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REACTIVE AGGREGATE IN CONCRETE STRUCTURES

Reza Akhavan
Colorado Department of Highways
4201 East Arkansas Avenue
Denver, Colorado 80222

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U.S. Department of Transportation
Federal Highway Administration

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16. Abstract

Colorado frequently experiences pavement deterioration due to reactive aggregates. This study examined whether alkali-silica reactivity was also causing damage to bridge structures. A number of bridges were inspected and samples were extracted from five and subjected to a petrographer's analysis. Three of the five samples showed conclusive evidence of alkali-silica reactivity. Evidence was not conclusive in two other samples.

Implementation

Colorado Department of Highway specifications now require low-alkali cement in all concrete.

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REACTIVE AGGREGATE IN CONCRETE STRUCTURES

I. PROBLEM STATEMENT

The Colorado Division of Highways (CDOH) has experienced extensive problems with reactive aggregates in pavements, causing cracking and deterioration of concrete. It is not certain whether reactive aggregates are a contributing factor in causing deterioration in concrete structures.

II. OBJECTIVES OF THE STUDY

The objective of this study was to determine if reactive aggregates had caused appreciable deterioration of structures. Structures were examined for evidence of cracking that may have been the result of alkali-silica reaction. Five sets of concrete samples were selected from structures in eastern Colorado for examination.

III. BACKGROUND

The devastating results of alkali-silica reaction in concrete has long been a great concern to concrete users. This reaction, which disturbs the well being of concrete, subsequently destructs and degrades the strength and durability of concrete used in the structure. Based on factual evidence, alkali-silica reaction emerges when the amorphous silica in the aggregate reacts with the alkali in the cement and forms a gel which absorbs water and begins to expand. This expansion would initially propagate micro-cracks in the concrete and eventually contribute to rapid deterioration of the structure. The presence of excessive water and the use of a more porous aggregate causes a greater degree of expansion, and consequently, undesirable conditions.[1,2]

Proper design is one solution to minimizing and perhaps eliminating this destructive reaction. Several methods have long been in practice and have demonstrated to be helpful in reducing the occurrence of alkali-silica reaction. Among these methods are the three most commonly used test procedures for determining the potentially reactive materials: chemical method (ASTM C289), petrographic exam (ASTM C295), and the mortar bar method (ASTM C277). Historically, when these tests have provided an indication that the aggregate in question is reactive, the responsible authorities have frequently used one or more of the following remedial measures:

1- use of a mineral admixture

2- use of a cement containing less than 0.6% total alkalies.

3- use of another, less reactive aggregate

IV. WORK PLAN

For this study, we selected several potential areas throughout the state. The selected structures were in the areas where reactive aggregates had exhibited distress in structures or adjacent pavements. The investigators were instructed to study the structures and if necessary obtain samples for examination. The following structures were investigated for possible or potential alkali-silica reaction:

1- Structure D-19-N, overpass structure at Roggen

driving lane....................................Picture #1 & #2

curb concrete...................................Picture #3

Description: 1959 structure; northbound, some fine map cracking; bottom of deck appears to be in good shape; center pier and cap were repaired with metallic grout.

2- Structure D-19-O & D-19-P, eastbound and westbound I76 over Lost Creek

No pictures available

Description: 1959 structure; concrete girders and bottom of deck in good shape; deck overlaid; concrete curb in good condition.

3- Structure D-20-AC

driving lane ....Picture #4

curb...Picture #5

Description: 1959 structure; parabolic concrete girders; there is some moderate cracking in the pavement; bottom of deck and girders are in fairly good shape; there is some map cracking in wingwall and curb; deck has been overlaid.

4- Structure D-20-AE & D-20-AD, Kiowa Creek overpass

curb...Picture #6

Description: there is some moderate to severe cracking in the pavement; moderate cracking in curb; the bottom of the deck and substructure is in good shape.

5- Structure D-20-AG, County Rd

curb...Picture #7

Description: there is some moderate to severe cracking in the pavement; the bottom of the deck is in good shape; minor cracks observed in curb; deck has been overlaid.

6- Structure D-20-AH

No pictures available.

Description: moderate to severe cracking in the pavement; bottom of deck and girders in good shape; deck overlaid (some cracks); minor cracking in curb.

7- Structure D-20-B & D-20-C, Bijou Creek

No pictures available

Description: deck has recently been overlaid; the bottom of the deck is in good condition; there are no signs of alkali-silica reactivity.

8- Structure D-21-P & D-21-Q

No pictures available

Description: this is a new bridge, there are no apparent problems with the concrete.

9- Structure C-21-BC, County Rd overpass at town of Bijou

deck..Picture #8

Description; this is a 1959 structure with parabolic arch girders; the bottom of the deck and girders appear in good shape; the deck has been overlaid; there is some minor cracking and some exposed rebars.

10- Structure C-21-BD

curb..Picture #9

Description: bottom of deck and girders is in good condition; minor cracking at ends of pier cap directly under expansion device; moderate cracking in curb; original concrete deck in good shape.

11- Structure C-21-E & C-21-B, over SH 144

curb..Picture #10

Description: this is a 1959 structure with parabolic concrete girders; there is some transverse cracking in the deck; bridge approach is in bad shape; there are some minor cracks in curb.

12- Structure C-21-M & C-21-I, over SH 52 Ft Morgan

approach pavement...........................Picture #11

Description: this a 1959 structure with parabolic concrete girders; deck has been overlaid; the expansion joint north of NB structure leaks badly.

13- Structure C-22-A & C-22-E

No pictures available

Description: this is a 1961 structure with parabolic concrete girders; deck has been overlaid; the bottom of the deck and the curb look good.

14- Structure C-22-BE & C-22-BG

abutment wall & deck.....................Pictures #12 & #3

Description: 1961/1964 structure; bridge being overlaid today; concrete spalling off the top of the deck, this may be due to lack of clearance above rebars; bottom slab and prestressed girders look ok; the spalling on the pier cap appear to be caused by the leaking expansion joint.

15- Structure C-22-BL & C-22-BM, over County Rd

approach pavement............................Picture #14

Description: there is some moderate cracking in the approach pavement; substructure, girders and bottom slab look good; there are some cracks on SE parapet wall in structure BL.

16- Structure C-23-AR & C-23-AQ

No pictures available

Description: 1964 structure; there is some moderate cracking in the approach pavement; the bottom slab and girders are in good shape; there are leaking joints.

17- Structure B-24-AG & B-24-AH

No picture available

Description: 1964 structure; the previous samples taken here indicate alkali-silica reaction in the structure.

18- Structure B-23-AR & B-23-AS, SH 63

under slab..................................Picture #15

Description: 1964 structure; there is some moderate to severe cracking in the approach pavement; the deck has been overlaid; there are some repair patches on the deck.

19- A-25-k & A-25-J, SH 55 intersection

No pictures available

Description: 1966 structure; there are leaking joints; the bottom of the slab is in good condition; this is a bare deck; some rebars showing due to spall.

20- A-25-I & A-25-D, County Rd, MP 141

different angles............................Pictures #16-#19

Description: massive leaks at joints; some efflorescence under slab on SB; NB under slab ok; on the NB deck some rebars showing due to spalling, there are a few asphalt patches; there are some severe cracks on the SB deck and some badly corroded rebars showing thorough. There is also some severe cracking in the approach pavement.

21- B-24-I & B-24-J

pier..Picture #20

Description: 1966 structure; spalling off at the edge of girder.

During visits to these structures, the crew gathered several samples from various structures. Of these five sets of concrete samples were randomly selected and submitted to the petrographer for analysis. The selection is as follows:

#1. Nunn, North of U.S. 85 Northeast of Fort Collins.

#2. B-24-AG, at Milepost 118.52, Base of slope paving in the West Side.

#3. B-24-J South, at Milepost 133.49.

#4. B-24-AN/AO, IR76-2(23) Bridge Deck (Sterling).

#5. SH287 and Boulder Creek Structure.

Each set of samples contained one or more pieces of concrete. #1 four, #2 one, #3 six, #4 three, and #5 one. The petrographer's review of these samples and his findings are documented in Appendix B in this report.

V. FINDINGS AND CONCLUSIONS

The petrographer's report suggests the importance in gaining a complete understanding about the chemical compositions of the alkali-silica reactions in order to determine the potential reactive constituents, and to be able to avoid future occurences of damage to concrete structures. The study also concludes the absence of alkali-silica reaction in those samples obtained from Nunn and milepost 118.52 locations. Although these samples were initially thought to be reactive, the study results show otherwise. The symptoms observed by the field investigators may have only represented an early stage in development of the reaction. Nevertheless, it is a justified assumption to suspect the alkali-silica reaction as being a culprit in many Colorado structures.

There have been several recommendations for preventing the occurrences of the alkali-silica reaction. Recently, Colorado Department of Highway specifications were modified to include Class F fly ash with low-alkali portland cement to be used in any class of concrete for all concrete pavements. The amount of fly ash required is specified to be equal to 20 percent of the cement weight added to the mix in addition to the weight of cement. The use of fly ash in concrete mix has been proven to be one of many methods of reducing the concrete permeability, which decreases water penetration into the concrete mass.

For structures, the use of low-alkali cement without any additional fly ash is considered sufficient to prevent the alkali-silica reaction.

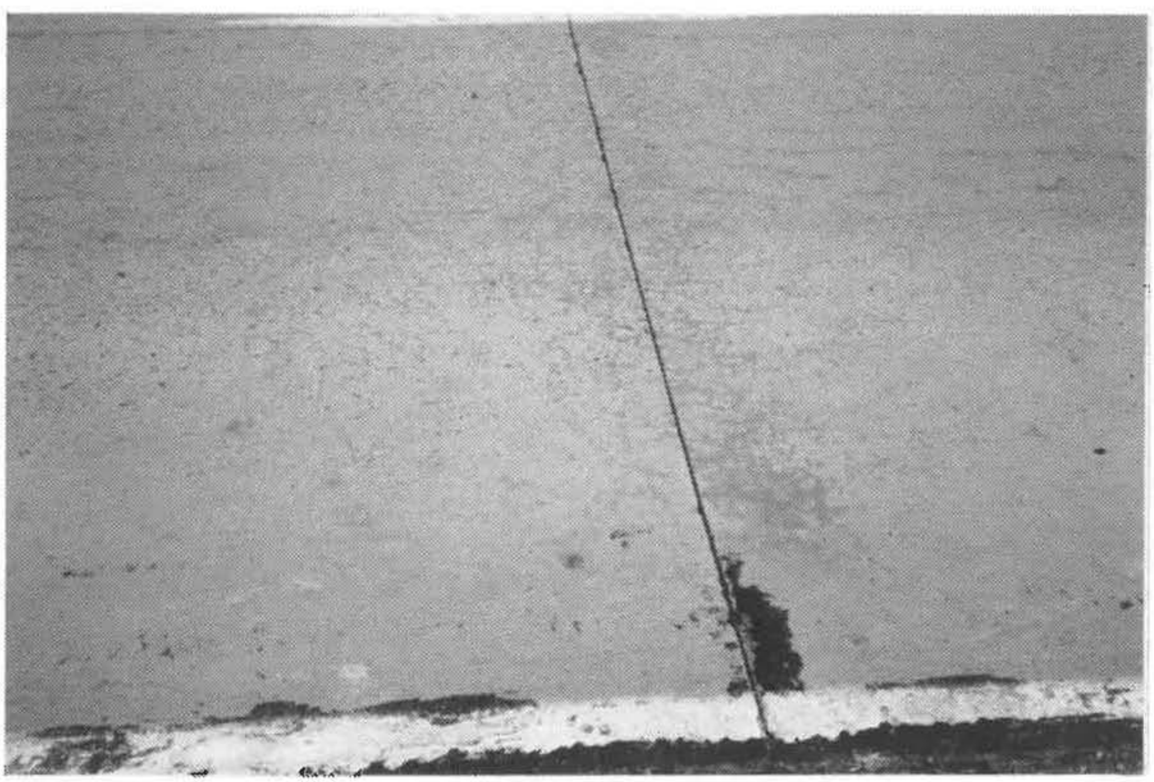
This study also revealed that the pavements adjacent to structures were far more severely affected, even though the concrete was essentially the same. Structures are more drained and dryer than pavements and as a result they should be less susceptible to moisture damage. The CDOH feels that the use of low-alkali cement, without Class F fly ash will be sufficient to prevent or reduce damage due to the alkali-silica reaction.

VI. IMPLEMENTATION

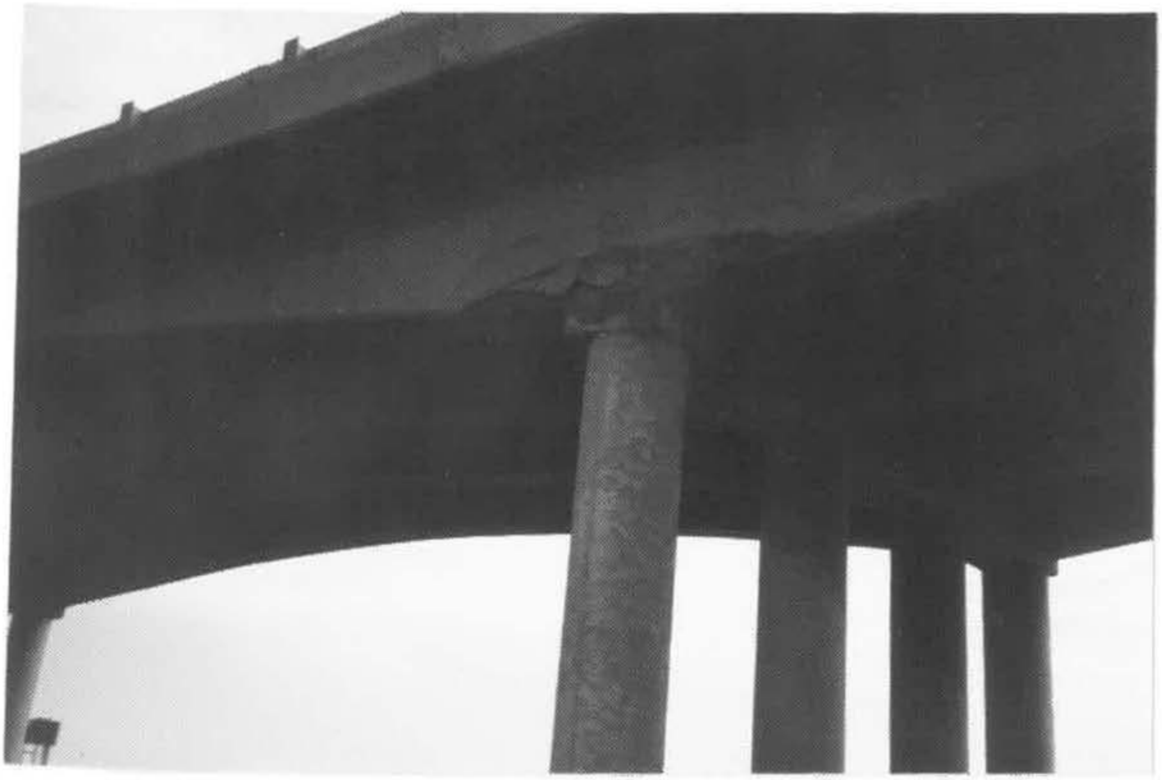
The Colorado Department of Highways has modified the specifications to require low-alkali portland cement for minimizing alkali-silica reaction in structures. It was also decided that fly ash may be substituted for cement, up to 20% by weight, at the option of the contractor. For pavements, 20% class "F" fly ash is required in addition to the minimum cement content to mitigate the more severe reaction.

APPENDIX A

PICTURE #1
STRUCTURE D-19-N,
OVERPASS STRUCTURE
AT ROGGEN
DRIVING LANE



PICTURE #2
STRUCTURE D-19-N,
OVERPASS STRUCTURE
AT ROGGEN



PICTURE #3
STRUCTURE D-19-N, OVERPASS STRUCTURE AT ROGGEN

PICTURE #4
STRUCTURE D-20-AC DRIVING LANE

PICTURE #5
STRUCTURE D-20-AC
MAP CRACKING IN CURB

PICTURE #6
STRUCTURE D-20-AE & D-20-AD, KIOWA CREEK OVERPASS

PICTURE #7
STRUCTURE D-20-AG, COUNTY ROAD

PICTURE #8
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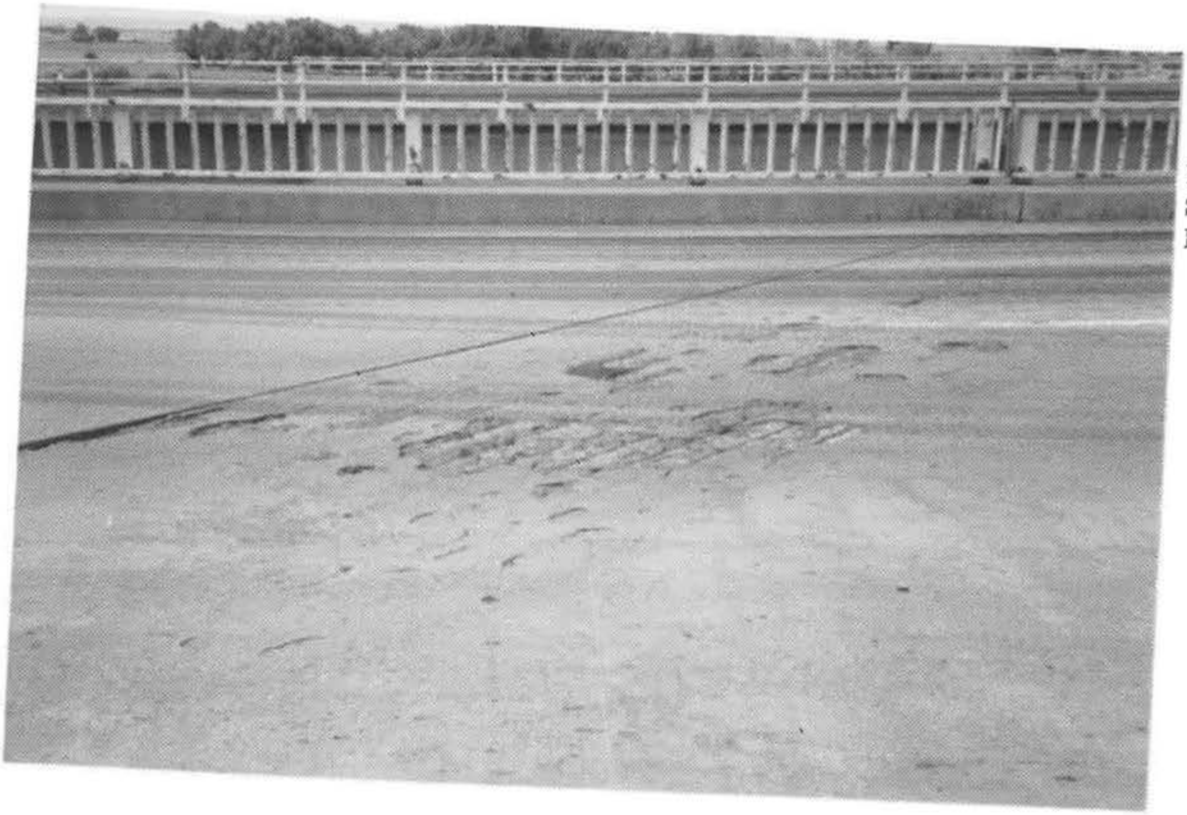
PICTURE #9
STRUCTURE C-21-BD

PICTURE #10
STRUCTURE C-21-E &
C-21-B, OVER SH 144

PICTURE #11
STRUCTURE C-21-M &
C-21-I, OVER SH 52
FT MORGAN

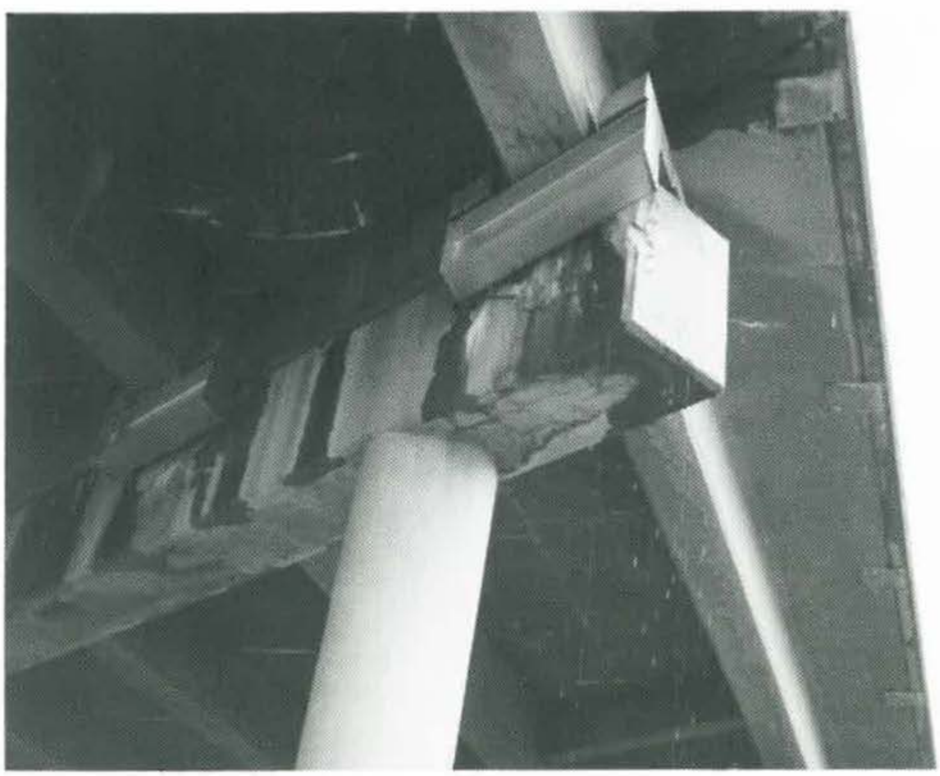
PICTURE #12
STRUCTURE C-22-BE &
BG



PICTURE #13
STRUCTURE C-22-BE & BG

PICTURE #14
STRUCTURE C-22-BL & C-22-BM, OVER COUNTY RD

PICTURE #15
STRUCTURE B-23-AR
& B-23-AS, SH 63

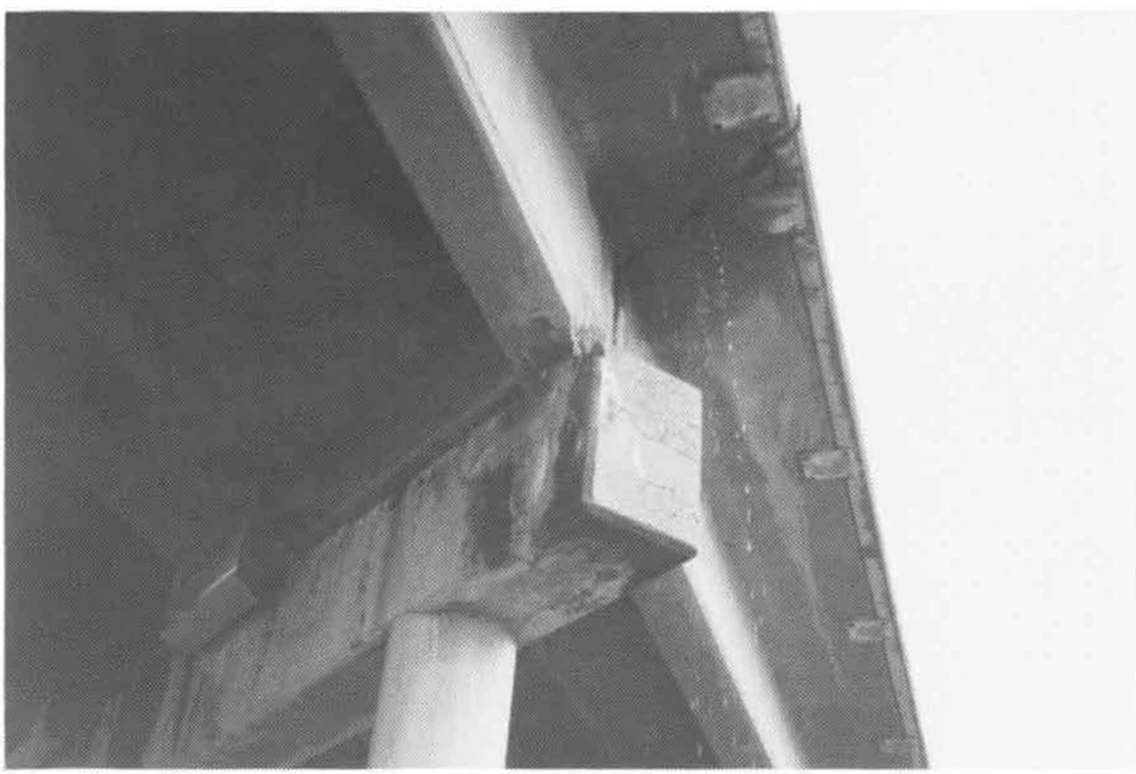


PICTURE #16
A-25-I & A-25-D,
COUNTY ROAD, MP 141
REPAIRED PIER-CAP

PICTURE #17
A-25-I & A-25-D,
COUNTY ROAD, MP 141

PICTURE #18
A-25-I & A-25-D,
COUNTY ROAD, MP 141

PICTURE #19
A-25-I & A-25-D,
COUNTY ROAD, MP 141



PICTURE #20
B-24-I & B-24-J

APPENDIX B

Petrographer's Report[3]

All pieces were examined, as received, visually and microscopically. One piece each, from sets #1, #2, and #4, was sawed and polished in order to examine reaction characteristics and cracking in more detail. Due to the small sizes, pieces from set #3 and #5 were not sawed and polished. Data from individual pieces are designated A, B, C, etc. under "Appendix." When only one piece was examined, no letter designation is given.
The examination was made in accordance with ASTM C856 "Petrographic Examination of Hardened Concrete" and ASTM C294 "Constituents of Natural Mineral Aggregates."

DISCUSSION

Characteristics indicative of alkali-silica reaction in concrete include secondary deposits of white gel in voids (especially when voids are adjacent to aggregates particles) and in cracks or fractures (e.g., micro-cracks), cracks inside the periphery of aggregate, radial cracking in aggregate, reaction rims around aggregate, and the presence of rock types that are reactive. Cracking or fracturing in concrete or rims around aggregate alone, however, are not conclusive evidence for alkali-silica reactivity. Cracking or fracturing can be induced during the removal of concrete whenever coring or sawing are not utilized. Rims around natural gravel frequently are the result of weathering, rather than alkali-silica reactivity. Therefore, it is necessary to detect additional characteristics in conjunction with cracking or fracturing and rims around aggregate in order to conclude that alkali-silica reactivity has occurred.

Samples #1, Nunn North of U.S. 85, and #2, B 24 AG Milepost 118.52, do not display conclusive evidence for alkali-silica reactivity. Pieces from both sets of samples contain cracking, which may be due to alkali-silica reactivity or could have been induced during concrete removal. Other evidence, described above, indicating reactivity was not detected. A few voids in pieces from sample #1 contain white material that could not be confirmed as silica gel.

The structures represented by samples #1 and #2 are similar to the situation described by Meilenz (1961, p. 14). He states, "evidence of alkali-aggregate reaction may be meager in a given sample of concrete even though the structure from which the sample is taken is severely affected by expansion and cracking caused by this reaction. In particular, alkali-aggregate reaction may be poorly developed in superficial concrete, to a depth of three inches, because of the dry condition prevailing to that depth, whereas the reaction may be proceeding vigorously in the interior of the structure." Additional samples, preferably cores, might be valuable to confirm or deny alkali-silica reactivity in the two structures.

Sample #3, B-24-J South, Milepost 133.49, exhibits alkali-silica reactivity. Several to many voids in the paste contain silica gel and the reactive aggregate has adjacent voids filled with silica gel. Many reactive aggregate particles have reaction rims. Three pieces of concrete had a few micro-cracks and two had many abundant reactive aggregate present. A total of twenty-five particles from 1/32 to 3/4 inch in size were counted in the six pieces of concrete examined. Three particles of 3/16 to 5/8 inch argillite and one 3/4 inch particle of quartzite were detected.

Sample #4, B 24 AN AO, IR76-2(23), also shows alkali-silica reactivity. Two of the three pieces of concrete examined have many voids filled with silica gel and one piece has open, gel-free voids in the paste. The reactive aggregate in all three pieces have reaction rims and adjacent silica gel-filled voids. Two pieces have a few micro-cracks and one piece has numerous micro-cracks. Five reactive rock types are present. Rhyolite, as in sample #3, is the most abundant reactive aggregate, with fifteen 1/32 to 1/2 inch particles detected in the three pieces. Six 1/16 to 5/16 inch particles of strained quartz, two 1/8 to 1/4 inch particles of argillite, one 1/8 inch particle of altered volcanic ash(?), and one 1/4 inch particle of basalt were also detected.

Sample #5, SH 287 and Boulder Creek, had a substantial amount of alkali-silica reactivity. Most of the voids contained a white reaction product consisting predominantly of opal. Numerous fractures are present, with the reaction product coating apparent fracture planes. All coarse aggregate particles are tan to pink crushed sandstone containing crystalline and microcrystalline quartz. Some of the sandstone is also present in the fine aggregate down to 3/32 inch in size. All sandstone particles observed exhibit reactivity. It is very likely that the sandstone was originally opal cemented. During the alkali-silica reaction, it is likely that the opal, which is very reactive, was leached out of the sandstone to form the reaction product. In addition to opal, the microcrystalline quartz in the sandstone would have contributed to the alkali-silica reaction.

NOTES

#1. Nunn, North of U.S. 85:

A. Voids predominantly open and free of secondary deposits. One tiny void near aggregate socket contains unidentified white material. A few micro-cracks passing through and around aggregate. No secondary deposits (e.g., silica gel) observed in cracks.

B. Voids predominantly open and free of secondary deposits, including hydration products. Two voids in paste area contain unidentified white material. One micro-crack. Some hairline and micro-cracks transecting cement paste and aggregate. No secondary deposits in cracks. No evidence of reaction rims or cracks inside periphery of coarse and fine aggregate.

C. Voids predominantly open and free of secondary deposits. Some micro-cracks through cement paste and around aggregate. Some secondary deposits in cracks.

D. Voids predominantly open and free of secondary deposits. Three voids in paste filled with unidentified white material. Some micro-cracks. No secondary deposits in cracks.

#2. B-24-AG, Milepost 118.52:

One surface dotted with asphalt. Many voids contain a lining of soft white material, which appears to be a hydration product rather than silica gel. No silica gel-filled voids adjacent to aggregate. Numerous micro-cracks transecting paste and going around aggregate. No cracks inside periphery, radial cracking, or reaction rims on coarse and fine aggregate.

#3. B-24-J South, Milepost 133.49:

A. Several voids in cement paste contain silica gel. A number of micro-cracks transecting paste, one contains white silica gel. Alkali-reaction rock types present: five pieces 1/8 inch to 1/4 inch rhyolite, yellow, tan, pink, with reaction rims, one piece with adjacent silica gel-filled voids; one piece 1/2 inch argillite, green, with micro-cracks extending into paste, reaction rim bordered by silica gel.

B. Several voids in paste contain silica gel. Numerous micro-cracks transecting paste. Reactive rock type present: three pieces 3/32 inch to 3/16 inch rhyolite, light gray, tan, with adjacent voids containing white silica gel.

C. Numerous silica gel-filled voids in paste. A few micro-cracks in paste. Reactive rock types present: five pieces 3/32 inch to 3/4 inch rhyolite, gray, pink, light gray, contains glass, surrounded by silica gel reaction rim, adjacent silica gel-filled voids; one piece 5/8 inch argillite, greenish-gray, contains small amount of glass, surrounded by reaction rim, adjacent silica gel-filled voids.

D. Many silica gel-filled voids throughout paste. Very few micro-cracks in paste. Reactive rock types present: nine pieces 1/32 inch to 5/16 inch rhyolite, tan, gray, pink, brown, with adjacent silica gel-filled voids.

E. A few silica gel-filled voids in paste. A few micro-cracks in paste. Reactive rock types present: two pieces 1/16 inch to 3/32 inch rhyolite, tan, trace silica gel on surface, reaction rim; one piece 3/4 inch quartzite, yellow, abundant inclusions in quartz, reaction rim, adjacent voids filled with silica gel.

F. A few silica gel-filled voids in paste. Numerous micro-cracks transecting paste. Reactive rock types present: one 3/16 inch piece argillite, gray, with reaction rim containing white silica gel, adjacent silica gel-lined voids; one piece 1/16 inch rhyolite, tan, pink, nearby silica gel-filled void, reaction rim of silica gel.

#4. B-24-AN/AO, IR76-2(23), Bridge Deck (Sterling):

A. Many voids contain white silica gel. Some voids contain calcium hydroxide platelets. Numerous micro-cracks transect paste. Reactive rock types present; eleven pieces 1/32 inch to 3/8 inch rhyolite, pinkish-brown, tan, red-brown, surrounded by reaction rim of silica gel and void containing silica gel; two pieces 1/8 inch to 1/4 inch argillite, brownish-gray, silty, surrounded by reaction rims and voids filled with silica gel; four pieces 1/8 inch to 5/16 inch strained quartz, pink, tan, white, surrounded by reaction rims and voids containing silica gel; one piece 1/8 inch yellow soft clay-like particle surrounded by white silica gel border (probably is altered volcanic ash).

B. Numerous scattered voids filled with white silica gel. A few micro-cracks transecting paste. Reactive rock types present: two pieces 1/16 inch to 1/2 inch rhyolite, brown, weathered, surrounded by silica gel reaction rim and silica gel-filled voids; two pieces 1/16 inch to 3/16 inch strained quartz, pink, surrounded by voids filled with white silica gel; one piece 1/4 inch basalt, black, with cracks and adjacent silica gel-filled void.

C. Voids predominantly open and free of silica gel. A few micro-cracks transect paste. Reactive rock type present; two 3/32 inch to 3/16 inch pieces rhyolite, tan, pink, surrounded by reaction rim and adjacent voids filled with silica gel.

#5. SH 287 and Boulder Creek:

Majority of voids contain white reaction product. The reaction product coats many paste areas along what may be fracture planes. Numerous hairline fractures, some transecting aggregate particles, reactive rock type present: all pieces of aggregate from 3/32 inch to 3/4 inch are crushed sandstone, tan to pink, fine grained, slightly calcareous, consisting of crystalline and microcrystalline quartz. All sandstone particles are surrounded by white, layered, translucent to chalky appearing reaction rims. The predominant constituent in the reaction product is opal.

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3. PETROGRAPHER'S REPORT WAS PREPARED BY FRANCIS C. HOODMAKER, C.P.G.S. 4298.