Evaluation of Six Bridge Structures along Interstate 395 in Bangor, Maine

Field Site and Petrographic Evaluation

ASR Development and Deployment Program
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16. Abstract

This report presents the findings of an evaluation of six bridge structures along the Interstate 395 in Bangor/Brewer, Maine. The evaluation consisted of a visual examination of the different structural elements of the structures and the extraction and testing of cores; testing at this stage has been limited to petrographic assessment using the Damage Rating Index (DRI).

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1 Introduction

This report presents the findings of an evaluation of six bridge structures along the Interstate 395 in Bangor/Brewer, Maine. The evaluation consisted of a visual examination of the different structural elements of the structures and the extraction and testing of cores; testing at this stage has been limited to petrographic assessment using the Damage Rating Index (DRI).

2 Field Work

2.1 Site Inspection

Dr. Michael Thomas of C&CS Atlantic Inc. visited the structures on April 8, 2009, in the company of Mr. Dale Peabody of Maine DOT. Following his visit, Dr. Thomas proposed a series of sites for the extraction of cores for petrographic examination; the coring proposal thus prepared is given in the Appendix A of this report.

2.2 Extraction of Cores

Dr. Benoit Fournier and his colleague Mr. Sean Beauchemin of Laval University visited the various sites on June 15 and 16, along with Mr. Dale Peabody of Maine DOT. During that period, a total of 20 cores were extracted from the structures by DOT personnel. The local coring team completed the extraction of four additional cores on June 17th.

3 Laboratory Testing of Cores

Concrete cores were sent to Dr. Benoit Fournier at Laval University, Québec, Canada. The 24 cores were examined by petrography to determine the Damage Rating Index (DRI).

3.1 Damage Rating Index

Grattan-Bellew (1992) and Dunbar and Grattan-Bellew (1995) described a method to evaluate the condition of concrete by counting the number of typical petrographic features of ASR on polished concrete sections (18x magnification) (Table 1). A grid is drawn on the polished concrete section, which includes a minimum of 150 grid squares, 1 cm by 1 cm in size. The *Damage Rating Index* represents the normalized value (to 100 cm^2) of the presence of these features after the count of their abundance over the surface examined has been multiplied by weighing factors representing their relative importance in the overall deterioration process (Table 1).

Table 1: Petrographic Features and Weighing Factors for the Damage Rating Index

Petrographic feature	Abbreviation	Weighing factor
Coarse aggregate with cracks	CrCA	x 0.75
Open crack in coarse aggregate	OCrCA	x 4.0
Coarse aggregate with cracks and reaction products	Cr + RPCA	x 2.0
Coarse aggregate debonded	CAD	x 3.0
Reaction rims around aggregate	RR	x 0.5
Cement paste with cracks	CrCP	x 2.0
Cement paste with cracks and reaction products	Cr+RPCP	x 4.0
Air voids lined or filled with reaction products	RPAV	x 0.50

4 Results of the Field and Laboratory Investigations

4.1 Visual inspection and coring of the structures

Photographs of the coring sites are shown in the Appendix B. Table 2 summarizes the visual observations made during the coring of the structures. In general, the extent of cracking in the different elements of the structures examined is directly related to the severity of the exposure conditions. Sections or elements of the structures sheltered from direct exposure to rain and sun show no or light visible cracking while those exposed to the above elements show significantly more cracking and deterioration. This is particularly the case for the wing walls and exposed portions of the abutments of the bridge structures which often show moderate to severe map cracking and, in some cases, a regular vertical cracking pattern (e.g. Figures B1-D, B5-B, and B7-C).

4.2 Petrographic examination of the cores

The results of the DRI for the 24 cores examined are summarized in Table 3 and illustrated in Figures 1 to 6. Table 4 gives a summary of the petrographic observations (in terms of the typical crack width observed) and a rating of the extent of ASR damage in the concrete. Photographs of the polished core sections and the detailed results of DRI are given in the Appendix C.

There is currently no rating system for the DRI that indicates whether a concrete is not affected, or mildly, moderately or severely affected by ASR. However, our experience is such that values below 200-250 are indicative of a low degree of reaction / deterioration, while DRIs in excess of about 500-600 represent a high degree of ASR.

The concrete specimens examined incorporate a greywacke/argillite coarse aggregate. Several concrete specimens show typical signs of ASR consisting of cracking in the coarse aggregate particles and in the cement paste, often filled with alkali-silica reaction products, and reaction rims around reactive aggregate particles. The extent of the petrographic signs of ASR is, again, very much a function of the exposure conditions of the concrete. Concrete cores extracted from those parts of the structures that are exposed to rain and excess moisture generally show significantly higher DRI values.

4.2.1 I395 over Main Street (3 cores) (Figure 1)

The DRI values for this set of cores range from 133 (I395 MS-1) to 528 (I395 MS-3). Signs of ASR are observed in all cores; however, the extent of ASR ranges from low, for core MS-1 that was extracted in the abutment under the bridge deck (sheltered) (Figure B1-B), to moderate for core MS-3 that came from the exposed and cracked wing wall (Figure B1-E). The core MS-3 shows fairly extensive cracking in the coarse aggregate particles and in the cement paste (with and without ASR products) (Figures C3, C4-E and C4-F). Reaction rims were observed around a large number of coarse aggregate particles (Figure C4-F).

Core MS-2, which was extracted from the exposed part of the abutment, shows significant cracking with ASR products in the coarse aggregates and the cement paste (Figures C2, C4-C and C4-D); however, the extent of ASR in that core is considered low despite a fairly severe pattern of surface cracking on the exposed abutment (Figure B1-D).

Typical crack widths in the cement paste range from about 0.02 to 0.04mm (Table 4).

4.2.2 I395 over Penobscot River (10 cores) (Figure 2)

Cores extracted from that structure can be separated in two sets. Cores PR1 and PR2 were extracted from the abutment located on the east shore of the river (Figure B2). Cores 3 to 8 were extracted from large reinforced concrete columns on the west shore of the river (Figure B3).

The DRI values for the first set of cores (PR1 and PR2) range from 208 (I395 PR-1a) to 764 (I395 PR-2). Signs of ASR are observed in all cores; however, the extent of ASR ranges from low, for core PR-1b which was extracted in the abutment under the bridge deck (sheltered) (Figures B2-B and D), to high for core PR-2 which came from the exposed portion of the abutment (Figure B2-E). Both cores PR1a and 2 show fairly extensive signs of ASR, including cracking in the coarse aggregate particles and in the cement paste (with and without reaction products), as well as reaction rims around coarse aggregate particles (Figures C5, C7, C15-A, C15-B, C15-D to F). Core PR-1b, which was extracted from the sheltered part of the abutment, shows noticeable cracking in both the coarse aggregates and the cement paste but limited signs of reaction (Figure C6). Typical crack widths in the cement paste of this first set of cores range from about 0.02 to 0.05mm, with some high values up to 0.10mm in the case of cores PR-1a and PR-2 (Table 4).

The DRI values for the second set of cores (PR3 and PR8) are all within a fairly narrow range, i.e. from 196 (I395 PR-4b) to 240 (I395 PR-7). Signs of ASR are observed in all cores but the extent is generally considered low. The highest values corresponds to cores PR-5 and PR-7, which were taken on the east face of the columns, i.e. facing the river, and which shows some map cracking. Petrographic signs of deterioration includes cracking in the coarse aggregate particles and in the cement paste, sometimes with reaction products (cores PR-6 and PR-7; Figures C12 and C13), as well as reaction rims around a few coarse aggregate particles (Figure C15-G to C15-J). Typical crack widths in the cement paste range from about 0.02 (mainly) to 0.05mm (Table 4).

4.2.3 5th Parkway over I395 (3 cores) (Figure 3)

The DRI values for this set of cores range from 279 (I395 5th-1) to 882 (I395 5th-2). Signs of ASR are observed in all cores; however, the extent of ASR ranges from fair (DRI=279), for core 5th-1 that was extracted in the abutment under the bridge deck (sheltered) (Figure B4-C), to high (DRI=882) for core 5th-2 that came from the exposed portion of the abutment (Figures B4-B and D). All cores show extensive cracking in the coarse aggregate particles and in the cement paste, with ASR products being more abundant in core 5th-2, thus resulting in the highest DRI value (882) (Figures C17 and C19). Reaction rims are also observed around a large number of coarse aggregate particles. Typical crack widths in the cement paste range from about 0.02 to 0.05mm, with some high values up to 0.10mm in the case of cores 5th-2 and 5th-3 (Table 4).

4.2.4 South Parkway over I395 (3 cores) (Figure 4)

The DRI values for this set of cores range from 152 (I395 SP-3) to 531 (I395 SP-1). Signs of ASR, including extensive cracking in the coarse aggregate particles and in the cement paste (with ASR products), as well as reaction rims around coarse aggregate particles, are most abundant in the core SP-1 (Figures C20, C23-A to C23-D). This core was taken in the external/exposed column on the eastern side. ASR is observed, but at a low degree, in cores SP2 and SP3 (Figure C23-E and C23-F). Typical crack widths in the cement paste range from about 0.02 to 0.05mm, with some high values up to 0.10mm in the case of the core SP-1 (Table 4).

4.2.5 Green Point Road over I395 (2 cores) (Figure 5)

The DRI values for this set of cores are basically identical, i.e. 499 (GPR-1) and 479 (GPR-2), and result from moderate signs of ASR. The latter include fairly extensive cracking in the coarse aggregate particles and in the cement paste (with and without ASR products), as well as reaction rims around several coarse aggregate particles (Figures C24 to C26). Typical crack widths in the cement paste range from about 0.02 to 0.05mm, with some high values up to 0.10mm (Table 4).

4.2.6 Route 1A over I395 (3 cores) (Figure 6)

The DRI values for this set of cores range from 258 (I395 R1A-1) to 636 (I395 R1A-3). Signs of ASR are observed in all cores; however, the extent of ASR ranges from fair, for core R1A-1 extracted in the abutment under the bridge deck (sheltered) (Figures B7-A and B), to high for cores R1A-2 and R1A-3 which came from the exposed portion of the abutment and the wing wall, respectively (Figure B7-C and B7-D) Both cores R1A-2 and R1A-3 show fairly extensive signs of ASR, including cracking in the coarse aggregate particles and in the cement paste (with and without reaction products), as well as reaction rims around coarse aggregate particles (Figures C28, C29, C30-C to C30-F). Core R1A-1, which was extracted from the sheltered part of the abutment, shows significant cracking in both the coarse aggregates and the cement paste but the presence of reaction products is limited. In the case of the core R1A-1, typical crack widths in the cement paste are about 0.02 - 0.03mm. For cores R1A-2 and R1A-3, which show a higher degree of deterioration, typical crack widths in the cement paste range from 0.02 to 0.05mm, with some high values up to 0.10mm (Table 4).

5 Summary of Findings

The extent of ASR and ASR damage in the concrete ranges from low to high and there is significant variation in the damage from one location to another as a function of the exposure conditions of the structural element examined. Much of the concrete components sheltered from direct exposure to rain and sun show no or limited visible cracking or hairline cracking and this is consistent with the low DRI values for cores taken from these locations. In the case of the exposed portions of the abutments and the wing walls, petrographic signs of ASR ranging from moderate to high are generally observed.

The confirmed presence of ASR and the range of ASR-related damage in the various structures examined should allow the application of different types of approaches for the treatment of the affected sections.

6 Recommendations

A number of locations have been selected for treatment as discussed below. To determine the effectiveness of a treatment, it is necessary to have an untreated control section with a similar degree of damage and in the same exposure condition. Both the treated and untreated sections will be monitored (length change, crack mapping and internal relative humidity) for at least 3 years. Once a sufficient period of time has passed to enable the effectiveness of the treatments to be evaluated, a recommendation will be made by the team to treat the control sections.

6.1 South Parkway over I395

The six columns at mid-span provide an excellent opportunity to compare three different treatments of columns exhibiting different levels of ASR. Numbering the columns from 1 to 6 starting from the west, we recommend the following treatment:

Column #	ASR Severity (DRI)	Repair
1	Severe (531)	FRP Wrap
2	Moderate (203)	Electrochemical Lithium Impregnation
3	Mild (152)	Silane
4 - 6	Not tested	Controls

Although columns 4, 5 and 6 were not tested, the general appearance of these columns is similar to columns 1, 2 and 3, respectively. As such, these columns will provide suitable untreated controls.

6.2 I395 over Penobscot River

Most of the piers appear to be in reasonable condition with little visible cracking. The exception is the two land-based piers supporting the 2nd and 3rd spans counting from the west abutment. It is proposed that one of these piers is treated with silane and that the other is left untreated as a control.

The abutments are in similar condition based on a visual examination (cores were only taken from one abutment). It is proposed that one of these abutments be treated with a silane and that the other be left untreated as a control.

6.3 Other Bridges

For the remaining five bridges, it is proposed that one of the abutments be treated with a sealer with the other abutment left untreated as a control. Different sealers will be select for the different treatments.

7 References

Dunbar, P.A. and Grattan-Bellew, P.E. 1995. "Results of Damage rating Evaluation of Condition of Concrete from a Number of Structures Affected by AAR". *In* Proceedings of CANMET/ACI International Workshop on AAR in Concrete, Dartmouth, Nova Scotia, CANMET, Department of Natural Resources Canada, pp. 257-265.

Grattan-Bellew, P.E. 1992. "Comparison of laboratory and field evaluation of alkali-silica reaction in large dams". *In* Proceedings of the First International Conference on Concrete Alkali-Aggregate Reactions in Hydroelectric Plants and Dams, September-October 1992, Fredericton, NB, Canada, 23p.

Table 2: Visual Survey and Characteristics of Cores Extracted from the Bridges in Bangor / Brewer

Bridge structure	**Notes on the coring sites and the structural elements**	**Photo (Appendix B)**	**Core identification**	**Length, inch (all cores are 4-in diameter)**
I395 over Main Street	General view of the coring sites – north side of the bridge; west side of the street.	B1-A		
	Coring site 1: in the abutment under the bridge deck, sheltered. No cracking was observed in the section from where the core was extracted.	B1-B	I395 MS-1	9.5
	Coring site 2: in the abutment, exposed. The section sampled shows a fairly severe network of vertical and horizontal cracks.	B1-C B1-D	I395 MS-2	8
	Coring site 3: in the wing wall, exposed. Coring was performed in a section of the wall showing moderate map cracking.	B1-E	I395 MS-3	7
I395 over Penobscot River (Brewer side)	General view of the sites (east side of the river) where cores 1 and 2 were collected.	B2-A		
	Coring site 1a: in the abutment under the bridge deck, sheltered. Coring was performed in a section showing map/pattern cracking due to leaking joint in the deck.	B2-B B2-C	I395 PR-1a	9.5
	Coring site 1b: in the same abutment under the bridge deck, about 25 feet south of site 1a, sheltered. Coring was performed in a section with no visible cracking.	B2-B B2-D	I395 PR-1b	9
	Coring site 2: in the wing wall, exposed. Coring was performed in a section showing fairly severe map cracking.	B2-E	I395 PR-2	7.5

Table 2 (cont'd): Visual Survey and Characteristics of Cores Extracted from the Bridges in Bangor / Brewer

Bridge structure	Notes on the coring sites and the structural elements	Photo (Appendix B)	Core identification	Length, inch (all cores are 4-in diameter)
	General view of the bridge (east shore of the river).	B3-A		
	Coring site 3: first row of piers; external pier partially exposed. Coring was performed in the external pier which shows light map cracking. Coring was done down to the first row of reinforcing bars, about 5 inches deep.	B3-A B3-B	I395 PR-3	5.75 (stopped against large reinforcing bar)
	Coring site 4a and 4b: first row of piers; middle pier, totally sheltered. The pier shows light map/pattern cracking. Coring (4a and 4b) was done down to the first row of reinforcing bars, about 4 inches deep.	B3-C	I395 PR-4a	4 (stopped against large reinforcing bar)
I395 over Penobscot River (Bangor side)			I395 PR-4b	4 (stopped against large reinforcing bar)
	Coring site 5: 2^{nd} row of piers; south pier, east face (facing the river).	B3-D	I395 PR-5	10
	Coring site 6: 2^{nd} row of piers; south pier, west face.	B3-D	I395 PR-6	10
	Coring site 7: 2^{nd} row of piers; north pier, east face (facing the river).	B3-D	I395 PR-7	11
	Coring site 8: 2^{nd} row of piers; north pier, west face. Longitudinal cracking can be observed on the exposed surface of the arch of the pier.	B3-E	I395 PR-8	4 (stopped against large reinforcing bar)

Table 2 (cont'd): Visual Survey and Characteristics of Cores Extracted from the Bridges in Bangor / Brewer

Bridge structure	**Notes on the coring sites and the structural elements**	**Photo (Appendix B)**	**Core identification**	**Length, inch (all cores are 4-in diameter)**
5th Parkway over I395	General view of south part of the structure.	B4-A		
	Coring site 1: in the abutment, sheltered. Coring was performed in a section with no visible cracking.	B4-B B4-C	I395 5th-1	10
	Coring site 2: in the abutment, exposed. Coring was performed in a section showing fairly severe vertical and horizontal cracking.	B4-B B4-D	I395 5th-2	7.5
	Coring site 3: in the wing wall, exposed. Coring was performed in a section of the wall showing moderate map cracking.	B4-E	I395 5th-3	11
South Parkway over I395	General view of the middle part of the bridge. There are six circular columns supporting the structure at that location.	B5-A		
	Coring site 1: in the first column on the east side of the bridge, exposed. Coring was performed in the exposed part (eastern side) of the column showing regularly-spaced vertical cracks connected by map cracking.	B5-B	I395 SP-1	9
	Coring site 2: in the second column (from the east side of the bridge), sheltered. Coring was performed in the eastern part of the column showing light vertical cracking.	B5-C	I395 SP-2	10
	Coring site 3: in the third column (from the east side of the bridge), sheltered. Coring was performed in the eastern part of the column showing light vertical cracking.	B5-D	I395 SP-3	11

Table 2 (cont'd): Visual Survey and Characteristics of Cores Extracted from the Bridges in Bangor / Brewer

Bridge structure	**Notes on the coring sites and the structural elements**	**Photo (Appendix B)**	**Core identification**	**Length, inch (all cores are 4-in diameter)**
Green Point Road over I395	General view of the south part of the structure	B6-A		
	Coring site 1: in the abutment, sheltered. Coring was performed in a section showing light map cracking.	B6-B B6-C	I395 GPR-1	10.5
	Coring site 2: in the abutment, exposed. Coring was performed in a section showing moderate map cracking.	B6-D	I395 GPR-2	11
Route 1A over I395	General view of the east part of the structure.	B7-A		
	Coring site 1: in the abutment, sheltered. Coring was performed in a section with no visible cracking.	B7-B	I395 R1A-1	11
	Coring site 2: in the abutment, exposed. Coring was performed in a section showing vertical cracks connected by map cracking.	B7-C	I395 R1A-2	9.25
	Coring site 3: in the wing wall, exposed. Coring was performed in a section of the wall showing moderate map cracking.	B7-D	I395 R1A-3	9

Table 3: Results of the Damage Rating Index

Structure	Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	DRI
I395 over Main Street	I395 MS-1	80	0	0	37	0	0	17	0	**133**
	I395 MS-2	91	0	28	27	16	5	27	0	**195**
	I395 MS-3	96	2	103	159	97	2	65	4	**528**
I395 over Penobscot River	I395 PR-1a	113	15	43	243	34	6	73	5	**530**
	I395 PR-1b	119	2	7	61	0	0	19	0	**208**
	I395 PR-2	95	20	153	293	111	18	70	5	**764**
	I395 PR-3	113	8	2	74	7	0	27	0	**230**
	I395 PR-4a	132	0	4	36	4	0	21	0	**198**
	I395 PR-4b	135	0	5	29	5	4	17	1	**196**
	I395 PR-5	88	0	0	112	0	0	27	0	**228**
	I395 PR-6	87	0	16	78	7	0	12	0	**200**
	I395 PR-7	106	1	34	44	13	3	38	0	**240**
	I395 PR-8	74	0	0	91	0	3	32	0	**201**
5th Parkway (Robertson) over I395	I395 5th-1	143	0	21	67	20	0	26	2	**279**
	I395 5th-2	143	6	124	361	145	13	87	3	**882**
	I395 5th-3	122	3	39	167	36	1	57	2	**427**
South Parkway over I395	I395 SP-1	125	0	61	239	44	0	62	1	**531**
	I395 SP-2	86	0	10	82	8	0	17	1	**203**
	I395 SP-3	107	0	0	28	0	1	14	1	**152**
Green Point Road over I395	I395 GPR-1	123	2	69	198	31	9	62	5	**499**
	I395 GPR-2	99	0	53	231	41	5	48	2	**479**
Route 1A over I395	I395 R1A-1	105	0	3	90	3	4	51	3	**258**
	I395 R1A-2	109	5	66	305	54	22	65	2	**627**
	I395 R1A-3	116	6	84	257	92	11	69	1	**636**

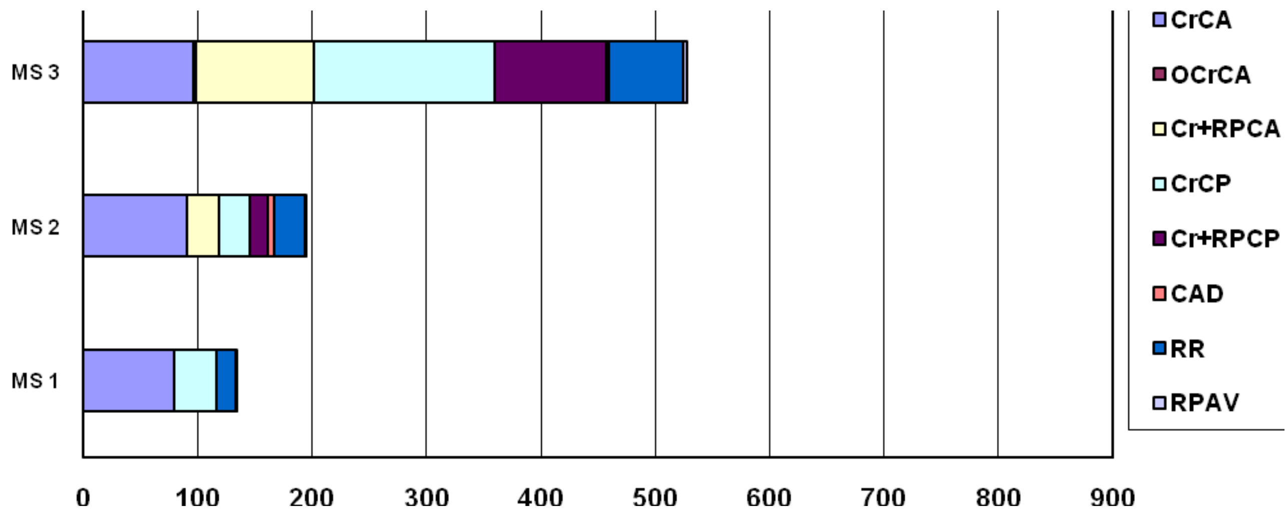


Figure 1: DRI values for the cores extracted from I395 over Main Street

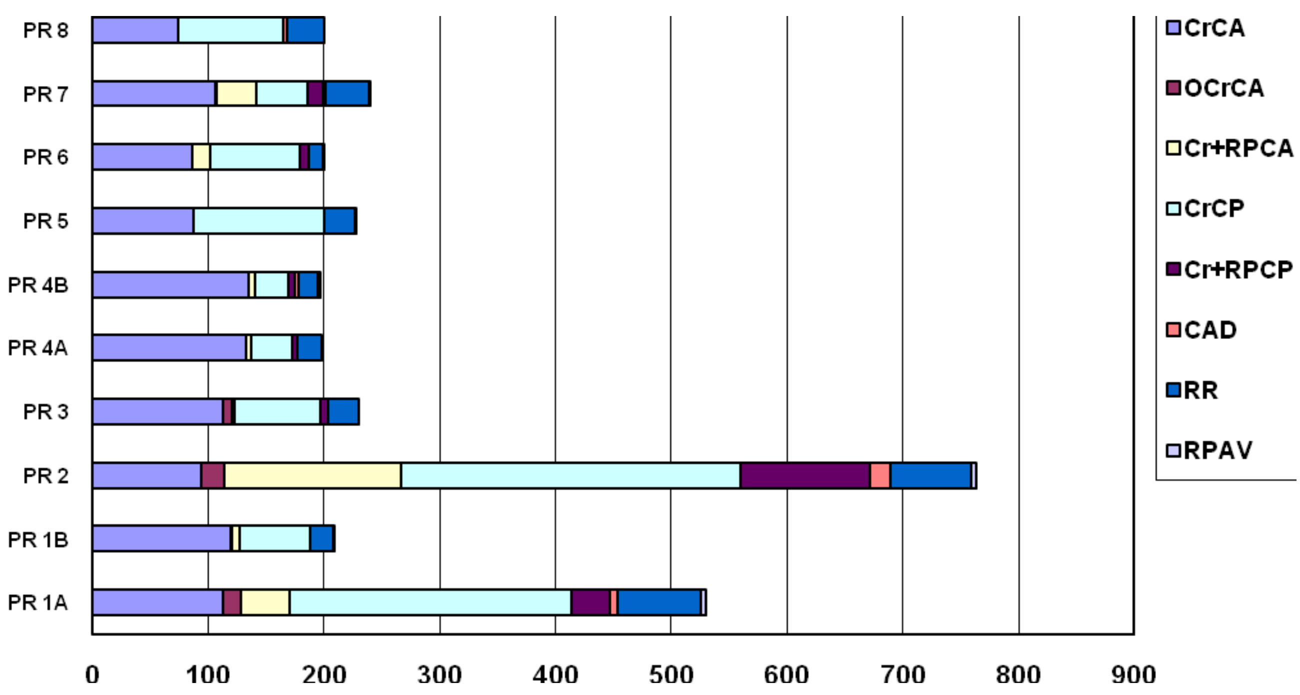


Figure 2: DRI values for the cores extracted from I395 over Penobscot River

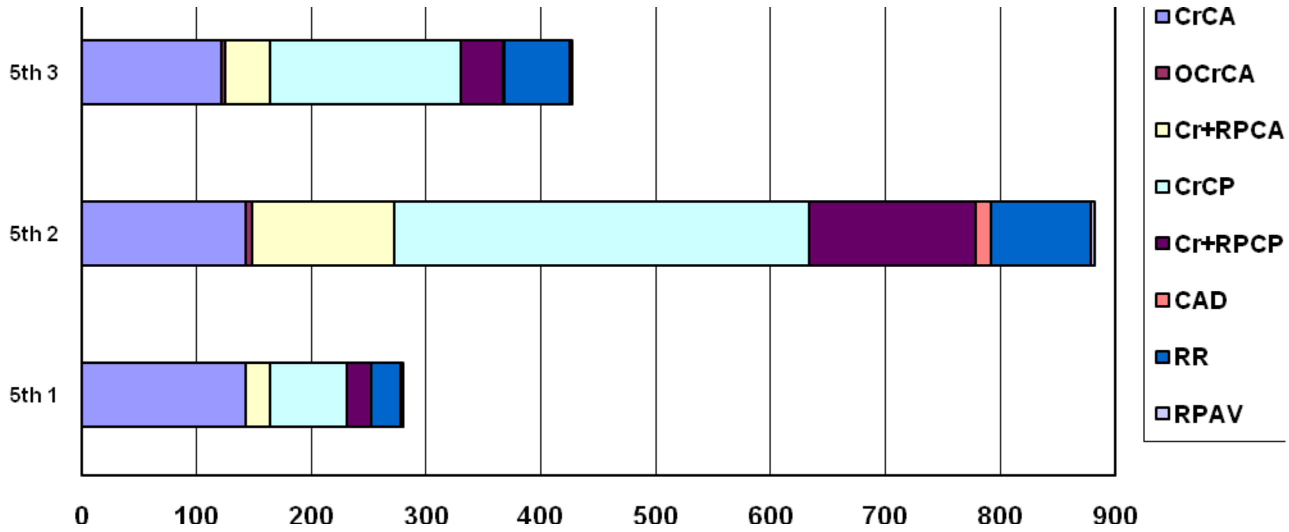


Figure 3: DRI values for the cores extracted from 5th Parkway over I395

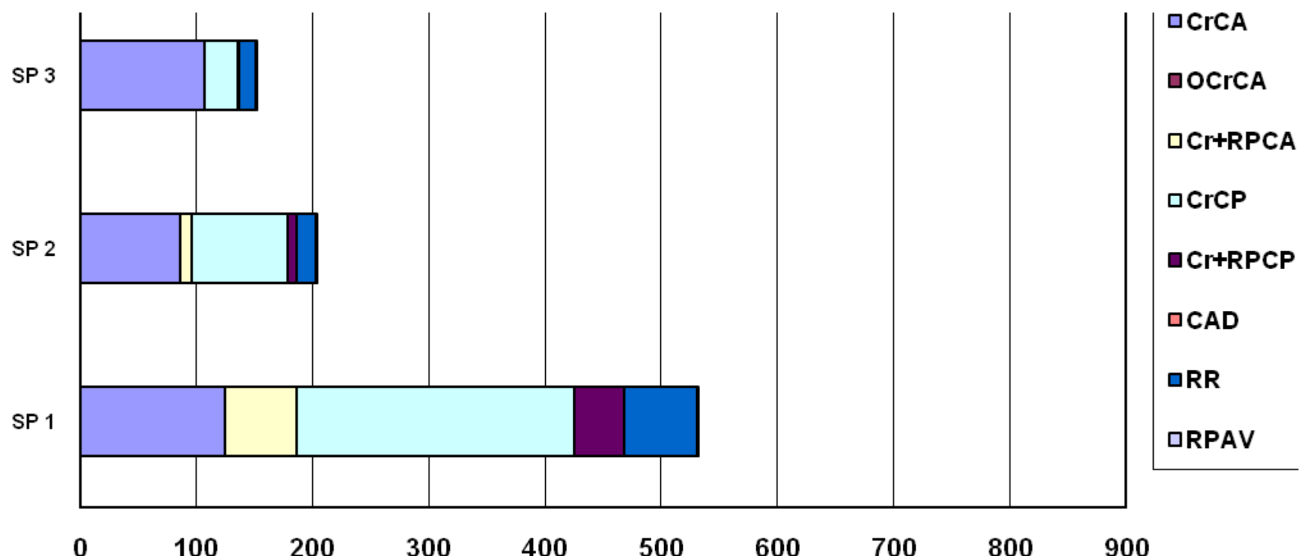


Figure 4: DRI values for the cores extracted from South Parkway over I395

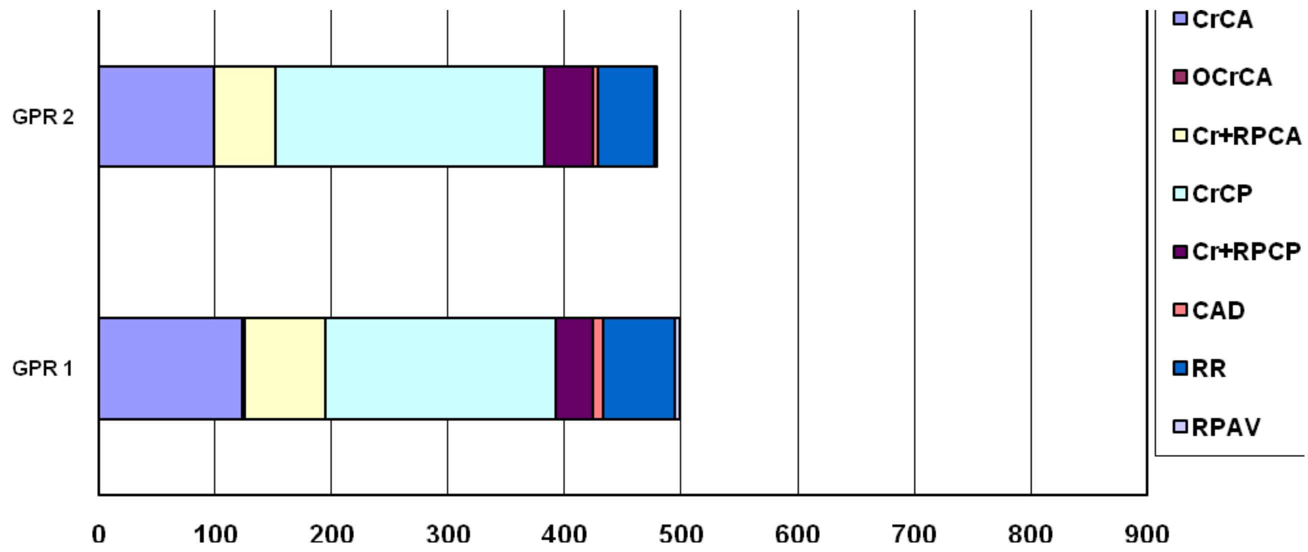


Figure 5: DRI values for the cores extracted from Green Point Road over I395

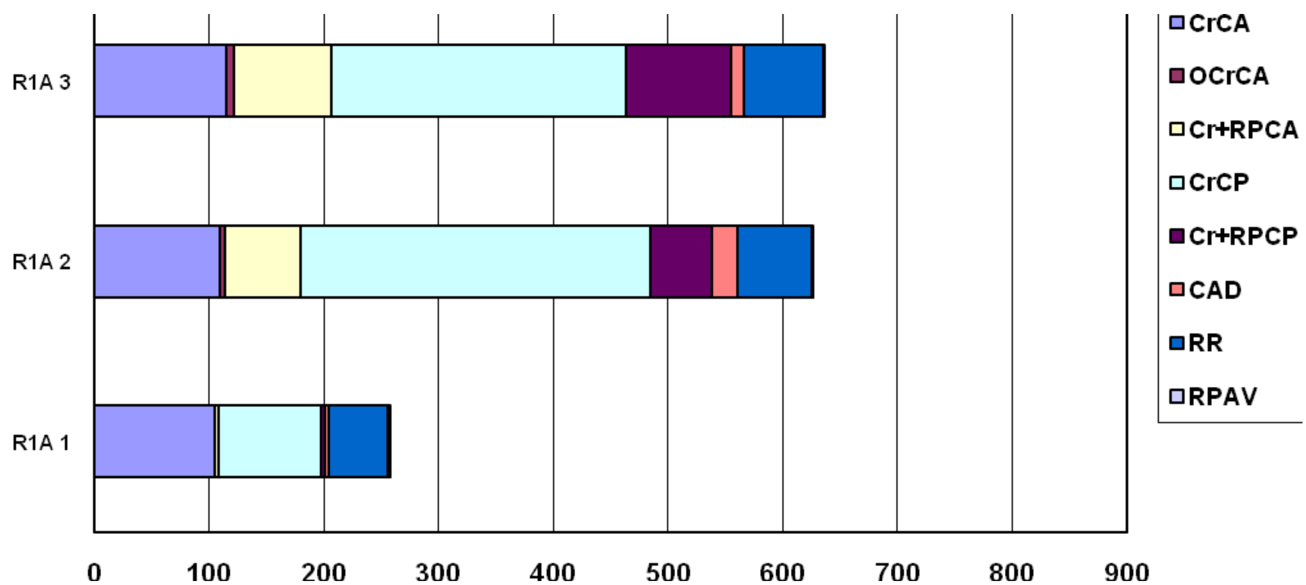


Figure 6: DRI values for the cores extracted from Route 1A over I395

Table 4: Summary of the Petrographic Observations on the Cores from Maine

Structure	**Sample**	**DRI**	**Typical crack width in the cement paste (mm)**	**Extent of ASR**
I395 over Main Street	I395 MS-1	**133**	< 0.02	Traces to Low
	I395 MS-2	**195**	< 0.02	Low
	I395 MS-3	**528**	< 0.04	Moderate
I395 over Penobscot River	I395 PR-1a	**530**	< 0.05, sometimes up to 0.10	Moderate
	I395 PR-1b	**208**	< 0.02	Low
	I395 PR-2	**764**	< 0.05, sometimes up to 0.10	High
	I395 PR-3	**230**	< 0.02	Low
	I395 PR-4a	**198**	< 0.02	Low
	I395 PR-4b	**196**	< 0.02	Low
	I395 PR-5	**228**	< 0.02	Low
	I395 PR-6	**200**	< 0.02	Low
	I395 PR-7	**240**	< 0.05	Fair
	I395 PR-8	**201**	< 0.02	Low
5th Parkway (Robertson) over I395	I395 5th-1	**279**	< 0.02	Fair
	I395 5th-2	**882**	< 0.05, sometimes up to 0.10	High
	I395 5th-3	**427**	< 0.05, sometimes up to 0.10	Moderate
South Parkway over I395	I395 SP-1	**531**	< 0.05, sometimes up to 0.10	Moderate
	I395 SP-2	**203**	< 0.02	Low
	I395 SP-3	**152**	< 0.02	Low
Green Point Road over I395	I395 GPR-1	**499**	< 0.05, sometimes up to 0.10	Moderate
	I395 GPR-2	**479**	< 0.05, sometimes up to 0.10	Moderate
Route 1A over I395	I395 R1A-1	**258**	< 0.02-0.03	Fair
	I395 R1A-2	**627**	< 0.05, sometimes up to 0.10	High
	I395 R1A-3	**636**	< 0.05, sometimes up to 0.10	High

Appendix A

Coring Proposal

Appendix B

Photographs of the Bridge Structures Investigated
and Coring Sites

Figure B1: I395 over Main Street

A: General view of the western part of the structure. B: Coring site no. 1. C: Coring sites no. 1 and 2. D: Coring sites no. 2 and 3. E: Coring site no. 3.

A

B

C

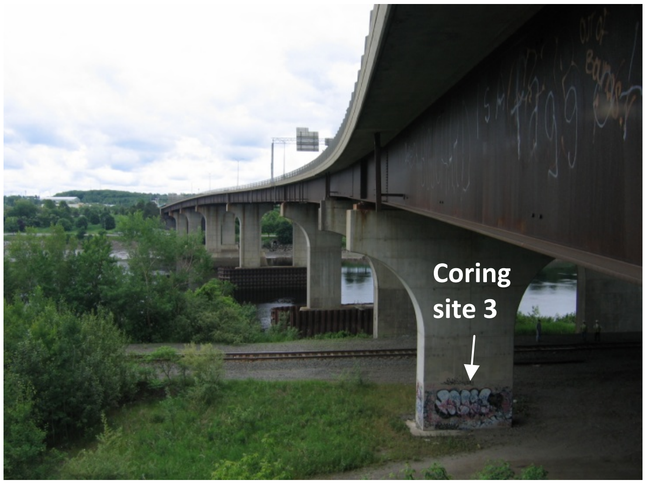
D

E

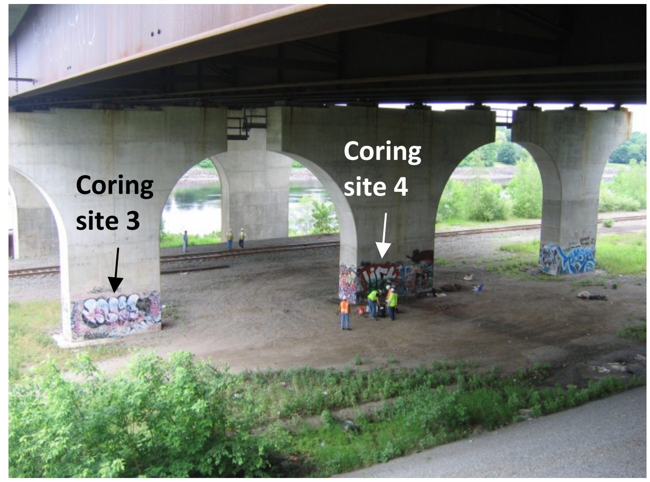
Figure B2: I395 over Penobscot River

A: General view of the abutment on the east shore of the river (coring sites no. 1 and 2). B: Coring sites no. 1a and 1b. C: Coring site no. 1a. D: Coring site no. 1b. E: Coring site no. 2.

A



B



C

E

D

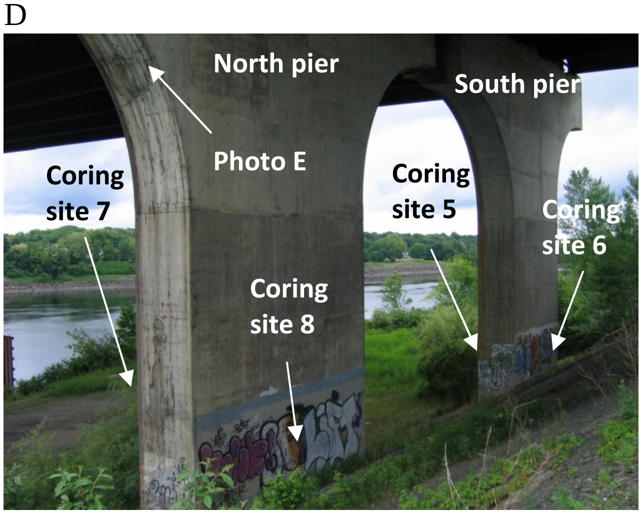
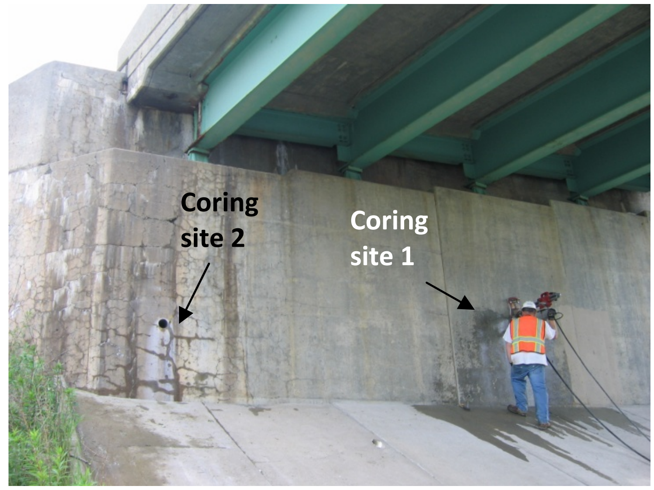


Figure B3: I395 over Penobscot River

A: General view of the bridge from the west shore of the river. B: Coring site no. 3 and 4 (first row of piers). C: Coring site no.4. D: Coring sites no. 5 to 8 (2nd row of piers). E: Closer view of cracking in the arch of the north pier, 2nd row of piers (coring sites 7 and 8).

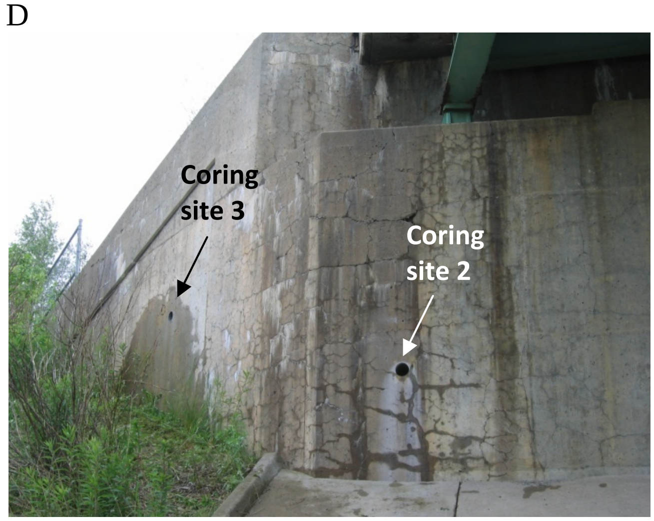
A

B



C

D



E

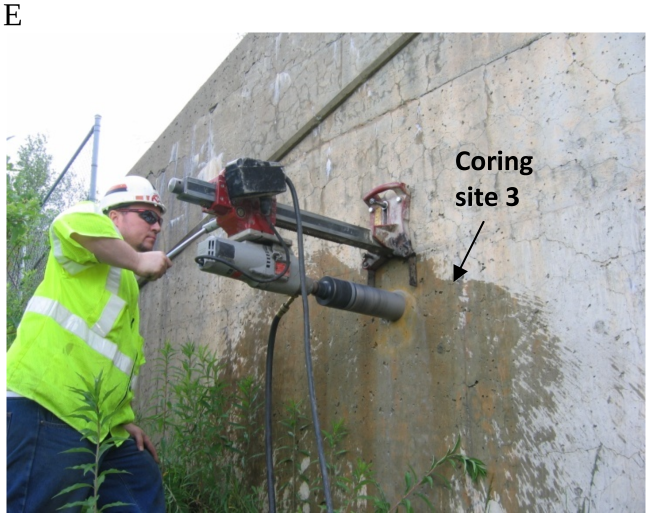


Figure B4: 5th Parkway (Robertson) over I395

A: General view of the structure (south side). B. Coring sites no. 1 and 2. C: Coring site no. 1. D: Coring sites no. 2 and 3. E. Coring site no. 3.

A

B

C

D

Figure B5: South Parkway over I395

A: General view of the middle (supported) part of the bridge. B. External pier (east side - coring site no. 1. C: Second pier from the east side (coring site no. 2). D: Third pier from the east side (coring site no. 3).

Figure B6: Green Point Road over I395
A: General view of the structure (south side). B: General view of the coring sites no. 1 and 2. C: Coring site no. 1. D: Coring site no. 2.

A

B

C

D

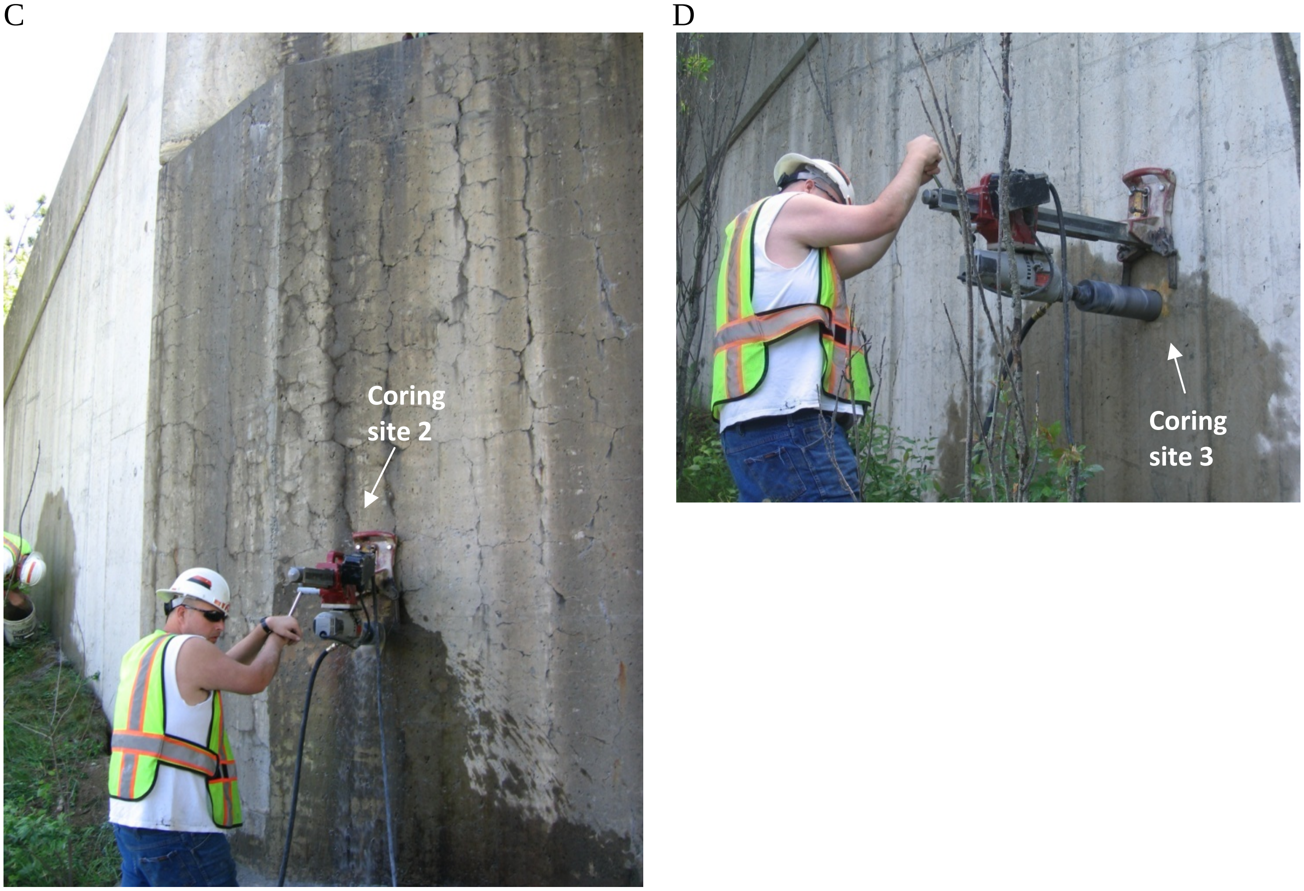
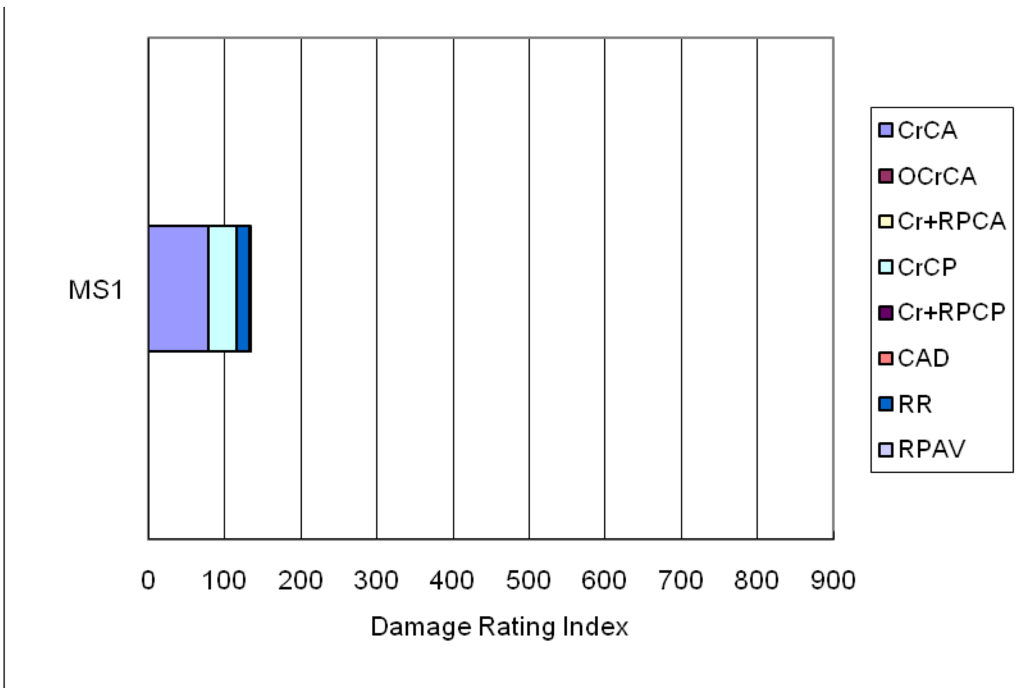


Figure B7: Route 1A over I395
A: General view of the structure (east side). B: Coring site no. 1. C: Coring site no. 2. D: Coring site no. 3.

Appendix C

Photographs of the Polished Core Sections,
Detailed Results of the DRI and
Micrographs of the Petrographic Symptoms of Deterioration.

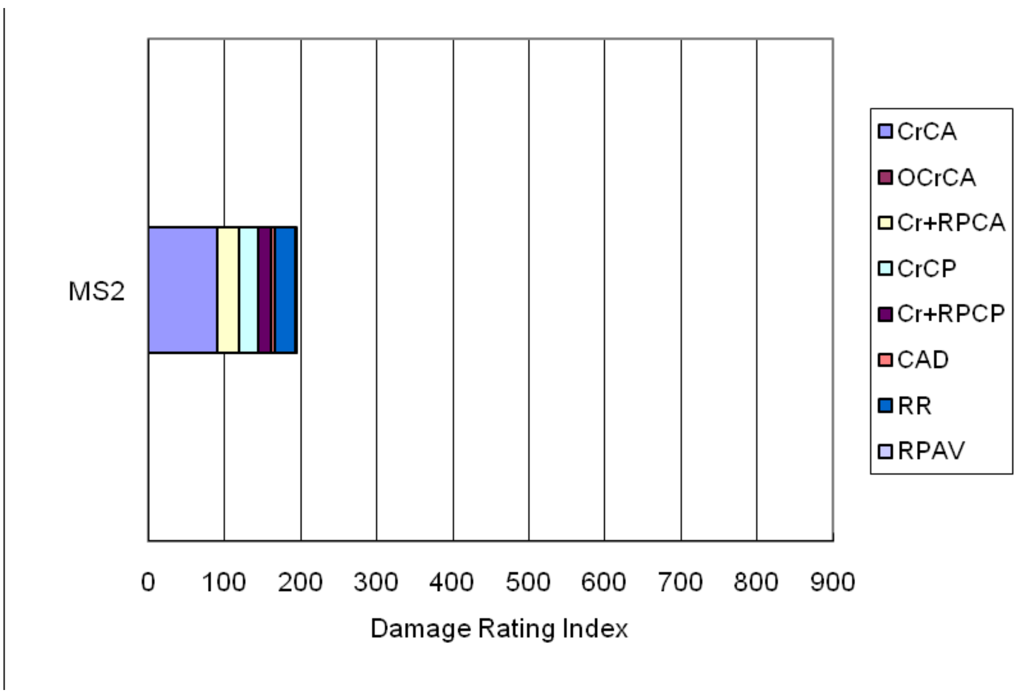
I395 over Main Street - CORE I395 MS1



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
MS1	80	0	0	37	0	0	17	0	**133**

Figure C1: DRI results for Core I395 MS1

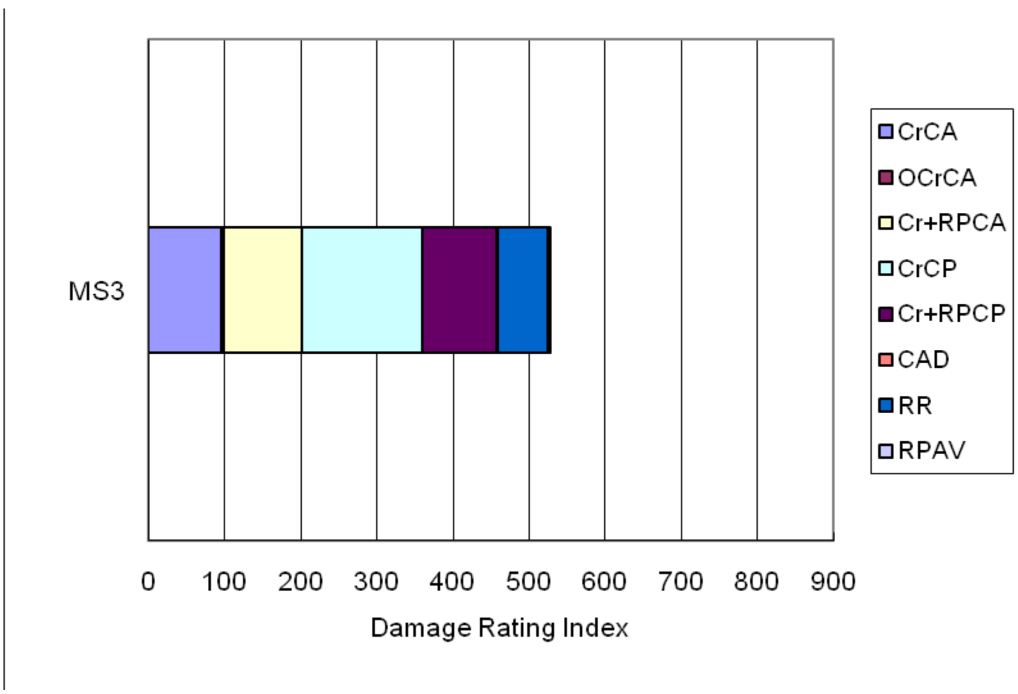
I395 over Main Street - CORE I395 MS2



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
MS2	91	0	28	27	16	5	27	0	**195**

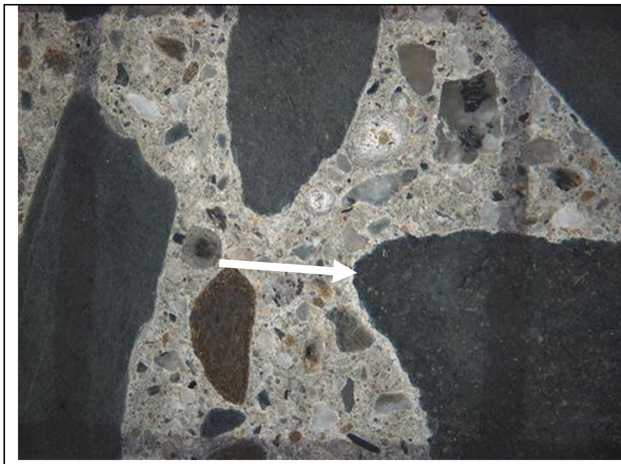
Figure C2: DRI results for Core I395 MS2

I395 over Main Street - CORE I395 MS3

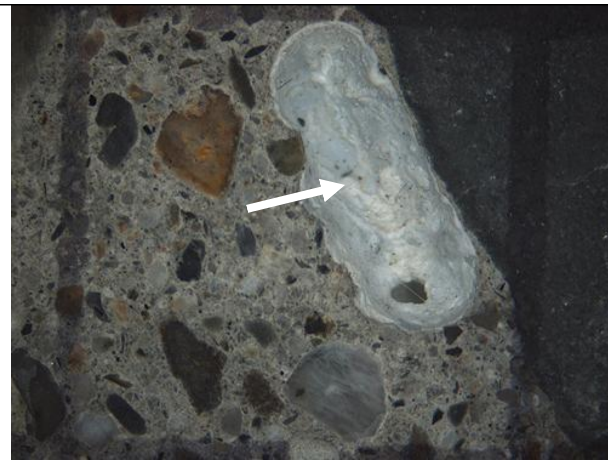


Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
MS3	96	2	103	159	97	2	65	4	**528**

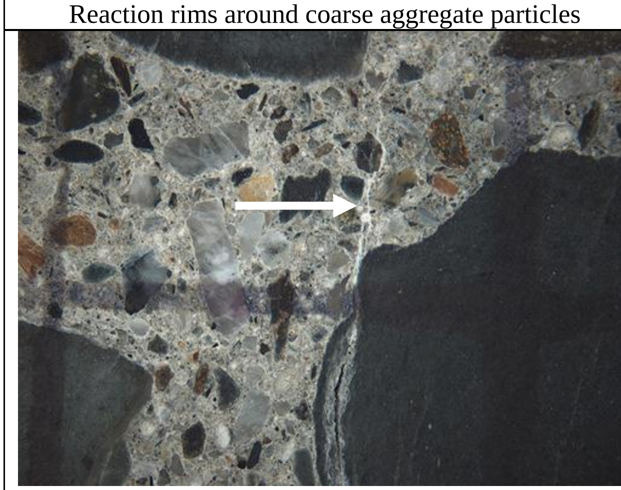
Figure C3: DRI results for Core I395 MS3



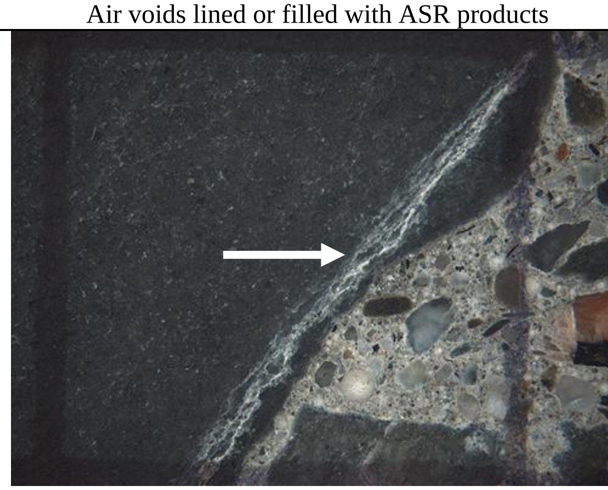
A: I395 MS1
Reaction rims around coarse aggregate particles



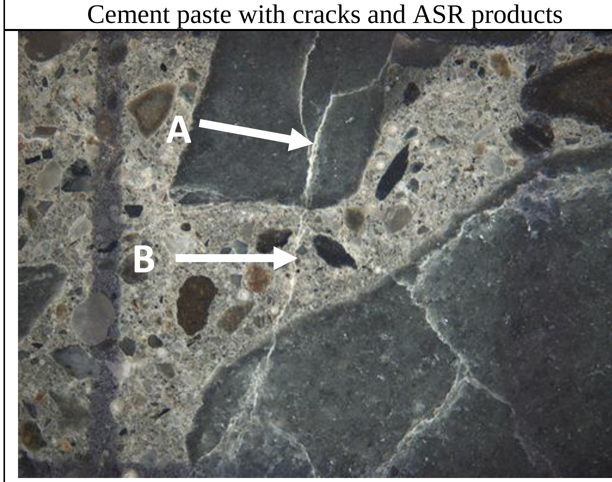
B: I395 MS2
Air voids lined or filled with ASR products



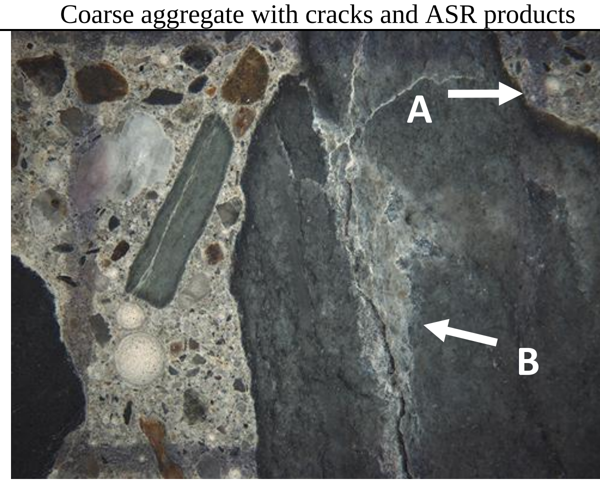
C: I395 MS2
Cement paste with cracks and ASR products



D: I395 MS2
Coarse aggregate with cracks and ASR products



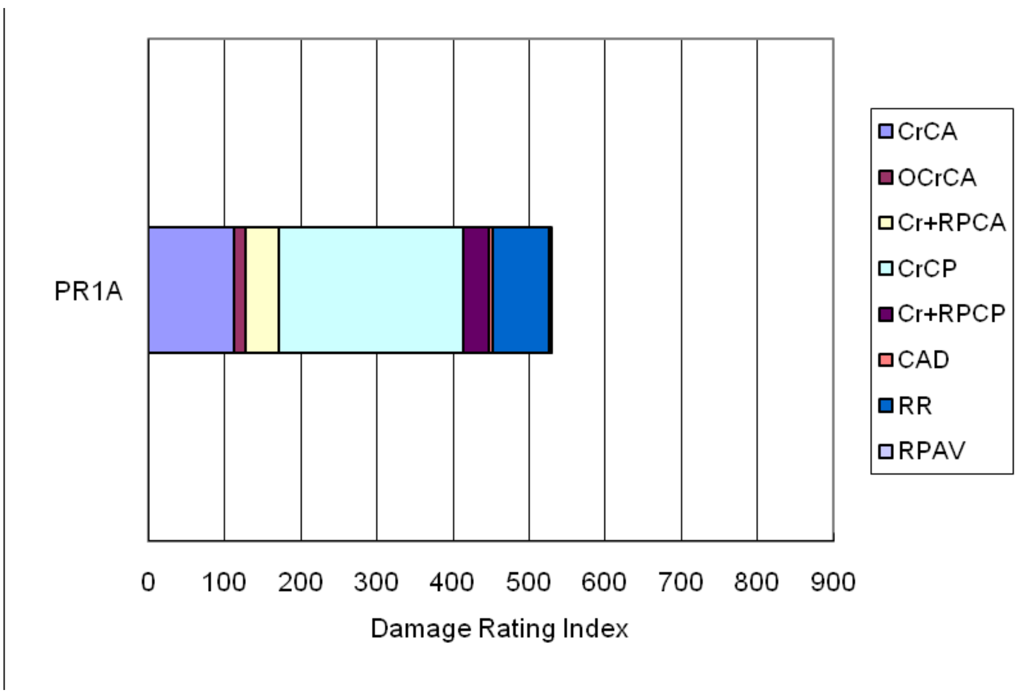
E: I395 MS3
Coarse aggregate with cracks and ASR products (A) and cement paste with cracks and ASR products (B)



F: I395 MS3
Reaction rims around aggregate particle (A) and coarse aggregate with cracks (B)

Figure C4: Micrographs illustrating petrographic features of deterioration in cores from the structure I395 over Main Street.

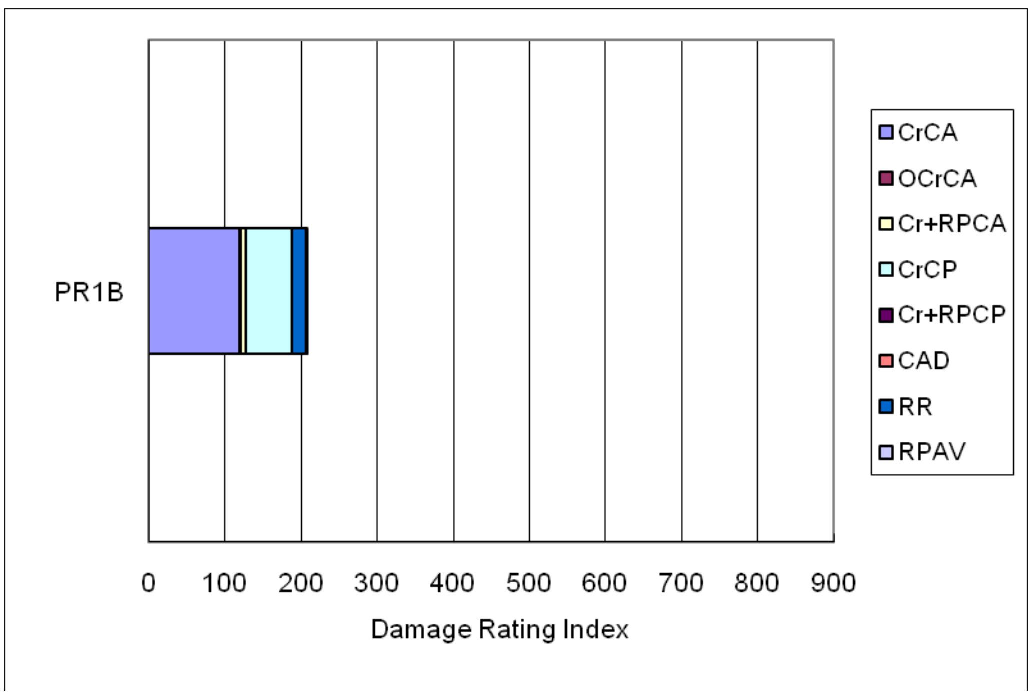
I395 over Penobscot River - CORE I395 PR1a



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
PR1a	113	15	43	243	34	6	73	5	**530**

Figure C5: DRI results for Core I395 PR1a

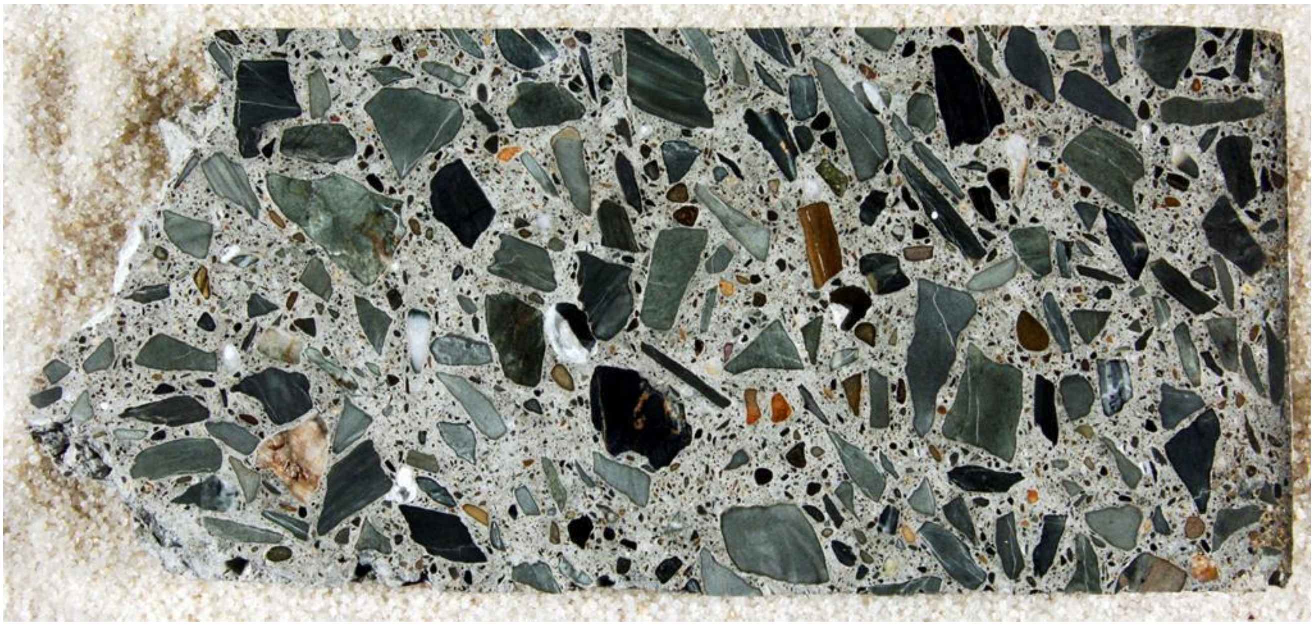
I395 over Penobscot River - CORE I395 PR1b

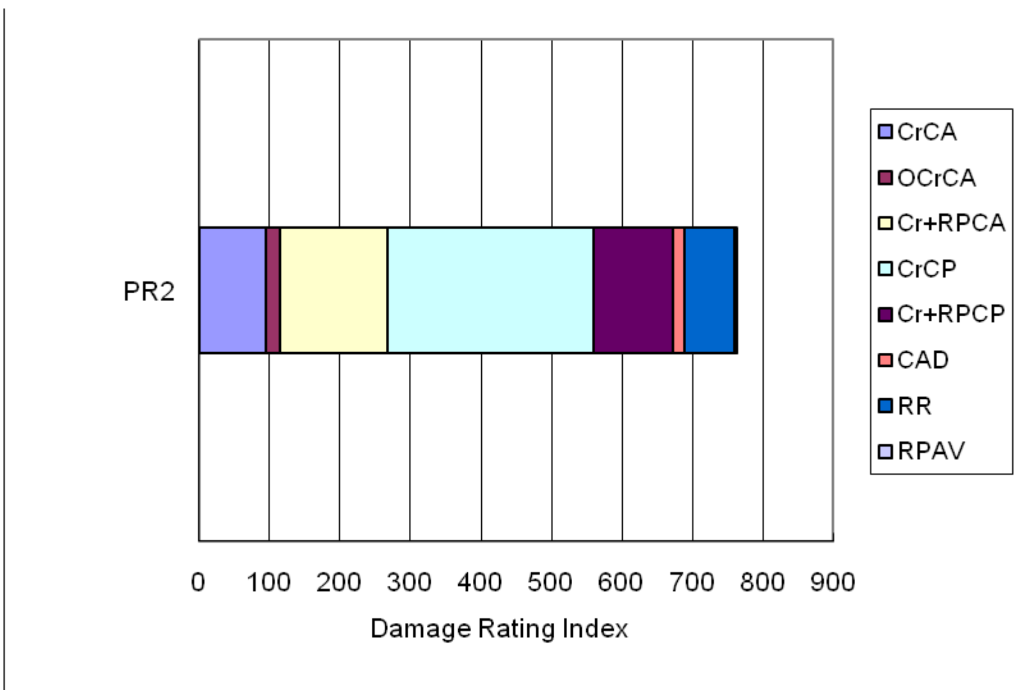


Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
PR1b	119	2	7	61	0	0	19	0	**208**

Figure C6: DRI results for Core I395 PR1b

I395 over Penobscot River - CORE I395 PR2

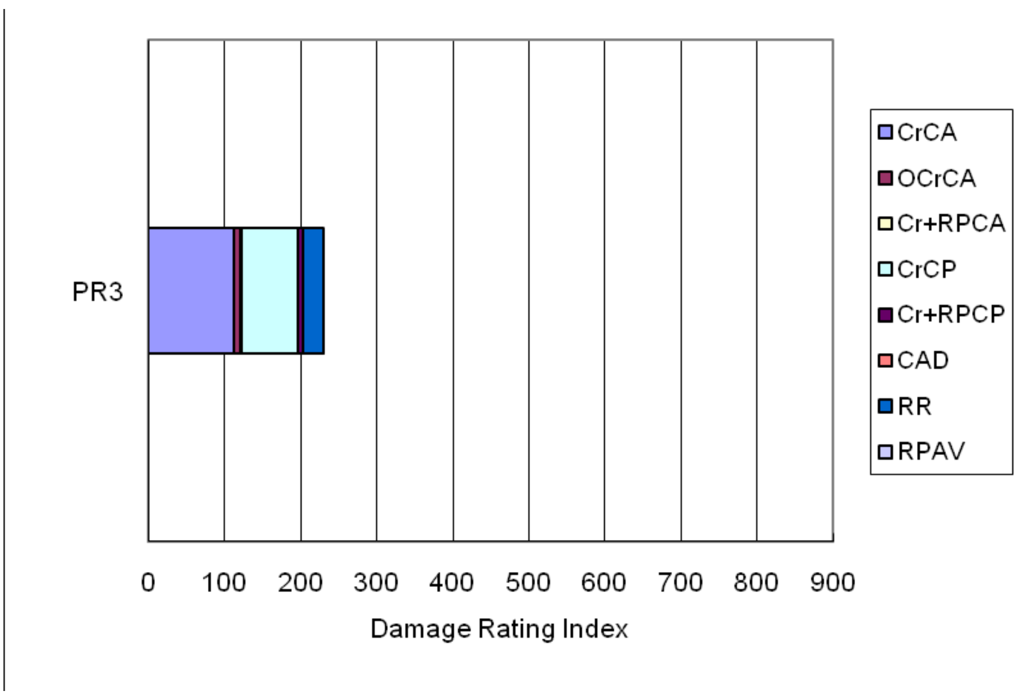




Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
PR2	95	20	153	293	111	18	70	5	**764**

Figure C7: DRI results for Core I395 PR2

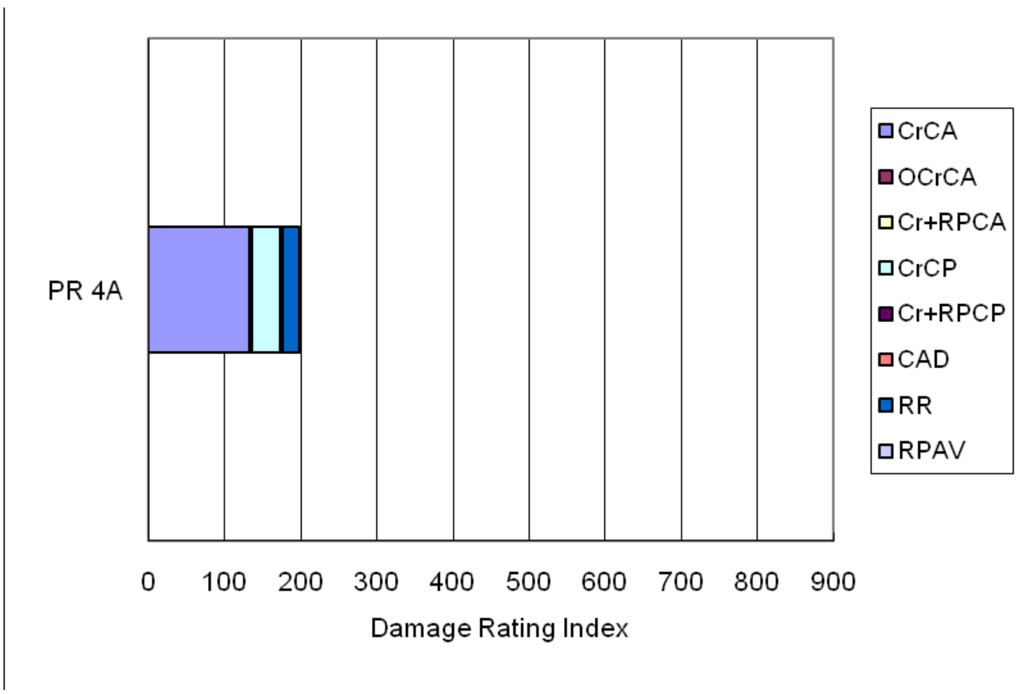
I395 over Penobscot River - CORE I395 PR3



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
PR3	113	8	2	74	7	0	27	0	**230**

Figure C8: DRI results for Core I395 PR3

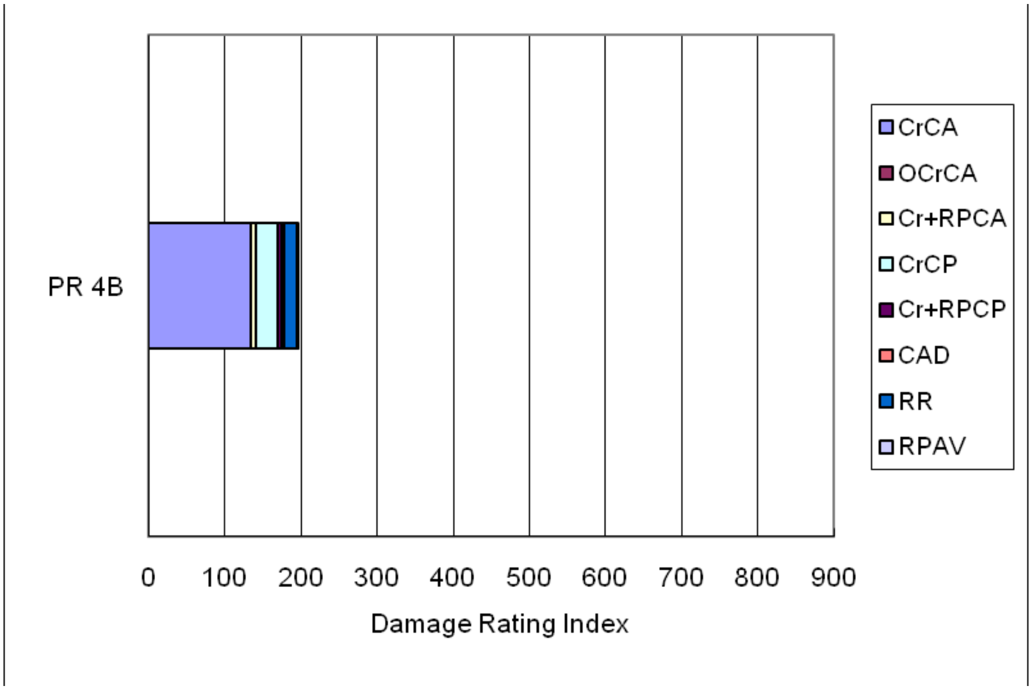
I395 over Penobscot River - CORE I395 PR4a



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
PR 4A	132	0	4	36	4	0	21	0	**198**

Figure C9: DRI results for Core I395 PR4a

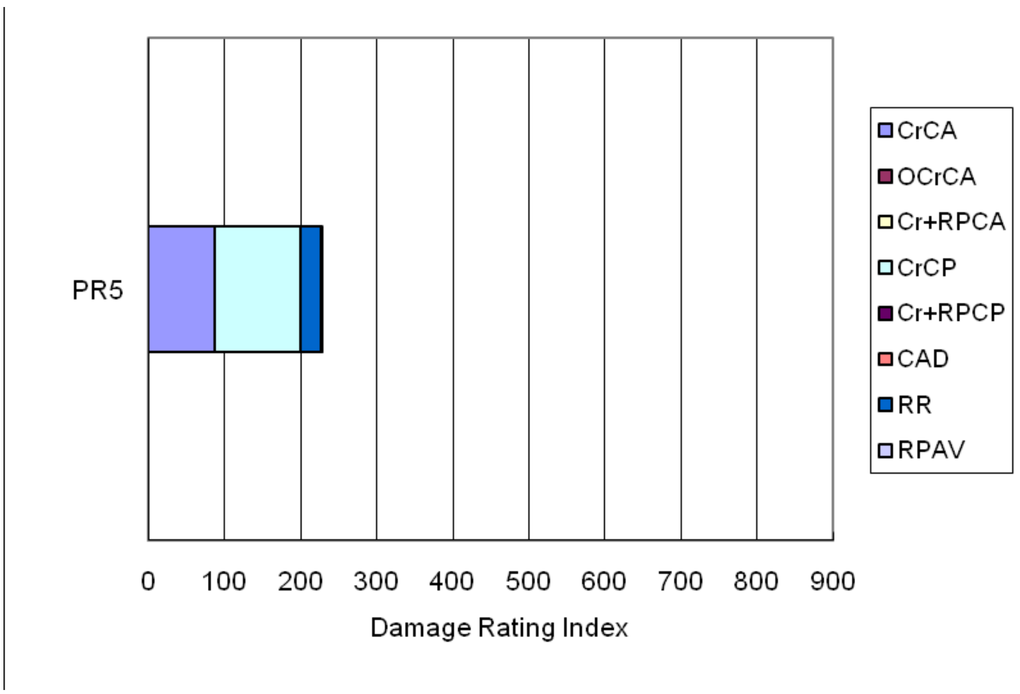
I395 over Penobscot River - CORE I395 PR4b



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
PR 4B	135	0	5	29	5	4	17	1	**196**

Figure C10: DRI results for Core I395 PR4b

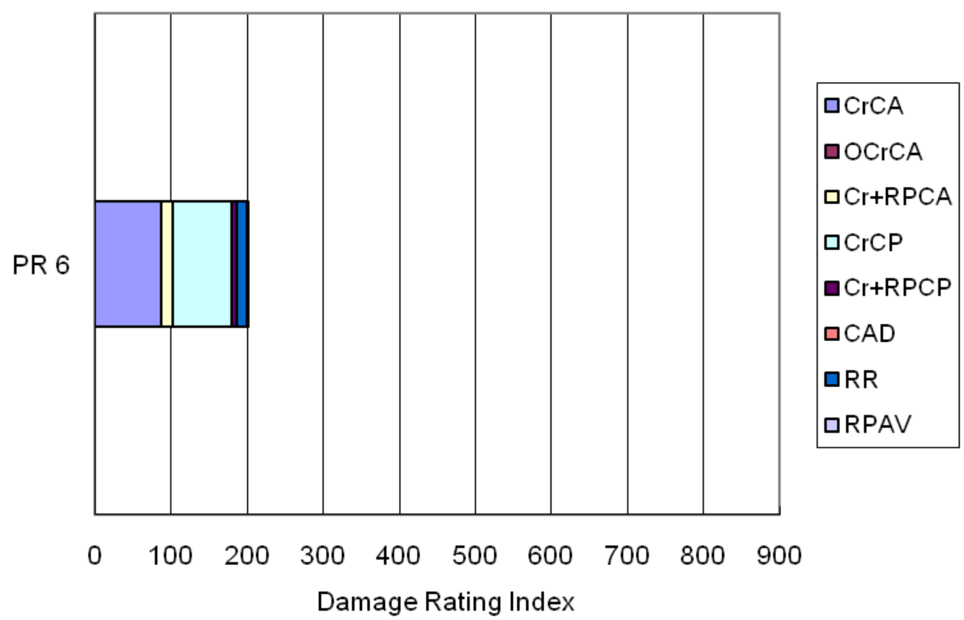
I395 over Penobscot River - CORE I395 PR5



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
PR5	88	0	0	112	0	0	27	0	**228**

Figure C11: DRI results for Core I395 PR5

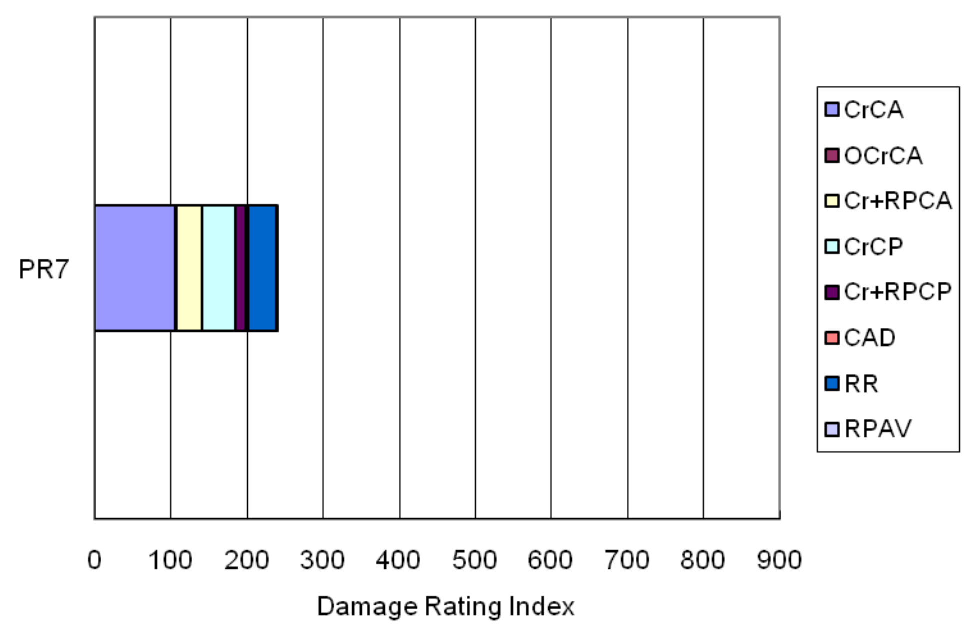
I395 over Penobscot River - CORE I395 PR6



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
PR 6	87	0	16	78	7	0	12	0	**200**

Figure C12: DRI results for Core I395 PR6

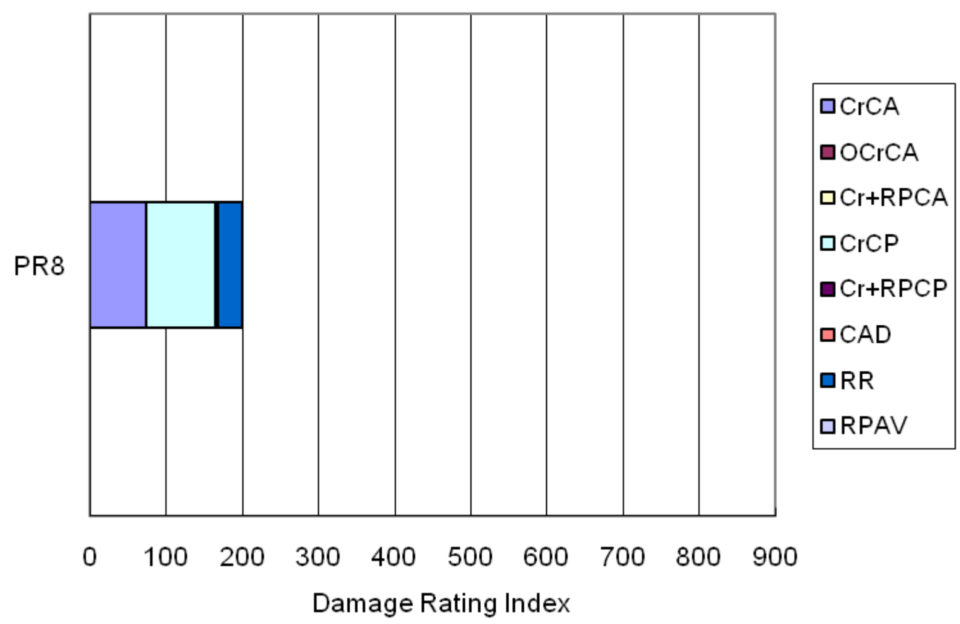
I395 over Penobscot River - CORE I395 PR7



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
PR7	106	1	34	44	13	3	38	0	**240**

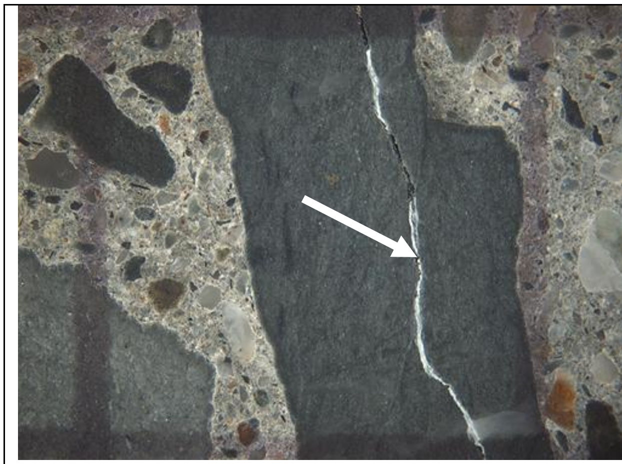
Figure C13: DRI results for Core I395 PR7

I395 over Penobscot River - CORE I395 PR8

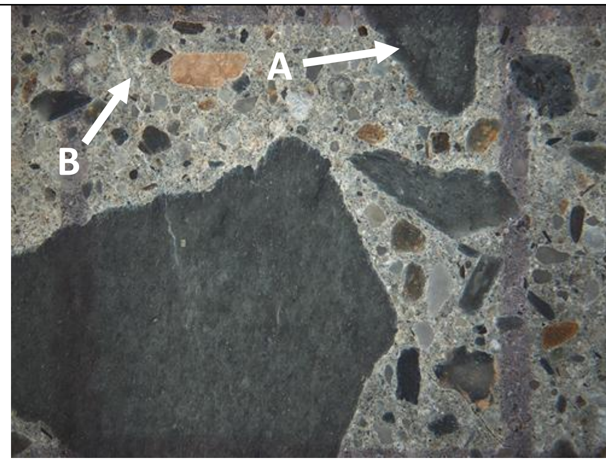


Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
PR8	74	0	0	91	0	3	32	0	**201**

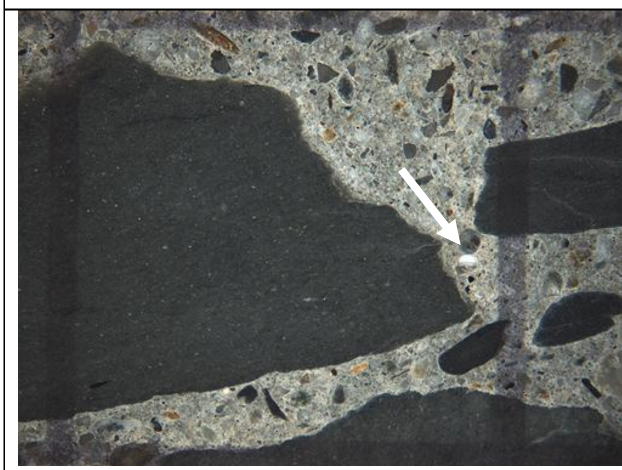
Figure C14: DRI results for Core I395 PR8



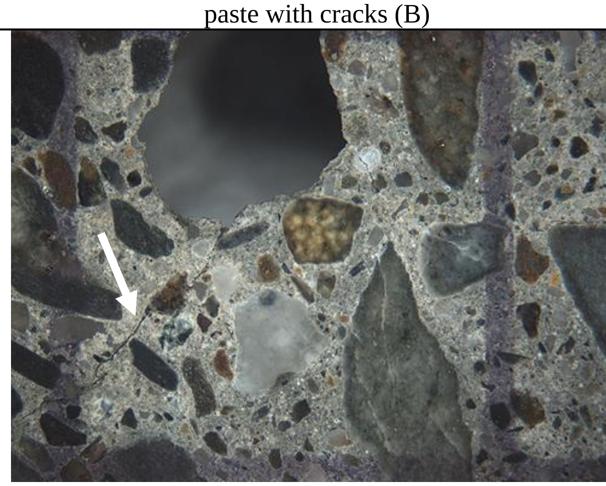
A: I395 PR1a
Coarse aggregate particle with crack and ASR products



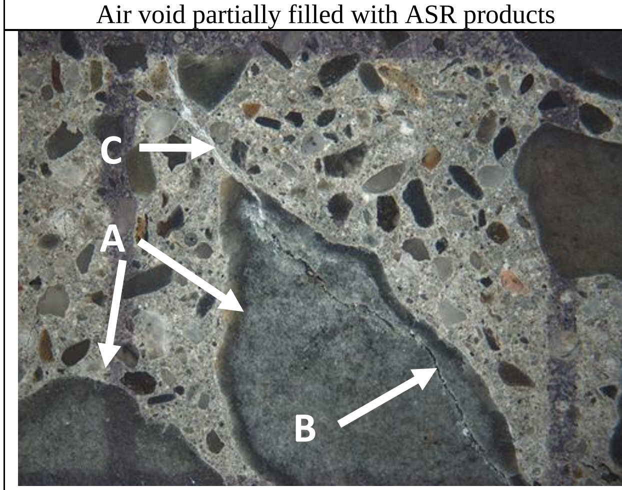
B: I395 PR1a
Reaction rims around aggregate particle (A) and cement paste with cracks (B)



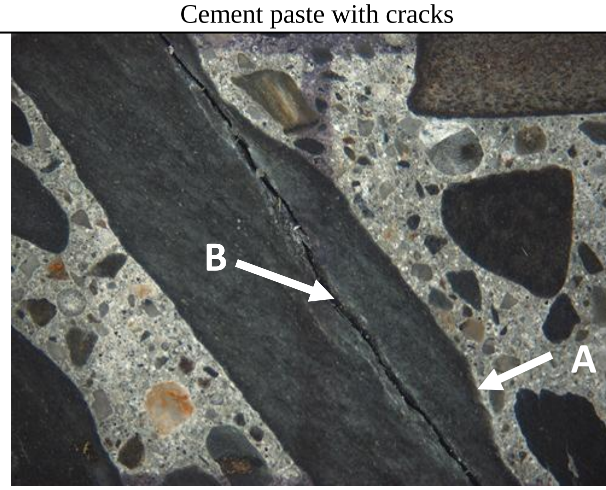
C: I395 PR1b
Air void partially filled with ASR products



D: I395 PR2
Cement paste with cracks

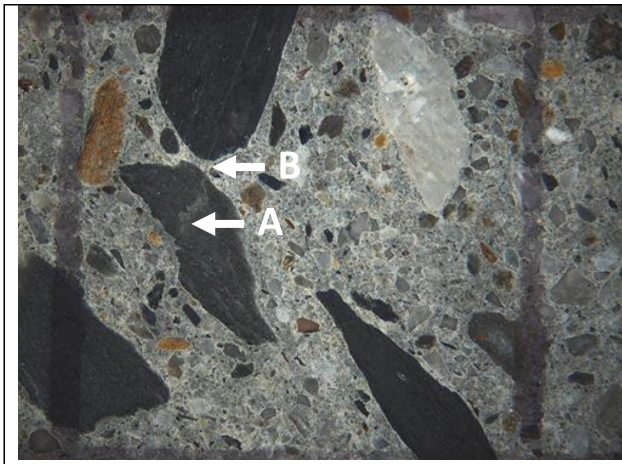


E: I395 PR2
Coarse aggregate with reaction rims (A), cracks and ASR products (B) and cement paste with cracks and ASR products (C)

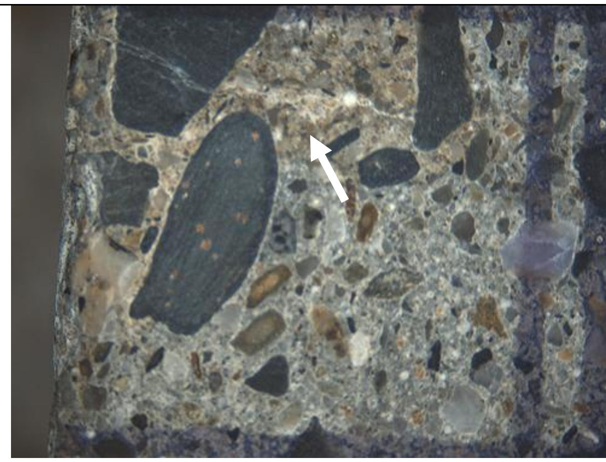


F: I395 PR2
Coarse aggregate particle with reaction rim (A) and open crack (B)

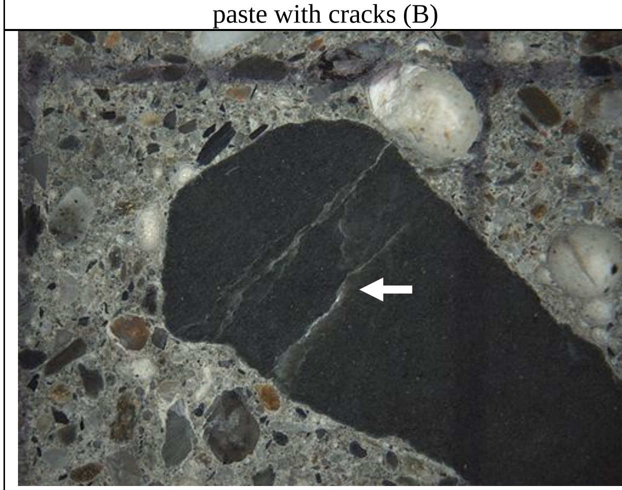
Figure C15: Micrographs illustrating petrographic features of deterioration in cores from the structure I395 over Penobscot River.



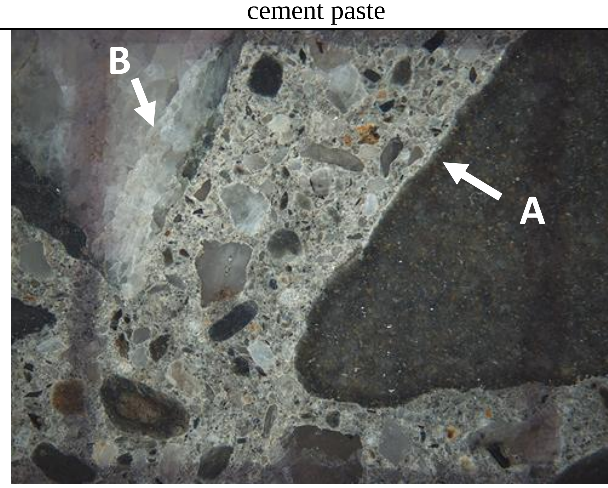
G: I395 PR5
Coarse aggregate particle with cracks (A) and cement paste with cracks (B)



H: I395 PR6
Carbonation on first cm of the core along the crack in the cement paste



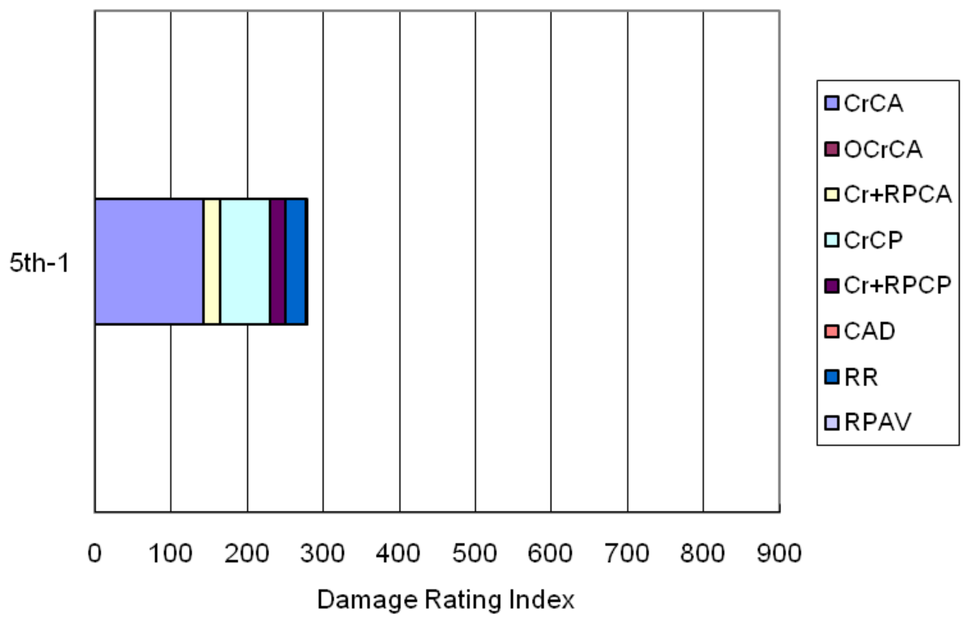
I: I395 PR7
Coarse aggregate particle with cracks and ASR products



J: I395 PR8
Coarse aggregate particles with reaction rim (A) and cracks (B)

Figure C15 (cont'd): Micrographs illustrating petrographic features of deterioration in cores from the structure I395 over Penobscot River.

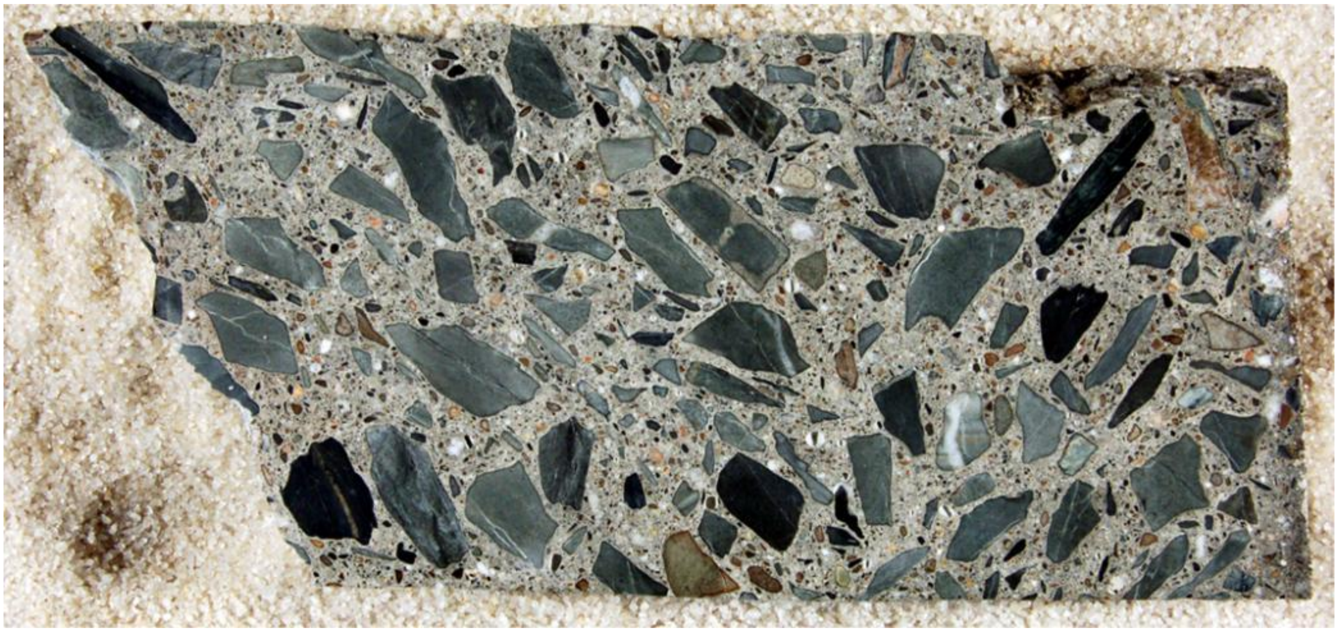
5^{th} Parkway over I395 - CORE I395 5^{th}-1

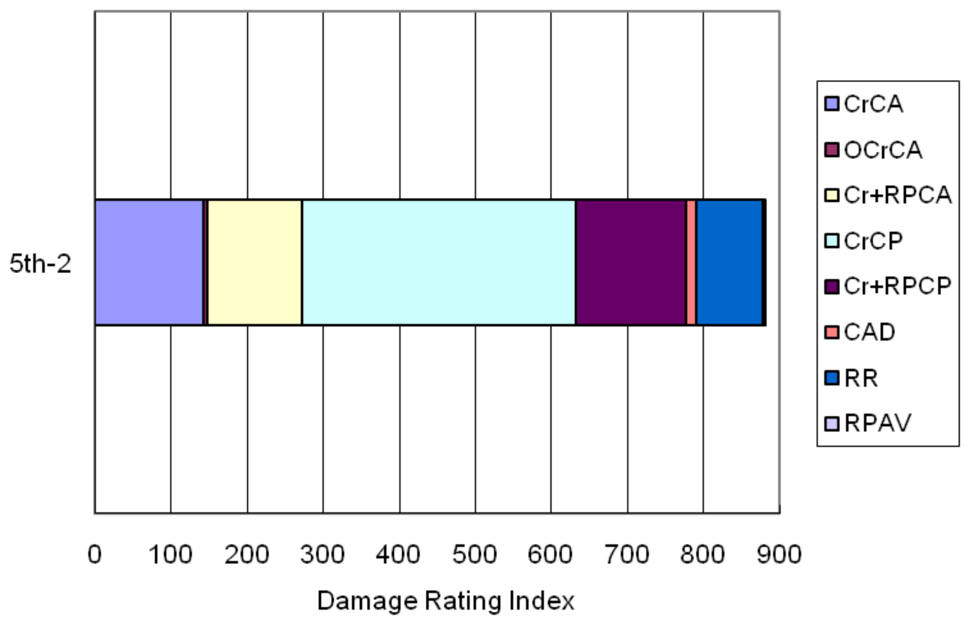


Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
5th-1	143	0	21	67	20	0	26	2	**279**

Figure C16: DRI results for Core I395 5^{th}-1

5th Parkway over I395 - CORE I395 5th-2

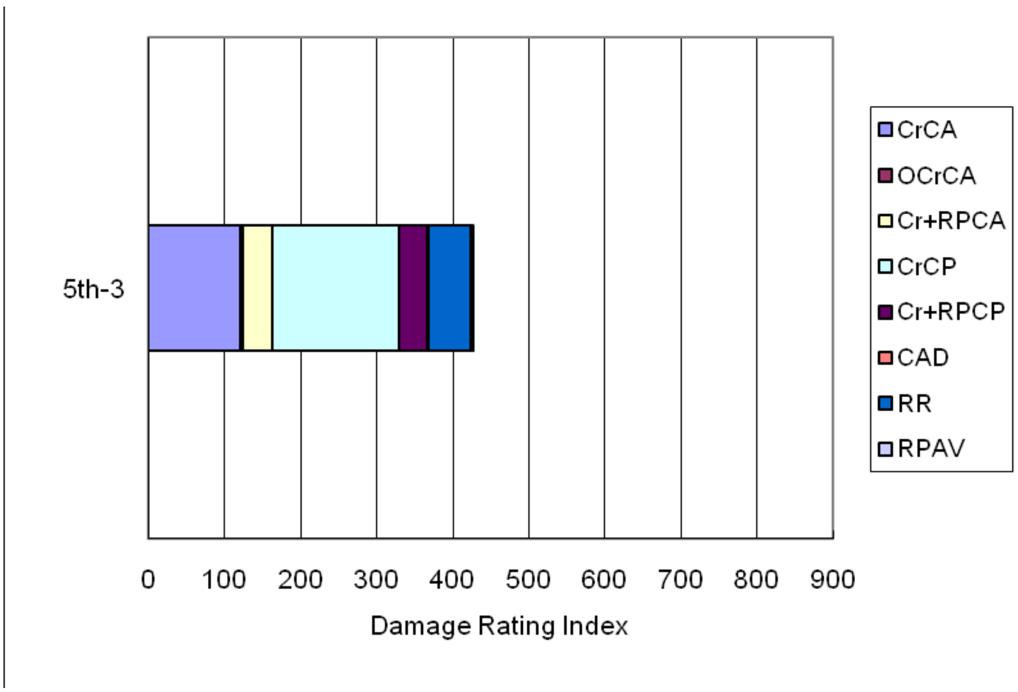




Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
5th-2	143	6	124	361	145	13	87	3	**882**

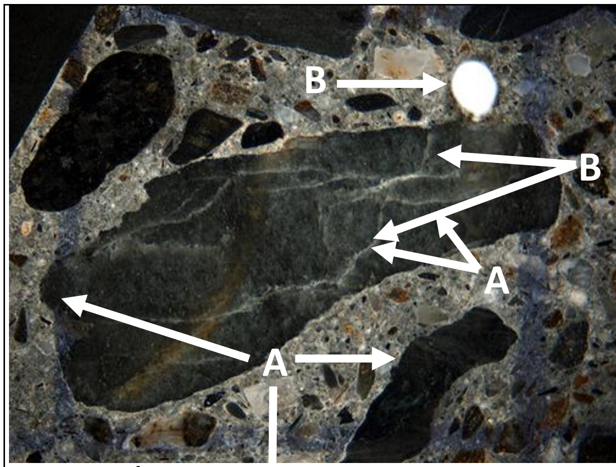
Figure C17: DRI results for Core I395 5th-2

5^{th} Parkway over I395 - CORE I395 5^{th}-3

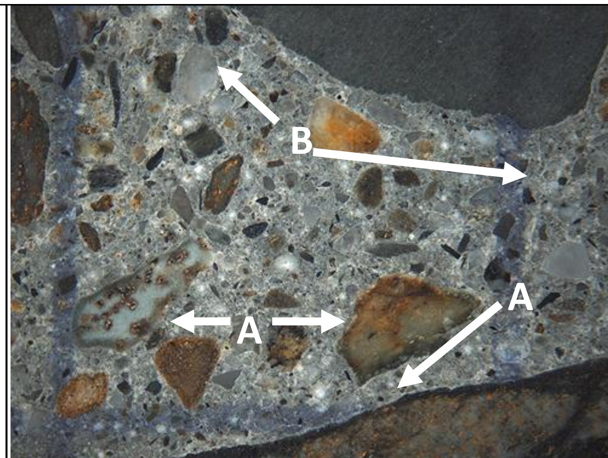


Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
5th-3	122	3	39	167	36	1	57	2	**427**

Figure C18: DRI results for Core I395 5^{th}-3

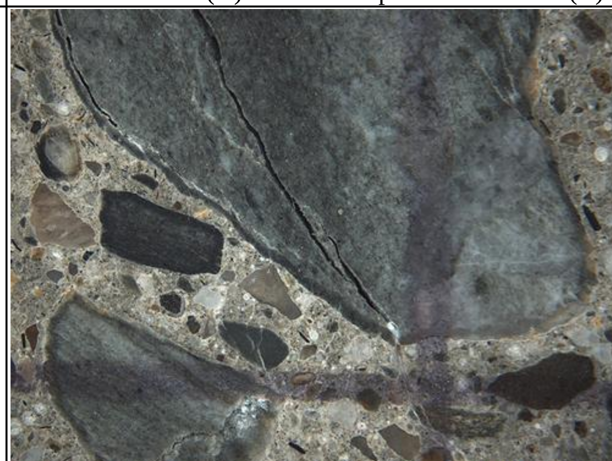


A: I395 5^{th}-1: Coarse aggregate particle with cracks (A) and air void with ASR products (B)

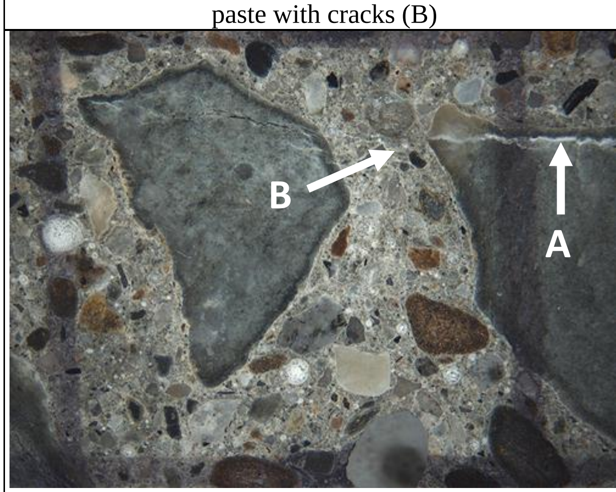


B: I395 5^{th}-1
Reaction rims (A) and cement paste with cracks (B)

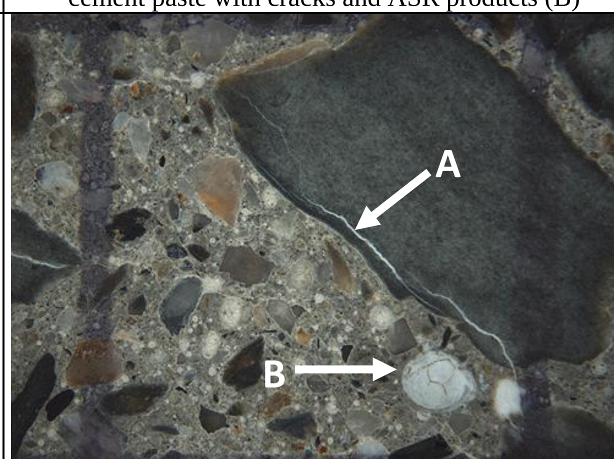
C: I395 5^{th}-2
Coarse aggregate particles with cracks (A) and cement paste with cracks (B)



D: I395 5^{th}-2
Coarse aggregate with cracks and ASR products (A) and cement paste with cracks and ASR products (B)



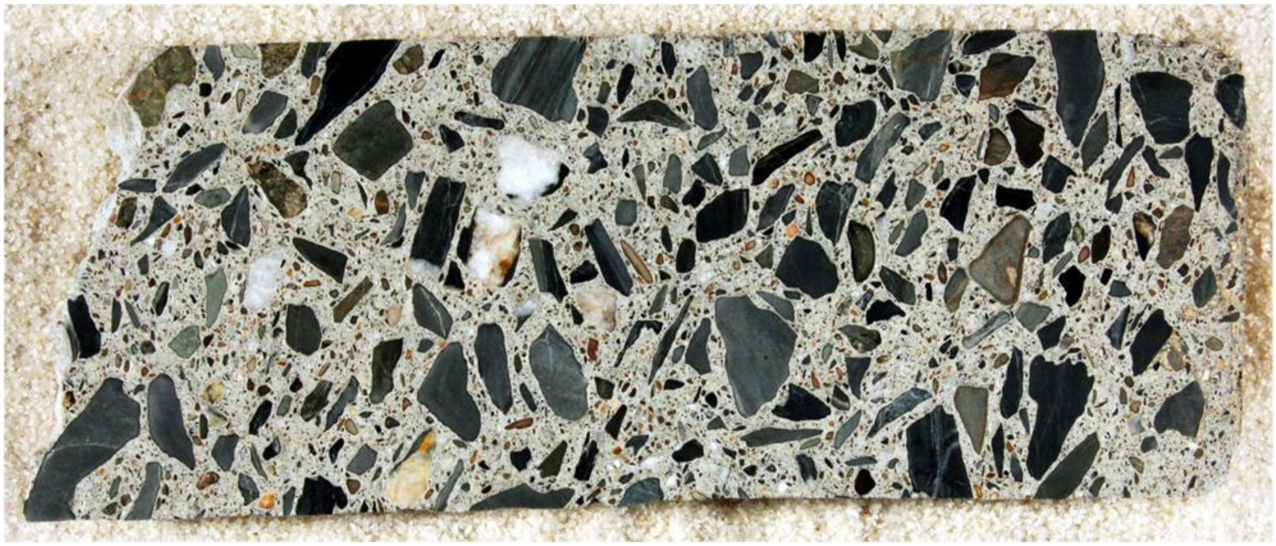
E: I395 5th-2
Coarse aggregate with cracks and ASR products (A) and cement paste with cracks and ASR products (B)

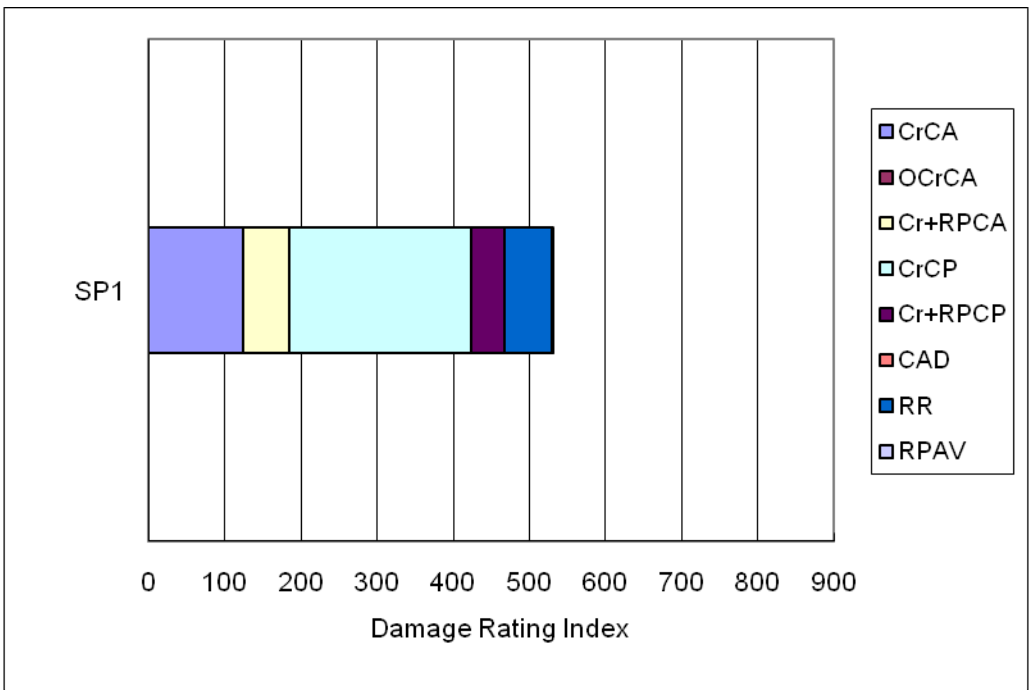


F: I395 5^{th}-3
Coarse aggregate with cracks and ASR products (A) and an air void filled with ASR products (B)

Figure C19: Micrographs illustrating petrographic features of deterioration in cores from the structure 5^{th} Parkway over I395.

South Parkway over I395 - CORE I395 SP-1

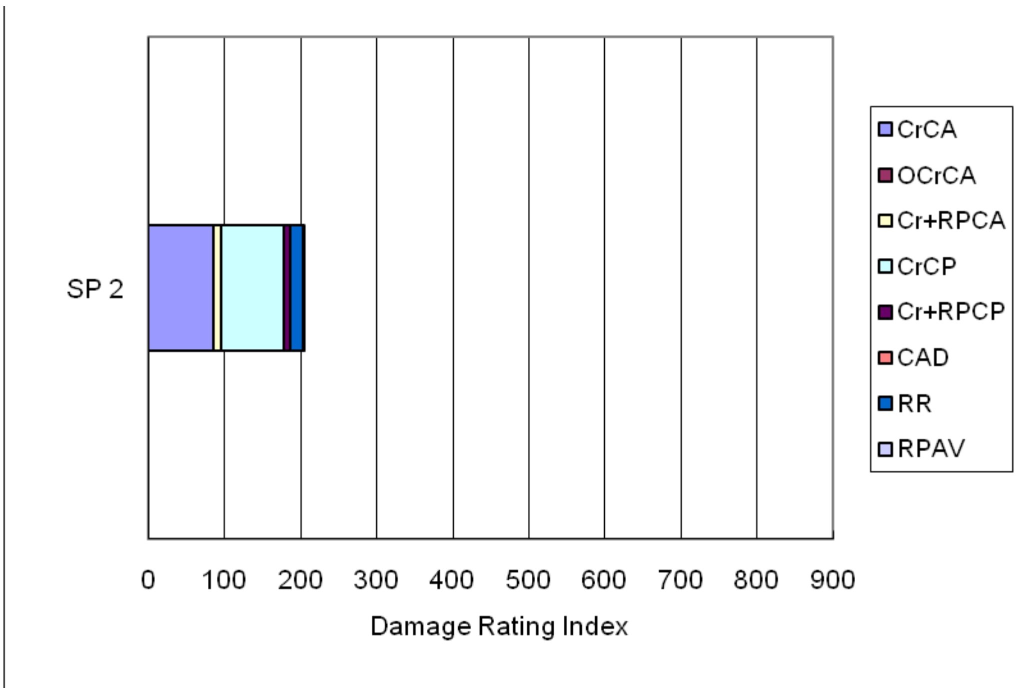




Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
SP1	125	0	61	239	44	0	62	1	**531**

Figure C20: DRI results for Core I395 SP-1

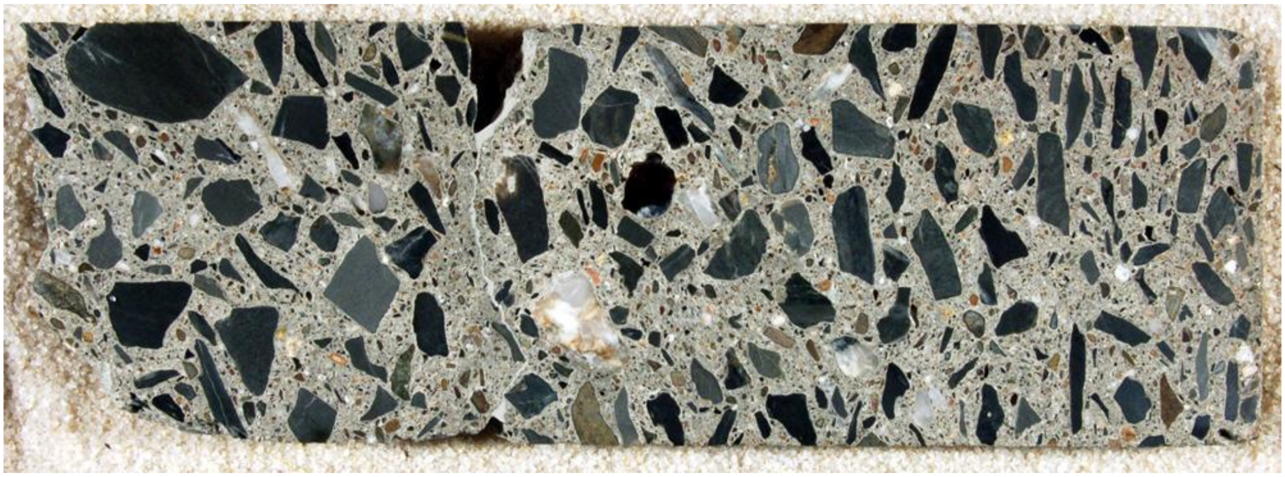
South Parkway over I395 - CORE I395 SP-2

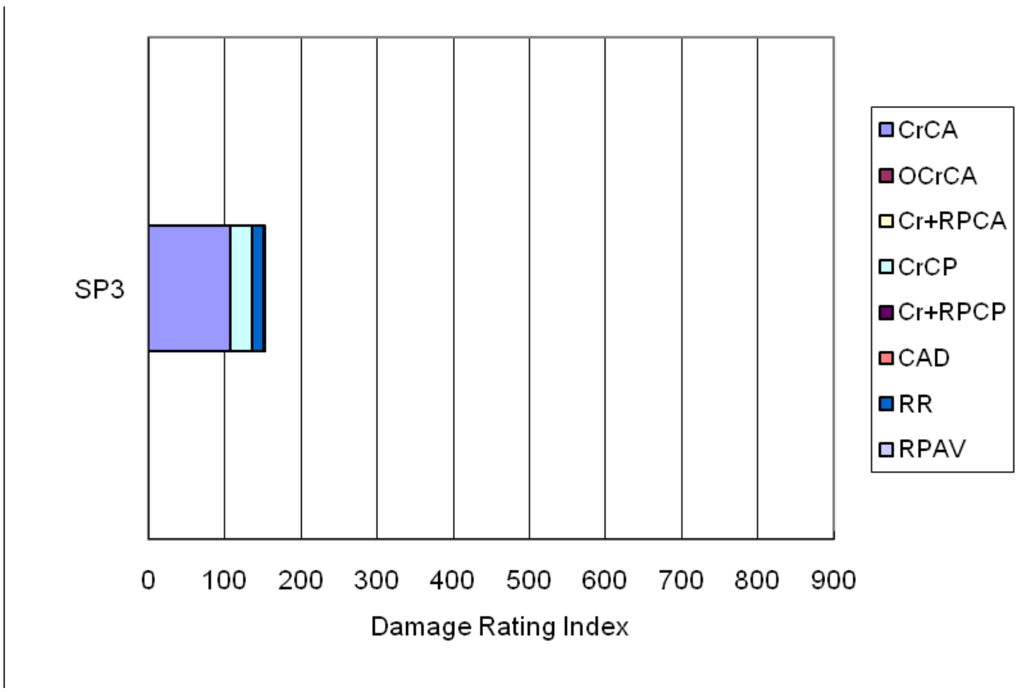


Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
SP 2	86	0	10	82	8	0	17	1	**203**

Figure C21: DRI results for Core I395 SP-2

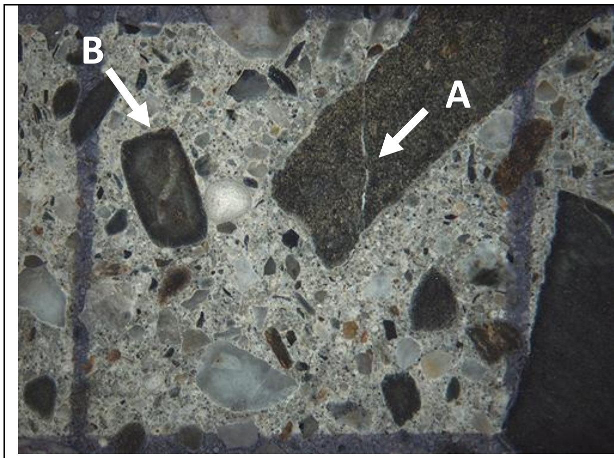
South Parkway over I395 - CORE I395 SP-3



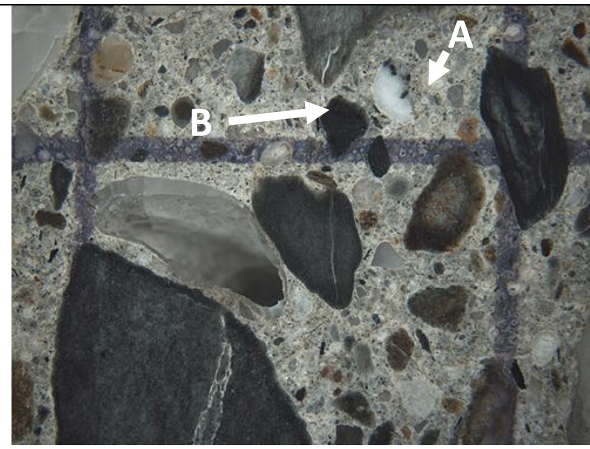


Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
SP3	107	0	0	28	0	1	14	1	**152**

Figure C22: DRI results for Core I395 SP-3

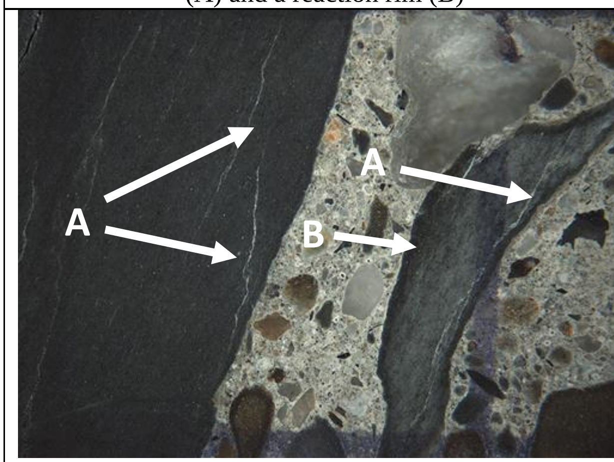


A: I395 SP1
Coarse aggregate particle with cracks and ASR products (A) and a reaction rim (B)

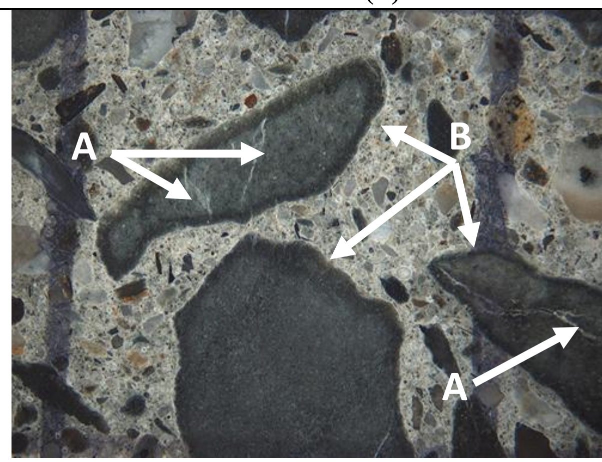


B

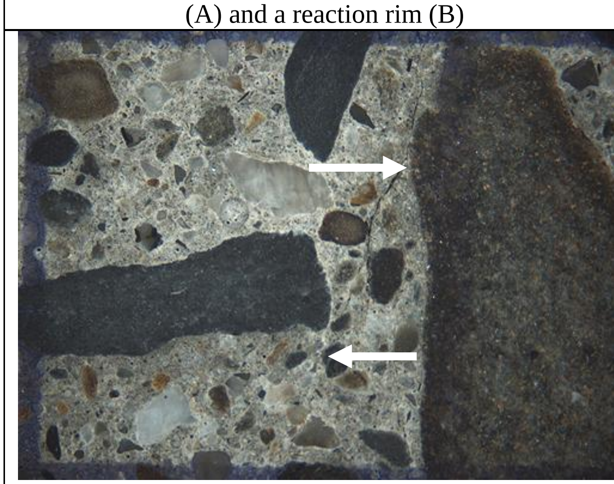
: I395 SP1
Air voids lined with ASR products (A) and cement paste with cracks (B)



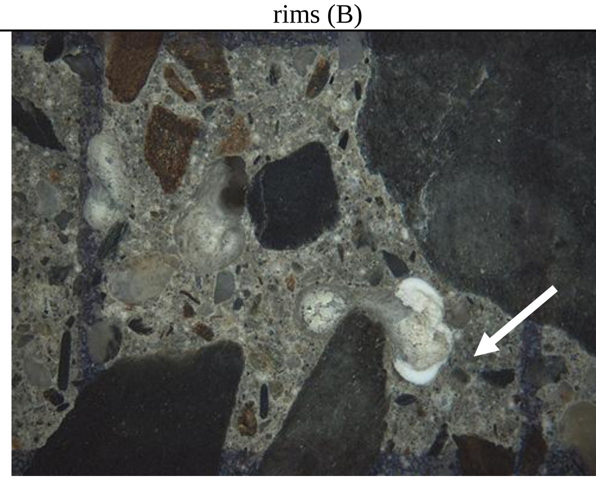
C: I395 SP1
Coarse aggregate particles with cracks and ASR products (A) and a reaction rim (B)



D: I395 SP1
Coarse aggregate particles with cracks (A) and reaction rims (B)



E: I395 SP2
Cement paste with cracks

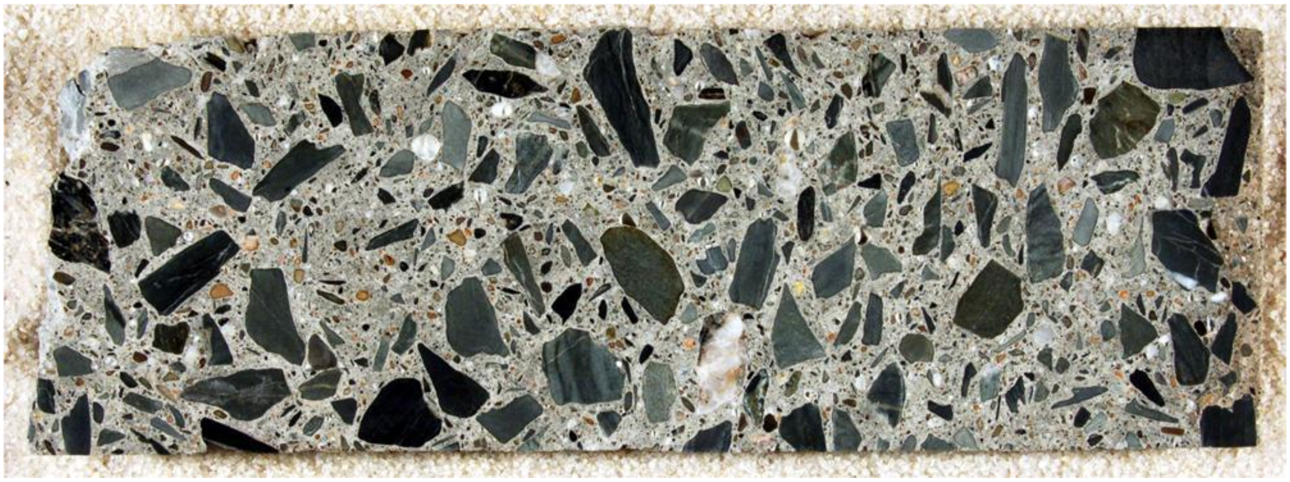


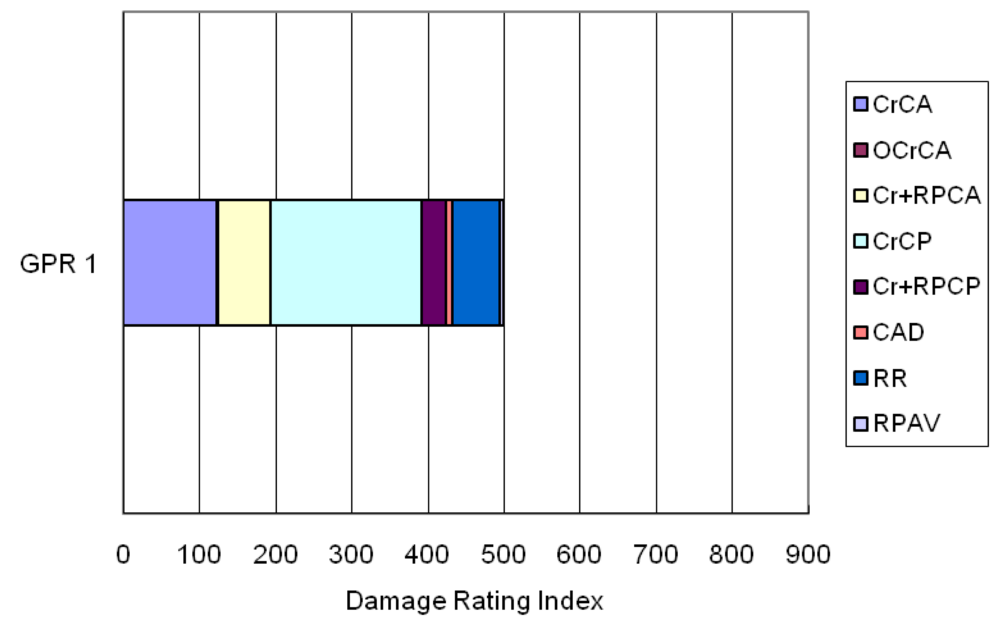
F

: I395 SP3
Air void filled with gel

Figure C23: Micrographs illustrating petrographic features of deterioration in cores from the structure South Parkway over I395.

Greenpoint Road over I395 - CORE I395 GPR-1

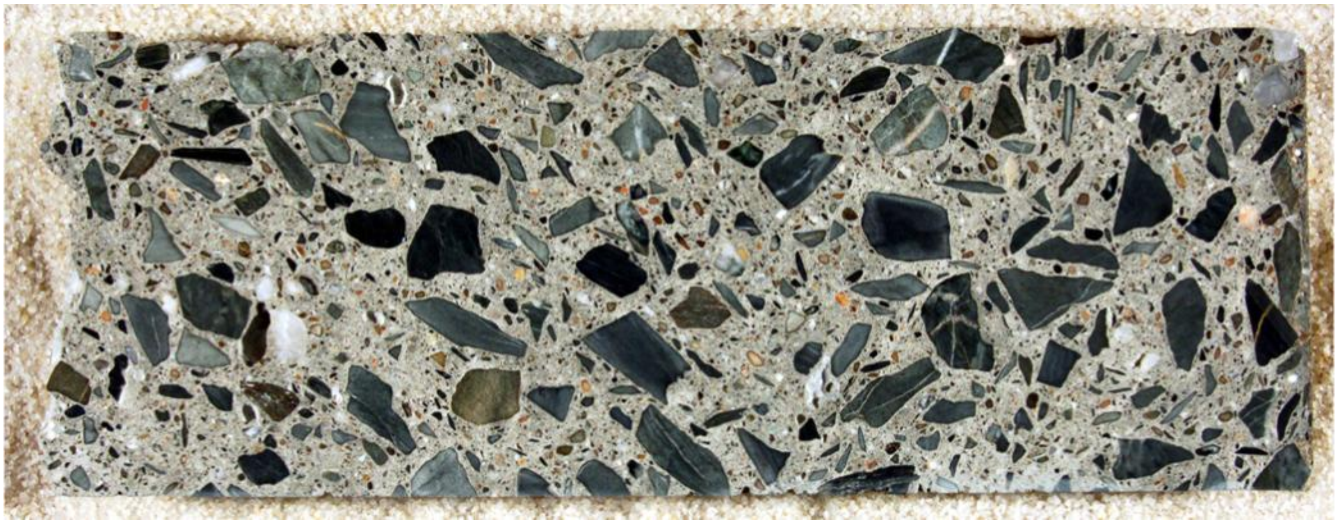


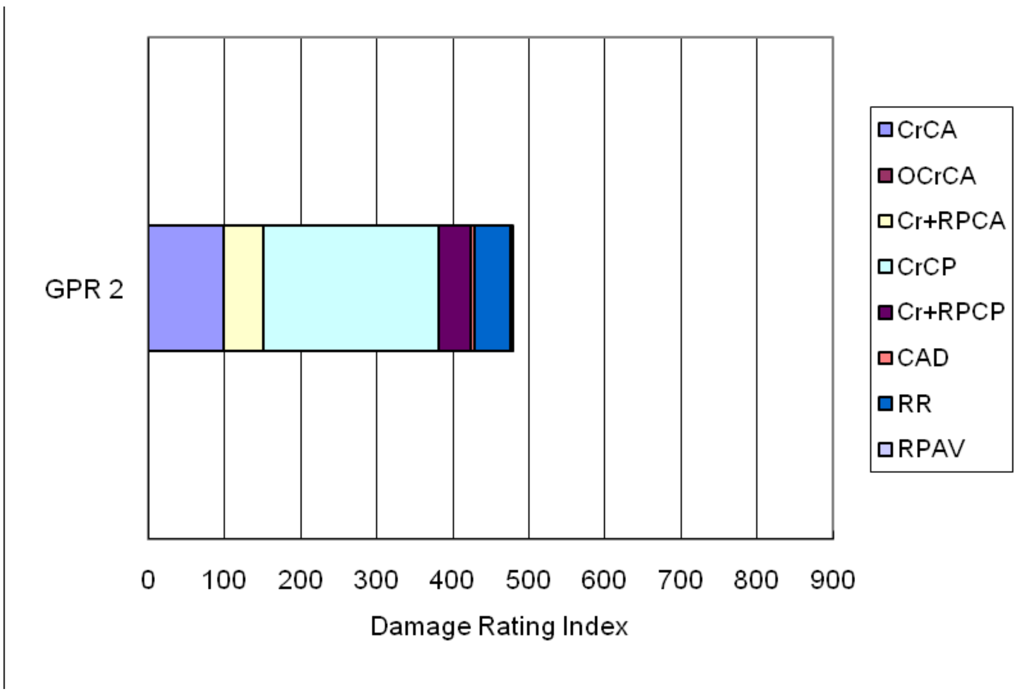


Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
GPR1	123	2	69	198	31	9	62	5	**499**

Figure C24: DRI results for Core I395 GPR-1

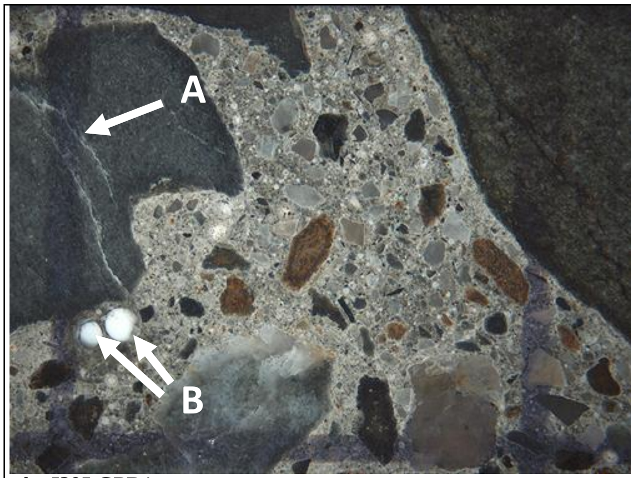
Greenpoint Road over I395 - CORE I395 GPR-2



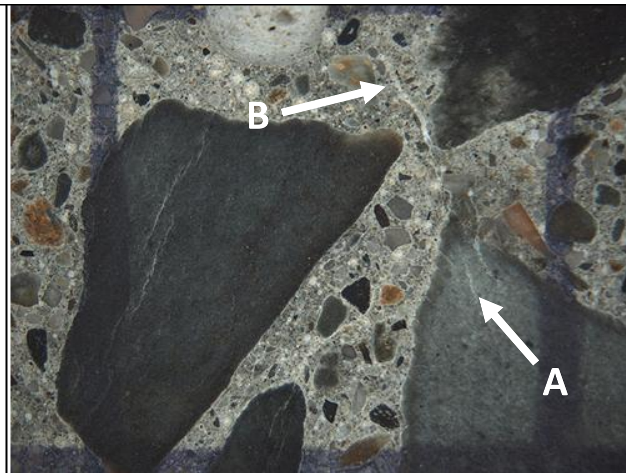


Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
GPR2	99	0	53	231	41	5	48	2	**479**

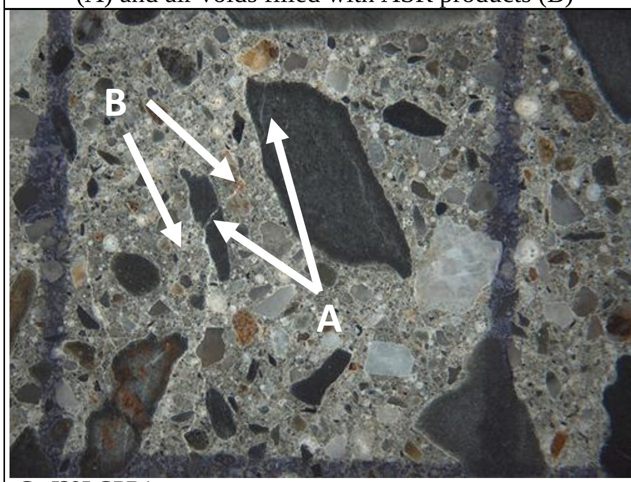
Figure C25: DRI results for Core I395 GPR-2



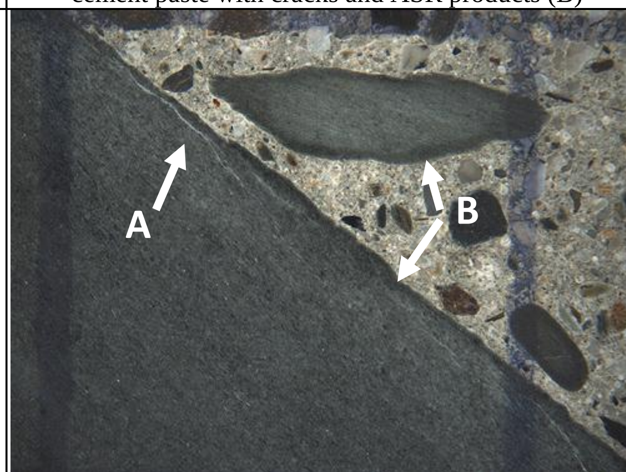
A: I395 GPR1
Coarse aggregate particle with cracks and ASR products (A) and air voids filled with ASR products (B)



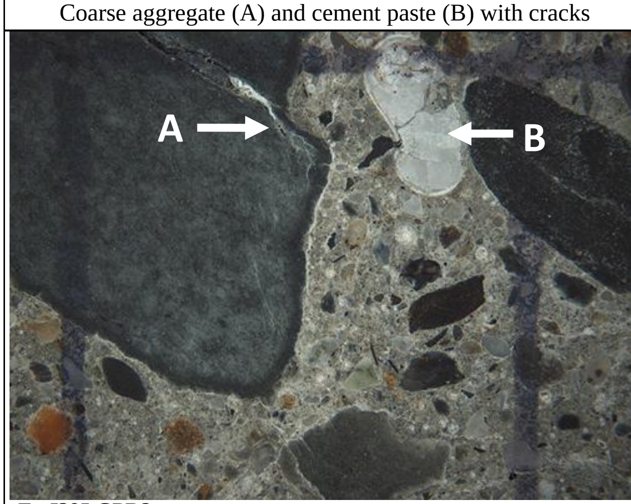
B: I395 GPR1
Coarse aggregate with cracks and ASR products (A) and cement paste with cracks and ASR products (B)



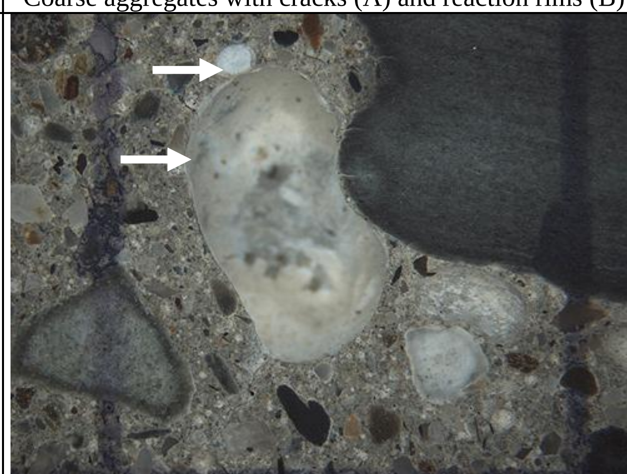
C: I395 GPR1
Coarse aggregate (A) and cement paste (B) with cracks



D: I395 GPR2
Coarse aggregates with cracks (A) and reaction rims (B)



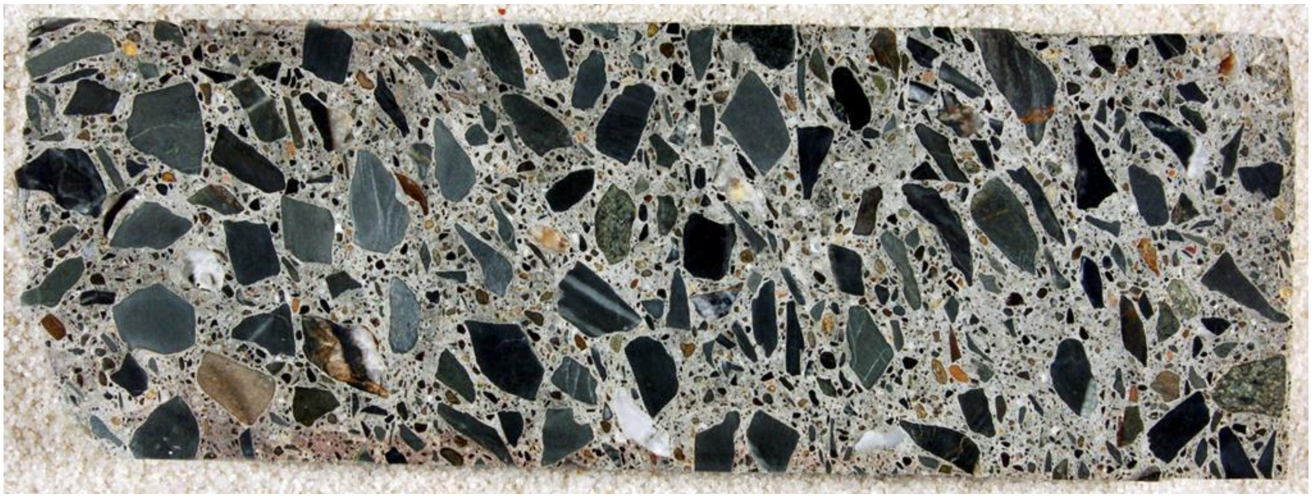
E: I395 GPR2
Coarse aggregate particle with cracks and ASR products (A) and air void filled with ASR products (B)

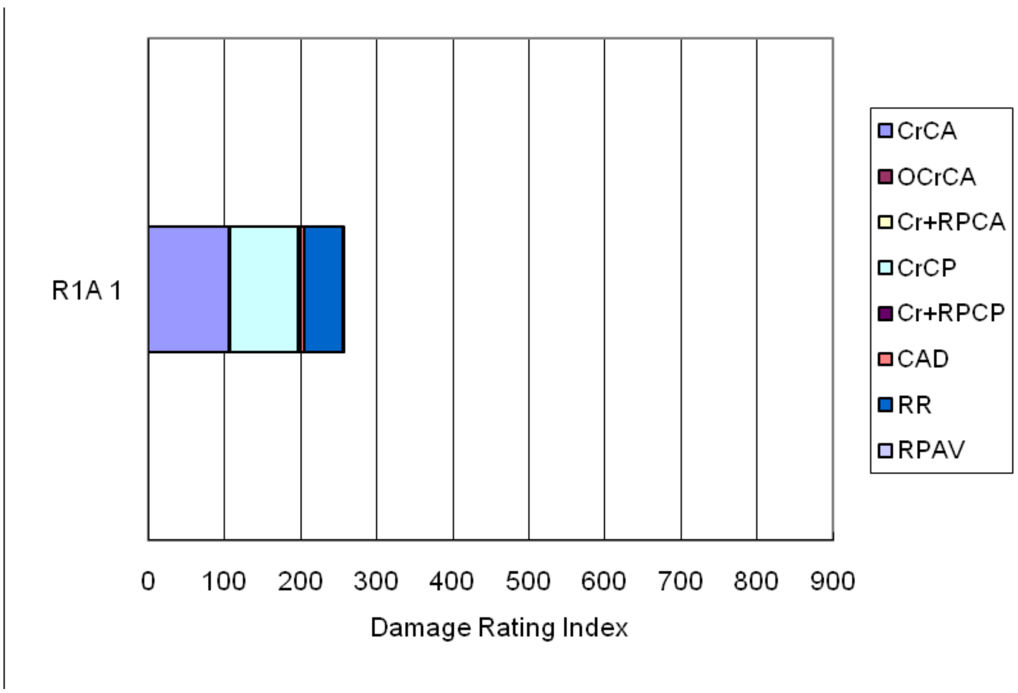


F: I395 GPR2
Air voids filled with ASR products

Figure C26: Micrographs illustrating petrographic features of deterioration in cores from the structure Green Point Road over I395.

Road 1A over I395 - CORE I395 R1A-1

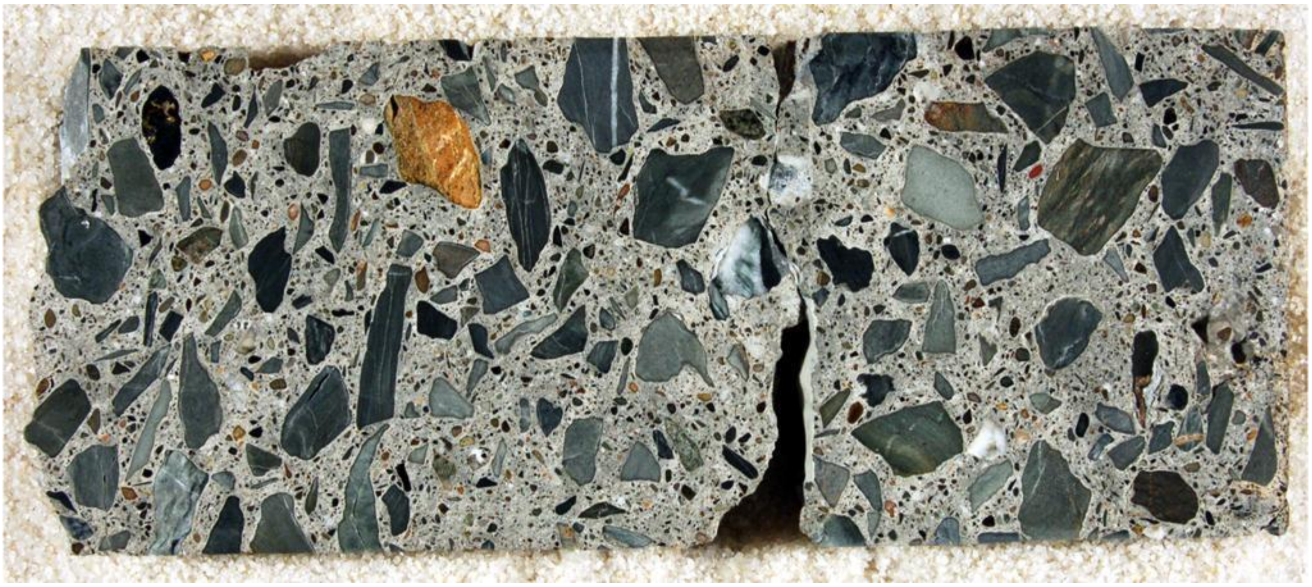


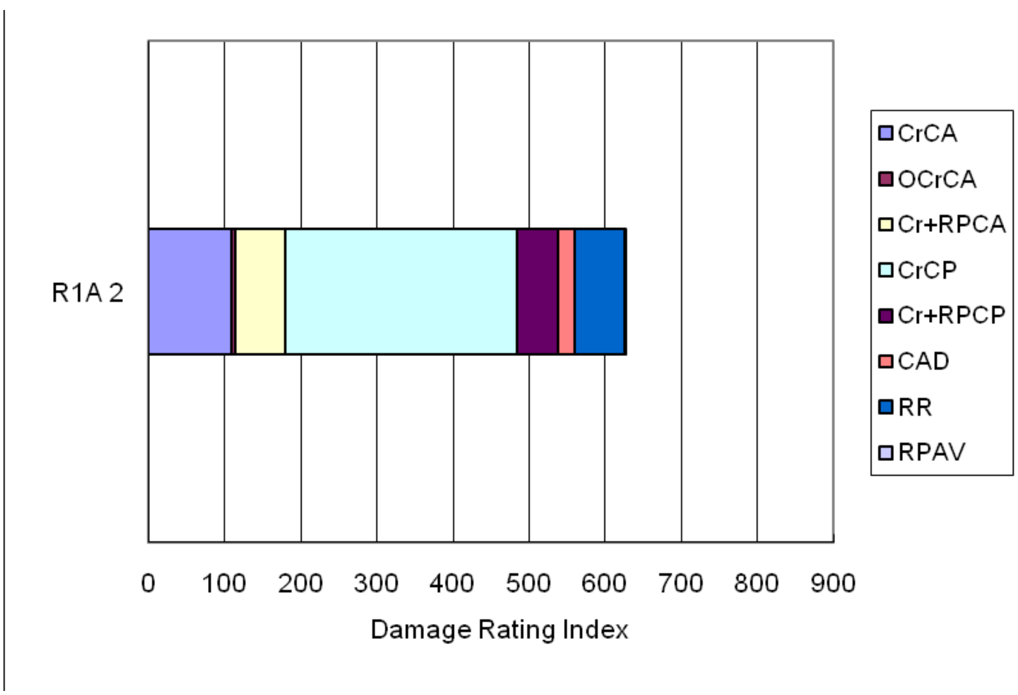


Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
R1A 1	105	0	3	90	3	4	51	3	**258**

Figure C27: DRI results for Core I395 R1A-1

Road 1A over I395 - CORE I395 R1A-2

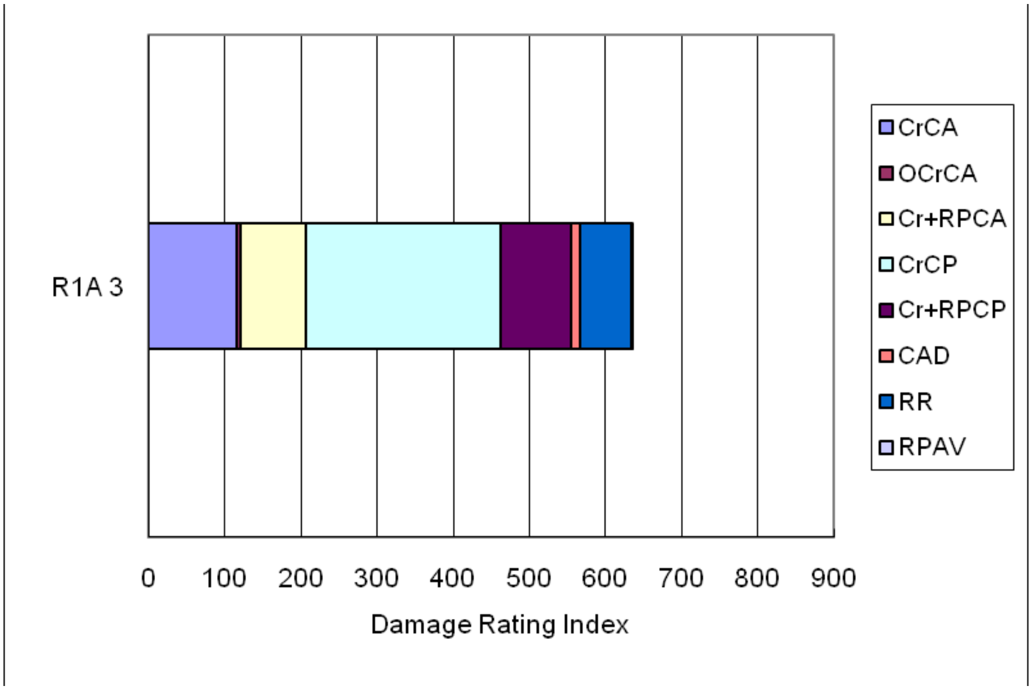




Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
R1A 2	109	5	66	305	54	22	65	2	**627**

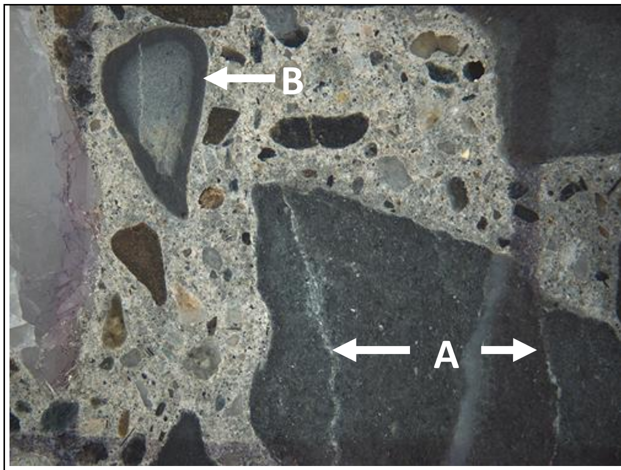
Figure C28: DRI results for Core I395 R1A-2

Road 1A over I395 - CORE I395 R1A-3

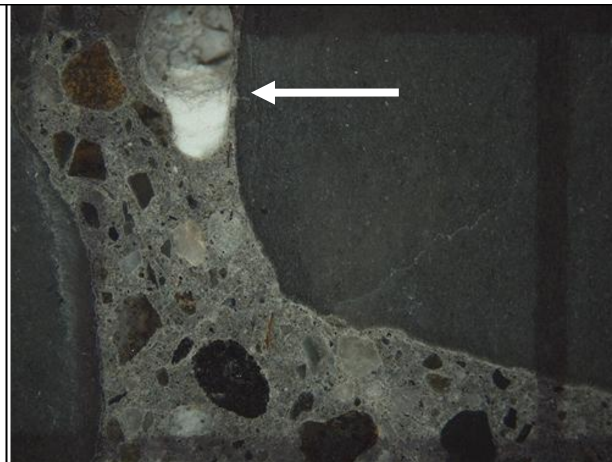


Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
R1A 3	116	6	84	257	92	11	69	1	**636**

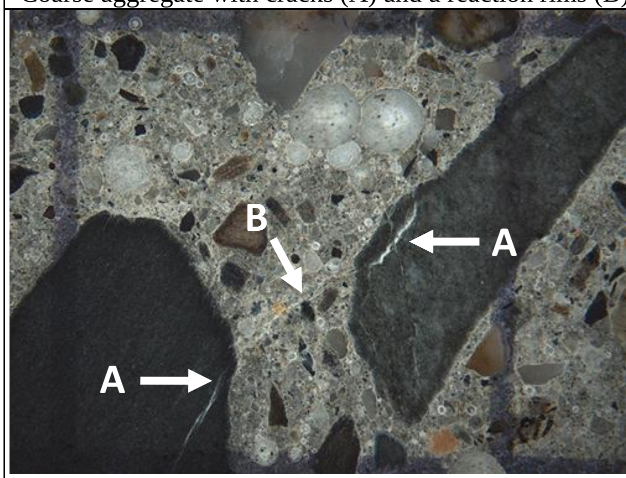
Figure C29: DRI results for Core I395 R1A-2



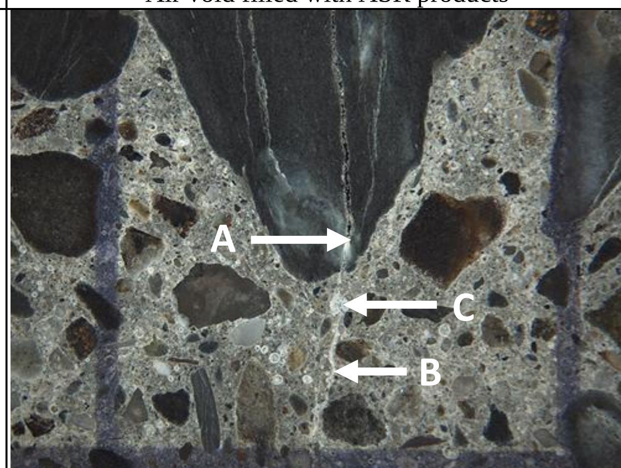
A: I395 R1A1
Coarse aggregate with cracks (A) and a reaction rims (B)



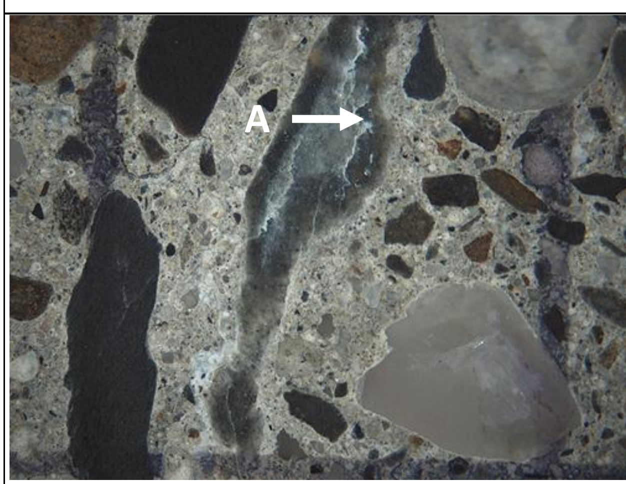
B: I395 R1A1
Air void filled with ASR products



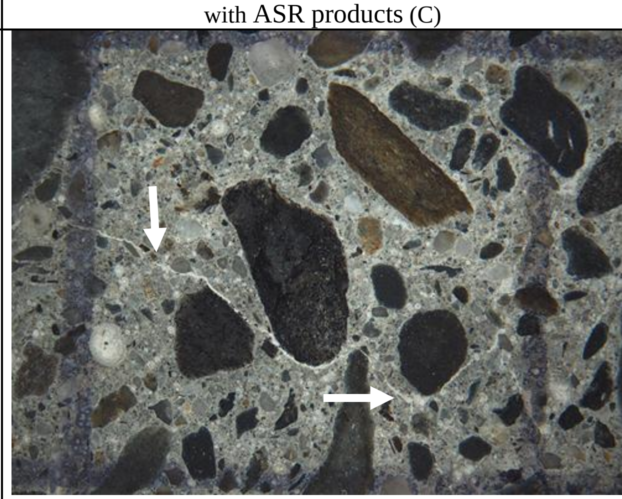
C: I395 R1A2
Coarse aggregate with cracks and ASR products (A) and cement paste with cracks and ASR products (B)



D: I395 R1A2
Coarse aggregate with cracks and ASR products (A), cement paste with cracks and ASR products (B) and an air void filled with ASR products (C)



E: I395 R1A3
Coarse aggregate with cracks and ASR products (A)



F: I395 R1A3
Cement paste with cracks

Figure C30: Micrographs illustrating petrographic features of deterioration in cores from the structure Route 1A over I395.