SHRP-C/FR-91-101

Handbook For The Identification Of Alkali-Silica Reactivity In Highway Structures

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Strategic Highway Research Program
National Research Council
Washington, D.C. 1991

SHRP-C/FR-91-101
SHRP-87-C202

January 1991

Key Words: aggregate, alkali-silica reactivity, bridge, cement alkali, cracking, drying shrinkage, expansion, gel, highway, moisture, UV light, uranyl acetate

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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) is addressing this problem through its Project C-202, Eliminating or Minimizing Alkali-Silica Reactivity. One task of this research is 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 stage. 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**
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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: the occurrence and disposition of cracking and displacement of concrete, and 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 reinforcing steel, superimposed loading, or plastic shrinkage, may have occurred in the structure under inspection. Distress similar to that resulting from ASR but is not caused by ASR is pointed out.

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 procedure for identifying ASR gel reaction products was developed by Drs. Hover and Natesaiyer of Cornell University. (1, 2)

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 Insitu 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 pavements. 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 product provides the greatest assurance whether expansive ASR has developed in the concrete structure.

1. THE NATURE OF ASR

Three requirements must be met for expansive ASR to occur: reactive forms of silica or silicate in the aggregate; sufficient alkali (sodium and potassium) primarily from the cement; 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 Product
2. Gel Reaction Product + 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.

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. 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.

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 or 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.

2. ASR IN PAVEMENTS

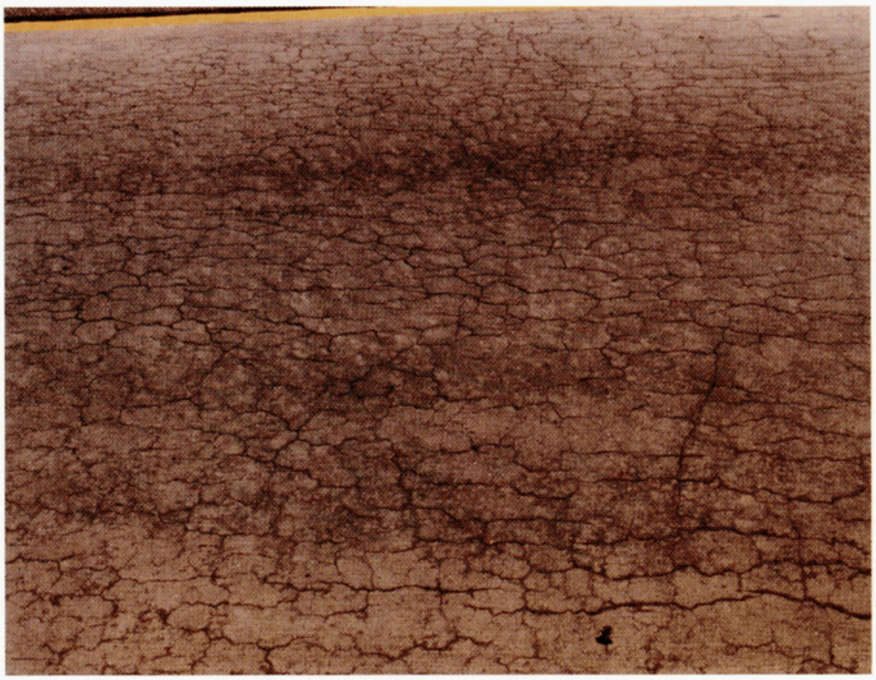
Fig. 1 - Close-up of pavement surface showing very early development of cracking associated with **ASR.** Cracks show generally random orientation with no preferred direction of strongest crack development. Such cracking is more visible on smooth surfaces than on textured or grooved surfaces, and can be enhanced visually by viewing after partial drying of a wetted surface (e.g. after a rain).

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.

ASR IN PAVEMENTS

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 wheelpaths may be more apparent due to infiltration of dirt and apparent greater width due to crumbling of crack edges. Both result from traffic wear. The crack pattern is similar for jointed and continuously reinforced pavement.

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.



ASR IN PAVEMENTS

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.

Fig. 6 - Cylindrical surfaces of 4-in. 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 cracks, thus producing relatively dark fringes that follow cracks. Note vertical cracks near top surface, and subhorizontal orientation of many cracks below the surface. ASR has, however, developed through the full thickness of the pavement slab.

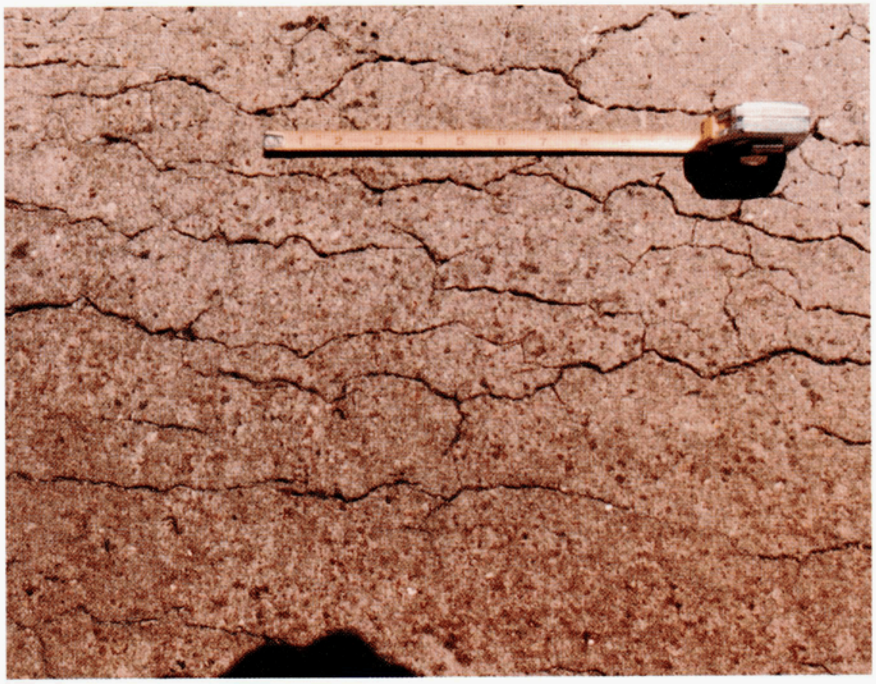



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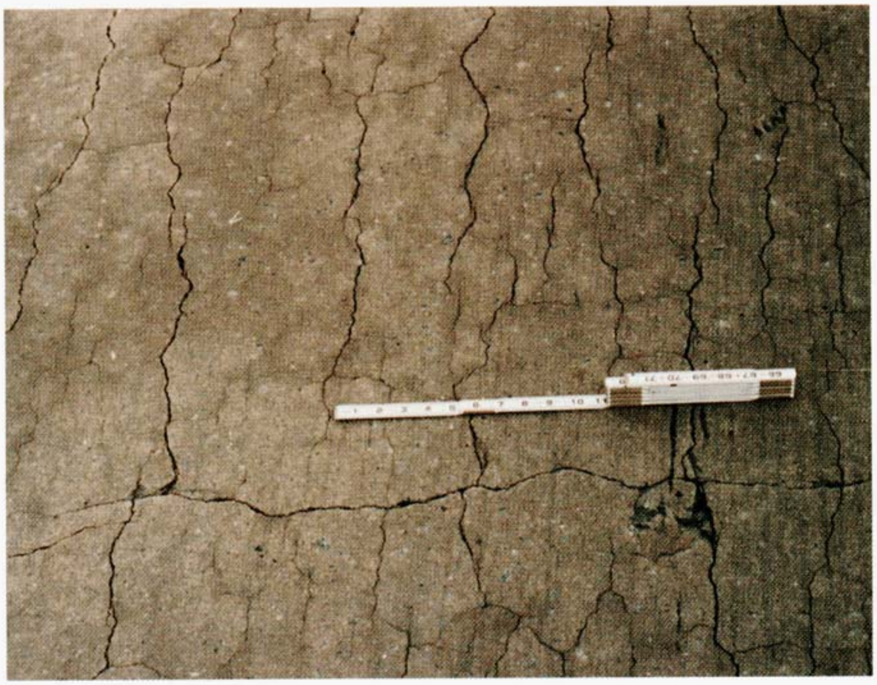
Fig. 7 - Severe cracking associated with ASR in continuously reinforced concrete pavement (CRCP). Cracks are most frequently oriented in longitudinal direction of pavement (top to bottom in photo), and are interconnected by finer transverse or random cracks, producing a generally rectilinear crack pattern.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

Fig. 8 - 4-in. diameter cores taken from CRCP shown in Fig. 7. Note shallow depth (1 to 2-1/2 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 in. 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.



ASR IN PAVEMENTS

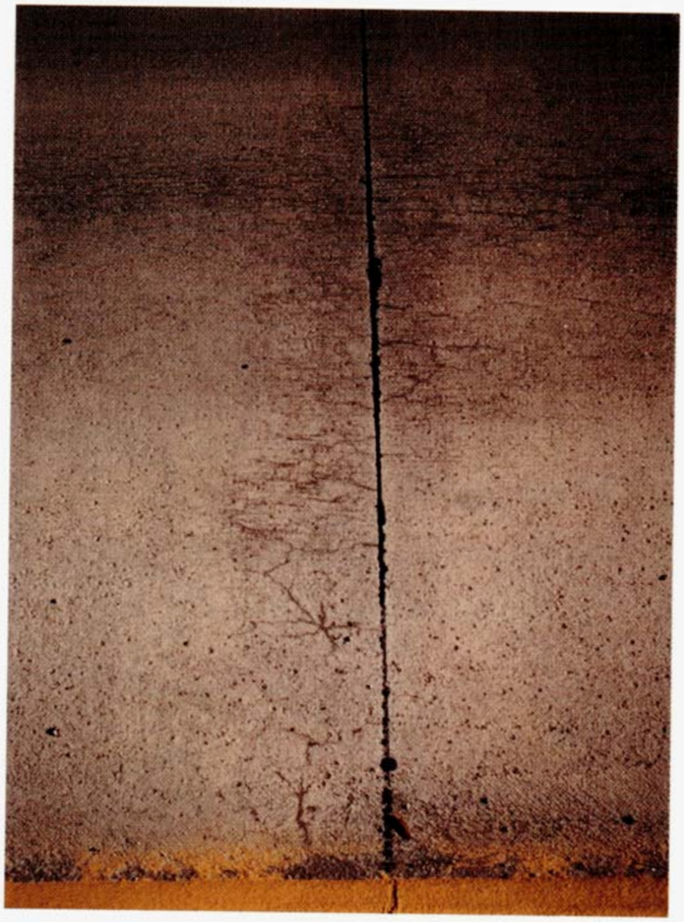


Fig. 9 - An early stage of cracking associated with ASR in jointed pavement. Occasionally, cracking first appears or is more severe along joints. This may lead to confusion with D-cracking (see Fig. 10). Note that, in cracking associated with ASR, numerous individual cracks are approximately normal to the direction of the joint.

D-CRACKING IN PAVEMENT

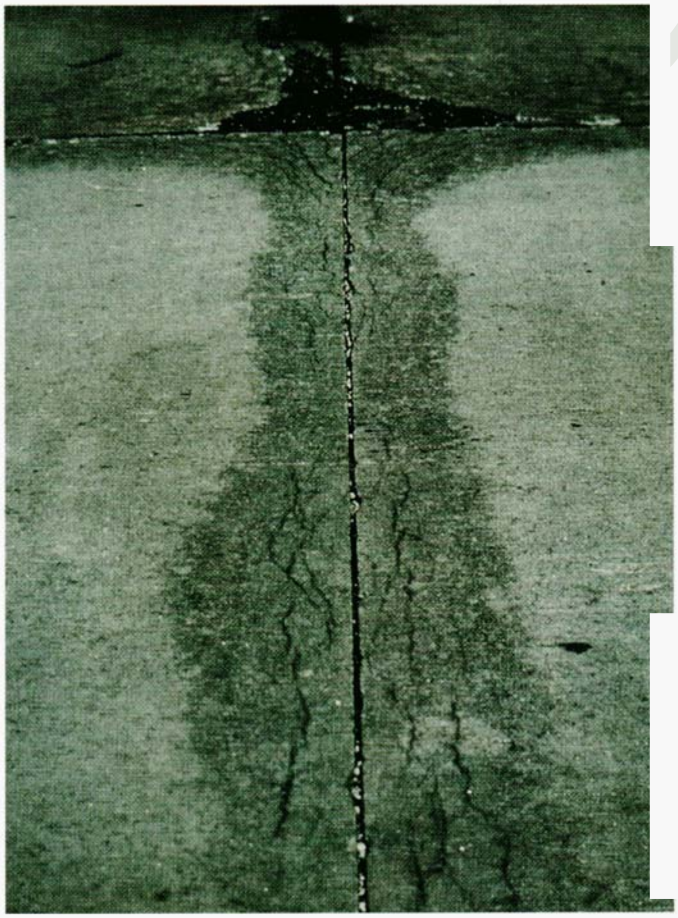
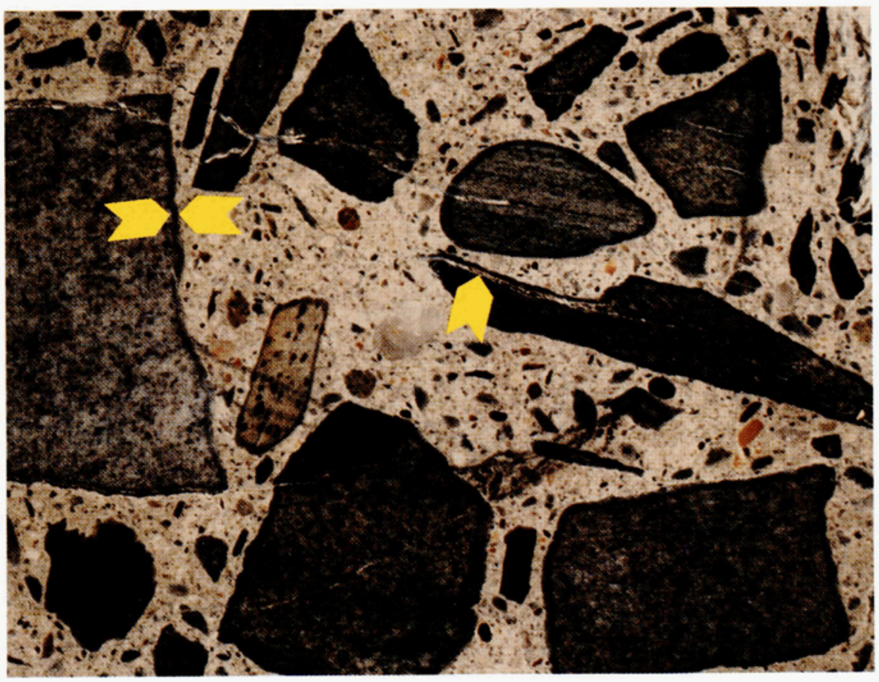


Fig. 10 - D-cracking due to freeze-thaw deterioration of coarse aggregate along transverse joint. In contrast to cracking associated with **ASR,** cracks are roughly parallel to the adjacent joint. Cracking along joint that has been induced by **ASR,** as in Fig. 9, is commonly associated with fainter map-cracking elsewhere in the pavement slab. D-cracking normally progresses away only from joints, intermediate cracks, and free edges of pavement slabs.

ASR IN PAVEMENTS

Fig. 11 - Fracture surface of 4-in. 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.



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.

ASR IN BRIDGE STRUCTURES

Fig. 15 - 4-in. diameter core taken from area of bridge deck shown in Fig. 14. Major cracking occurs full-depth in the core and is enhanced by 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.

ASR IN BRIDGE STRUCTURES

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 **is** necessary to verify association **of ASR** with cracking.

ASR IN BRIDGE STRUCTURES

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.

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. 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.

ASR IN BRIDGE STRUCTURES

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 is not indicative of **ASR.** Presence of **ASR** gel must be confirmed in other ways.

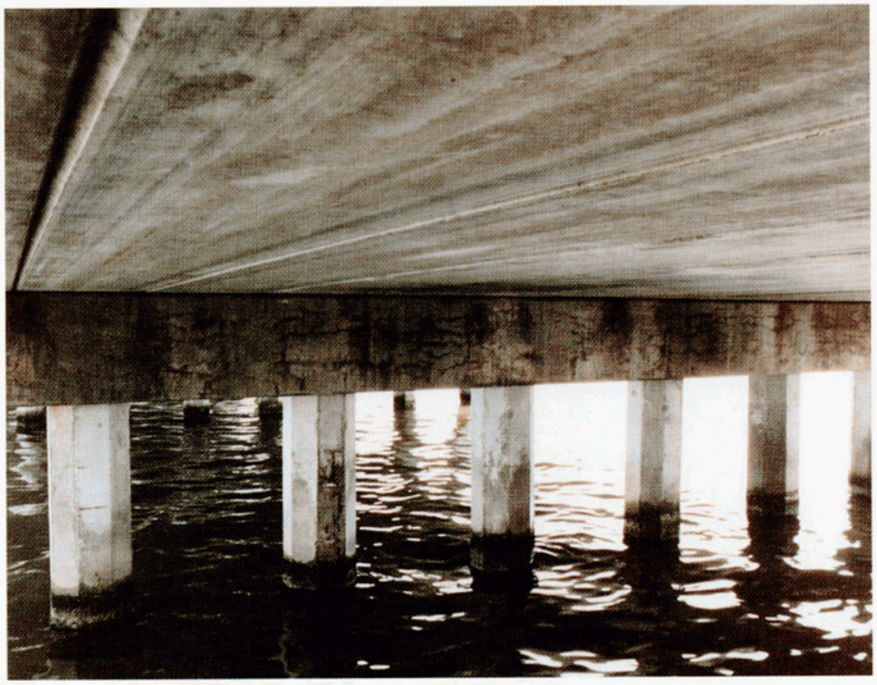
ASR IN BRIDGE STRUCTURES

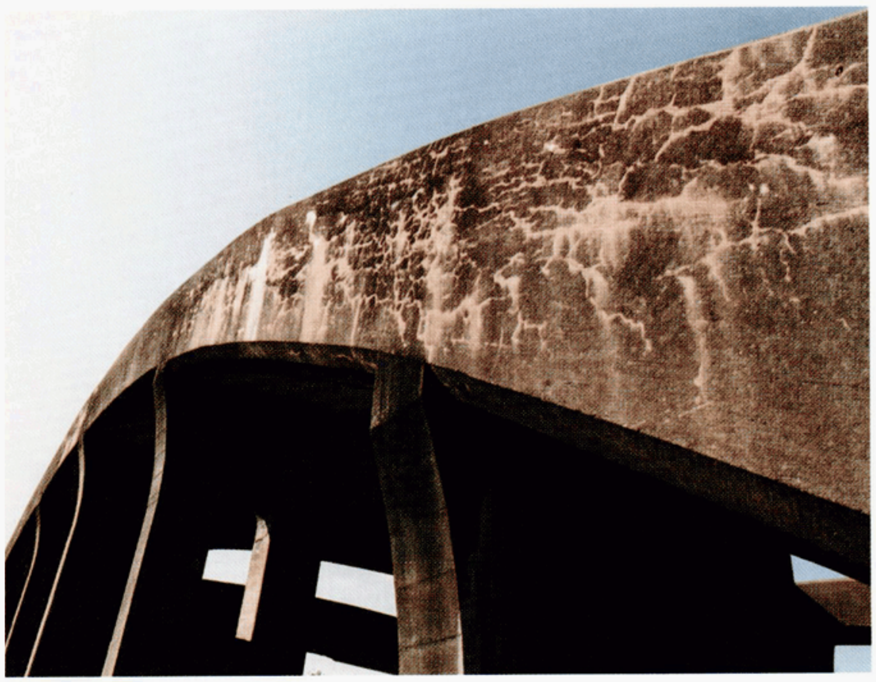
Fig. 20 - Closed joint between sections of parapet wall may have resulted from expansion due to ASR, as shown. Inspection should be made to determine if a foundation shift may have caused a tight joint. Such evidence should be used only as supporting evidence of ASR unless indicated otherwise.

ASR IN BRIDGE STRUCTURES

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. 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 might 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.





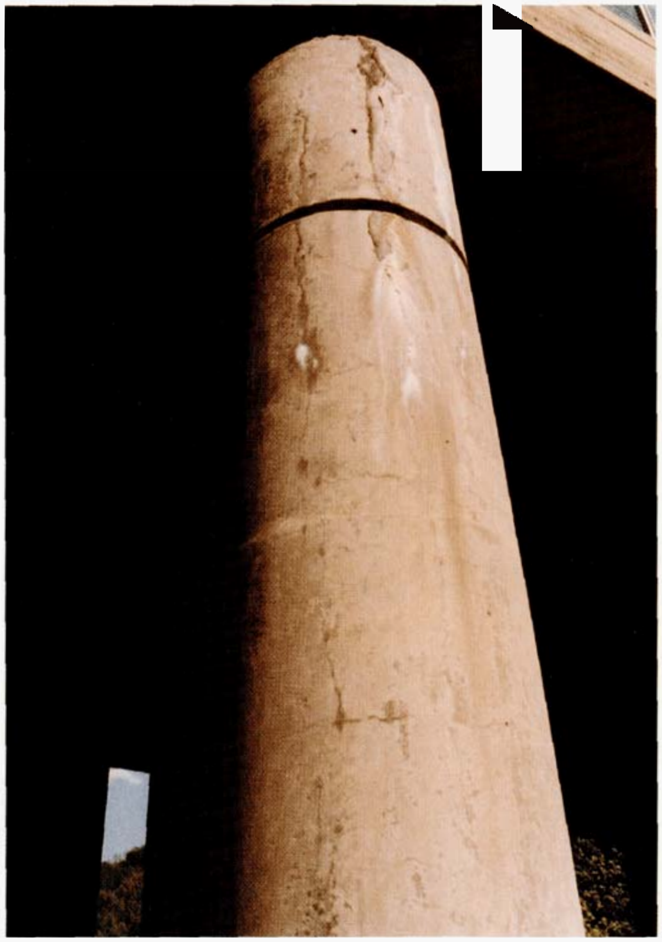


Fig. 23 - Bridge column showing cracking associated with **ASR.** Predominant cracks are oriented longitudinally, but are interconnected in irregular pattern by short transverse cracks and by fine random microcracks. White deposits on column contain **ASR** gel.

ASR IN BRIDGE STRUCTURES

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.

ASR IN BRIDGE STRUCTURES

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.

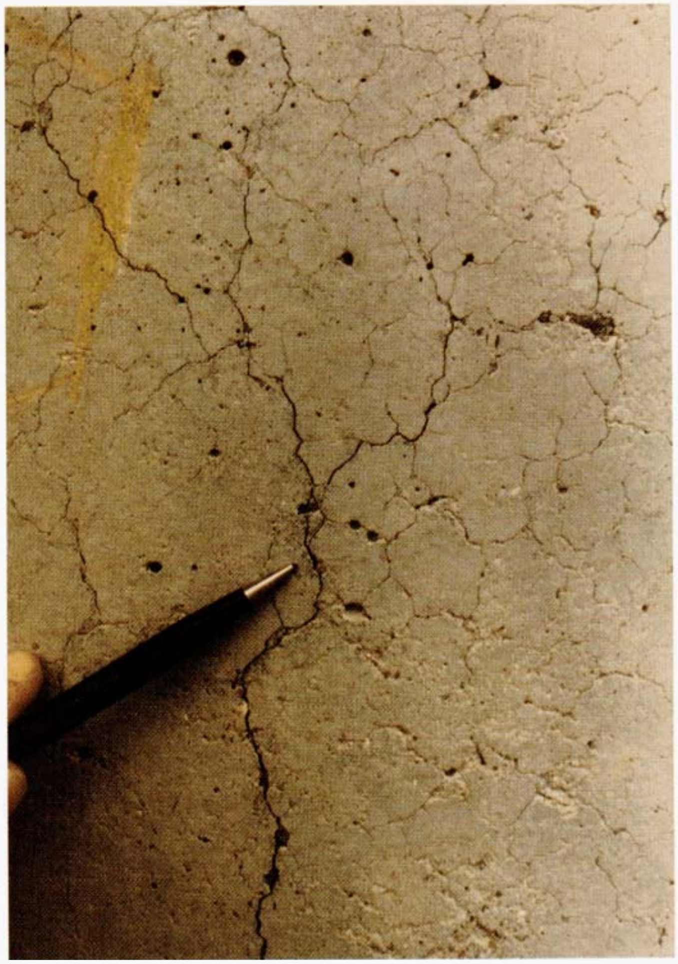


Fig. 26 - Closeup of cracking associated with **ASR** in bridge column. The most prominent crack is oriented approximately longitudinally in the column and usually does not extend along the full length of column. Finer microcracks interconnect **in** random fashion. Drying shrinkage may have contributed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

ASR IN BRIDGE STRUCTURES

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. 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 of 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. Use of the uranyl (uranium) acetate fluorescence method has been 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 the following sections.

BASIS FOR RECOGNITION

As stated earlier, **ASR** is uniquely characterized by production of a gel-like reaction product. It is composed essentially of silica, the alkalis (sodium and potassium), and calcium and water. Uptake of water by gel primarily determines volume changes associated with **ASR.** The gel may be present in large or minute amounts in aggregates, aggregate sockets, air voids, fractures, and on external formed surfaces of the concrete. By applying a uranyl acetate solution to a surface containing the gel, the uranyl ion substitutes for alkali in the gel, thereby imparting a characteristic yellowish-green glow when viewed in the dark using short wavelength (254 nanometer) ultraviolet light. **ASR** gel fluoresces much more brightly than cement paste due to the greater concentration of alkali and, subsequentially, uranyl ion in the gel.

EQUIPMENT AND MATERIALS

The following equipment is required to perform the test for the presence of ASR gel.

1. A source of 254 nanometer (short wavelength) ultraviolet (UV) light. The UV lamp should produce a peak intensity of at least 1200µW/sq cm at 6 in.

2. Powdered reagent grade uranyl acetate.

3. Plastic storage and squeeze or spray bottles.

4. UV absorbing protective eye wear. Special lightweight plastic glasses are available.

5. Protective eye wear (goggles or glasses) for mixing chemicals.

6. Lightweight rubber gloves.

7. Any type of viewing box which can be placed over the surface to be viewed. Provision must made for admitting UV light from the lamp and excluding ordinary light.

8. Surface preparation equipment, such as powder-driven grinding wheel or hammer to produce fresh surface. Cores also can be treated and examined.

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 200 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. Thereafter, proceed with the following steps.

Step 1

Prepare surface to be examined as follows:

a. **Old formed, finished, or wearing surface:** Use grinding wheel on electric drill or other means to grind off up to 1/4 in. of concrete. Rinse with tap water.

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

c. **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 eye wear (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 eye wear (chemical goggles or glasses) and gloves.

Step 4

Put on UV absorbing protective eye wear. 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: 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.

INTERPRETATION

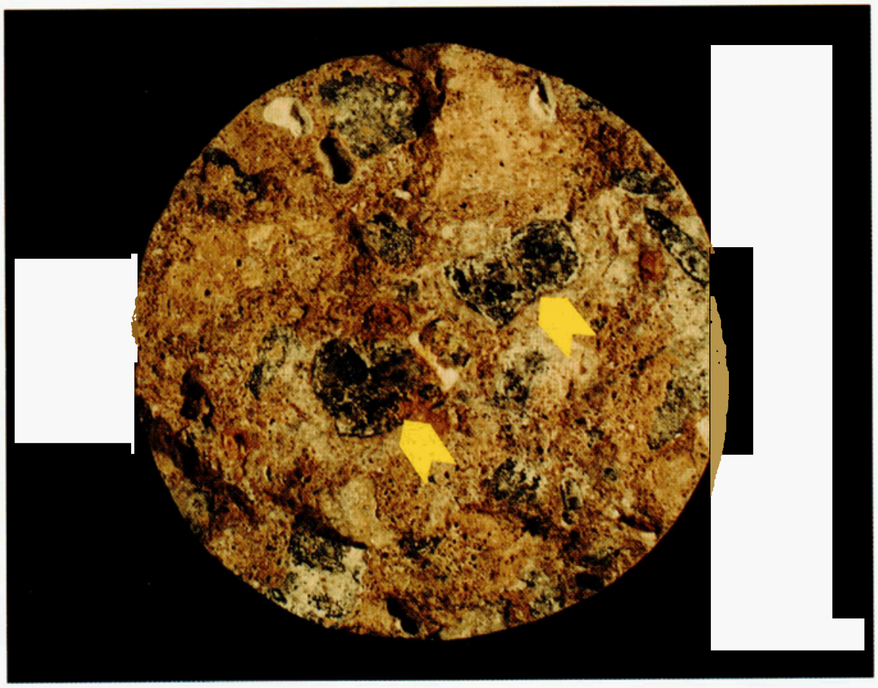
The presence of ASR gel will be revealed in UV light by a yellowish-green fluorescent glow. Deposits will be localized in cracks, air voids, certain aggregate particles and, in severe cases, as broad films in aggregate particles and fractured surfaces. Such films on sawed and cored surfaces may reflect smearing during surface sawing or coring. Fractured surfaces eliminate this effect and most clearly reveal undisturbed ASR gel deposits.

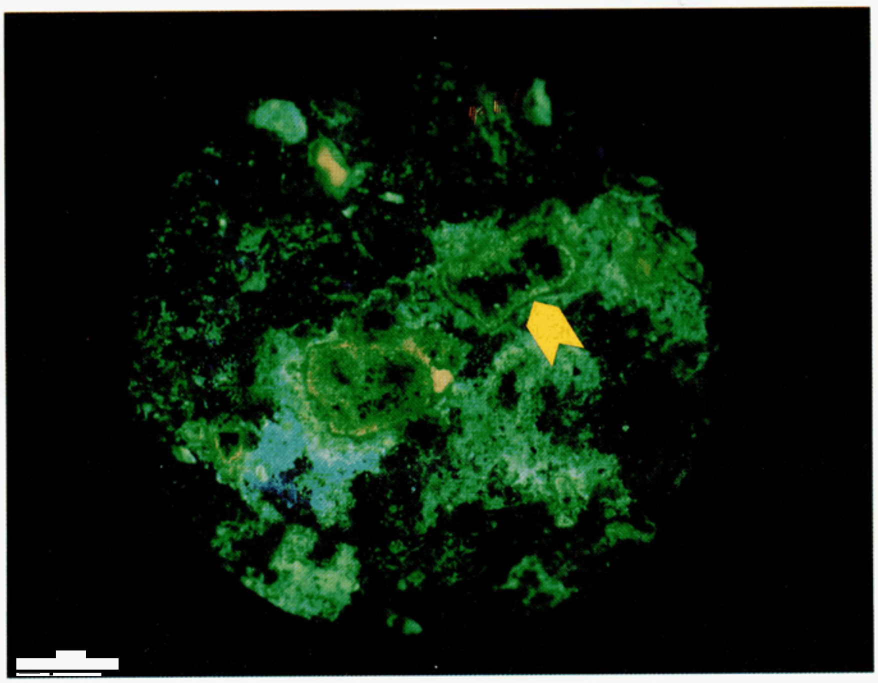
Figures (29) through (32) illustrate typical occurrences of ASR gel as seen in ordinary and UV light. Interpretations are offered of representative occurrences of gel in distressed concrete.

ASR GEL DETECTION

Fig. 29 - 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. ***30*** **-** Same fractured surface shown in Fig. 29 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.

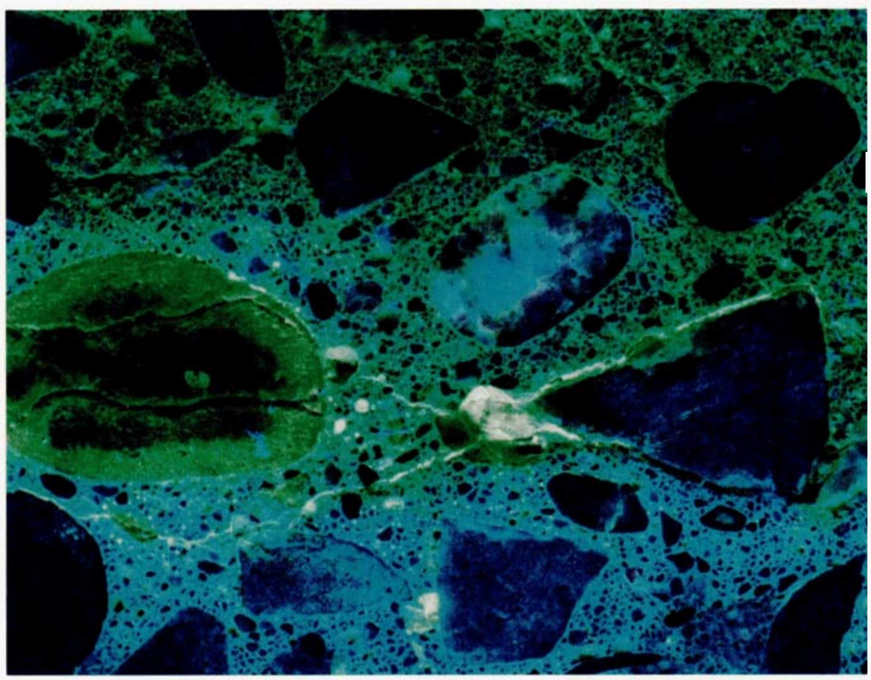




ASR GEL DETECTION

Fig. 31 - 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. 32 - Same field of view as shown in Fig. 31 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.

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 gamma 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. 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. 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.

Chronic Exposure:
Principal hazards are kidney and liver damage resulting from prolonged contact and absorption. Radioactivity induced tumors or malignancies are also possible.

Aggrevation 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.