United States was in June 1992 in Albuquerque, New Mexico. Over the years, various members of the Team have visited this site of eleven sections and reviewed the data collected now as part of the Long Term Pavement Performance.

Under the FHWA ASR Implementation effort other ASR mitigation field test sites were installed in Pennsylvania, South Dakota, and New Hampshire. While PENNDOT (Margo Thomson) and SDDOT (Dan Johnston) are responsible for monitoring their sections, the University of New

Hampshire (David Gress) is in charge of theirs. The location and design parameters of these field sites should not be forgotten, and their performance should be monitored with the test results documented.

The research work being conducted by CANMET (Benoit Fournier) in Ottawa, Ontario is being done with money and materials supplied by the ASR Lead State Team members of the FHWA, FMC, and New Mexico, and by the Friends of the Team of Wyoming, and Minnesota. The results of the CANMET work will be interesting, as it will document correlation between field performance and laboratory tests.

FMC (Claudio Manissero) and others have been following this and other international research such as activities at the Building Research Establishment in London, and at the University of Toronto. The Team has been kept apprised of the status of these various ongoing research efforts.

A point to make is that the Team has established a network of contacts outside the envelope of the ASR Lead State Team, which has been an integral part of the Team's operation and process. It has lead to improvements otherwise not available or permitted under a strict AASHTO oriented team structure.

Gaps

Two gaps are identified in what the ASR Lead State Team envisioned in their revised objectives shown in Appendix C, and in where the objectives are to date. Since ASR Lead State Team members have experience in these areas, AASHTO would benefit by retaining the team members as advisors in completing these initiatives. These are 1) the cooperative training course of FHWA- ACI Concrete Durability Workshops, and 2) cost and benefit procedures.

FHWA- ACI Concrete Durability Workshops

For the first, an FHWA-ACI cooperative training course on concrete durability was planned and work on it has been initiated. Completed portions include the set up of the FHWA-ACI training course with ACI buy-in, and the drafting of a training program for review and approval of Team and ACI. The current course outline is shown in Appendix G.

Unfortunately, this course is still in the development stage, and has yet to be implemented through ACI. Once developed the course will need to be adapted for the AASHTO Team members' use.

Cost and Benefit Procedures

For the second, procedures based on cost and benefits were planned in selecting methods to mitigate ASR. A survey was developed (see the Appendix H) for other AASHTO members to obtain from them information about costs and benefits associated with ASR, but this was as far as the effort progressed.

Unfortunately, the survey was never distributed to collect information due to differences of opinion over the extent, detail, and validity of the proposed questions. As a result the costs and benefits were not gathered, nor were it established if they were available to document for reporting purposes. Should this information be collected there is still a need to analyze the data to establish the costs and benefits of implementing SHRP ASR technology.

Current Challenges

Even though the ASR Lead State Team has been very successful in accomplishing most of their proposed activities, it has not always been and easy process, nor have all the obstacles been eliminated to successful implementation. The Team currently faces challenges that are the result of both internal and external influences.

Internal Team Challenges

- There continues to be too few opportunities for team meetings. The volume and magnitude of the Team's planned activities would have been accomplished with greater ease with more face to face working events.
- Some unproductive team members have been identified as deadwood on the team. As a result, a few of the more committed Team members have shouldered a greater share of the duties.

Challenges External to the Team

- Some agencies do not actively support travel for the team members. Therefore, at the few Team meeting that were held, those agencies were not represented.
- The various agencies involved have placed competing demands on time resources for individual team members, often at the expense of the ASR Lead State Team.
- A corollary to this is that while some members did have the full support of their top management, the middle management was not on board.
- Many times the program has had to work ahead of its resources, that is the funding for the various tasks either has to come later or not at all.
- There has been no clear institutional interagency structure to implement the publication of documents.
- There is still is a resistance to accept ASR as a problem or a potential problem. As a result, the recommended mitigation methods have gone unaccepted and unimplemented.

THE FUTURE

Future Challenges

Several barriers and challenges face the AASHTO Team that assumes the role of continuing the work of the ASR Lead State Team. These Potential Barriers are listed as follows:

No Current AASHTO Structure for ASR

No dedicated group for implementing ASR initiatives exists within AASHTO; neither does it have a structure for technology deployment across subcommittees. Specifically it has no dedicated group to address ASR and related issues. There will be a lag and loss of momentum as the program moves from the focused and specific ASR Lead State environment to a general oversight AASHTO committee environment. Therefore, the ASR Lead State Team recommends that AASHTO retains the current ASR Lead State Team with some minor changes together as a group for a period of two years to effect the transfer of the program. This will allow AASHTO to develop a group, which will be in charge of the ASR activities, and to determine specifically which technical section will be responsible for maintaining the guide specification.

Lack of Dedicated Funding

Money will need to be dedicated to the technology transfer initiatives and efforts. A reliable source has to be identified.

Undefined Personnel Requirements

With the primary responsibility for technology transfer shifted from the FHWA to State DOT personnel, and now to AASHTO Subcommittees, states must be able to attract and retain people capable of doing this work. Since some states don't have the personnel to do this work, and can't do it with voluntary effort or part time employees, consultants must be retained to fulfil the goals. Unfortunately, this requires additional money as described above.

Perceived Lack of Need

There still exists a perceived lack of need to expend effort on ASR initiatives. ASR continues to be identified in new areas, so there is a need for continued education at state and local levels. Fragmentation and turn over within state agencies leads to "pockets" of educated people and others who know nothing about ASR.

Who

Two AASHTO Subcommittees will be the recipients of the efforts of the ASR Lead State Team information, specifically the Subcommittees on Materials and Construction. They need to identify which technical sections within their oversight will be responsible for continuing the ASR program. They also need to identify their individual champions and liaisons that will work with the ASR Lead State Team during the transition. Together these individuals with the ASR Lead State Team will form an Ad Hoc transition team.

Both subcommittees need to identify a primary liaison, and, in addition the Subcommittee on Materials needs to identify a champion from each of the technical sections that deal with the various ASR technologies. The primary contacts should be selected before the Team sunsets, and the technical section champions identified in time for the Team to coordinate with them for the fall AASHTO meeting.

What

These Subcommittees will receive the information from the ASR Lead State Team, which may be summarized as follows:

1. Partially completed work in the area of problem definition by geographical limits identified in preliminary and informal survey work to try and determine the existence and immediate scope of the problems with ASR nationwide. The survey extent includes evaluated/known problems from those states whose work in the subject has been dictated by early failure/distress indicators revealed in completed facilities. The full scope of possible problems geographically and mineralogically has not been identified in this country, although survey results show increasing awareness of ASR presence.

2. Mitigation practices under evaluation or in use in other countries. This would include research currently underway, as known to members of the lead state team and networking with national and international entities addressing ASR problems.

3. Initial guide specifications to address mitigation of ASR and updated SHRP publications.

4. A small number of mitigation projects in this country using various mineral and chemical additives, which are being monitored to evaluate the mitigation methods.

5. A current web site for ASR subject areas (http://leadstate.tamu.edu/asr)

6. Procedures for identification of ASR in highway structures.

Where

Within the Subcommittee on Materials, the following Technical Sections could have significant involvement as the full scope of ASR presence is identified, testing methods are improved, guide specifications on material properties are revised, or concrete mix testing and evaluation is further developed.

- 1C - Aggregates and Stabilized Mixtures
- 3A - Hydraulic Cement and Pozzolanic Materials
- 3B - Concrete Materials and Fresh Concrete Properties
- 3C - Hardened Concrete Properties

When

During the two-year continuation period recommended above for the ASR Lead State Team, the Ad Hoc team would be responsible for the completion of the remaining action items. During this period, it is recommended that the AD Hoc Team meet at least four times a year.

How

Under such an Ad Hoc team approach, close coordination within the full technical section agenda could be performed while making progress to the benefit of the community. The cost of such an ASR Ad Hoc approach would involve travel to joint meetings where there is technical section involvement, such as TRB, the annual Subcommittee on Materials technical section meeting, and also include other communication checkpoints with the technical section chair.

Contact with the world community involved with alkali-aggregate reactivity could be maintained by the ASR Ad Hoc team members and bring a broader scope of knowledge to bear on the concerns of the technical section. The technical section would become the conduit to transfer knowledge gained on a continuing basis during the two year time frame of the Ad Hoc team and would have an available tool for technical section use in research matters within the Regional Advisory Committees for research, and in a subject area not yet fully defined.

Future Key Players and Organizations

As stated above, AASHTO should keep the ASR Lead State Team (with minor modifications) together as group for the following reasons:

1. They will be an excellent resource to highway agencies as AASHTO implements the guide specifications and then refines it for particular circumstances.
2. They will be a focal point for the collection and dissemination of current information related to ASR in highway structures.
3. They will assist in keeping the guidelines up-to-date.

Future interagency coordination is recommended with the contacts shown in Appendix I.

CONCLUSIONS AND RECOMMENDATIONS

Lessons Learned

The purpose of the Lead States program was to demonstrate the value of SHRP by improving highway construction practices through application of the information it generated and implementation of the technologies it developed. The most notable aspect of the Lead States approach was the emphasis placed on using a "managing by values" approach to achieve this purpose. The "managing by values" approach may have been beneficial to the Task Force in planning and executing the Lead States program. However, its application at the team level was a severe impediment to the Team's effort to sort out the real purpose of the Lead State program. It focused too much attention on the process thus detracting from the technological assessments necessary to make reasoned recommendations regarding what to disseminate, what to implement, and where to focus future research efforts.

In order to succeed, there was a need for a multidisciplinary team with a variety of skills. The concept of forming teams with federal, state, industry, and academic representatives was recognized to have a high value in this type of endeavor, however as with every committee effort, the level of participation varied among the individual members. Consequently, the Team should have made efforts during their initial formation process to identify and recruit interested and active individuals to full participation in the effort.

After the formation of the Team and based on individual participation and contribution, it became clear that champions should not have been designated, but rather allow them to volunteer as their interests dictated. This would have avoided "dead wood" on the Team, and minimized or prevented some of the frustration experienced by the Team's leader in attempting to elicit work from individuals who felt little allegiance to the Team.

Eventually the Team recognized that they could benefit from a more diverse pool of active industry representatives with broad, national outlooks. As a result the "Friends of the Team" concept was initiated. They sought the technical advice of "friends" from other agencies and national trade associations to provide a more balanced approach and to add to the Team's overall expertise. If the ASR Lead State Team is retained to serve in an advisory role to an AASHTO subcommittee, efforts should be made to continue this broad perspective the team provides.

To achieve a successful ASR Lead State program, individual participants had to expend considerable time and effort, far in excess of what was originally anticipated. To provide for this, individual members required the strong backing and support of their institutions to assure active participation, along with a dedicated source of funding. Likewise, the AASHTO subcommittees only will achieve success if they recognize this and incorporate it into their programs.

Determining the needs of customers, and specifically, who and where they were, was a challenging task. Having this information before hand would have allowed more focused effort to directly fill the needs. One survey was conducted, but the team was generally unable to formulate a definitive direction based on the results. The team faced a similar problem in trying to assess the benefits of the effort. A better approach for determining the needs specific to ASR, as well as assessing the effort to fill those needs, should have been developed. The ASR Lead State Team would be invaluable for providing input and action on these issues to the AASHTO subcommittees interested in specific ASR areas.

ASR is a significant durability problem that affects the performance of concrete in transportation systems in a number of locations. However, it is not the sole concrete durability issue facing AASHTO members and should not be addressed as if it is. The challenge for the future is to integrate the information gained on avoiding ASR into a comprehensive approach to design concrete that will be durable in its specific service environment, in other words, durable concrete. The FHWA-ACI Concrete Durability Workshop, being developed at the suggestion of the ASR Team, will attempt to provide this broader approach. As the AASHTO subcommittees look to the future, they should develop a comprehensive, integrated approach to design and specify concrete for durability. They would undoubtedly be well served by having an advisory team. This advisory team could bring a broad expertise in concrete materials and durability to the table.

Abrupt changes to the membership of the ASR Lead State Team resulted in a lack of progress on those tasks assigned to the person removed from the Team. These voids generated an unnecessary level of stress; higher work loads, and in at least one instance resulted in an irretrievable loss of information. A period of overlap in assignments should have been allowed to achieve a smooth transition.

A concerted effort to use the new ASR technology helped identify essential research needs for effective implementation of technology. A good technology transfer program should distinguish between those promising technologies that can be easily implemented and the ones that need further development. Those technologies that can be easily deployed should have a technology implementation plan. Those that need further development should have the support of management and researchers to bring them into an implementable stage.

The SHRP program, the FHWA-SHRP implementation, and the Lead State Program have changed the culture within the transportation professional community. The new ideas and changes are more readily accepted now than, say, 6 to 7 years ago. The general approach to the use of new technologies and products has become relatively more positive. Lessons learned from these programs can be summarized as follows:

- Plan research, evaluation and implementation together at the same time.
- Involve the users (customers) right from the beginning.
- Big size programs are more likely to succeed and be implemented than a series of limited scope efforts.
- Implementation must receive organizational support from top-down as well as from bottom-up.
- Successful implementation requires both the manpower and financial resources.
- Industry's role in the implementation is vital. A true partnership must be formed between the agencies and the industries. The two entities should specially work together as a team in the development of standards and the training programs needed for the new technologies.

- Identify champions who are committed to promote a given technology and support their efforts to the extent possible.
- Form regional groups such as users producer group and professional groups from the contiguous states committed to evaluate and promote the new technology.
- Establish a dialog with the local governments who are also the potential users of the new technologies in transportation.
- Intense and frequent communication must be maintained at all levels and with all parties involved in the implementation of technology. Use all modes of communication including electronic media, web sites, briefs and presentations.
- Benchmark and measure the progress on, 'as you go basis'.
- Most research when completed, must be converted into usable products, standards, specifications, equipment development, and training for the users, before it can be implemented. This work is not only necessary; it could be very resource intensive.
- Governments should simplify the procurement policies. These policies often jeopardize timely innovations.
- A comprehensive marketing plan must be developed for implementation.
- Costs / benefits data must be collected and analyzed for the new technologies.
- Continue the use of innovative concepts, such as the lead state program, for technology transfer.
- Demonstration projects and showcases are often desirable for gaining acceptance of the new products.
- There is a need to collect implementation data in a uniform manner and maintain this database at the national level.

Future Needs

The ASR Lead State Team recommends to the AASHTO subcommittees the following items that need future work.

Provide construction guidance for design of ASR-resistant PCC and managing ASR in existing concrete.

This would include the use of lithium as well as strategies using combination of technologies for the cost-effective control of ASR. Consideration to when these technologies should be used, quantities required as a function of aggregate reactivity, and for the case of mitigating existing ASR, when is it too late to justify the use of lithium.

Special consideration must be given to assure that current accepted strategies are in fact viable ways to control ASR. For example, it has been suggested that technologies using fly ash will eventually react with ASR and likewise durable concrete may very well be only temporary exempt and that eventually it may be subject to excessive ASR. Consideration must be given to evaluating such possibilities until a better understanding of ASR is achieved. Knowledge of such effects such as ash composition, addition rate and aggregate lithology/reactivity is essential for the development of better strategies for effective mitigation as compared to current one-size-fits-all procedures for designing ASR-proof concrete.

It might also include determining methods of predicting service life of facilities as well as life-cycle costs for new and existing concrete before and after applying mitigating strategies and developing strategies for evaluating current service life of ASR affected PCC. Such work has to factor in the effect of traffic, climate, aggregate reactivity, original and available cement alkali, deicing and freeze-thaw potential.

Continue collecting and distributing ASR information under one unified umbrella.

This would include monitoring the designated test sites, keeping the ASR Guide Specification current, publishing the round robin data, conducting a ruggedness data/study done, reviewing the proposed guide specification, and the paper by Fournier, Berube, and Rogers: Proposed Guidelines for the Prevention of Alkali-Silica Reaction in New Concrete Structures, and determining the degree to which ASR-affected concretes are creating problems.

As performance data become available from field-test sites, there will be a need for new research and technology implementation efforts. Continued technology transfer activities, outreach and other communication efforts will continue to be important.

Develop methods that will rapidly and reliably evaluate performance of concrete mixtures for ASR susceptibility.

An accelerated test procedure to test an actual mix. There is an absolute need for a test which will evaluate the potential reactivity of a comprehensive mix design, including the effects of the total alkali loading from the actual cement and pozzolan contents, the effects of unaltered coarse and fine aggregates, and the effects of the specific liquid admixtures. Without this information, extrapolations made from the existing tests remain guesses, at best.

Recommended Action Plan

Identify and Commit Personnel to the ASR Effort
- The Subcommittee(s) sponsoring the formation of the ASR Ad Hoc Team should communicate the need for experts from the individual AASHTO member states to participate in efforts of this new team.
- Convince the member agencies of the necessity to commit to allowing these experts time and funding to participate in the effort. It is recommended that this commitment be formalized in writing to lend authority to the individual expert.

Establish an AASHTO Structure for Addressing ASR Related Initiatives
- Keep the ASR Lead State Team involved in the AASHTO Subcommittee Task Forces to give them a structure to start with for dealing with ASR initiatives.

Establish source of Dedicated Funding
- Seek SP&R funds to support activities through a "host"
- Look at ways to combine private and public funding to raise support
- Look at ways for team to get paid for providing advice;
- Conduct cooperative agreements with private industry.

Continue collecting and distributing ASR information under one unified umbrella.

- Continue the condition monitoring of the existing ASR field test sites.
- Participate in other ASR related activities sponsored by other organizations such as ACI, ASTM, ICAR, CANMET, and PCA.

Provide construction guidance for design of ASR-resistant PCC and managing ASR in existing concrete.

- AASHTO should approve and publish the guide specification.
- Establish Ad Hoc team to review and revise the guide specification as the technology changes.
- Establish user producer groups with cement, fly ash, aggregate, and admixture industries; and with the user agencies.
- Sponsor self-sustaining training programs in conjunction with industry.
- Continue communication and sharing of information.
  - Establish a comprehensive communication network, which encompasses all public and private agencies that specify concrete, to collect and share ASR information.
  - Maintain ASR Lead State Team web site.
  - Publish a regular ASR-related newsletter.
- Finalize the cost and benefit survey questionnaire, distribute it for data collection, collate the information, and summarize the results to provide guidance on ASR mitigation selection.

Support development of methods that will rapidly and reliably evaluate performance of concrete mixtures for ASR susceptibility.

- Establish an Ad Hoc Team to investigate and promote new ASR technology with financial assistance and support of top management within AASHTO.

In conclusion, the ASR Lead State Team has championed the further awareness of ASR, and the continued development and promotion of ASR avoidance and mitigation. In transitioning the program to AASHTO, the Team is confident that the AASHTO Subcommittees are a capable group. The ASR Lead State Team looks forward to a strong sustained cooperation with the AASHTO Subcommittees in carrying on the program.

APPENDIX A

INITIAL OBJECTIVES (AS OF 1996)

INITIAL OBJECTIVES (AS OF 1996)

Mission

To provide a clearinghouse to share and deliver information and technical assistance in identification, prevention, and rehabilitation of alkali silica reactivity to the public, private, and academic sectors of transportation.

Goals

1. Establish a mechanism for gathering and disseminating ASR information and providing technical assistance.
2. Increase awareness of ASR information.
3. Complete research and evaluation, and develop guide specifications.
4. Continue implementation of current and future ASR technology.
5. Expand on implementation of ASR technology.

Strategies

1. Gather and evaluate ASR information.
2. Package information.
3. Evaluate options for dissemination of information.
4. Identify and qualify resources, partners, and media for providing technical assistance.
5. Provide opportunity for short term and long term training.
6. Develop and implement a marketing communications plan.
7. Develop a feedback plan.
8. Set target dates for completing research, evaluations, and guide specifications.
9. Identify benefits and establish life cycle costs by utilizing value engineering.
10. Maintain management commitment and financial support.
11. Incorporate findings of continued and completed research and evaluations, and implement into revised specifications and ASR information database.
12. Complete and analyze round-robin testing program.
13. Provide for a partnership with industry.

Action Plan

1. Roger Surdahl will utilize FHWA resources, if necessary, to help assure that all Lead State team members are accessible by Internet by March 1997.
2. Claudio Manissero and Roger Surdahl will send articles and bibliographies to Margo by February 17, 1997.
3. Margo Thomson will categorize the bibliographic information by source and topic by July 21, 1997.
4. Moy Biswas will develop an electronic database of the ASR information by key words from a standard format by October 20, 1997.

5. The lead states on Team ASR will set target dates to complete research, evaluation, and guide specifications and will send this information to Margo Thomson by September 27, 1996.

6. The individual Team ASR members will compile a list of people, equipment, materials, literature, videos, slides, photos, computers, and available money which can be used to provide technical assistance and send it to Claudio Manissero by October 21, 1996. Claudio Manissero in turn will compile this list and return it to the Team ASR members for review by November 11, 1996. The final product is envisioned as a directory of resources made available to the public. The means of publication has yet to be decided.

7. Margo Thomson will start working with the help of the other Team ASR members, on evaluating options for disseminating the information by June 1997.

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APPENDIX B

REVISED OBJECTIVES AND MEMBERSHIP (as of 1997)

REVISED OBJECTIVES AND MEMBERSHIP (as of 1997)

Mission

To provide a clearinghouse to share and deliver information and technical assistance in identification, prevention, and rehabilitation of alkali silica reactivity to the public, private, and academic sectors of transportation.

Goal 1

To implement SHRP ASR technologies through AASHTO to all members and local agencies to ensure that:

a. Testing procedures to identify potential reactivity are implemented;

b. Safe PCC mix designs to prevent premature failure are developed and implemented;

c. Existing ASR problems are identified; and

d. Rehabilitation strategies are implemented to extend the working life of ASR-affected PCC pavements and structures.

Goal 2

To implement an education and technology transfer and assistance program to ensure that the financial benefits of SHRP ASR technology implementation are achieved in 50% of AASHTO members states and appropriate local agencies by September 2000.

Action Plan 1

Gather ASR information:

- Claudio Manissero and Roger Surdahl gather previous ASR surveys and distribute to Team by 9/30/97.
- Bryce Simons and Joe Barela design updated survey with help from Kevin Wylie and Phil Reid; draft done by 11/97.
- Bryce Simons and Joe Barela distribute survey to target customers and obtain results of survey by and of first quarter of 1998.
- Bryce Simons and Joe Barela collate and analyze results of survey by end of second quarter of 1998.
- Bill Carey, with input from the rest of the Team, identifies key literature on ASR from the database collected for the web site by the end of the first quarter of 1998.

Action Plan 2

Disseminate ASR information:

- Margo Thomson obtains funding for web site by end of 9/97.
- Whole Team agrees on web site design by end of fourth quarter of 1997.
- Claudio Manissero and Moy Biswas develop and implement Web site by the end of the second quarter of 1998.
- Bryce Simons sets up ACI-SHRP ASR training course and obtains ACI buy-in by the end of the fourth quarter of 1997.

• Bryce Simons drafts up an ASR training program for review and approval of Team and ACI by the end of the second quarter of 1998.

• Bryce Simons implements training courses through ACI by the end of the fourth quarter of 1998.

• Bryce Simons adepts training course for use of AASHTO Team members' use by the end of the fourth quarter of 1998.

• Claudio Manissero and Margo Thomson develop a marketing communications plan and establish a budget for this plan by the end of the fourth quarter of 1997.

Action Plan 3

Develop Guide Specifications:

• Roger Surdahl will develop the draft guide specification based on the Mid-Atlantic ASR guide specification into the AASHTO format in active voice, and distribute it to the Team by November 10, 1997.

• The Team will meet in Albuquerque, NM on November 19 through 21, 1997 to rework and revise the draft specification.

• The ASR Team will accept a final Guide Specification at their meeting at TRB in January 1998.

• Margo Thomson will present the final ASR Guide Specification to the AASHTO Materials Subcommittee and Construction Subcommittee for acceptance ballot by July 1998.

Action Plan 4

Provide Technical Assistance:

• John Dewar will set up an FHWA funded travel account to assist in travel to other states by June 1998.

• Dan Johnston and Dave Gress will develop and distribute a one-page flyer to advertise the availability of the Team's technical assistance by May 1998.

• Individual ASR Team members will conduct site visits on request to view and discuss ASR problems and solutions beginning June 1998.

• Individual ASR Team members will answer inquiries and report each contact to Margo Thomson on a quarterly basis, beginning in June 1998.

Action Plan 5

Review Technology on ASR by September 2000:

• All Team members perform an annual review of existing ASR technology and submit the results of their review to the Team coordinator. The Team coordinator compiles this review material into an interim report, which is to be completed by the last quarter of the year.

• The Team will survey all states at the end of 1999 to gather feedback on the usefulness of item's for identification techniques, aggregate evaluation methods, mitigative methods, remediation methods, and the AASHTO ASR Guide Specification.

• The Team coordinator will establish a sub-team by the end of 1998 to develop the survey. The Team coordinator will distribute and collect the survey by 6/30/99.

• The final report on the review of ASR technology will be due at sunset (September 2000) from the Team coordinator and the sub-team, which developed the survey.

Action Plan 6

Estimate cost-benefit ratio of implementing ASR technology:

- Claudio Manissero will gather cost data from lead states based on their experiences by January 1998.
- Claudio Manissero will develop a survey for other AASHTO members to obtain from them information about costs associated with ASR by November 1997. Margo Thomson will distribute this survey to AASHTO members by December 1997, and collect the survey by March 1998.
- Claudio Manissero will lead the effort to analyze the data obtained in a. and b. above to obtain cost benefits of implementing SHRP ASR technology by September 1998.

ASR Lead State Team (as of 1997)

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APPENDIX C

FINAL OBJECTIVES AND MEMBERSHIP (as of 1998)

FINAL OBJECTIVES AND MEMBERSHIP (as of 1998)

Mission

To provide a clearinghouse to share and deliver information and technical assistance in identification, prevention, and rehabilitation of alkali silica reactivity to the public, private, and academic sectors of transportation.

Goals

1. To implement SHRP ASIR technologies through AASHTO to all members and local agencies to ensure that:

   a. Testing procedures to identify potential reactivity are implemented;

   b. Safe PCC mix designs to prevent premature failure are developed and implemented;

   c. Existing ASR problems are identified, and

   d. Rehabilitation strategies are implemented to extend the working life of ASR-affected PCC pavements and structures.

2. To implement an education and technology transfer and assistance program to ensure that the financial benefits of SHRP ASIR technology implementation are achieved in 50% of AASHTO members states and appropriate local agencies by Sept. 2000.

Strategies

1. Gather ASR information.

Action Plan

a. Claudio Manissero and Roger Surdahl gather previous ASR surveys and distribute to Team by 9/30/97.

b. Bryce Simons and Joe Barela design updated survey with help from Ken Wylie and Phil Reid; draft done by 11/97.

c. Bryce Simons and Joe Barela distribute survey to target customers and obtain results of survey by end of first quarter of 1998.

d. Bryce Simons and Joe Barela collate and analyze results of survey by end of second quarter of 1998.

e. Steve Lane, with input from the rest of the Team, identifies key literature on ASR from the database collected for the Web-site by 09/01/98.

2. Disseminate ASR information.

Action Plan

a. Margo Thomson obtains funding for Web-site by end of 9/97.

b. Whole Team agrees on Web-site design by end of fourth quarter of 1997.

c. Claudio Manissero designs and implements Web-site by the end of the fourth quarter of 1998.

d. Bryce Simons sets up ACI-SHRP ASR training course and obtains ACI buy-in by the end of the fourth quarter of 1998.

e. Bryce Simons draft up an ASR training program for review and approval of Team and ACI by the end of the third quarter of 1998.

f. Bryce Simons implements training courses through ACI by the end of the fourth quarter of 1999.

g. Bryce Simons adapts training course for use of AASHTO Team members' use by the end of the fourth quarter of 1999.

h. Claudio Manissero and Margo Thomson develop a marketing communications plan and establish a budget for this plan by the end of the fourth quarter of 1998.

3. Develop guide specifications.

Action Plan

a. Roger Surdahl will develop the draft guide specification based on the Mid-Atlantic ASR guide specification into the AASHTO format in active voice, and distribute it to the Team by November 10, 1997.

b. The Team will meet in Albuquerque, NM, on Nov. 19 through 21, 1997 to rework and revise the draft specification.

c. The ASR Team will accept a final Guide Specification at their meeting at TRB in January 1998.

d. Margo Thomson will present the final ASR Guide Specification to the AASHTO Materials Subcommittee and Construction Subcommittee for acceptance ballot by July 1998.

4. Provide technical assistance.

Action Plan

a. Dan Johnston and Dave Gress will develop and distribute a one-page flyer to advertise the availability of the Team's technical assistance by December 1998.

b. Individual ASR Team members will conduct site visits on request to view and discuss ASR problems and solutions beginning June 1998.

c. Individual ASR Team members will answer inquiries and report each contact to Margo Thomson on a quarterly basis, beginning in June 1998.

5. Review technology on ASR by Sept. 2000.

Action Plan

a. All Team members perform an annual review of existing ASR technology and submit the results of their review to the Team coordinator. The Team coordinator compiles this review material into an interim report, which is to be completed by the last quarter of the year.

b. The Team will survey all states at the end of 1999 to gather feedback on the usefulness of items for identification techniques, aggregate evaluation methods, mitigative methods, remediation methods, and the AASHTO ASR Guide Specification. The Team coordinator will establish a sub-team by the end of 1998 to develop the survey. The Team coordinator will distribute and collect the survey by 6/30/99.

c. The final report on the review of ASR technology will be due at sunset (Sept. 2000) from the Team coordinator and the sub-team, which developed the survey.

6. Estimate cost-benefit ratio of implementing ASR technology.

Action Plan

a. Claudio Manissero will gather cost data from lead states based on their experiences by 1/l/99.

b. Claudio Manissero will develop a survey for other AASHTO members to obtain from them information about costs associated with ASR by 11/1/98. Margo Thomson will distribute this survey to AASHTO members by 12/30/98, and collect the survey by 3/30/99.

c. Claudio Manissero will lead the effort to analyze the data obtained in a. and b. above to obtain cost benefits of implementing SHRP ASR technology by 9/30/99.

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APPENDIX D

ASR SURVEY

ASR SURVEY

AASHTO LEAD STATES TEAM
SURVEY ON ALKALI-SILICA REACTIVITY (ASR)

1 - Agency Completing Survey

2 - Address

3 - Person Completing Survey

4 - Title of Person Completing Survey

5 - Phone and. Fax Number

GENERAL

6 - Has your State/ Province experienced unexpected concrete cracking/deterioration problems?

7 - Has there been an assessment of the causes of the deterioration?
(a) Any that are attributed to alkali-silica reactivity (ASR)? Yes No Not sure
(b) If yes, what type of assessment was performed?
(c) What type of testing was performed?

8 - If you've determined that the cracking/deterioration is attributed to ASR, is the reaction widespread or localized?

(a) If localized, what areas of your State/Province are affected? and, who in the district, region, or area is the contact person?
(b) Can you provide the Team with any surveys, reports, or studies on the ASR problem you've encountered?
(c) How long after construction did the cracking/deterioration occur?
(d) What detection techniques are being used?

9 - What steps or techniques are used to remediate ASR caused cracking/deterioration in new and old construction? Are you testing and/or treating the aggregate? if so, how? Are you using low-alkali cement, blended fly ash/cement, fly ash, silica fume, or ground granulated blast-furnace slag for mitigation?

10 - How long have the techniques been implemented?
(a) Are your current ASR mitigation techniques affective? Why or why not?

11- What if any, specifications address ASR in your State/Province? Can you provide a copy?

12 - Does your agency offer programs or training on detection, prevention. and remediation of ASR to Personnel within your agency?

13 - Would you be interested in additional information on ASR? What types of information would you be interested in?

Guide specifications
Testing specifications
Detection of ASR
Case histories
Remediation of ASR
SHRP reports
Other

14 - If the AASHTO Lead States Team on ASR were to offer a showcase on ASR, would your State/Province be interested in hosting such an event?

15 - If the ASR Lead States Team were to offer other services, which of the following would you be interested in?

Field Surveys
Field detection using UV testing kit
Uranyl acetate testing in the laboratory
Laboratory testing training
Assistance in writing specifications
Field inspection training
Assistance with mix design
Field demonstration assistance
Laboratory study set-up
Other

The full results of this survey are tabulated in the attached Microsoft Excel file, "Appendix D ASR-Survey.xls."

ST	6 Cracking Problem Y / N	7 Assessment of Problems Y / N	7a Attrib to ASR Y / N	7b Type of Assessment (See Tab 7b)	7c Types of Testing (See Tab 7c)	8 Is ASR widespread or Localized	8a If Localized, Name of Contact Person	8b Survey Results	8c How Long After Construction did Problems Occur	8d Detection Techniques Used (See Tab 8d)
AL	Y	Y	N	g,h		Localized	S. Rodriguez	See Attachments	See Attachments	a,b,c
AK	N		N			N/A				
AZ	NS	N	NS			Not Sure				none
CO	Y	Y	Y	a, b	a,b,c	Localized	See Tab 8a		5-15 years	a
CT	N	N	N			N/A				
FL	Y	Y	N	N/A	N/A					
GA	N	N	N		N/A	N/A				
HI	N	N	N			N/A				
ID	Y	Y	Y	c	i	Localized	A.F. Stanley	See Attachments	< 10 Years	b,c
IN	Y	Y	Y	b	h	Widespread		See Attachments	< 30 Years	a,b
KS	Y	Y	N							
KY	N	Y	N			N/A				
ME	Y	Y	Y	b,f,c		Widespread	M. Redmond		+10 years	b,c
MD	Y	Y	Y	f	d,h	Localized		No	4-7 years	C,f
MI	Y	Y	NS	b	h	Widespread		none	< 5 years	B
MS	Y	Y	NS	b	none	Localized	NE Area	No	10 years	A
MT	Y	Y	N			N/A				
NE	Y	Y	Y	b,j	h	Widespread		In-Progress	5-10 years	a,b
NH	Y	Y	Y	c,f	e	Widespread	R. Lane	In-Progress	Unknown	B
NJ	Y	Y	Y	c	h	Localized			approx 13 years	a,b
NM	Y	Y	Y	a,b,c,f	d,h	Widespread	B. Simons	Done	5-20 Years	a,b,c
NY	Y	Y	N	b	h					
NC	Y	Y	Y	b	b,h,j,k,l,m,n,o,p	Localized	M. Biswas	Yes (none attached)	< 8 years	a,b
NS	Y	Y	Y	b,h	d,h	Localized	G. Pyke	See Attachments	15-20 years	E
OH	N	N/A	N		N/A	N/A				
ON	Y	Y	Y	Various	c,d,e	Widespread			4-10 years	A
OR	Y	Y	Y	c	b	Localized	K. Johnston	No	1-30 years	A
PA	Y	Y	Y	c	d	Unknown		See Attached	4-10 years	b,c
RI	NS	N/A	NS	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SK	Y	Y	Y	b	d	Localized	H. Bachelu	none	approx 15 years	A
SC	N	N/A	N			N/A				
SD	Y	Y	Y	c,f,g	e,f,g	Widespread		Done	5-25 years	a,d
TX	Y	Y	Y	b	b	Localized	El Paso			A
UT	Y	Y	Y		d	Localized	C/S Utah		approx 30 years	A
VT	Y	Y	Y	Not Sure		Localized		No	approx 10 years	B
DC	N	N	N							
DC	Y	Y	NS		d	N/A				
WI	Y	Y	N	c,h,i		N/A				

ST	9	10	10a	11	12	13: Interested?						
	Remediation Techniques (See Tab 9)	How Long Been Used	Are Techniques Effective	What Specs Address ASR	Do You Offer Training	Guide Specs	Testing Specs	Detection of ASR	Case Histories	Remediations of ASR	SHRP Efforts	Other
AL	a,e	Unknown	Yes	none	No		Yes					
AK	g				No							
AZ	g,h	15 years		Attached	No	Yes	Yes					
CO	a,b,c	10 Years	Yes	See Quest 9	No	Yes			Yes	Yes	Yes	
CT	N/A	N/A		N/A	No	Yes	Yes	Yes				
FL	N/A	N/A		none	No							
GA	a,e,f	> 15 years		N/A	No			Yes				
HI	N/A	N/A		none	No	Yes	Yes	Yes	Yes	Yes	Yes	
ID	a,h	< 5 years	not sure	See Attached	No	Yes	Yes			Yes		
IN	a,e	New	not sure	See Quest 9	No	Yes				Yes		
KS	a,j,l,k	>50 years	Yes	See Quest 9	No							
KY	N/A	N/A		none	No							
ME	a,e,f	2 years		Attached	No					Yes		
MD	e	6 years	Yes		Yes							
MI	e	N/A		none	No		Yes	Yes				
MS	a	+25 years	not sure	See Quest 9	No		Yes	Yes			Yes	
MT												
NE	l	3-4 years	Yes	See Attached	No					Yes		
NH	none	Unknown		none	No	Yes	Yes	Yes	Yes	Yes	Yes	
NJ	e	New		In-Progress	No							
NM	a,f,g,l,n,q,t,p	Recent	Unknown	New-See Attached	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
NY	a,q,r,s	>30 years	Yes	See Attached	No							
NC	a,e	8 years	Yes	See Quest 9	No	Yes		Yes	Yes			
NS	a,e	3 years	not sure	CIP Specs Attached	No	Yes	Yes	Yes		Yes	Yes	
OH	N/A	N/A		none	No	Yes	Yes	Yes	Yes	Yes	Yes	
ON	d	15 Years	Yes	Attached	No				Yes			
OR	a,d,e	15 years	not sure	none	No							
PA	a,e,l	6 years	partially	See Attached	No			Yes				
RI	a,e	approx 15 yrs	not sure	none	No	Yes	Yes	Yes	Yes	Yes	Yes	
SK	a,p	4 years	Unknown	See Quest 9	No	Yes	Yes	Yes	Yes	Yes		
SC	a	N/A			N/A	Yes	Yes	Yes	Yes	Yes	Yes	
SD	a,h,m,No	approx 6 years	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	
TX	a,e,f,l,o	Recent	Unknown	See Comment	No	Yes	Yes	Yes	Yes	Yes		
UT	a,h		Yes	UDOT PCCP Spec	No		Yes					
VT	none	N/A		none	No		Yes	Yes		Yes		
DC	i				No	Yes	Yes	Yes	Yes	Yes	Yes	
DC	a			See Attached	No	Yes	Yes	Yes	Yes	Yes	Yes	
WI				none	Yes							

	14	15: Interested?									
ST	Will You Host Seminar?	Field Surveys	Field Detection Using UV Test Kit	Uranyl Acetate in Laboratory	Laboratory Testing Training	Assist. In Writing Specifications	Field Inspection Training	Assist With Mix Design	Field Demo Assist.	Laboratory Study Set-up	Other
AL	Yes										Petrographic Analysis
AK	No										
AZ	Yes		Yes	Yes	Yes					Yes	
CO	Maybe	Yes	Yes		Yes	Yes		Yes	Yes	Yes	
CT	No	Yes	Yes	Yes			Yes		Yes		
FL	No										
GA	No	Yes	Yes								
HI	No										
ID	No					Yes					
IN	No					Yes			Yes		
KS	No										
KY	No										
ME	No										
MD	No						Yes				
MI	No			Yes	Yes					Yes	
MS	Yes			Yes	Yes				Yes	Yes	
MT											
NE	No										
NH	Yes	Yes		Yes		Yes	Yes	Yes	Yes		
NJ	No										
NM	No										
NY	No										
NC	No										
NS	?						Yes		Yes		
OH	No										
ON	No										
OR	No										
PA	Yes	Yes					Yes				
RI	No	Yes			Yes	Yes	Yes	Yes	Yes		
SK	No	Yes	Yes				Yes				
SC	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes		
SD		Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes	
TX	No										
UT	?							Yes			
VT				Yes	Yes	Yes	Yes				
DC	No										
DC	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
WI	No		Yes				Yes				

	Test Assessment Method	Respondent
a:	Performance Review of Concrete with specific aggregates	
b:	Visual Inspection	CDOT, Indiana. Michigan, Nova Scotia, Nebraska, Texas, Sasketchewan, North Carolina, New Jersey,
		New Mexico, Mississippi
c:	Petrographic Examination C-856	Ontario, Oregon, South Dakota, Idaho, New Hampshire, Pennsylvania, New York, New Mexico
d:	Live Load Testing w two 100 ton vehicles	Ontario
e:	Strength Testing	Ontario
f:	UV Light Kit	Maine, South Dakota, Maryland, New Hampshire, New Mexico
g:	Mapping of Cracks	Alabama
h:	Obtaining Cores from Affected area	Alabama, South Dakota, Nova Scotia
i:	Refractive Index	Wisconson
j:	Chemical	Nebraska

		Test Designation	Respondent Using Method
a:	Mortar Bar Test	C-227	CDOT
b:	Petrographic Examination of Aggregates	C-295	CDOT
c:	Chemical Method	C-289	CDOT, Oregon, Ontario
d:	Petrographic Examination of Concrete	C-856	Oregon, Utah, Nova Scotia, Maryland, Washington DC, Pennsylvania, Texas, Sasketchewan, N. Carolina, New Mexico
e:	Aggregates Tested	C-1260/T303	South Dakota, New Hampshire
f:	Aggregates Tested	C-227	South Dakota
g:	Aggregates Tested	C-289	South Dakota
h:	UV Test Method		Indiana, Michigan, Nova Scotia, Maryland, Nebraska, North Carolina, New Jersey, New York, New Mexico
i:	Expansion Testing		Idaho
j:	Fluorescence Image Analysis		North Carolina
k:	Chemical Analysis		North Carolina
l:	Residual Expansion		North Carolina
m:	Dynamic Modulus		North Carolina
n:	Compressive Strength		North Carolina
o:	Splitting Tensile Strength		North Carolina
p:	X-Ray Defraction		North Carolina

Contact Names for Localized ASR Distress

Name	State or Province	Region or District	Phone Number
Gerald Peterson	CDOT	1	303/757-9134
Kenneth L. Wood	CDOT	4	970/350-2131
Michael Redmond	Maine	Statewide	207/287-2262
Keith Johnston	Oregon	Central Lab	503/986-3053
Sergio Rodriguez	Alabama	Central Lab	334/206-2410
Gary Pyke	Nova Scotia	Central Lab	902/860-2999
A.F. Stanley	Idaho	Central Lab	208/334-8443
Richard M. Lane	New Hampshire	Central Lab	603/271-3151
Herve Bachelu	Sasketchewan	Central Lab	306/787-4830
Mrinmay "Moy" Biswas	North Carolina	Central Lab	919/715-2465
Bryce Simons	New Mexico	Central Lab	505/827-5191

Detection Techniques Used to Discover ASR

	Detection Technique Used	Respondent Answering
a:	Visual Observation and Inspection	CDOT, Ontario, Mississippi, Oregon, Alabama, Utah, Indiana,
		Nebraska, Texas, Saskatchewan, North Carolina, New Jersey, New Mexico
b:	UV Light	Maine, Alabama, Vermont, South Dakota Indiana, Michigan, Idaho,
		New Hampshire, Pennsylvania, Nebraska, North Carolina, New Jersey, New Mexico
c:	Petrographic C-856	Maine, Alabama, Idaho, Pennsylvania, New Mexico
d:	Copper Sulfate	South Dakota
e:	CSA Test Procedures	Nova Scotia
f:	Education of Personnel	Maryland

Remediation Techniques Used

	Remediation Techniques Used	Limits	Respondent
a:	Low Alkalie Cement	<0.6 Alkalies	CDOT, Mississippi, Oregon, Alabama, Kansas. South Dakota, Indiana, Nova Scotia, Washington DC,
			South Carolina, Pennsylvania, Texas, Georgia, Sasketchewan, North Carolina, New York (< 0.7%),
			Rhode Island, Maine
b:	Mandatory 20% Fly Ash	Class F	CDOT
c:	AC Overlay	Repair	CDOT
d:	Use of Non-Reactive Aggregate		Ontario, Oregon
e:	General use of fly ash, silica fume, ggbfs, slag cement		Rhode Island, Oregon, Alabama, Indiana, Michigan, Nova Scotia, Maryland, Pennsylvania,
			Texas, Georgia, North Carolina, New Jersey, Rhode Island, Maine
f:	Aggregate Evaluation by C-1260/T 303		Maine, Texas, Georgia
g:	Type II Cement		AZ, Alaska
h:	Allows use of Class F Ash up to 20%		AZ, Utah, South Dakota, Idaho
i:	T 303		Washington
j:	Wetting Drying Test (Attached)		Kansas
k:	Use of 30%Limestone, dolomite or approved gravel or		Kansas
	25% chat to mitigate ASR		
l:	Type IP Cement		Kansas, Pennsylvania, Nebraska, Texas
m:	Type V Cement		South Dakota
n:	Lithium Treatment		South Dakota
o:	Aggregate Evaluation by C-1293		Texas
p:	Silica Fume		Sasketchewan
q:	Aggregate Evaluation by C-295	% Chert	New York
r:	Aggregate Evaluation by C-227		New York
s:	Flyash modified high alkali cements		New York
t:	Required Use of at least 20% Class F Ash		New Mexico

APPENDIX E

UPDATED SHRP-C-315

UPDATED SHRP-C-315

Handbook for the Identification of Alkali-Silica Reactivity in Highway Structures

The following provides the full text without pictures of SHRP C-315, one of the key products of the Strategic Highway Research Program, Contract C-202, ASR project developed by the National Research Council, 2101 Constitution Avenue N.W., Washington, DC 20418. Author of the original manuscript is David Stark, Construction Technologies Laboratories, Inc., Skokie, IL, USA.

The original text is supplemented to reflect recent findings and conclusions developed by the AASHTO ASR Lead State Team Members since this document was printed in 1994. For reference, all text that has been added or modified from the original document appears in *Italics*.

TABLE OF CONTENTS

FOREWORD

Alkali-Silica Reactivity (ASR) is a major cause of the deterioration of highway structures and pavements in the United States. The Strategic Highway Research Program (SHRP) *has* addressed this problem through its Project C-202, Eliminating or Minimizing Alkali-Silica Reactivity. One task of this research *was* to find means to mitigate damage caused by ASR in existing concrete structures and pavements. The first steps toward achieving this goal are to detect ASR and to distinguish it from other types of damage, particularly in its early stages. This handbook is intended to serve this purpose. It uses color photographs of actual examples to illustrate the ASR damage in a number of field structures. It then describes a simple and rapid chemical test for ASR detection. An early diagnosis of the problem should greatly help in the timely and economical repair or rehabilitation of the affected concrete structure.

Inam Jawed
Project Manager
Strategic Highway Research Program

INTRODUCTION

This handbook provides guidance for the field identification of Alkali-Silica Reactivity (ASR) in portland cement concrete structures such as highway pavements and bridges. ASR development is assessed on two bases: 1) the occurrence and disposition of cracking and displacement of concrete, and 2) the presence of reaction products from ASR. Descriptions and color photographs provide detailed information.

Other causes of cracking or volume changes, such as freezing and thawing, corrosion of reinforced steel, superimposed loading, or plastic shrinkage, may have occurred in the structure under inspection. Distress similar to that resulting from ASR but not caused by ASR is *also identified. The reader should keep in mind that distress to concrete can be very complicated, and that it is not uncommon for secondary distress mechanisms such as freezing and thawing and corrosion of reinforced steel to be accelerated once the integrity of concrete is affected by ASR-induced cracking. This handbook, therefore, is meant to act as a guide for an initial assessment of potential ASR distress in the field, not for definitive assessment of distress mechanisms. Any field observations should be confirmed in the laboratory by an experienced petrographer before making definitive conclusions.*

The descriptions and photographs of evidence of ASR presented in this handbook are based on almost 30 years of field and laboratory investigations of a wide variety of concrete structures. Most of the information presented was obtained under SHRP Project C-202, "Eliminating or Minimizing Alkali-Silica Reactivity." The *uranyl acetate* procedure for identifying ASR gel reaction products was developed by Drs. K. Hover and K. Natesaiyer of Cornell University. (1, 2)*The ASRDetect procedure was developed by Bill Carey and George Guthrie at the DOE Los Alamos National Laboratories.*

REFERENCES

1. NATESAIYER, K. and Hover, K.C., "Insitu Identification of ASR products in Concrete", *Cement and Concrete Research*, Vol. 18, May 1988, pp. 455-463.

2. NATESAIYER, K. and Hover, K.C., "Some Field Strategies of the New In situ Method for Identification of Alkali Silica Reaction Products in Concrete", *Cement and Concrete Research*, Vol. 19, September 1989, pp. 770-778.

ORGANIZATION OF HANDBOOK

This handbook is divided into four sections. Color photographs are used throughout the handbook to aid in accurate identification. Section 1 describes the nature of ASR and its causes and effects. Section 2 deals with the manifestations of ASR-related volume changes in highway pavement. Section 3 covers ASR in bridge structures. Section 4 describes a rapid field procedure to identify the presence of ASR reaction products in concrete. The presence of the reaction products is indisputable evidence of ASR, but it does not necessarily reflect development or severity of distress. Thus, assessment of associated distress together with identification of reaction products provides the greatest assurance whether expansive ASR has developed in the concrete structure. *Confirmation of ASR by petrographic analysis is recommended to reach reliable conclusions that the distress is indeed due to ASR expansion.*

1. THE NATURE OF ASR

Three requirements must be met for expansive ASR to occur: 1) reactive forms of silica or silicate in the aggregate, 2) sufficient alkali (sodium and potassium) primarily from the cement, 3) and sufficiently available moisture in the concrete. If any one of the three requirements is not met, expansion due to ASR cannot occur.
In its simplest form, ASR can be visualized as a two-step process:

1. Alkali + Silica = Gel Reaction Products
2. Gel Reaction Products + Moisture = Expansion

Actual expansion occurs in the second step when the ASR gel reaction product swells as it absorbs moisture. Potentially expansive gel reaction product does not form unless the first step occurs.

As a general rule, two of the three requirements for ASR, cement alkali and reactive silica, are basically fixed components of the concrete and therefore present the potential for expansion, regardless of exposure condition. *However, alkali levels can be increased from those in initial mix by external sources such as from salt water and mist in coastal areas or from deicer salts, or the alkalis present can be concentrated in areas of the concrete causing localized reaction. Some of the causes of concentration can be wetting and drying cycles in the concrete or cases where reinforced concrete is being protected by cathodic protection.* The third requirement, moisture availability is a major variable in concrete and has a significant impact on the severity of distress and volume change due to ASR.

Moisture availability in concrete varies significantly with distance from exposed surfaces in most, if not all, highway structures. This is most pronounced under severe atmospheric drying conditions such as those in arid desert-like regions in the southwestern United States. The resulting crack pattern associated with ASR may thereby become accentuated through shrinkage induced by prolonged, severe drying. *It is thus not uncommon for secondary distress mechanisms such as drying shrinkage, freezing and thawing and corrosion of reinforced steel to be accelerated once the integrity of concrete is affected by ASR-induced cracking.*

Restraint, due both to abutting concrete and to embedded reinforcing steel, influences the development of cracking associated with ASR. Its effects are observed in highway pavements and bridge structures, as will be seen in the illustrations. Cracking associated with ASR is not uniformly developed throughout concrete members due in part to restraint. Creep is a major factor that tends to relieve ASR-induced stress. Since neither restraint nor creep are uniform in all directions, ASR-related distress is not uniformly developed. For example, abutting pavement slabs offer restraint parallel to the longitudinal direction of the pavement. Cracking therefore tends to be more pronounced in the longitudinal direction; that is, differential movement is greater in the transverse and vertical directions, resulting in the typical cracking illustrated in the photographs in this handbook. *Finally, nonuniform cracking patterns can be caused by* *differences in wetting and drying in portions of a concrete member as by sprinkling or watering systems, or leakage from joints in the deck on bridge substructures.*

2. ASR IN PAVEMENTS

FIG.1 - Close-up of pavement surface showing very early development of cracking associated with ASR. Cracks show generally random orientation with no preferred direction of strongest crack development. Such cracking is more visible on smooth surfaces than on textured or grooved surfaces, and can be enhanced visually by viewing after partial drying of a surface *wetted with water (e.g. after a rain) or with a 1% Potassium Iodide (KI) solution. Appearance at these early stages can easily be misinterpreted as drying shrinkage cracking.*

FIG.2 - Pavement surface showing slightly greater development of cracking than is illustrated in Fig. 1. Cracks show generally random orientation with no strongly preferred direction. Longitudinal grooving tends to obscure cracks. *Gel appearing as a translucent wet deposit or as a white deposit may be visible at this stage. Width of cracks varies, with the widest cracks usually visible in portions of the slab where there is less restraint, e.g. the edges of the pavement.*

FIG.3 - A well-defined crack pattern associated with the development of ASR in highway pavement. Crack pattern is commonly identified as "map-cracking" or "pattern-cracking." Orientation of predominant cracks is longitudinal as shown. Crack pattern is generally developed uniformly across the width of the pavement, although cracks in wheel paths may be more apparent due to infiltration of dirt and apparent greater width due to crumbling of crack edges. Both result from traffic wear. *Often pavement that has reached this level of distress also exhibits a sheen or slightly wet look, particularly in the wheel path, caused by spreading of the silica gel exuding from the cracks. Although* the crack pattern is similar for jointed and continuously reinforced concrete pavement *(CRCP) there is usually a higher concentration of longitudinal cracking at the joints in jointed pavement than is visible at this stage at the normal transverse cracks that develop in CRCP. In both cases these areas tend to be the weak points of the pavement where spalling will occur as the reaction progresses.*

FIG.4 - Closer view of well-developed pattern of cracking associated with ASR, as viewed transversely across jointed pavement. Pattern somewhat resembles that which develops on dried mud flats, but tends to show more prominent cracks in longitudinal (left to right) direction of pavement. Cracks may be filled with secondary reaction products which may or may not be ASR gel.

FIG.5 - Close-up view of severe cracking associated with ASR in jointed pavement. Orientation of predominant cracks is longitudinal (left to right). Interconnecting cracks are randomly oriented. Virtually all cracks are open and are not filled with secondary deposits at the surface. Severe desert drying occurs in this region, thus probably increasing the severity of cracking. *At this stage of damage spalling at joints is normally observed, as well as secondary damage by freeze-thaw in areas subjected to freeze-thaw cycles.*

FIG.6 - Cylindrical surfaces of 4-inch diameter cores removed from area of pavement shown in Fig. 5. Note predominance of cracks in upper half of pavement, which is typical of ASR-related

distress. These cracks are more sharply defined on these partially dried cores by water remaining in the cracks, thus producing relatively dark fringes that follow cracks. Note vertical cracks near top surface, and sub horizontal orientation of many cracks below the surface. ASR has, however, developed through the full thickness of the pavement slab. *Cracking is not evident in the bottom half due to restraint produced by the weight of the concrete in the top half.*

FIG.7 - Severe cracking associated with ASR in continuously reinforced concrete pavement (CRCP). Cracks are most frequently oriented in longitudinal direction of pavement (top to bottom in photo), and are interconnected by finer transverse or random cracks, producing a generally rectilinear crack pattern. Relatively smooth wearing surface shown in photo, in contrast to grooved and textured surfaces, enhances appearance of cracks.

FIG.8 - Four (4) - inch diameter cores taken from CRCP shown in Fig. 7. Note shallow depth (1 to 2 ½ in.) of vertical cracks that appear as well-defined longitudinal and transverse or random cracks at the wearing surface. Vertical longitudinal cracks also extend upward about 2 to 3 inches from bottom of middle core and core at right side. Although not readily seen in the photo, cracks near mid-depth in the cores, in the vicinity of the reinforcing steel, are oriented generally horizontally, in contrast to the vertical orientation of cracks at the top and bottom surfaces. *This is due to localized restraint provided by the reinforcing steel.*

FIG.9 - An early stage of cracking associated with ASR in jointed pavement. Occasionally, cracking first appears or is more severe along joints. This may lead to confusion with D-cracking (see Fig. 10). Note that, in cracking associated with ASR, numerous individual cracks are approximately normal to the direction of the joint. *It must be noted that, in areas that experience a number of freeze-thaw cycles, secondary damage due to freeze-thaw can occur at the joints resulting in a secondary cracking pattern parallel to the joint which can easily be confused with D-cracking.*

FIG.10 - D-cracking due to freeze-thaw deterioration of coarse aggregate along transverse joint. In contrast to cracking associated with ASR, cracks are roughly parallel to the adjacent joint. Cracking along joint that has been induced by ASR, as in Fig.9, *is usually normal to the joint and is* associated with a fainter map-cracking elsewhere in the pavement slab. D-cracking normally progresses away only from joints, intermediate cracks, and free edges of pavement slabs. *ASR affected pavement with secondary freeze-thaw damage initiated by the ASR cracking will normally exhibit a combination of the two types of cracking patterns.*

FIG.11 - Fracture surface of 4 inch diameter core from pavement where ASR has developed. Note white deposit in several dark coarse aggregate particles, with particular buildup along periphery of particles. This deposit contains ASR gel reaction product that is characteristic of reacted particles (arrows).

FIG.12 - Smooth, lapped surface of concrete showing reaction rims on coarse aggregate particles (paired arrows), microcracks through particles, and white ASR gel reaction products (single arrow). Confirmed gel deposits are positive evidence that ASR has occurred. *Reaction rims are characterized as darker rims surrounding the aggregate. Note that cracking pattern extends from coarse aggregate through the paste, through another coarse aggregate particle, etc.*

creating a continuous crack pattern throughout the concrete matrix. The ASR gel reaction products appear to have migrated through this crack pattern demonstrating the relative fluidity of the gel.

3. ASR IN BRIDGE STRUCTURES

FIG.13 - Cracking associated with ASR at mid-span in bridge deck. Predominant cracks are oriented longitudinally with respect to deck (top to bottom in photo), and are interconnected by short, tight microcracks that extend transversely or randomly between longitudinal cracks. Cracking may be more severe over girders. No consistent relationship exists between location of cracks and steel in top reinforcing mat.

FIG.14 - Characteristic cracking associated with ASR in corner of bridge deck. Cracks tend to "curve" around corner from transverse orientation at end of deck to longitudinal orientation toward middle of span (See Fig.13). End of deck is along tarred strip at bottom of photo. *Cracking pattern is due to restraint developed by the reinforcing steel and other concrete members in and around the deck. Areas, such as around drains, where rainwater and/or solubilized deicer flows or collects on a deck tend to show more severe cracking.*

FIG.15 - Four (4) inch diameter core taken from area of bridge deck shown in Fig.14. Major cracking occurs full-depth in the core and is enhanced by *wetting and* partial drying. Dark bands follow cracks that still contain water. Initiation of cracking is attributed to ASR. Restraint by reinforcing steel to volume change may have influenced crack pattern.

FIG.16 - Longitudinal crack, along top of parapet wall, associated with ASR. Other, much finer cracks form network of cracking on top surface. Such cracking could be attributed to drying shrinkage or corrosion of embedded steel. Corroborating evidence, *such as petrographic analysis,* is necessary to verify association of ASR with cracking.

FIG.17 - Cracking associated with ASR in end block of concrete guard rail on bridge deck. This type of cracking could result from freezing and thawing. In essentially frost-free climates, ASR is the likely cause of cracking. Individual cracks are stained and filled with calcium carbonate and ASR gel. Evidence of overall abnormal expansion due to ASR may not be apparent in such concrete units. Do not interpret this type of cracking as confirming evidence of ASR in areas of freezing and thawing. *In these cases, however, initial cracking due to ASR may lead to faster progression of freeze-thaw damage by creating a pathway for moisture to enter into the concrete mass expanding the cracks upon freezing.*

FIG.18 - Cracking and differential movement of abutting sections of parapet wall in bridge structure affected by ASR. Joint is tightly closed and lateral offset has occurred. Cracking and spalling have developed on left side of joint, and cracking and incipient spalling have developed around embedded metal plate on right side. *Deposits that most likely include ASR reaction products are clearly visible in and around cracks.* In such cases confirmation should be made that distress has not resulted from other factors, such as foundation movements, freezing and thawing or vehicle impact. *In cases where cracking has advanced to this stage the visible damage, although initiated by ASR, is probably due to a combination of factors and the structure*

will continue to deteriorate. In addition, damage immediately attributable to ASR can continue at an expedited rate because the advanced cracking provides easy channels for greater ingress of moisture and external sources of alkali such as from deicer salts. This effect is particularly noticeable in cases where extent of reaction is limited by the amount of moisture or available alkali.

FIG.19 - Major vertical crack with less prominent horizontal and random cracks in end of parapet wall. White deposit at base is mixture of ASR gel and calcium carbonate. This evidence is typical of advanced stages of ASR. However, such deposits most commonly consist of calcium carbonate, which *by itself* is not indicative of ASR. Presence *of occurrence of ASR expansion and* of ASR gel must be confirmed in other ways.

FIG.20 - Closed joint between sections of parapet wall may have resulted from expansion due to ASR, as shown. Inspection should be made to determine if a foundation shift may have caused a tight joint. Such evidence should be used only as supporting evidence of ASR unless indicated otherwise. *Evidence of closed joints such as the one in the picture throughout the structure are usually indications that the cause is ASR rather than foundation shifts.*

FIG.21 - Horizontal cracking extending the length of the pier cap of bridge over fresh water. Such cracking is often associated with ASR but might also be due to corrosion of embedded reinforcing steel, *or a combination of the two. This area is moist and collects condensation thus insuring sufficient moisture for ASR. Initial ASR cracking allows the ingress of moisture and carbon dioxide into the concrete close to the steel, resulting in a drop in pH around the steel providing the right conditions for initiation of corrosion.* Corroborative evidence is necessary to confirm ASR as a likely cause of this type of cracking.

FIG.22 - Cracking in top cord of concrete arch bridge. White deposits of ASR gel and calcium carbonate exude from cracks. Such cracking may also develop from freezing and thawing, and the white deposits may or may not contain ASR gel. In frost-free climates, ASR is the most probable cause of the cracking but corroborating evidence should be obtained to confirm its development.

FIG.23 - Bridge column showing cracking associated with ASR. Predominant cracks are oriented longitudinally, but are connected in irregular pattern by short transverse cracks and by fine random microcracks. White deposits on column contain ASR gel. *Cracking patterns are related to the configuration of the embedded reinforcing steel.*

FIG.24 - Bridge columns showing longitudinal crack at base near sloped concrete surface of bridge embankment. This cracking could be due to ASR or, for example, to corrosion of embedded reinforcing steel. Further investigation, including microscopic examination of concrete, is necessary to confirm causes. In this case, ASR has developed in the concrete. *In these situations cracking at the base is more apparent and prevalent than in the rest of the column due to wicking of moisture from underlying soil and splashing by passing vehicles. If chloride deicers are used in the area, ASR cracking will promote ingress of chloride into the concrete and trigger corrosion of reinforcing steel.*

FIG.25 - Cracking associated with ASR in bridge column. Predominant cracks are oriented longitudinally in column, and are interconnected by short transverse and random cracks. Longitudinal cracks occasionally develop at regular spacings, possibly controlled by location of embedded vertical reinforcing steel. Drying shrinkage has probably enlarged cracks.

FIG.26 - Closeup of cracking associated with ASR in bridge column. The most prominent crack is oriented approximately longitudinally in the column and usually does not extend along the full length of column. Finer microcracks interconnect in random fashion. Drying shrinkage may have contributed to cracking shown in photo.

FIG.27 - Cracking associated with ASR in wingwall of bridge structure. Major cracks tend to show subhorizontal orientation and are more strongly developed at lower levels, *where humidity and moisture are at the highest due to wicking effects from soil and shielding from solar drying.* Cracking of this type also may result from frost action and must be corroborated with other evidence to positively assign ASR as a cause. In climates that are essentially frost-free, ASR is a probable cause.

FIG.28 - Curb section bordering approach slab to bridge structure. Curb shows distress due to ASR. Displaced wedge-shaped curb section shows uplift from original position. Longitudinal and fine random cracks are typical distress due to ASR, but uplift may have resulted from other causes, such as shifting of entire approach slab. Use such observations only as possible evidence of ASR.

4. IDENTIFICATION OF ASR GEL IN FIELD STRUCTURES

INTRODUCTION

The only indisputable evidence that ASR has developed in concrete is the presence of ASR gel reaction products. In the early stages of reactivity, or under conditions where only small quantities are produced, ASR gel is virtually undetectable by the unaided eye, and revealed only with difficulty by a skillful observer using a microscope. Thus, ASR may go unrecognized in field structures for some period of time, possibly years, before associated severe distress develops to force its recognition and structure rehabilitation. *In addition, due to the difficulties associated with interpretation of field inspections of distressed concrete, it is often misdiagnosed leading owners to implement rehabilitation strategies that are ineffective with ASR. It is therefore important to implement procedures and methodology in the field that will successfully diagnose potential ASR reactivity as soon as possible so proper rehabilitation methods can be implemented that will be successful in extending the useful life of concrete pavement and structures.*

Under the SHRP Program, the use of the uranyl (uranium) acetate fluorescence method *was* developed so that it can be utilized to monitor possible ASR prior to development of serious distress. The method, rapid and economical, is described in *Section a. below. The method can be utilized both in the laboratory and in the field using portable equipment. While the method has proven useful in screening distressed concrete for potential ASR distress, it does present a few issues in its implementation which have prevented its widespread use in field inspections. The method utilizes a chemical solution which contains a slightly radioactive uranium isotope. While* *the level of radioactivity presents minimal risk, its use is regulated by a number of agencies and care must be taken in removing all materials from the inspections that have been in contact with the uranium. Secondly, a portable UV light box must be utilized to visualize the test section after treatment with the uranyl acetate. A bushhammer fitted to an impact drill is needed to expose the surface. A vacuum is needed to collect all contaminated powder and chips. The UV light box, impact drill and vacuum used in the method require electricity, thus making it imperative to have either a source of electricity or a generator available at the site of inspection.*

More recently, due to the difficulties encountered with the uranyl acetate method, the Department of Energy (DOE) Los Alamos Laboratories have developed a method that is easier to use, only requires easy to handle non-toxic reagents, and achieves visualization of ASR gel by the naked eye, thus not requiring a special light box. This method is described in Section b. below. This method is still experimental and not yet available in the marketplace. It is presented here because results to date are very promising and it is expected the method will be marketed in the form of a test kit within the next six months. Check back with this site for further information.

a. Uranyl Acetate Procedure - (Now AASHTO T 299)

URANYL ACETATE SOLUTION

Use the following steps to prepare the uranyl acetate solution for ASR gel recognition. Be sure to wear protective eye wear (goggles or glasses) and rubber gloves while mixing the solution.

1. Prepare dilute acetic acid solution by adding 5 mL of glacial acetic acid to deionized or distilled water to make up 100 mL of solution.
2. Add 5 g of uranyl acetate powder to the dilute acetic acid solution. Warm, but do not boil, to dissolve the powder.
3. Store in closed plastic bottles. Reagent solution has shelf life of a year or more.

PROCEDURE

This procedure can be used on any concrete surface to identify ASR gel. However, experience has shown that formed or sawed surfaces that have been exposed for years are not always satisfactory. Thus, it is best to use surfaces that are newly formed, such as fresh fractures, cores, and ground or sawed surfaces. *In the field this can be accomplished by the use of a bushhammer, or by coring and fracturing a core.* Thereafter, proceed with the following steps.

Step 1

Prepare surface to be examined as follows :

1. Old Formed, finished, or wearing surface : Use grinding wheel on electric drill or other means, *such as a bush hammer*, to grind off up to ¼ inch of concrete. Rinse with tap water.

2. Fractured surface : Break off piece from concrete structure or fragment and rinse freshly fractured surface with tap water.

3. New concrete core : Rinse off cylindrical surfaces after core retrieval. If core has been

dried, rewet and wash with tap water, if necessary, to remove solids from coring slurry.

Step 2

Put on protective eyewear (goggles or glasses) and rubber gloves. Apply uranyl acetate solution from plastic squeeze bottle or sprayer. Only a momentary application of solution film is necessary to adequately wet the surface with solution.

Step 3

Allow solution to react for 3 to 5 minutes with any ASR gel that might be present on the surface. Then rinse surface with water. Remove protective eyewear (chemical goggles or glasses) and gloves.

Step 4

Put on UV absorbing protective eyewear. View the concrete surface using UV light in a darkened room or, when in the field, through viewing openings in a box that prevents light from reflecting on the concrete surface.

NOTE :

1. Once treated, the surface can be viewed at later ages without further solution application. However, it is advisable to first rewet the surface with water.
2. *All liquids, powders and surfaces exposed to uranyl acetate, including any clothes that may have come in contact with the material, should be collected and disposed of properly according to federal and local rules and regulations.*

The pictures below demonstrate how the method is applied in the field for ASR screening. Note methods used to insure that any material that comes in contact with uranyl acetate is collected for proper disposal.

FIG. 29 - Impact drill, UV-light viewing box, and vacuum used in preparing and removing test surfaces. Drill is fitted with bushhammer.

FIG. 30 - Bushhammered surface rinsed and ready for uranyl acetate application.

FIG. 31 - Drops of uranyl acetate solution being applied to vertical surface using plastic squeeze bottle. Note cloth held against concrete bushhammered surface to absorb excess solution.

FIG. 32 - Bushhammering treated surface to remove uranyl acetate contaminated layer. Note hose attachment to vacuum to collect powder and chips generated by bushhammering.

INTERPRETATION

The presence of ASR gel will be revealed in UV light by a yellowish-green fluorescent glow. Deposits will be localized in cracks, air voids, certain aggregate particles and, in severe cases, as broad films in aggregate particles and fractured surfaces. Such films on sawed and cored surfaces may reflect smearing during surface sawing or coring. Fractured surfaces eliminate this effect and most clearly reveal undisturbed ASR gel deposits. *This smearing is not likely in a* *bushhammered surface.*

Figures 33 through 36 illustrate typical occurrences of ASR gel as seen in ordinary and UV light. Interpretations are offered of representative occurrences of gel in distressed concrete.

FIG.33 - Fractured surface of concrete pavement core showing location of reactive granite gneiss particles (arrows), as photographed in ordinary light. There is no positive indication of ASR gel on this surface in ordinary light.

FIG.34 - Same fractured surface shown in Fig. 33 after uranyl acetate treatment. Green and bright yellow areas display ASR gel. Note band of ASR gel along periphery of granite gneiss particle (arrow) while interior of particle is free of reaction product. Film of ASR gel has spread over about one-half of surface shown.

FIG.35 - Badly cracked coarse aggregate and concrete from pavement showing severe cracking similar to that illustrated in Figs. 4 and 5. Cracking at pavement wearing surface was typical of that associated with ASR.

FIG.36 - Same field of view as shown in Fig. 35 but photographed in UV light after treating with uranyl acetate solution. Brown fractured coarse aggregate particle to left displays peripheral green film of ASR gel. Microcracks between triangular coarse aggregate particle to right and brown particle with peripheral band contain light greenish-yellow deposit of ASR gel. Crack with ASR gel extends above brown particle and along periphery of triangular particle. Development of ASR is confirmed by these observations.

PRECAUTIONS

The following precautions must be taken when conducting the UV light examination for ASR gel.

1. WEAR UV LIGHT-ABSORBING PROTECTIVE GLASSES WHENEVER THE UV LAMP IS IN OPERATION. UV RADIATION WILL DAMAGE SIGHT IF POINTED FROM ANY ANGLE AT THE EYES. A protective glass is built into the field UV-light box.

2. Wear rubberized, waterproof lightweight gloves when handling uranyl acetate solution and concrete to which the solution has been applied. The uranyl (uranium) acetate is radioactive but emits only alpha radiation. Even though only dilute solutions are used, gloves must be worn for safety purposes and to avoid yellow discoloration of the skin.

3. Do not allow the uranyl acetate solution to come in contact with the skin and particularly the eyes. Wear chemical goggles or glasses when working with the solution.

4. Check with your state and local authorities regarding use of uranyl acetate in the laboratory and the field prior to implementation of test procedure and follow all existing rules and regulations.

5. Obtain MSDS for uranyl acetate and study carefully prior to use. Follow all recommended precautions. See health hazard information for further guidance.

HEALTH HAZARD INFORMATION

INHALATION :

Soluble uranium salts are moderately hazardous on inhalation. Coughing, sneezing and breathing difficulty may be expected and damage to kidneys and liver may occur after continued exposure.

INGESTION :

The toxicity rating is not high (slight to moderate) due to the low absorption rate of soluble uranium compounds. Solubility may be increased when material is dissolved in acetatic acid solution. However, gastrointestinal discomfort with vomiting and diarrhea may follow sizeable ingestions. Kidneys and liver may be damaged as well.

SKIN CONTACT :

Mild irritation, reddening and possible soreness may be experienced in cases of prolonged exposure to moist skin.

EYE CONTACT :

Absorption of soluble uranium compounds through eye tissues is reported. No specific symptoms of eye irritation by uranyl acetate have been found although the reddening and pain due to chemical substances can probably be expected. Reddening and burning may be increased when material is dissolved in acetatic acid solution.

CHRONIC EXPOSURE :

Principal hazards are kidneys and liver damage resulting from prolonged contact and absorption. Radioactivity induced tumors or malignancies are also possible.

AGGRAVATION OF PRE-EXISTING CONDITIONS :

Persons with pre-existing skin disorders or eye problems or impaired liver or kidney function may be more susceptible to the effects of the substance.

FIRST AID

INHALATION :

Remove to fresh air. Get medical attention for any breathing difficulty.

INGESTION :

If swallowed, induce vomiting immediately by giving two glasses of water, or milk if available, and sticking finger down throat. Call a physician immediately. Never give anything by mouth to an unconscious person.

SKIN EXPOSURE :

Remove any contaminated clothing. Wash skin with soap or mild detergent and water for at least 15 minutes. Get medical attention if irritation develops or persists.

EYE EXPOSURE :

Wash eyes with plenty of water for at least 15 minutes, lifting lower and upper eyelids occasionally. Get medical attention immediately.

APPENDIX F

ASR GUIDE SPECIFICATION

ASR GUIDE SPECIFICATION

Proposed AASHTO Guide Specification For Highway Construction, 1998
Developed and Submitted by the AASHTO Lead State Team on ASR

SECTION 56X
Portland Cement Concrete Resistant to Excessive Expansion Caused by Alkali-Silica Reaction

56X.01 Description. Provide a portland cement concrete (PCC) that is resistant to excessive expansion caused by alkali-silica reactivity (ASR) (hereafter designated as "deleterious ASR"). Use PCC resistant to deleterious ASR also in all concrete designated as High Performance Concrete, and all PCC that will be exposed to moisture in service.

56X.02 Material.

Portland cement	701.01	AASHTO M 85
Blended hydraulic cement	701.01	ASTM C 1157
Fine aggregate	703.01	AASHTO M 6
Coarse aggregate	703.01	AASHTO M 80
Air entraining admixture	703.02	AASHTO M 154
Chemical admixture	713.03	AASHTO M 194
Lithium admixture	713.04	
Water	714.01	AASHTO M 157
Fly ash	714.11	AASHTO M 295
Ground Granulated Blast Furnace Slag (GGBFS) Grade 100 and 120	714.12	AASHTO M 302
Silica fume	714.13	AASHTO M 307

56X.03 Requirements.

Proportion PCC mixes under Section 808 of this Guide or AASHTO M 157 to include materials that meet either Subsection A or B below. Provide certified material test reports from AASHTO Accredited laboratories that show the cementitious materials source, composition, and alkali contents.

A. Aggregates.

Assess the potential for deleterious reactivity of the aggregate by evaluation of field performance using the criteria of Table 56X-1(A), or by laboratory evaluation using at least one of the procedures in Table 56X-1(B). Aggregates meeting the criteria for nonreactivity are allowed to be used without restriction. Aggregates not meeting the criteria for nonreactivity shall only be used with cementitious materials meeting the requirements of Subsection B.

Use field performance when available to identify nonreactivity of aggregates. Perform laboratory tests on the aggregates for added confirmation, or when the field performance is unavailable.

Include field performance information using ASTM C 856 from at least 5 structures that have been in service for a minimum of 10 years, including structures that have used cathodic protection. Use caution in concluding that aggregates are nonreactive when using information from structures in service for less than 20 years. Select structures that were built with similar cement factors, water cement ratios, and cement alkali contents to those proposed for use in the mix design, and which were exposed to environments similar to those in which the proposed structure will be built.

B. Deleterious ASR Prevention Criteria.

Select a material or a combination of materials that meet the criteria shown in Table 56X-2.

Demonstrate under the method options below that the proposed mixture is effective in preventing deleterious ASR. Use the materials proposed for the project. Use the same proportion of cement and mineral admixture for each *test mixture* as that proposed for the *actual mix* design. Provide to the Agency certified documentation of the mixture's effectiveness to prevent deleterious ASR.

Method 1. ASTM C 441 Mixture Effectiveness.

Determine the selected mixture's effectiveness to prevent deleterious ASR using ASTM C 441, or as modified below. Ensure the total equivalent alkali level of the *test mixture* is within 0.05 percent of the actual mix.

Assume a *test mixture* to be effective under any of one of the following ASTM C 441 modifications when its linear expansion:

a. (generally for all cementitious mixes) does not exceed at 56 days:
   (1) 0.10 percent when the AASHTO T 303 test result for any aggregate to be used with the *test mixture* is more than 0.50 percent, and
   (2) 0.15 percent when the AASHTO T 303 test result for all aggregate to be used with the *test mixture* is less than 0.50 percent, or

b. (generally for fly ash, GGBFS, and silica fume mixes) is less than or equal to the expansion of a comparison *control mixture* prepared with cement of alkali between 0.40 and 0.60 percent, or

c. (generally for low alkali cement mixes) achieves at 14 days a 55 percent minimum reduction in expansion with the selected *test mixture* as compared to the *control mixture* using a cement with an alkali content of 1.00 percent plus or minus 0.05 percent.

Method 2. AASHTO T 303 Mixture Effectiveness.

Determine the selected mix proportion's effectiveness to prevent deleterious ASR using AASHTO T 303.

Assume a *test mixture* to be effective when its linear expansion at 14 days is less than or equal to 0.08 percent for metamorphic aggregates, and 0.10 percent for all other aggregates.

Method 3. ASTM C 1293 Mixture Effectiveness.

Determine the selected mix proportion's effectiveness to control ASR using ASTM C 1293.

Add NaOH to the mix water to raise the sodium equivalent (Na_2Oeq) to 1.25 percent by mass of cementitious material as described by ASTM C 1293. When cement portions are replaced with pozzolans or GGBFS, add NaOH to raise the Na_2Oeq using just the cement portion of the cementitious material.[1]

(1)Based on the practice recommended in *Canadian Standards Association A23.1-94, Concrete Materials and Methods of Concrete Construction, Appendix B, Section 5.3, Supplementary Cementing Materials.* See note at the end of this document for instructions on where to obtain a copy of CSA A23.1-94.

Assume a *test mixture* to be effective when its expansion does not exceed 0.04% linear expansion at two years.

Table 56X-1: Nonreactive Aggregate Tests and Properties

A. Tests Performed on Existing Structures Incorporating the Proposed Aggregates		
Procedure	Description	Limits
Visual examination of structure(1)	SHRP-C-315, Handbook for Identification of ASR	Lack of observable map cracking
AASHTO T 299(1) Rapid Identification of Alkali Silica Reaction Products in Concrete	UV light kit / uranyl acetate procedure	Lack of bright yellowish-green fluorescent glow in and around aggregate particles, air voids, and cracks under ultraviolet light. See SHRP-C-315.
ASTM C 856 Petrographic Examination of Hardened Concrete	Petrographic analysis of cores	Petrographer's report stating that concrete shows no signs of deleterious ASR
B. Tests and Criteria for Proposed Aggregates		
Procedure	Description	Limits
AASHTO T 303(2) Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction	Mean mortar bar expansion at 14 days	0.08% (max) metamorphic aggregates 0.10% (max) all other aggregates
	Perform a polynomial fit(3) of data at 3, 7, 11, and 14 days to determine reliability of results	Repeat the AASHTO T 303 if r^2 is less than 0.95.
ASTM C 1293 Concrete Aggregates by Determination of Length Change of Concrete Due to Alkali-Silica Reaction	Mean concrete prism expansion at 1 year	0.04% (max)(4)
ASTM C 295(5) Petrographic Examination of Aggregates for Concrete	Optically strained, microfractured, or microcrystalline quartz	5.0% (max)(6)
	Chert or chalcedony	3.0% (max)(6)
	Tridymite or cristobolite	1.0% (max)(6)

	Opal	0.5% (max)(6)
	Natural volcanic glass	3.0% (max)(6)

(1) Use ASTM C 856 as a verification check to either the visual examination or the AASHTO T 299 result.
(2) In rare occasions, some aggregates known to be reactive in the field may give a false negative in this test, in that the expansion at 14 days may be below the limit that defines the aggregate as reactive. This is usually because the amount of reactive constituent in the aggregate is partially removed by the preparation of the aggregate for the test. As an extra measure, ASTM C 295 may be used to guard against this possibility.
(3) Use a second order polynomial of $\%Exp = A_0 + A_1 SQRT(t) + A_2 t$. See Johnston, D. *Alkali Silica Reactivity of Fine Aggregates in South Dakota.* South Dakota DOT, Office of Research, Pierre, South Dakota, 1994. Study SD92-04-F.
(4) In some instances, fine aggregates from the upper Midwest which appear to be reactive based on service history do not develop more than 0.04% expansion in the ASTM C 1293 prisms at one year. The prisms made with these fine aggregates, however, develop extensive crack networks on the surface of the prisms, as well as severe popouts from the prism surfaces. ASTM C 1293 prisms that exhibit such damage, but do not develop expansion greater than 0.04% at one year, shall be examined for signs of deleterious ASR development using ASTM C 856.
(5) Use ASTM C 295 as a verification check to either AASHTO T 303 or ASTM C 1293.
(6) Based on the total aggregate sample.

Table 56X-2: Prevention Methods for Deleterious ASR in New Concrete

A. Cement Methods		
Material	Cementitious Material Percentage	Effectiveness Check(1)
Low alkali cement	100%	Method 1
Blended cement	100%	Meets requirements for Option R, ASTM C 1157, or Method 1, 2, or 3
B. Mineral Admixture Methods		
Material	Cementitious Material Percentage(2)	Effectiveness Check(1)
Fly ash - Class F	15% (min)	Method 1, 2, or 3
Fly ash - Class C	30% (min)	Method 1, 2, or 3
Class N pozzolan	not specified	Method 1, 2, or 3
GGBFS	25% (min)	Method 1, 2, or 3
Silica fume	5% (min)	Method 1, 2, or 3
C. Chemical Admixture Methods		
Material	Addition Rate	Effectiveness Check(1)
$LiNO_3$ Lithium Nitrate	Use 4.6 liters or 5.5 kilograms (min)(3) of $LiNO_3$ per kilogram of Na_2Oeq.(4) Deduct from the mix water an equivalent volume of 85% of the $LiNO_3$ solution.	Method 1 or 3

Li_2CO_3 Lithium Carbonate	Use 0.9 kilograms (min)(3) of Li_2CO_3 per kilogram of Na_2Oeq.(4)	
$LiOH \cdot H_2O$ Lithium Hydroxide Monohydrate	Use 1.0 kilograms (min)(3) of $LiOH \cdot H_2O$ per kilogram of Na_2Oeq.(4)	
LiOH Lithium Hydroxide	Use 6.0 liters or 6.6 kilograms (min)(3) of LiOH per kilogram of Na_2Oeq.(4)	
	Deduct from the mix water an equivalent volume of 100% of the LiOH solution.	

(1) See Section 56X.03.B for Methods 1, 2, and 3.
(2) Measure this minimum content of cementitious material as percent by mass of cement plus mineral admixture. Waive this minimum when used in combination with other mineral admixtures, or lithium admixtures.
(3) Vary the dosage to obtain the optimum effectiveness, and waive this minimum when used in combination with mineral admixtures. Report the final dosage as a percentage of the standard dosage.
(4) Taken from the cement mill run certificate.

56X.04 Measurement.

A. Measure under Subsection 109.01 and as follows:

B. Include all material tests and effectiveness evaluations in the unit of measure.

56X.05 Payment.

Pay Item	Pay Unit
Concrete resistant to deleterious ASR	Cubic meter

Note:
This *Guide Specification for PCC Resistant to Excessive Expansion Caused by Alkali-Silica Reaction*, developed by the **AASHTO Lead State Team on ASR** over a period from November 1997 through March 1998, is in the form submitted to the AASHTO Subcommittees on Construction and Materials. The ASR Lead State Team has requested that AASHTO consider this for publication in the next edition of the *AASHTO Guide Specifications for Highway Construction*. A copy of this specification is available for download from the ASR Lead State Team's Internet web home page which can be accessed through the following URL: http://leadstates.tamu.edu/asr .

The CSA Standard A23.1-94, ***Concrete Materials and Methods of Concrete Construction,*** can be obtained from the Canadian Standards Association, 178 Rexdale, Toronto, Ontario, Canada, M9W 1R3. It can also be obtained from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112-5704 (Ph.: 1-800-854-7179; e-mail: global@ihs.com). Both organizations charge a fee for documents.

SHRP publications can be obtained from the FHWA Report Center:

FHWA Report Center
9701 Philadelphia Court, Unit Q
Lanham, MD
Phone: 301-577-0818, Fax: 301-577-1421

The ASR Lead State Team encourages highway and public works agencies to address alkali-silica reactivity in their standards by adopting measures to avoid deleterious ASR with their locally available materials. Technical assistance and advice on incorporating this specification, or on other ASR issues are freely available from each of the AASHTO ASR Lead State Team members listed below.

Joe Barela, New Mexico SH&TD, 505-827-5567, joe.barela@nmshtd.state.nm.us
Moy Biswas, North Carolina DOT, 919-715-2465, biswas@tpswp01.dot.state.nc.us
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John Dewar, FHWA Region 1, 518-431-4224 ext260, john.dewar@fhwa.dot.gov
David Gress, University of New Hampshire, 603-862-1410, dlgress@christa.unh.edu
George Guthrie, Los Alamos National Laboratory, 505-665-6340, guthrie@lanl.gov
Dan Johnston, South Dakota DOT, 605-773-5030, danj@dot.state.sd.us
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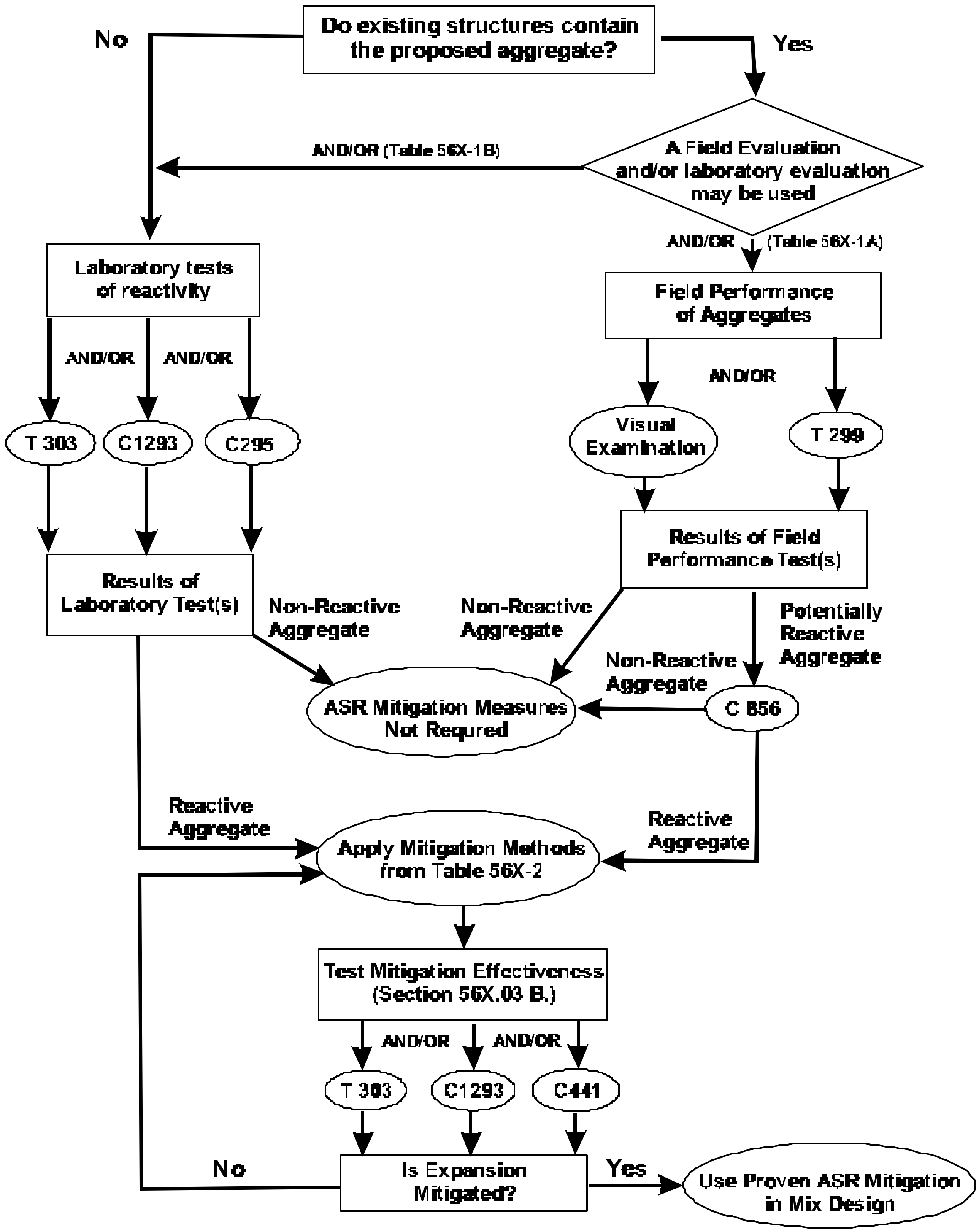
Jean-Claude Roumain, Holnam Inc., 303-984-6000, jcroumai@holnam.com
Roger Surdahl, FHWA CFLHD, 303-716-2158, roger.surdahl@fhwa.dot.gov
Margaret Thomson, Pennsylvania DOT, 717-787-1931, margaret_thomson@hotmail.com
Kenneth Wylie, Western Mobile, 505-343-7883, kwylie@lafargeus.com

Flow Chart for Portland Cement Concrete Resistant to Deleterious ASR



SECTION 713. Concrete Curing Materials and Admixtures

713.04 Lithium Admixtures. The lithium ion, Li^+, in several forms is capable of suppressing deleterious ASR, but different compounds have varying effects on the plastic and hardened properties of concrete. $LiNO_3$ (lithium nitrate) is safe to handle, and has the least effect on concrete properties, while it has the greatest effect in concrete to prevent deleterious ASR. $LiNO_3$ also does not generate hydroxide ions in concrete pore solutions, and therefore does not exhibit a pessimum effect. LiOH (lithium hydroxide) on the other hand is caustic, is a hazardous material, and both LiOH and Li_2CO_3 (lithium carbonate) exhibit a pessimum effect on deleterious ASR prevention. Lithium salts other than $LiNO_3$ can still be useful depending on the intended application. Test all mixtures under AASHTO M 194 to determine the admixture's affect on the plastic and final hardened concrete properties. Suppress deleterious ASR in concrete using primarily a lithium admixture of a nominal 30 percent by mass aqueous solution of $LiNO_3$ with a density of 1.2 kilogram per liter, or use other forms as shown below.

$LiNO_3$ aqueous admixture:

Constituent	Limit (percent by mass)
$LiNO_3$ (lithium nitrate)	30% ± 0.5%
SO_4^{-2} (sulfate ion)	0.1% max
Cl^- (chloride ion)	0.2% max
Na^+ (sodium ion)	0.1% max
K^+ (potassium ion)	0.1% max

Li_2CO_3 solid admixture:

Constituent	Limit (percent by mass)
Li_2CO_3 (lithium carbonate)	99% min
SO_4^{-2}(sulfate ion)	0.4% max
Cl^- (chloride ion)	0.1% max
Na^+ (sodium ion)	0.2% max
K^+ (potassium ion)	0.1% max

$LiOH \cdot H_2O$ solid admixture:

Constituent	Limit (percent by mass)
LiOH (lithium hydroxide)	55.9% min
SO_4^{-2}(sulfate ion)	0.4% max
Cl^- (chloride ion)	0.1% max
Na^+ (sodium ion)	0.2% max
K^+ (potassium ion)	0.1% max

LiOH aqueous admixture:

Constituent	Limit (percent by mass)
LiOH (lithium hydroxide)	8.75% ± 0.25% min
SO_4^{-2}(sulfate ion)	0.4% max
Cl^- (chloride ion)	0.1% max
Na^+ (sodium ion)	0.2% max
K^+ (potassium ion)	0.1% max

SECTION 714. Miscellaneous

714.13 Silica Fume for Use in Concrete and Mortar. AASHTO M 307.

APPENDIX G

FHWA- ACI Concrete Durability Workshops Project
ASR and Other Deterioration Mechanisms

FHWA- ACI Concrete Durability Workshops Project
ASR and Other Deterioration Mechanisms

Program Blocks

Instructors: E – Engineer / Materials Technologist, Concrete Materials and Mixture Experience
P – Petrographer / Geologist, Experience Investigating ASR and Other Deterioration
L – Local / Regional Expert on Deterioration Mechanisms in the Area

Texts Listed by T-#:

1. T-1 -- Notebook Binder Updated for AAR and Other Deterioration Mechanisms
    1. Table of Contents
    2. Syllabus
    3. Print-out of PowerPoint slides and notes (3 to a page)
    4. Copies of Standards That Will Be Referenced in the Workshop (Other than the ones included in separate texts.)
    5. Other miscellaneous required references, worksheets, or updates to publications that need to be Xeroxed, such as alternative specifications: VA, NM, CSA, C 33 Appx.

2. T-2 -- ***Handbook for the Identification of Alkali-Silica Reactivity in Highway Structures***. Publication SHRP-C-315, 1991, Reprinted 1994 by FHWA, and currently for sale by TRB. It is proposed that this handbook be used as now published with reference to the Addendum providing additional text information as given in the Revised Edition on the web site of the AASHTO Lead States Team on ASR. See T-9 below.

3. T-3 -- Manual on ***Rock and Mineral Identification for Engineers***, 1991, FHWA Publication No. FHWA-HI-91-025

4. T-4 --ACI 221.1R-98, ***State of the Art Report on Alkali-Aggregate Reactivity***, Reported by ACI Committee 221 on Aggregates, American Concrete Institute, 1998, 31 pages.

5. T-5 -- ACI 201.2R-92 ***Guide to Durable Concrete***, Reported by ACI Committee 201 on Durability, American Concrete Institute, 1992, 39 pages. (T-5a -- revision to provide updated sections on Chemical Sulfate Attack and on Physical Salt Attack in final review stages by ACI.)

6. T-6 -- Concrete Information on ***Diagnosis and Control of Alkali-Aggregate Reactions in Concrete***, by James A. Farny and Steven H. Kosmatka, PCA, with the Endorsement by ACPA, NAA, and NRMCA, Portland Cement Association, Publication IS 413.01T, 1997, 24 pages.

7. T-7 -- Concrete Information -- ***Guide Specification for Concrete Subject to Alkali-Silica Reactions***, Published by PCA with the Endorsement by ACPA, Developed by the Durability Subcommittee, Portland Cement Association, Publication IS 415.06T, 1998, 8 pages.

8. T-8 -- American Coal Ash Association, ***Fly Ash Facts for Highway Engineers***, Federal Highway Administration, FHWA SA-94-081, 1995, 70 pages

9. T-9 -- AASHTO Lead States Team on ASR, ***Proposed AASHTO Guide Specification for Highway Construction, Section on Portland Cement Concrete Resistant to Excessive Expansion Caused by Alkali-Silica Reaction***, FHWA *Focus*, October, 1999, and the Web Site '*leadstates.tamu.edu/ASR/library/gspec.stm*', at Texas A&M University, October, 1999.

10. T-10 -- TRB Circular 494, ***Durability of Concrete***, Transportation Research Board, Section on Concrete (A2E00), December 1999, 60 pages.

Workshop Schedule -- Day 1

Introduction (30 min.)

Objective: Provide background, scope, and purpose for the workshop

- Host DOT Welcome, Instructors
  Workshop Schedule, Notebook Binder, and Nine Additional Texts (Listed Above)

- FHWI-ACI Cooperative Agreement – DOT, FHWA, ACI
  Communicate the Technology for More Durable Concrete

- Damage, Money Loss Caused by Premature Deterioration, Life Cycle Costs, E
  Cost/Benefit, Asset Management

- Include All Segments of the Highway Construction Industry in Workshop, E
  DOT's, Local Agencies, Material Suppliers, Contractors, Laboratories

- Two Tracks – Brief Review of Covered Topics and Methods to Identify, Mitigate, and Prevent AAR and Other Deterioration Mechanisms

  (1) AAR is Alkali Aggregate Reactivity. It includes
  ASR, Alkali Silica Reactivity which is more common, and
  ACR, Alkali Carbonate Reactivity that is rare, confined to a few areas

  (2) Other Durability Concerns that Influence Material Selection and Proportioning
  Freezing and Thawing, Deicer Scaling, Sulfate Attack (Internal, External), Physical Salt Attack, Corrosion of Steel in Concrete, and the magnitude of Volume Changes – Drying Shrinkage and Thermal Expansion.

- Historical Perspective of ASR and the SHRP Research Accomplished

Executive Summary (60 min.)

Objective: Provide for top people a summary of the state-of-the-art technology reviewed in the workshop and resources available to help owners, specifiers, laboratories, and consultants reevaluate and update the methods they use to investigate concrete deterioration and to specify durability and assure service in future construction and repairs.

Texts – T-1, T-2, T-5, T-6, T-9, T-10

- Framework to Identify Existing Concrete Deterioration Mechanisms, E

  Consider Pavements and Structures -- Bridge Decks, including Walls, Columns.
  Use Observation, Date Records, and Petrography to Identify Mechanism(s)
  Find Out What the Problem is Not, and What it Might be.
  Were the Specifications Wrong for the Application and Exposure, Or
  Were the Specifications not Followed?

- Design for Durability, Assessment of Risks, E

  Do not just use a fixed cement content or just more cement.
  Use properly other cementitious materials, blended cement, and admixtures.
  Consider Exposure for the concrete as well as Construction Methods and Structural needs.

  Do not use the terms 'cement replacement' for other cementitious materials, blended cement, and admixtures

  Install a Quality Concrete System to address durability improvements of both ordinary and HPC – Learn what is needed for durable concrete in the various exposure conditions unique to areas in your state.

  TG B on Durability of ACI TAC HPC (Steve Forster, Chair)
  - Definition of HPC
  - Categories of HPC

- Mitigation, E The best mitigation is applied during design and construction.

  But there are some things that can be done to slow deterioration once it has begun.

- Description of ASR and the Conditions Under Which it Can Shorten Service Life, P

- Samples of the Use of Petrographic Tools to Identify ASR, and to Distinguish it from Other Deterioration Mechanisms, P

- Alternatives to Provide the Necessary Professional, Laboratory, and Petrographic Resources to Properly Address PC Concrete Durability Issues, P

- Communication for Durability through Specifications and Inspection

Deterioration Mechanisms (120 min.)

Objective: Provide instruction and resources for the understanding of how these forms of deterioration develop, and how they damage concrete, and how they can be identified with certainty. (Particular emphasis in this session on ASR and ACR. Also the brief introduction of the other mechanisms that will be covered later.)

- ASR –Explanation of Alkali-Silica Reaction in Concrete and its Identification (60 min.), P

  Texts – T-1, T-2, T-4, T-6

- ACR – Explanation of Alkali-Carbonate Reaction in Concrete and its Identification as Distinguished from ASR. (Since ACR will not be given much additional time in the workshop, mitigation and prevention of ACR should also be covered here.) (30 min.), P

  Texts – T-1, T-4

- Introduce Others Mechanisms Briefly, Along with the Inter-Relationship of Mechanisms Often Found in Deteriorating Concrete – (30 min.), E

  Texts – T-1, T-5, T-5a, T-10

  Freezing and Thawing,

  Chemical Sulfate Attack,

  Physical Salt Attack (Various Soluble Salts, Including Sulfates),

  Delayed Ettringite Formation (DEF),

  Corrosion of Rebar, Material from ACI 222

  Drying Shrinkage, Ref?

  Thermal Volume Change, Ref?

Petrography (30 min.), P

Objective: Provide a basic introduction to petrography and its use in improving the durability of concrete and aggregates. Show how the geologist and petrographer can work with highway engineers and technologists to understand mechanisms of deterioration exhibited in the field and to formulate improved specifications and qualification criteria for aggregates and mixtures.

Texts – T-1, T-2, T-3, T-6, T-10

- Importance of Petrography

- Introduction to Petrography Standards and Equipment

  ASTM Practices in Binder

- Example Case Study Showing the Progression of Field and Laboratory Techniques
  See list of potential case studies in the agenda.

- Review of Tools – Stereomicroscope, Petrographic Microscope, and Electron Microscope
  Petrographic Manual on-line at TF FHWA Lab (TFHRC)

Lunch Break

Rocks and Minerals Hands-on Exercise (30 min.), P

Objective: To reinforce among highway engineers and technologists that these resources are available. Also, they should learn the basics of geology and remember to call upon professionals in these areas when they see deterioration of concrete in the field, or when new, untried aggregates are to be used in a project.

Texts – T-1, T-2, T-3, ASTM Practices

- Exercise to Identify Some Rock and Mineral Samples Using Published Resources, With Concentration on Those Involved in ASR.

- Resources on the Web:

  USGS

  Minerals Data Base Sites

  NIST

  FHWA, Petrography Manual

Identification of Cause of Deterioration – Tools, Indicators (30 min.)

Objective: Use of a check list or decision tree approach to investigate deteriorated concrete both in the field and in the laboratory to identify the cause, or causes of deterioration, with particular emphasis on ASR and how combinations of other mechanisms may interact.

Texts – T-1, T-2, T-3, ASTM Practices

- Cracks, and Crack Patterns, Measuring and Monitoring Cracks, E

  Distinguish between large scale cracking (shrinkage and thermal) indicating movement of blocks of concrete and smaller scale cracking indicating internal deterioration and internal volume change.

- Volume Change Patterns, Monitoring Volume Change with Time, E

- Spalls, Surface Scaling, Pop-Outs, E

- Sampling Techniques for Observation and Petrographic Evaluation, E and P

- Deposits, Exudations, P

Is there a decision tree, flow chart we can use? Or do we need to construct one?

Reference to SHRP-P-338 Distress Identification Manual for the LTPP Project (Pavement)

See Chris Rogers Ontario MOT Form for "Petrographic Examination of Hardened Concrete"

Internal Distress Mechanisms -- Freeze-Thaw, Sulfate Attack, DEF, and Corrosion of Rebar (120 min.)

Objective: To cover the technology for identification, mitigation, and prevention of these non-AAR deterioration mechanisms. Typical test methods, specification provisions, and aggregate and concrete properties will be addressed.

Texts – T-1, T-5, T-5a, T-10

- Freezing-Thawing –
  (1) Coarse Aggregate, D-cracking;
  (2) Mortar, A/E, and Paste (60 min.), E

- Deicer Scaling

- Corrosion of Rebar (20 min.), E

- Chemical Sulfate Attack (20 min.), P

- DEF (20 min.), P

Regional/Local Issues (60 min.), L

Objective: To have a local expert or researchers review the types of durability issues and failures that have occurred in local and/or regional concrete pavements and structures. It is important to have as complete information as possible as to field case studies, along with laboratory and petrographic data to show the applicability of durability considerations in the region. Methods of identification, mitigation, and prevention should be addressed. (Preferably a PowerPoint Presentation that can be loaded on the computer used for the workshop.)

- Types of Deterioration

- Samples and Pictures

- Methods of Identification, Mitigation, and Prevention Used

- Case Studies

- Recommendations

End of Day 1 -- --

FHWA- ACI Concrete Durability Workshops Project
ASR and Other Deterioration Mechanisms

Workshop -- Day 2

Other Mechanisms – Drying Shrinkage, Thermal Volume Change, Physical Salt Attack (90 min.)
Objective: To cover the technology for identification, mitigation, and prevention of these mechanisms as a cause of deterioration. Typical test methods, specification provisions, and aggregate and concrete properties will be addressed.
Texts – T-1, T-5, T-5a, T-10

- Drying Shrinkage (30 min.), Additional references?
- Thermal Volume Change (30 min.), Additional references?
- Physical Salt Attack (30 min.), Recent ACI literature

Designing and Specifying Durable Concrete (90 min.), E
Objective: Alternative approaches to give durability considerations a high priority in the design, specification, construction, and maintenance of concrete pavements and structures. Balancing strength requirements with durability and permeability requirements.
Texts – T-1, T-4, T-4, T-7, T-8, T-9, T-10 and other specification options for ASR.

- Design for Durability (30 min.)
- Assessment of Risks (30 min.)
- What cementitious Materials are Economically Available in Your Area.
- Decision Tree for Performance Concrete (30 min.)
  We have one for ASR from the Lead States and other publications.
  Are there others that include the other mechanisms?

Aggregate Source Evaluation and Qualification (60 min.), P
Objective: To review the alternatives to qualify aggregates for different types of highway and transportation construction – both for new or changed aggregate resources with no service record, and for existing sources where detailed field service evaluations can be a valuable tool in the improvement of concrete durability.

- Evaluation of New Aggregate Resources (20 min.)

- Service Record of Existing Aggregates and Mixtures (20 min.)

- Special Aggregate Tests that are Useful for Different Climate Areas.

Lunch Break

Samples of Various Deterioration, Hands-on Exercise (30 min.), P

Objective: To reinforce among highway engineers and technologists the importance of detailed examination of suspected cases of deterioration in the field. The objective is to gather credible information about the mechanisms involved so that the durability of future construction can be improved. Also, in some cases mitigation measures can be applied to existing concrete.

- Exercise to Look at Hand Samples, and Sides from Microscopy Used in Investigations.
  Slides on Computer or Web for Viewing?

- Uranyl Acetate-UV light AASHTO T 299 Method to Identify Possible ASR Gel
  Have a few Pre-Treated Specimens for Observation with the UV Light

- Will it be Useful to Have a Microscope in the Back of the Room with Samples of ASR, ACR, and Freeze-Thaw Deterioration?

- Include an Exercise with the ASR Detect ™ system developed at Los Alamos.

Methods for Mitigation of ASR (60 min.), E

Objective: To review the proven and experimental methods that can be used to reduce or eliminate the incidence of deleterious ASR in concrete used in highway and transportation concrete.

Reference ASR Texts and Recent Research

- In Existing Concrete, To Slow the Deterioration (15 min.)
  Dry the Concrete, Apply Lithium, Confine the Concrete (Post-Tension?)

- The Use of Lithium Products (15 min.)

- In New Concrete, To Insure Against Damage (15 min.)

- The Use of Blends with Fly Ash, Ground Slag, Silica Fume, and Other Products (15 min.)

Specifications, Tests, and Laboratory Evaluation Techniques (120 min.)

Objective: To review the test methods and specifications that are now on the books, or have been proposed for use by agencies and specifiers to assure durable concrete construction.

- Specification Options – AASHTO, CSA, ASTM (30 min.), E
- Tests of Aggregates (30 min.), P
- Test of Mixtures (30 min.), E
- Inspection Methods and Management of Pavement and Structures (30 min.), E
- Communication for Durability

Summation and Question Period (30 min.), E, P, and L

- Suggestions for the Application of the Technology Covered in the Workshop
- Questions and Comments from Participants
- Evaluation of the Workshop, Suggestions for Future Workshops

End of Workshop ---

Alkali-Silica Reactivity (ASR) and Other Durability Standards for Concrete

Compiled By, Richard C. Meininger

ASTM, the American Society for Testing and Materials, is recognized worldwide as a nonprofit standardization organization that includes representatives of users, producers, and general interest groups. The organization's purpose is the development of voluntary consensus standards for materials, products, systems, and services. ASTM develops both standard specifications and standard methods of test. ASTM also develops many other standard practices and nomenclature documents.

AASHTO, the American Association of State Highway and Transportation Officials, is a similar group representing highway or transportation departments from each of the 50 States, the District of Columbia, Puerto Rico, several Canadian provinces, various U. S. territories; the U. S. Department of Transportation; and various commissions and authorities. AASHTO develops both specifications and test methods, many of which are similar to ASTM standards. Specification limits and test procedures generally allow agencies to use limits and test options that are based on their needs in a particular area or state.

ACI, the American Concrete Institute, is also known as ACI International. It is a non-profit technical and educational society dedicated to improving the design, construction, manufacture and maintenance of concrete structures. ACI's nearly 18,000 members are made up of structural designers, architects, civil engineers, educators, contractors, concrete craftsmen and technicians, representatives of materials suppliers, students, testing laboratories, and manufacturers from around the globe. ACI publishes standards (specifications and codes) and state-of-the-art reports (committee reports, practices, and guides) concerning the technology of concrete and concrete making materials.

CSA, the Canadian Standards Association, in 1999, became known as CSA International. It was the first organization in Canada formed exclusively to develop industrial standards. Today, CSA is an independent, not-for-profit, standards-writing, certification, testing and inspection organization. The Association provides an open forum for the public, governments and business to voluntarily reach agreement through the consensus process on the criteria that best meets the community interest for materials, products, structures and services in a wide variety of fields.

Note – Testing standards are discussed in Chapter 6, "Testing" of TRB Circular 494, ***Durability of Concrete***, Transportation Research Board, Section on Concrete (A2E00), December, 1999. AASHTO and ASTM Standards are also listed in the Reference section following Chapter 7.

Specifications

1. Aggregates, Mixtures, and Other Materials for Portland Cement Concrete:

- AASHTO M 6 Fine Aggregate for PC Concrete

- AASHTO M 80 Coarse Aggregate for PC Concrete

- ASTM C 33 Concrete Aggregates (fine and coarse)

- AASHTO M 195 (ASTM C 330) Lightweight Aggregates for Structural Concrete

- AASHTO Lead States, AASHTO Guide Specification for Highway Construction, Section on Portland Cement Concrete Resistant to Excessive Expansion Caused by Alkali-Silica Reaction, FHWA Focus, October, 1999, and the Web Site 'leadstates.tamu.edu/ASR/library/gspec.stm', at Texas A&M University, October, 1999

- CSA A23.1 / 23.2 Concrete Materials and Methods of Concrete Construction / Methods of Test for Concrete (In Revision 1999)

Note – Other specifications for concrete materials could be added here. See Chart J form the first meeting of the panel of experts, November, 1999.

2. Practices - General

- AASHTO R 1 (ASTM E 380) Metric Practice Guide

- AASHTO R 10 Definitions of Terms for Specifications Procedures

- AASHTO R 11 (ASTM E 29) Practice for Indicating Which Places of Figures Are to Be Considered Significant in Specified Limiting Values

- ASTM C 125 Terminology Relating to Concrete and Concrete Aggregates

Testing

3. General Testing

- AASHTO M 92 (ASTM E 11) Wire Cloth Sieves for Testing Purposes

- AASHTO M 132 (ASTM E 12) Terms Relating to Density and Specific Gravity

- AASHTO M 231 Weights and Balances Used in Testing

- ASTM Manual of Aggregate and Concrete Testing (appears in ASTM Volume 04.02 in the back in the gray pages)

- ASTM C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates

4. Sampling and Sample Preparation

- AASHTO T 2 (ASTM D 75) Sampling Aggregates
- AASHTO T 248 (ASTM C 702) Reducing Field Samples of Aggregate to Testing Size

5. Particle Size Analysis of Aggregates

- AASHTO T 27 (ASTM C 136) Sieve Analysis of Fine and Coarse Aggregates
- AASHTO T 11 (ASTM C 117) Amount of Material Finer than the No. 200 (75µm) Sieve
- AASHTO T 30 Mechanical Analysis of Extracted Aggregates

6. Properties of Fines in Aggregates

- AASHTO T 176 (ASTM D 2419) Sand Equivalent Test for Plastic Fines in Graded Aggregates and Soils
- Proposed by 4-19 Methylene Blue Value of Minus 75µm Fine Material in an Aggregate
- Proposed by 4-19 Particle Size Distribution of Minus 75µm Fine Material in an Aggregate by Laser Device
- California Test 227 Evaluating Cleanness of Coarse Aggregate (Cleanness Value -- CV)

7. Soundness of Aggregates (unconfined aggregate samples)

- AASHTO T 104 (ASTM C 88) Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
- AASHTO T 103 Soundness of Aggregates by Freezing and Thawing (Methods A, B, and C)

8. Freezing and Thawing Durability of Concrete and Aggregates in Concrete

- AASHTO T 161 TP17 (ASTM C 666) Resistance of Concrete to Rapid Freezing and Thawing

  Method A -- Freezing and Thawing in **Water**, Specimen in Boot or Other Container
  Method B -- Freezing in **Air** and Thawing in Water, Specimen not in Container

Method B (Modified) -- **Chloride** Treatment of Aggregate or Concrete before Freeze-Thaw

Method C -- Freezing in Air (**Moist Cloth Wrapped**) and Thawing in Water

- ASTM C 457 Practice for Microscopical Determination of Air-Void Content and Parameters of the Air-Void system in Hardened Concrete.

- ASTM C 672 Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals.

9. Abrasion and Degradation Resistance of Aggregates

- AASHTO T 96 (ASTM C 131) Resistance to Abrasion (degradation by abrasion and impact) of Small-Size Coarse Aggregate by Use of the Los Angeles Machine (Dry Test)

- ASTM C 535 Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine (Dry Test)

- AASHTO T 210 (ASTM C 3744) Aggregate Durability Index (DI) (Wet Test)

- ASTM C 1137 Degradation of Fine Aggregate Due to Attrition (Wet Test)

- AASHTO TP 58 Micro Deval Tests of Fine and Coarse Aggregate (Wet Test)

10. Deleterious Materials in Aggregates

- AASHTO T 21 (ASTM C 40) Organic Impurities in Sand for Concrete

- AASHTO T 71 (ASTM C 87) Effect of Organic Impurities in Fine Aggregate on Strength of Mortar

- AASHTO T 112 (ASTM C 142) Clay Lumps and Friable Particles in Aggregate

- AASHTO T 113 (ASTM C 123) Lightweight Pieces in Aggregate

11. Petrographic Evaluation of Aggregates

- ASTM C 294 Nomenclature of Constituents of Natural Mineral Aggregates

- ASTM C 295 Practice for Petrographic Examination of Aggregates for Concrete

12. Petrographic Evaluation of Concrete

- ASTM C 823 Practice for Examination and Sampling of Hardened Concrete in Constructions

- ASTM C 856 Practice for Petrographic Examination of Hardened Concrete

13. Alkali Aggregate Reactivity of Aggregates

- ASTM C 227 Alkali Reactivity Potential of Cement-Aggregate

- ASTM C 289 Potential Reactivity of Aggregates (Chemical Method)

- ASTM C 586 Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregate (Rock Cylinder Method)

- ASTM C 342 Volume Change Potential of Cement-Aggregate Combinations

- ASTM C 441 Mineral Admixture Effectiveness in Preventing Excessive Expansion Due to Alkali-Aggregate Reaction

- AASHTO T 303 (ASTM C 1260) Accelerated Potential Alkali Reactivity of Aggregates (Mortar Bar Method)

- ASTM C 1105 Alkali-Carbonate Rock Reaction in Concrete Prisms

- ASTM C 1293 Alkali-Silica Reaction in Concrete Prisms

- AASHTO T 299 Rapid Identification of Alkali-Silica Reaction Products in Concrete (Also appended to ASTM C 856)

- AASHTO Lead States, Proposed AASHTO Guide Specification for Highway Construction, Section on Portland Cement Concrete Resistant to Excessive Expansion Caused by Alkali-Silica Reaction, FHWA Focus, October, 1999, and the Web Site ‘leadstates.tamu.edu/ASR/library/gspec.stm’, at Texas A&M University, October, 1999

- ASR Detect Kit from James Instruments. (On ASR-contaminated concrete, the resultant stains reveal ASR presence. The stains' distribution shows the extent of ASR in the concrete, and the proximity to different components of the aggregate gives clues to the source of the trouble.)

- KS, NE Concrete Prism Test

14. Alkali Carbonate Reactivity of Aggregates

- ASTM C 856 Rock Cylinder

- ASTM C 1105 Concrete Prism

15. Specific Gravity, Absorption, and Unit Weight of Aggregates and Concrete

- AASHTO T 84 (ASTM C 128) Specific Gravity and Absorption of Fine Aggregate
- AASHTO T 85 (ASTM C 127) Specific Gravity and Absorption of Coarse Aggregate
- AASHTO T 19 (ASTM C 29) Unit Weight and Voids in Aggregate
- ASTM C 642 Specific Gravity, Absorption, and Voids in Hardened Concrete

16. Volume Change and Cracking Tendency of Concrete

- AASHTO T 160 (ASTM C 157) Length Change of Hardened Hydraulic Cement Mortar and Concrete
- AASHTO PP 34-99 Cracking Tendency Using a Ring Specimen

17. Chlorides in Concrete and Permeability of Concrete

- AASHTO T 277 (ASTM C 1202) Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
- AASHTO T 259 Resistance of Concrete to Chloride Ion Penetration
- ASTM C 1152 Acid-Soluble Chloride in Mortar and Concrete
- ASTM C 1218 Water-Soluble Chloride in Mortar and Concrete

APPENDIX H

COST AND BENEFIT SURVEY QUESTIONAIRE

COST AND BENEFIT SURVEY QUESTIONAIRE

AASHTO LEAD STATE TEAM
SHRP IMPLEMENTATION - COST / BENEFIT SURVEY
ALKALI-SILICA REACTIVITY

The ASR Lead Team is in the process of assessing costs / benefits of Implementation of SHRP the ASR Technologies and improvements developed in cooperation with the Lead States since conclusion of the SHRP projects. The following survey was designed to provide needed information from AASHTO members in order to make this assessment. Your cooperation in filling out this survey, or asking the appropriate personnel in your department to fill it out, would be greatly appreciated. It is understood that some of the information being requested may not be readily available or easily discernible from existing databases. In these cases your best estimate would be appreciated. Please make sure to mark these areas as "est."

The scope of this project goes beyond, and is planned to be more detailed than, the initial FHWA-sponsored study "Summary of SHRP Research and Economic Benefits of Concrete and Structures" outlined in Research Report Number 96-2 and available through the "RoadSavers" program. The data generated through this survey will be made available to all respondents.

The survey has been subdivided in two sections : 1) New Construction, and 2) Rehabilitation / Repair / Maintenance of existing ASR affected Pavements and Structures.

I. Respondent Information

Your Name ______________________________________
Your Title ______________________________________

State ______ Agency ______________________________
Department ______________________________________

Address ___________________________ Phone ____________________
___________________________ E-Mail ____________________
____

Do You Have Internet Access ? _ YES _ NO
Have you attended an ASR SHRP Showcase ? _ YES _ NO

I am responsible for (Check all Appropriate Boxes) :

_ New Pavement Construction	_ Materials
_ New Bridge / Structure Construction	_ Specifications
_ Pavement Maintenance	_ Engineering
_ Bridge Maintenance	_ Contracting
_ Research	_ Purchasing

II. General

Total Lane-Miles of Highways in the State ____________________
Total Lane-Miles of Highways in Concrete ____________________

Total Number of Bridges in the State _________________

Has your state experienced concrete durability problems ? _ YES _ NO
What Percent of all structures ? _____ %

What has been identified as causes for these problems ?

_ Alkali-Silica Reactivity (ASR) _ Alkali-Carbonate Reaction (ACR)
_ D-Cracking _ Freeze-Thaw
_ Sulfate Attack _ Delayed Ettringite Formation (DEF)
_ Construction Problems _ Drying Shrinkage
_ Subbase _ Other

Have there been any "loss of service" incidents due to ASR ?
_ YES _ NO _ DO NOT KNOW
If yes, please provide details : ____
____
____

If yes, what was the cost to the state ? $ ________

II. New Construction

A. Pavement

How Many Lane Miles of Highway are built annually in the State ? _______
What Percent is Concrete Construction ? _________
How many Cubic Yards of Concrete are poured per year ? ________
What is the Typical Cement Content ? ______________
What is Average Material Cost for Concrete ? ______/ cu.yd.
Installed Cost ? ______ / _____

B. Bridges

How many bridges are built annually in the state ? _______
How many cubic yards of concrete are poured / year ? ________

What is the Typical Cement Content ? __________
What is Average Material Cost for Concrete ? ______/ cu.yd.
Installed Cost ? ______ / _____

C. Life-Cycle Costing

For costing purposes, do you use Life-Cycle Costing ? _ YES _ NO
If yes, what is design life for concrete pavement ? _______ years
Bridges ? _______ years

Are user costs evaluated ? _ YES _ NO

Are Construction Decisions made based on LCCA ? _ YES _ NO

D. ASR Mitigation

Do you currently test aggregate for susceptibility to ASR ? _ YES _ NO

If yes, what test procedure do you use ? ________________________________

Do you have Material Specs that address ASR ? _ YES _ NO
(If yes please attach copy).

What Mitigation Technique Does Your State Use (Check all applicable) ?
What additional cost does this add to concrete per cubic yard ?

_ Low alkali cement Alkali Level _____ Cost : $ _____ / cu.yd.
_ IP Cement - Type : _____________ Cost : $ _____ / cu.yd.
_ Nonreactive Aggregate Cost : $ _____ / cu.yd.
_ Fly Ash Type : _ F _ C Cost : $ _____ / cu.yd.
Quantity : _____________ % substitution ? _ YES _ NO
_ Silica Fume Quantity : _____ % Cost : $ _____ / cu.yd.
_ GGBFS Quantity : _____ % Cost : $ _____ / cu.yd.
_ Other Pozzolan - Specify : _______________ Cost : $ _____ / cu.yd.
_ Lithium admixture Cost : $ _____ / cu.yd.
_ Other - Specify : ___________________ Cost : $ _____ / cu.yd.

If you use mitigation, have current methods been effective ? _ YES _ NO
If NO please provide details : _______________________________________
____
____

If you have experienced ASR, and do not now use any mitigation, please indicate what add-on cost per cubic yard of concrete your state would recognize as cost effective to prevent on-set of ASR.

In pavement :

_ $ 0 _ $ 2 _ $ 5 _ $ 8 _ $ 10 _ $ 12 _ $ 15 _ $ 20

In bridges :

_ $ 0 _ $ 2 _ $ 5 _ $ 8 _ $ 10 _ $ 12 _ $ 15 _ $ 20

III. ASR Remediation / Repair and Maintenance

A. General

What is the state's annual expenditure for :
Maintenance / Repair of Pavement - $ ________
What portion is for ASR affected pavement ? _____ %
Maintenance / Repair of Bridges - $ _________
What portion is for ASR affected bridges ? _____ %

What method / procedures does your state use to determine remediation / repair strategies for pavement ? _________________________________

____

For bridges ? ____

____

Are user costs evaluated to determine strategies ? _ YES _ NO

What methods are used to determine if a pavement or bridge is affected by ASR ?

____

____

B. ASR Affected Pavement

Does your state have specific strategies for ASR Affected Pavement ?
_ YES _ NO _ DO NOT KNOW

Please rank the following side-effects of ASR in pavement in terms of relative importance in determining repair / maintenance strategies. (1-most important, 8-least important)

- **____ Joint failure**
- **____ Spalling / potholing / rutting**
- **____ Loss of Ride / Noise**
- **____ Decrease in structural strength / Modulus of Elasticity**

____ **Buckling / curling**
____ **Increased freeze - thaw damage**
____ **Decrease of Service Life**
____ **Aesthetic concerns**

How long does it take for ASR cracking to occur ? _____ yrs
What percentage of the design service life is expected to be lost due to ASR ?
_ 10 % _ 15 % _ 20 % _ 30 % _ 40 % _ 50 % _ 75 %
What Repair / Maintenance Techniques are used with ASR Affected Pavement (Choose all that apply) ?

_ Application of sealer - What type ? __________________
Duration ? _____ yrs Cost / lane mile ? $ _________
_ Hotmix Overlay - Thickness ? _____ in.
Duration ? _____ yrs Cost / lane mile ? $ _________
_ Thin Whitetopping Overlay - Thickness ? _____ in.
Duration ? _____ yrs Cost / lane mile ? $ _________
_ Joint Repair - What Type ? _________________________
Duration ? _____ yrs Cost / lane mile ? $ _________
_ Patching - What Type ? ____________________________
Duration ? _____ yrs Cost / lane mile ? $ _________
_ Lithium Treatment - What Type ? __________
Duration ? _____ yrs Cost / lane mile ? $ _________
_ Crack repair with Methacrylate - What Type ? _____________
Duration ? _____ yrs Cost / lane mile ? $ _________
_ Crack Repair with Epoxy - What Type ? _________________
Duration ? _____ yrs Cost / lane mile ? $ _________
_ Replacement - Type _ Concrete _ Hotmix - Thickness ? _____ in.
Duration ? _____ yrs Cost / lane mile ? $ _________
_ Other - Please Detail ___________________________________
____
Duration ? _____ yrs Cost / lane mile ? $ _________

Of the above strategies, which one has been the most effective ?
____
Which the least ? _____________________________________

B. ASR Affected Bridges / Structures

Does your state have specific strategies for ASR Affected Bridges / Structures ?
_ YES _ NO _ DO NOT KNOW

Please rank the following side-effects of ASR in bridges / structures in terms of relative importance in determining repair / maintenance strategies. (1- most important, 8-least important)

____ **Deck failure**
____ **Spalling / potholing / rutting**
____ **Loss of Ride / Noise**

____ **Decrease in structural strength / Modulus of Elasticity**
____ **Increased Corrosion**
____ **Increased freeze - thaw damage**
____ **Decrease of Service Life**
____ **Aesthetic concerns**

How long does it take for ASR cracking to occur ? _____ yrs
What percentage of the design service life is expected to be lost due to ASR ?
_ 10 % _ 15 % _ 20 % _ 30 % _ 40 % _ 50 % _ 75 %
What Repair / Maintenance Techniques are used with ASR Affected Pavement (Choose all that apply) ?

_ **Application of sealer - What type ? ___________________**
Duration ? _____ yrs Cost / sq.ft. ? $ _________
_ **Hotmix Overlay - Thickness ? _____ in.**
Duration ? _____ yrs Cost / sq.ft. ? $ _________
_ **Thin Whitetopping Overlay - Thickness ? _____ in.**
Duration ? _____ yrs Cost / sq.ft. ? $ _________
_ **Deck Replacement - What Type ? __________________________**
Duration ? _____ yrs Cost / sq.ft. ? $ _________
_ **Patching - What Type ? _____________________________**
Duration ? _____ yrs Cost / sq.ft. ? $ _________
_ **Lithium Treatment - What Type ? __________**
Duration ? _____ yrs Cost / sq.ft. ? $ _________
_ **Crack repair with Methacrylate - What Type ? _____________**
Duration ? _____ yrs Cost / sq.ft. ? $ _________
_ **Crack Repair with Epoxy - What Type ? _________________**
Duration ? _____ yrs Cost / sq.ft. ? $ _________
_ **Replacement - Thickness ? _____ in.**
Duration ? _____ yrs Cost / sq.ft. ? $ _________
_ **Other - Please Detail _____________________________________**
____
Duration ? _____ yrs Cost / sq.ft. ? $ _________

Of the above strategies, which one has been the most effective ?
____
Which the least ? ______________________________________

IV. Other Costs to State related to ASR

Please provide approximate annual costs to the state for the following due to ASR. If unknown please leave blank :

1. **Testing, Internal : $ _______**
2. **Testing, Contract : $ _______**
3. **Inspection : $ ________**
4. **Engineering Surveys / Studies : $ ________**
5. **Consultants : $ ________**

6. **Corrosion : $ ________**
7. **Line Striping : $ ________**
8. **Vehicular Damage : $ ________**
9. **Change to noncorrosive deicers : $ ________**
10. **User Lawsuits : $ ________**
11. **User Costs : $ ________**
12. **Other : $ ________ Please Specify : ____________________________**

APPENDIX I

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ASR AGENCY CONTACTS

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