Evaluation of I-89/Dog River Bridge Barrier Walls near Montpelier, Vermont

Petrographic Evaluation and Recommendations

ASR Development and Deployment Program
Field Application and Demonstration Projects

U.S.Department of Transportation
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16. Abstract

This report presents the findings of the petrographic examination of six concrete cores extracted from the barrier walls of two bridges carrying interstate I89 over Dog River near Montpelier, VT. The evaluation mainly consisted of the Damage Rating Index (DRI), a method that provides a semi-quantitative assessment of the damage in concrete based on a count of petrographic features of deterioration generally associated with alkali-silica reaction (ASR).

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		32	

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

This report presents the findings of the petrographic examination of six concrete cores extracted from the barrier walls of two bridges (each carrying two lanes in one direction) carrying interstate I89 over Dog River near Montpelier, VT. The evaluation mainly consisted of the Damage Rating Index (DRI), a method that provides a semi-quantitative assessment of the damage in concrete based on a count of petrographic features of deterioration generally associated with alkali-silica reaction (ASR).

2 Field Work - Extraction of Cores

Coring was conducted by VDOT on May 12, 2010. Locations for coring were selected by Dr. Michael Thomas. Cores were extracted from the barrier walls adjacent to the passing lane on both the northbound and southbound bridges, as indicated in Table 1.

Table 1. Cores provided for petrographic examination

Core number	Location	Condition	Length (in)
I89-VT-N1	Northbound passing lane approx. 7 p from south abutment	Core in 1 section	5.5
I89-VT-N2	Northbound passing lane approx. 160 yards from south abutment	Core in 1 section	5.5
I89-VT-N3	Northbound passing lane approx. 270 yards from south abutment	Core in 1 section	6.0
I89-VT-S1	Southbound passing lane approx. 30 yards from south abutment	Core in 1 section	5.5
I89-VT-S2	Southbound passing lane approx. 70 yards from south abutment	Core in 1 section	4.5
I89-VT-S3	Southbound passing lane approx. 300 yards from south abutment	Core in 1 section	4.5

Details regarding the location of the bridges and photographs showing the condition of the concrete and locations of the cores are shown in Appendix B. Map cracking was evident on most of the barrier walls (see photos in Appendix B) and the nature of the cracking is consistent with alkali-silica reaction. There was no evidence of corrosion of embedded reinforcement or damage due to freeze-thaw.

3 Laboratory Testing of Cores – Damage rating Index (DRI)

The concrete cores were sent to Dr. Benoit Fournier at Laval University, Québec, Canada in May 2010. The six cores were first cut in two axially and polished, then examined under the stereomicroscope to determine the Damage Rating Index (DRI).

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 2). 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 2).

Table 2. Petrographic Features and Weighing Factors for the DRI (Grattan-Bellew and Mitchell 2006)

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 Petrographic Examination

Table 3 gives a summary of the petrographic observations (in terms of the typical crack width observed in the cement paste of the cores) and a rating of the extent of ASR in the concrete of the six polished sections examined as part of this investigation. The sections are illustrated in Figures 1 through 3, while the results of the DRI are summarized in Figure 4. The detailed results of DRI, including micrographs of the petrographic features in the cores examined, are given in the Appendix A.

The DRI was originally developed to quantify the damage in concrete affected by ASR in the coarse aggregate particles. We have thus adopted a procedure that consists in evaluating the presence of petrographic features of ASR in aggregate particles of minimum 2 mm in size. However, in the case of the I89 cores, the preliminary examination of the polished sections revealed that signs of ASR were actually present in the fine aggregate fraction of the concrete, and were especially visible in the coarser portion of the fine aggregates. For that reason, we modified slightly the DRI procedure to allow the identification of the petrographic signs of deterioration in aggregate particles down to 1mm in size.

There is currently no rating system for the DRI values that correspond to concrete affected to a low, moderate or severe degree by ASR. However, our experience is such that values below 200-250 are indicative of a low degree of reaction / deterioration, DRIs in excess of about 500-600 represent a high to very high (DRI > 1000) degree of ASR. It is important to mention, however, that since the DRI is not a standardized method, and values can vary significantly from one petrographer to another.

Table 3. Summary of the petrographic observations on the cores from Vermont (I89)

Sample	DRI	Noticeable petrographic features, including extent of cracking and typical crack width in the cement paste (mm)	Extent/degree of ASR
I89-VT-N1	**104**	• Traces of cracking in the cement paste (crack width < 0.05mm); • Mild cracking in the coarse (granitic) aggregate; • Reaction rims around a fair number of “coarse” sand grains.	Very low
I89-VT-N2	**202**	• Mild cracking both in the cement paste (crack width < 0.05mm) and in the coarse (granitic) aggregate; • Reaction rims around a fair number of “coarse” sand grains	Low
I89-VT-N3	**53**	• No visible cracking in the cement paste; • Mild cracking in the coarse (granitic) aggregate; • Reaction rims around only a few “coarse” sand grains	Very Low
I89-VT-S1	**104**	• Traces of cracking in the cement paste (crack width < 0.05mm); • Mild cracking in the coarse (granitic) aggregate; • Reaction rims around a fair number of “coarse” sand grains	Very Low
I89-VT-S2	**647**	• Significant cracking in the cement paste but at the microscale (crack width < 0.05mm), as mainly associated with signs of ASR in the coarse sand grains (cracks with alkali-silica gel and reaction rims around significant number of “coarse” sand grains); • Several voids in the cement paste with ASR gel and ettringite	Moderate
I89-VT-S3	**568**	• Significant cracking in the cement paste but at the microscale (crack width < 0.05mm), as mainly associated with signs of ASR in the coarse sand grains (cracks with alkali-silica gel and reaction rims around significant number of “coarse” sand grains); • Several voids in the cement paste with ASR gel and ettringite	Moderate

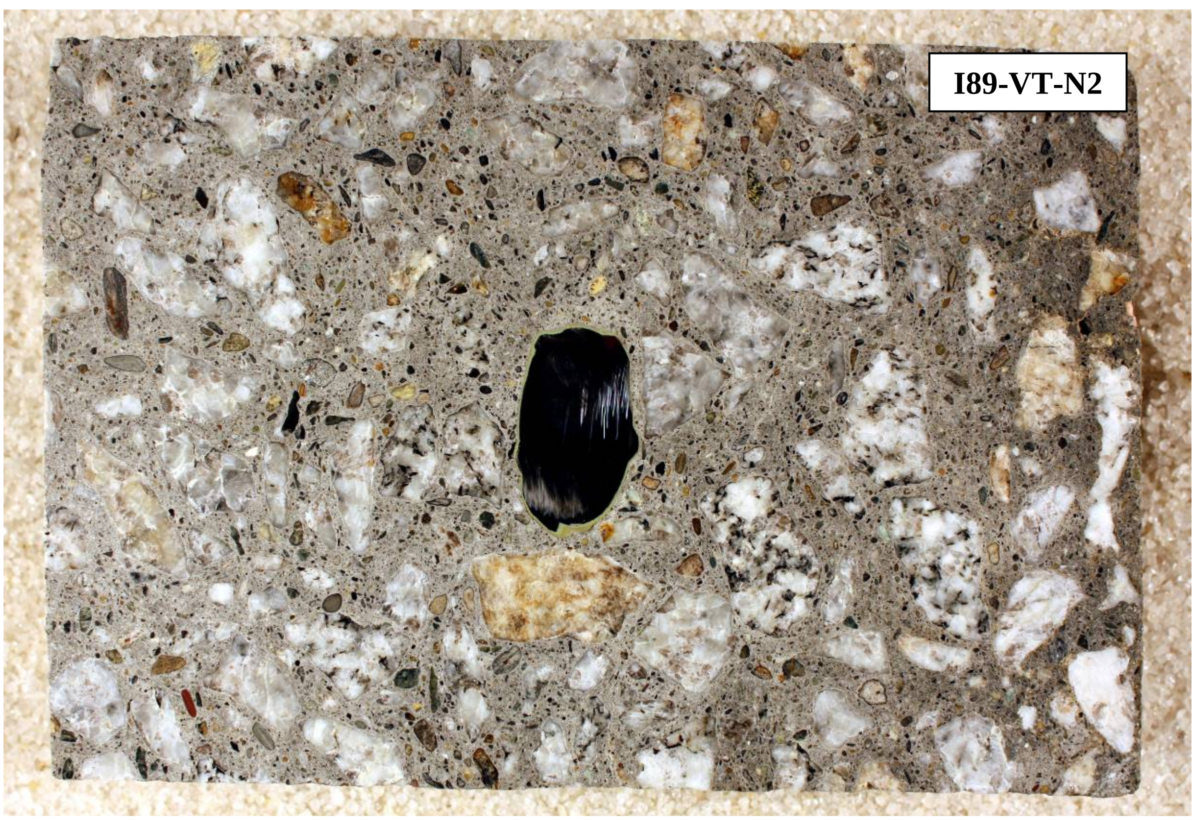
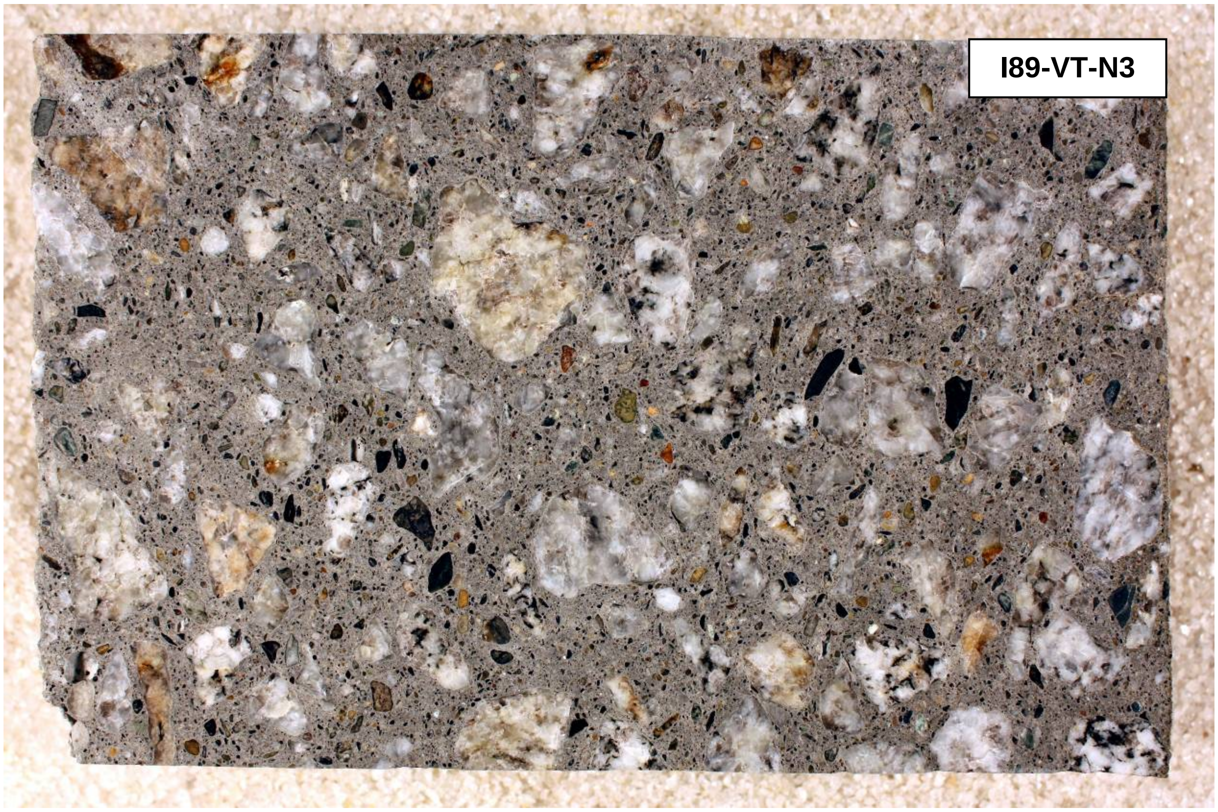


Figure 1. Polished concrete sections from the I89 structure in Vermont.



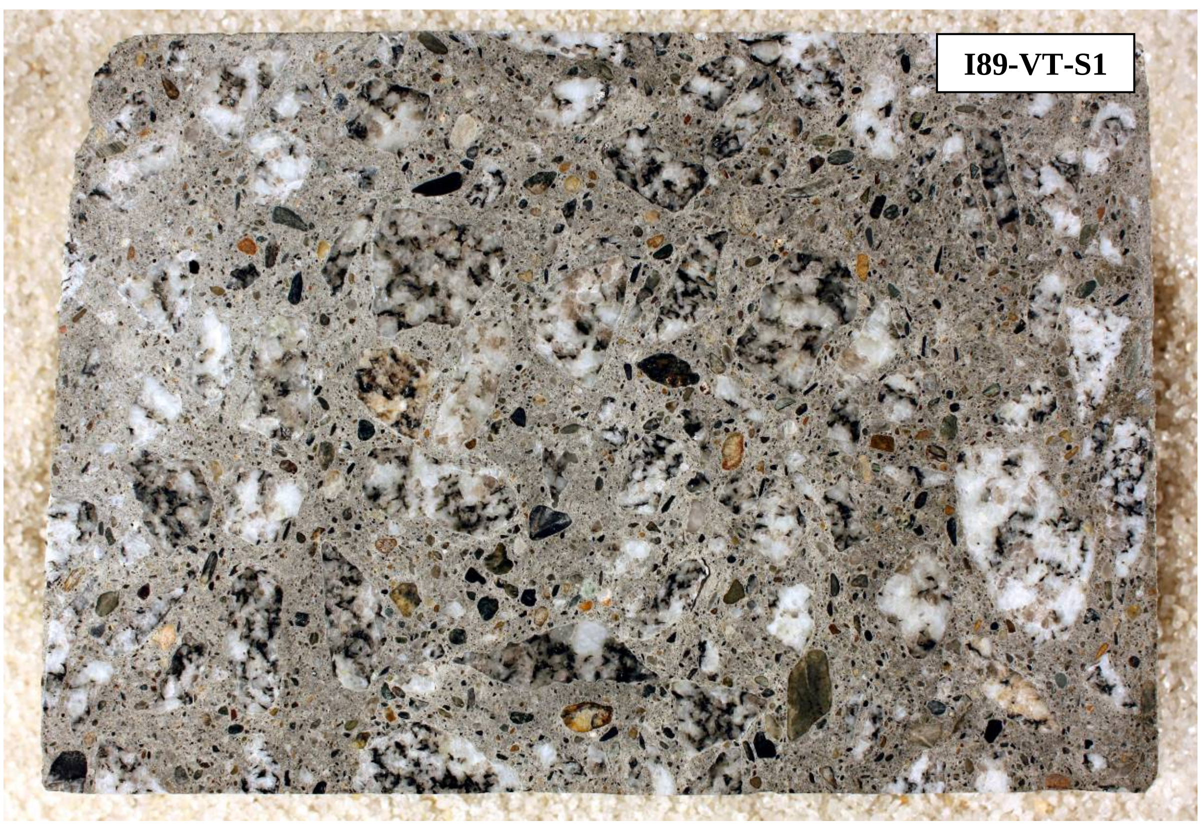


Figure 2. Polished concrete sections from the I89 structure in Vermont (cont'd).

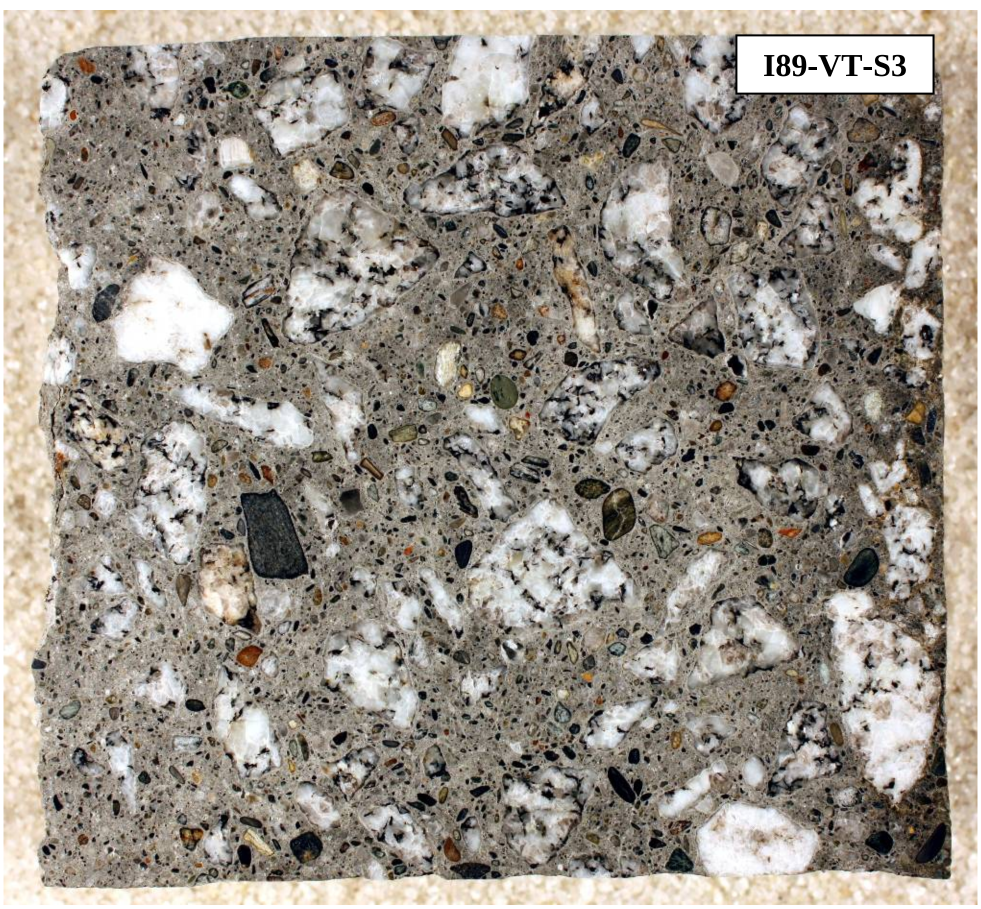


Figure 3. Polished concrete sections from the I89 structure in Vermont (cont'd).

Sample	Cracks in the aggregate particles			Cracks in the cement paste		CAD	RR	RPAV	DRI
	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP				
I89-VT-N1	45	2	8	10	0	0	39	0	**104**
I89-VT-N2	64	12	8	38	6	2	39	33	**202**
I89-VT-N3	40	0	0	0	0	0	12	0	**53**
I89-VT-S1	33	2	11	17	0	12	28	0	**104**
I89-VT-S2	65	14	128	189	119	6	98	29	**647**
I89-VT-S3	78	29	75	138	83	2	74	90	**568**

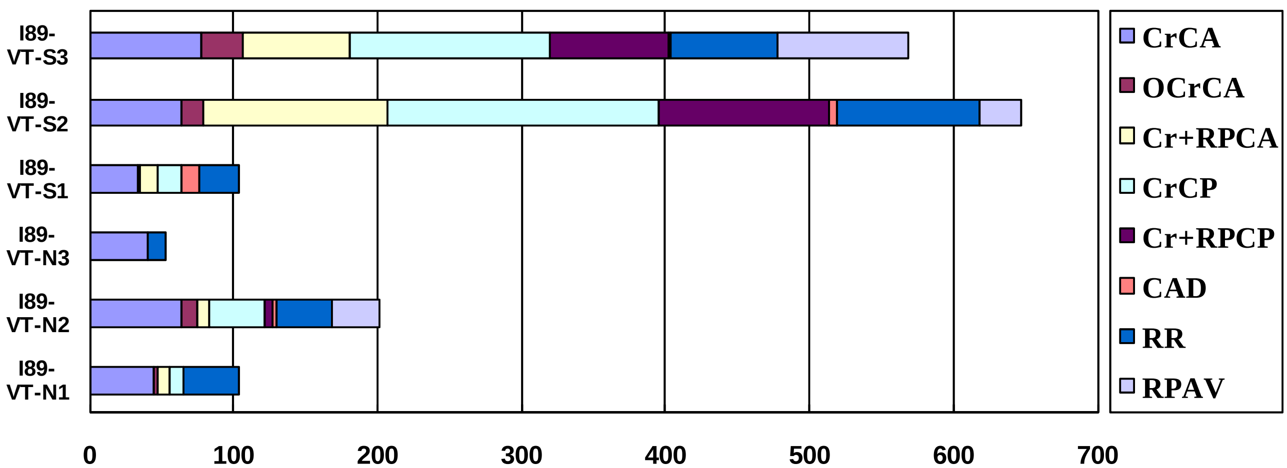


Figure 4. Results of the Damage Rating Index (DRI) for the Vermont cores

4.1 Cores I89 N1 to N3, S1

As illustrated in Figures 1 through 4, the polished concrete sections I89 N1 to N3 and I89 S1 show limited overall deterioration. Damage Rating Indices ranging from 53 to 202 were obtained for those cores, thus indicating low to very low degree of deterioration/damage due to ASR. Details of the DRIs and micrographs of the polished sections can be seen in the Appendix A, figures A1 to A8.

As indicated in Figure 4, the highest contributor to the DRI for this set of cores is *Cracks in the aggregate particles (CrCA and OCrCA)*. The coarse aggregate in the above cores essentially consists of a grayish granitic rock. The particles show fair amount of internal cracking (and grain joints forming discontinuities); however, there is no evidence, at this stage, that the internal particle cracking might be related to the ASR reactivity of the granitic aggregate as there is no cracking in the above particles filled with secondary reaction products (ASR gel) and/or extending into the cement paste, at least at the magnification (15x) used in the DRI.

Several particles of the fine aggregate, composed of different rock types (e.g. schist, microquartzite, sandstone, argilite) show dark/reaction rims (*RR*); the latter form the second most important contributor to the DRI values for this set of cores. Trace level (N1 & S1) to mild level (N2) of cracking is observed in the cement paste; crack are however very fine (crack widths <0.05mm).

The polished concrete core I89-N2 shows slightly more signs of deterioration, including surface cracking penetrating into the concrete (about 1 inch) with associated carbonation, mild cracking in the cement paste with sometimes secondary reaction products (ASR gel), and a fair number of voids in the cement paste lined or filled with secondary reaction products, mostly ettringite.

4.2 Cores S2 and S3

As illustrated in Figures 1 through 4, the polished concrete sections I89 S2 and S3 show a moderate degree of deterioration due to ASR. Damage Rating Indices of 647 and 568 were obtained for cores S2 and S3, respectively. Details of the DRIs and micrographs of the polished sections can be seen in the Appendix A, figures A9 to A12. It is important to mention that the deterioration essentially appears at the microscale since the reactivity is observed within the fine aggregate.

As indicated in Figure 4, the cores show important cracking in the aggregate particles, with and without reaction products (ASR gel). Similar to the previous set of cores (see Section 4.1), the coarse aggregate in the cores S2 and S3 essentially consists of a grayish granitic rock. Once again, the particles show fair internal cracking (and grain joints forming discontinuities); however, there is limited evidence, at this stage, that the internal particle cracking might be related to the ASR reactivity of the granitic aggregate since there is limited cracking in the above particles filled with secondary reaction products (ASR gel) and/or extending into the cement paste, at least at the magnification (15x) used in the DRI.

The polished concrete core I89-S2 shows surface cracking penetrating into the concrete (about 0.5 inch) with associated carbonation.

On the other hand, numerous particles of the coarse fraction of the sand, composed of different rock types (e.g. schist, microquartzite, sandstone, argilite), show internal cracking, with/without reaction products, and dark/reaction rims (*RR*) (see Figure 2, Appendix A, figures A10 and A12). The large majority of the counts for cracks with *reaction products in the coarse aggregate* (Cr+RPCA) in the DRIs of sections S2 and S3 (see Figure 4) actually correspond to cracking in the coarse fraction of the sand. Significant cracking is observed in the cement paste, with and without reaction products; in many cases, cracking extends into the cement paste (with reaction products) connecting "reacted" coarse sand particles (see Appendix A, Figures A10 and A12).

A fair number of voids in the cement paste are lined or filled with secondary reaction products, both alkali-silica gel and ettringite.

5 Conclusion - Summary of Findings

This report summarizes the results of the petrographic examination, using the *Damage Rating Index* method, of a set of six cores from the barrier walls of a bridge carrying Interstate 89 across Dog River in Montpelier, Vermont. In the case of cores I89-N2 and I89-S3, surface cracking was observed to penetrate about 0.5 to 1 inch into the concrete.

The cores were separated into two groups based on the degree of ASR observed. The first group, including cores I89 N1 to N3 and I89 S1, is characterized by limited overall deterioration (with Damage Rating Indices ranging from 53 to 202), thus indicating low to very low degree of deterioration/damage due to ASR. The second group, including cores I89 S2 and S3, is characterized by a moderate degree of deterioration due to ASR. Damage Rating Indices of 647 and 568 were obtained for cores S2 and S3, respectively.

For all cores examined, the coarse aggregate consists of a grayish granitic rock that shows fair amount of internal cracking (and grain joints forming discontinuities); however, there is no evidence, at this stage, that the internal particle cracking might be related to the ASR reactivity of the granitic aggregate.

In all cores examined, the sand is composed of different rock types, including particles of schist, microquartzite, sandstone, argillite and other undifferentiated magmatic rocks. Low to moderate degree of ASR was observed in cores I89-N2 and I89 S2 and S3, mainly associated to reactivity in the coarse fraction of the sand. The large majority of the counts for *Cracks with reaction products in the coarse aggregate* (Cr+RPCA) in the DRIs of sections S2 and S3 indeed correspond to cracking in the coarse fraction of the sand. Significant cracking is also observed in their cement paste, with and without reaction products; in many cases, cracking extends into the cement paste (with reaction products) connecting "reacted" coarse sand particles. A fair number of voids in the cement paste of the above cores are lined or filled with secondary reaction products, both alkali-silica gel and ettringite.

It is important to mention that the cracking in the cores S2 and S3 (showing moderate degree of ASR) is mainly observable at the microscale (i.e. under the stereomicroscope, crack widths > 0.05mm) as it is essentially related to ASR in the sand fraction.

It should be noted that the measured DRI's did not generally correlate with the visual observations. With the exception of one core, S1, all cores were taken from areas that were showing significant map cracking, the cracking being consistent with cracking caused by ASR.

6 Recommendations

It is recommended that the barrier walls be treated with suitable coating or sealant systems to retard the rate of further deterioration due to ASR. Breathable coatings or sealants, such as certain silanes, that are capable of preventing the ingress of liquid water (e.g. from rainfall) while allowing the passage of water vapor, have been found to be effective in reducing the internal relative humidity in concrete, especially in relatively slender elements such as barrier walls, and, thus, retarding the rate of future alkali-silica reaction.

The length of the bridges (estimated to be approximately 330 yards) provides an excellent opportunity to use a variety of different coating and sealing systems and monitor their performance with regards to controlling ASR. Measuring performance can be accomplished by monitoring the internal relative humidity within the concrete, determining future length changes and crack mapping selected locations. Non-destructive testing (NDT) techniques may also be employed.

It is understood that the bridge carrying the northbound lanes will be closed for repaving in August and this will provide an excellent window of opportunity to conduct treatment of the barrier walls on this structure.

It is recommended that a detailed plan for treatment and monitoring be developed for implementation in August to coincide with the DOT's schedule for repaving. This plan will be developed in collaboration with the DOT.

7 References

Dunbar, P.A. and Grattan-Bellew, P.E., “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, 1995.

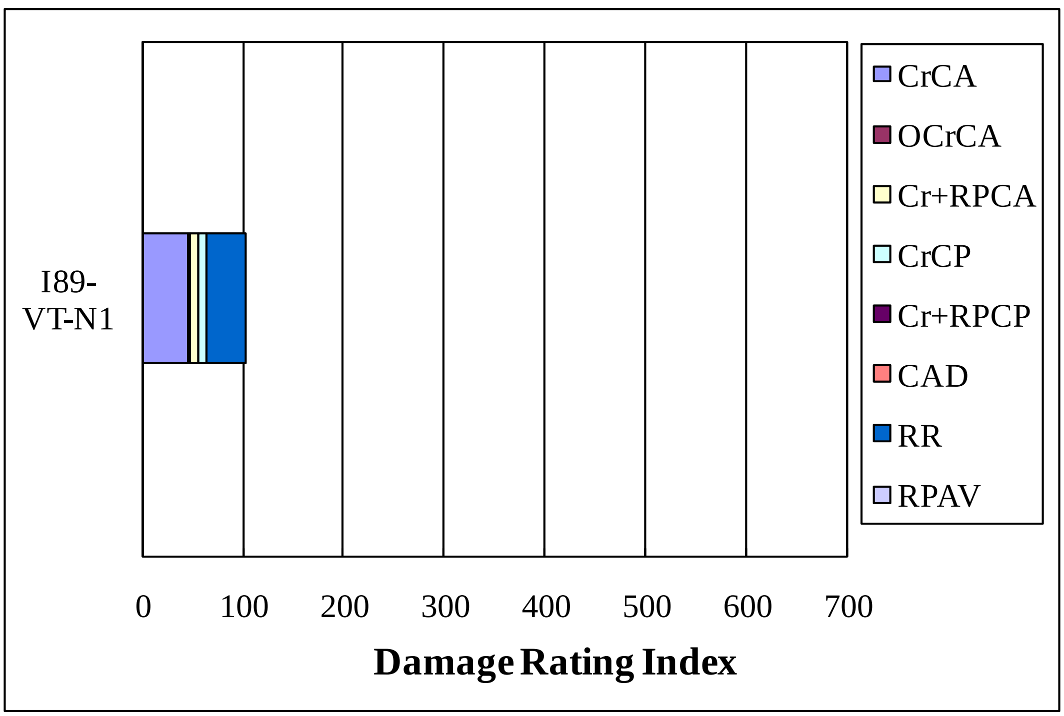
Grattan-Bellew, P.E., “Comparison of laboratory and field evaluation of alkali-silica reaction in large dams,” *In* Proceedings of the First International Conference on Concrete Alkali-Aggregate Reactions in Hydroelectric Plants and Dams, September-October 1992, Fredericton, NB, Canada, 23p, 1992.

Grattan-Bellew, P.E. and Mitchell, L.D., “Quantitative petrographic analysis of concrete – the damage rating index (DRI) method, a review,” Proceedings of *Marc-André Bérubé Symposium on Alkali-Aggregate Reaction (AAR) in Concrete*, Montréal (Canada), May 2006, edited by B. Fournier, CANMET-MTL, 45-70, 2006.

Appendix A

Photographs of the polished concrete core sections,
detailed results of the DRI and
micrographs of the petrographic symptoms of deterioration

CORE: I89-VT-N1



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
I89-VT-N1	45	2	8	10	0	0	39	0	**104**

Figure A1. Polished core section I89-VT-N1 and DRI results

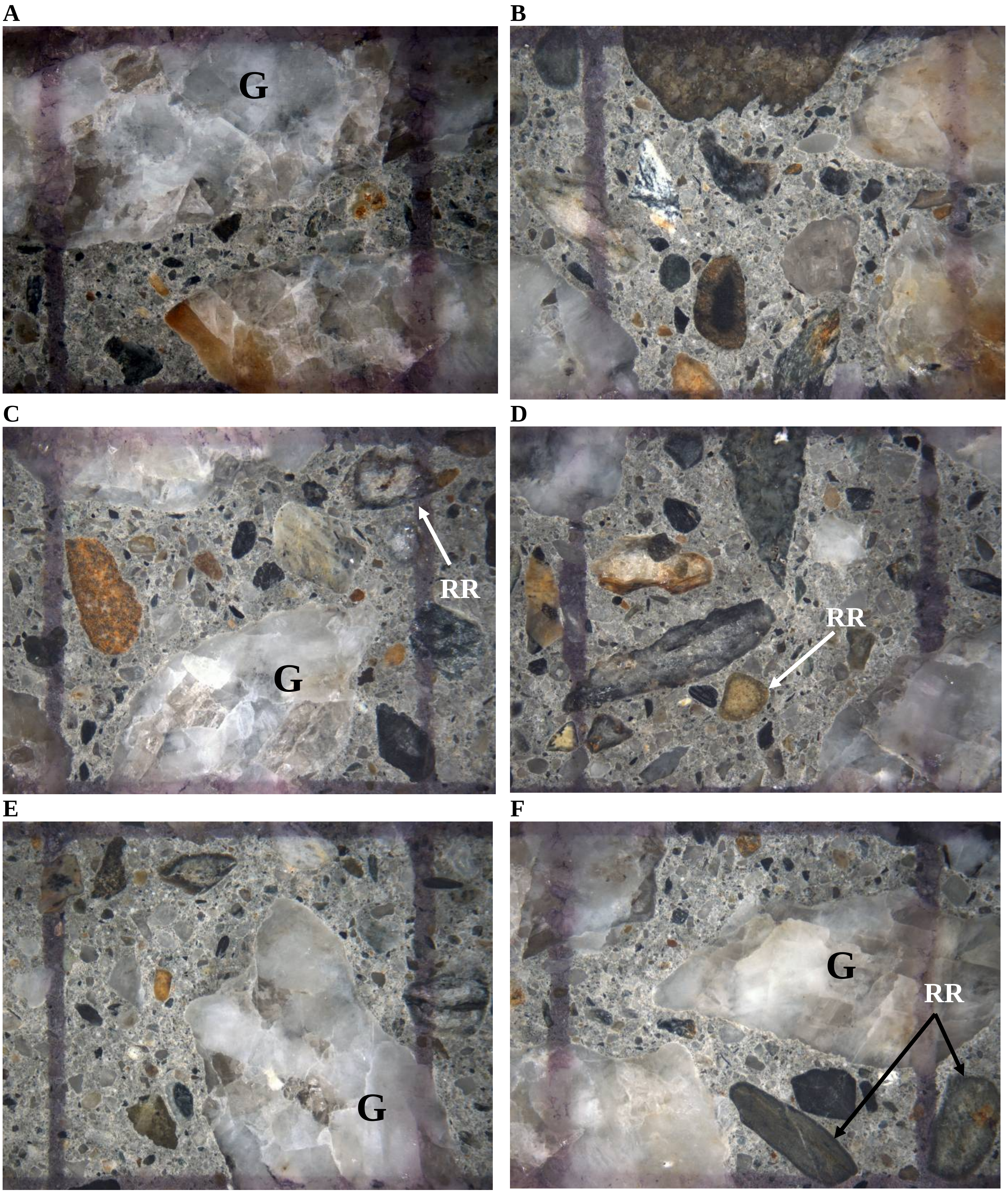
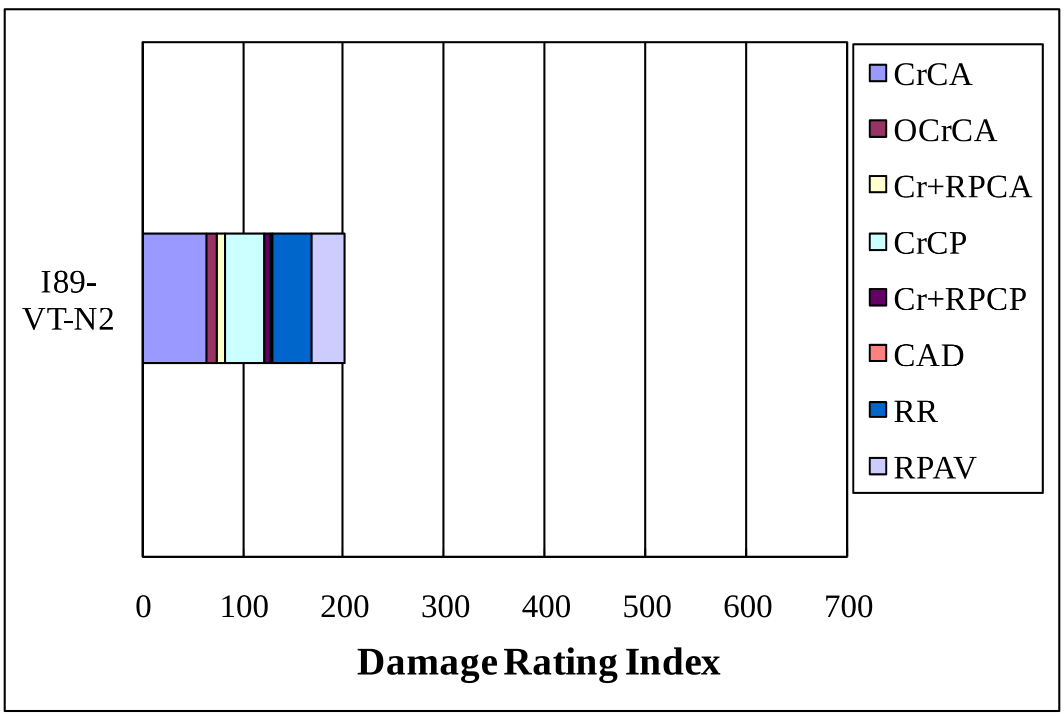


Figure A2. Micrographs of the polished core section I89-VT-N1 (distance between vertical lines = 1 cm). The micrographs show particles of the coarse aggregate, a grayish granitic-type rock (G), that often display internal cracking and grain joints; however, none of those cracks extend into the cement paste or cracks in the aggregate particles incorporate secondary reaction products. Several particles of the fine aggregate, composed of different rock types (e.g. schist, microquartzite, sandstone, and argilite) show dark/reaction rims (RR), but limited internal cracking. There is very limited cracking in the cement paste.

CORE: I89-VT-N2



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
I89-VT-N2	64	12	8	38	6	2	39	33	**202**

Figure A3. Polished core section I89-VT-N2 and DRI results

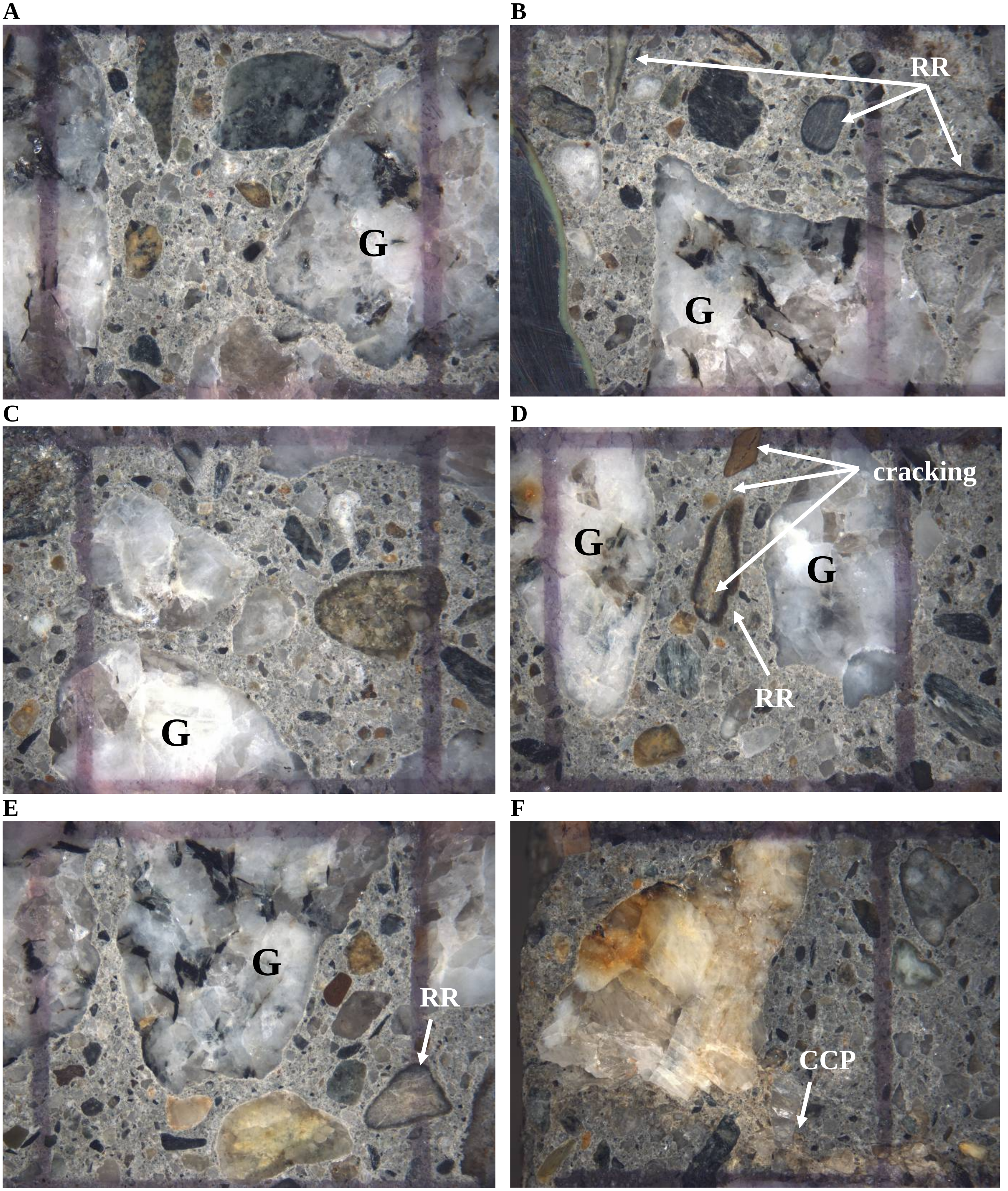
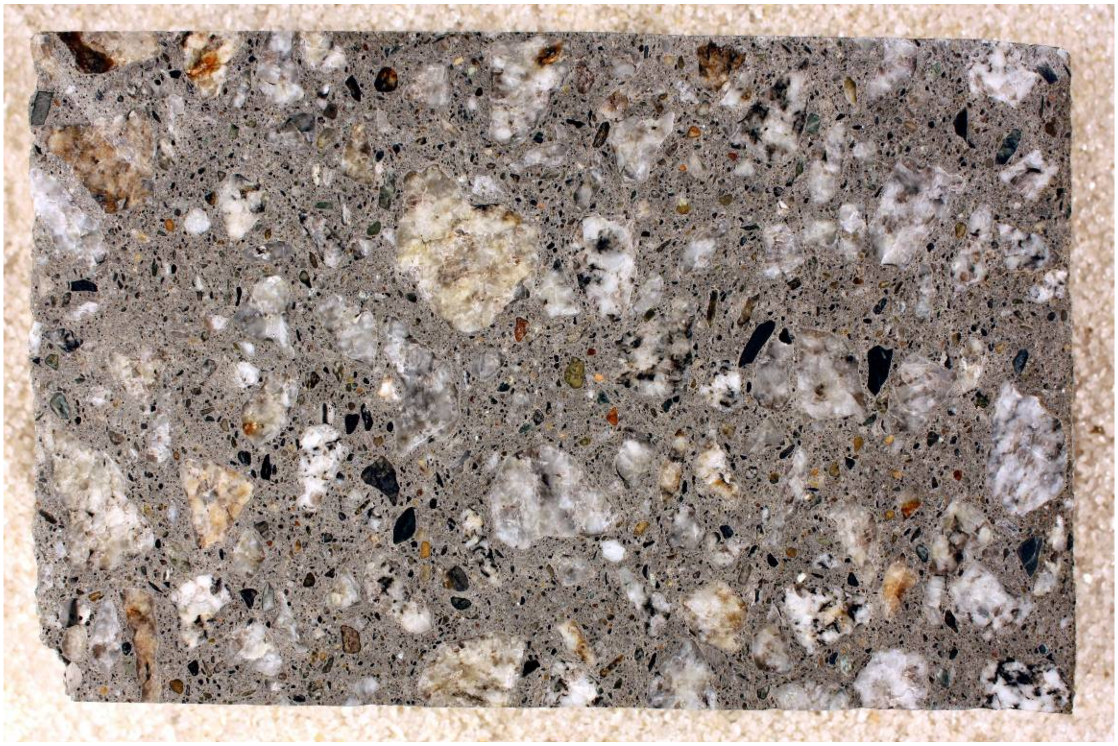
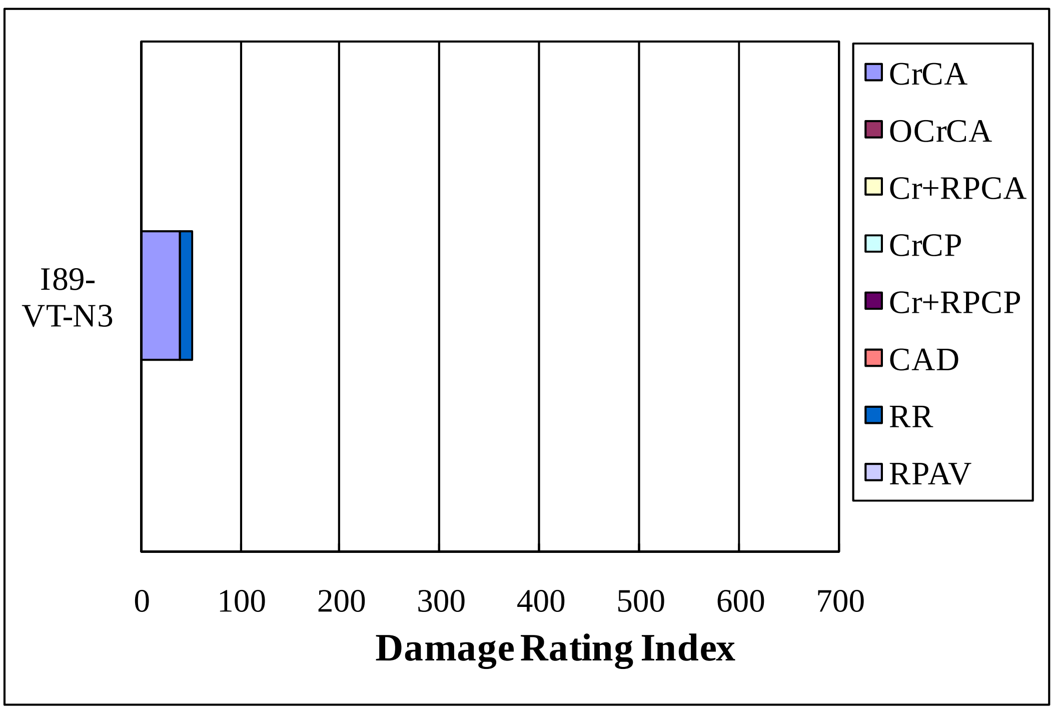


Figure A4. Micrographs of the polished core section I89-VT-N2 (distance between vertical lines = 1 cm)
The micrographs show particles of the coarse aggregate, a grayish granitic-type rock (G). Surface cracking (CCP) with associated carbonation penetrating into the core can be observed (micrograph F). Several particles of the fine aggregate (e.g. schist, microquartzite, sandstone, and argilite) show dark/reaction rims (RR) with some internal cracking (with/without reaction products) that sometimes extends into the cement paste (*cracking* in micrograph D). There is noticeable cracking in the cement paste. Micrograph B shows an epoxy-coated rebar on the left side.

CORE: I89-VT-N3





Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
I89-VT-N3	40	0	0	0	0	0	12	0	**53**

Figure A5. Polished I89-VT-N3 core section and DRI results

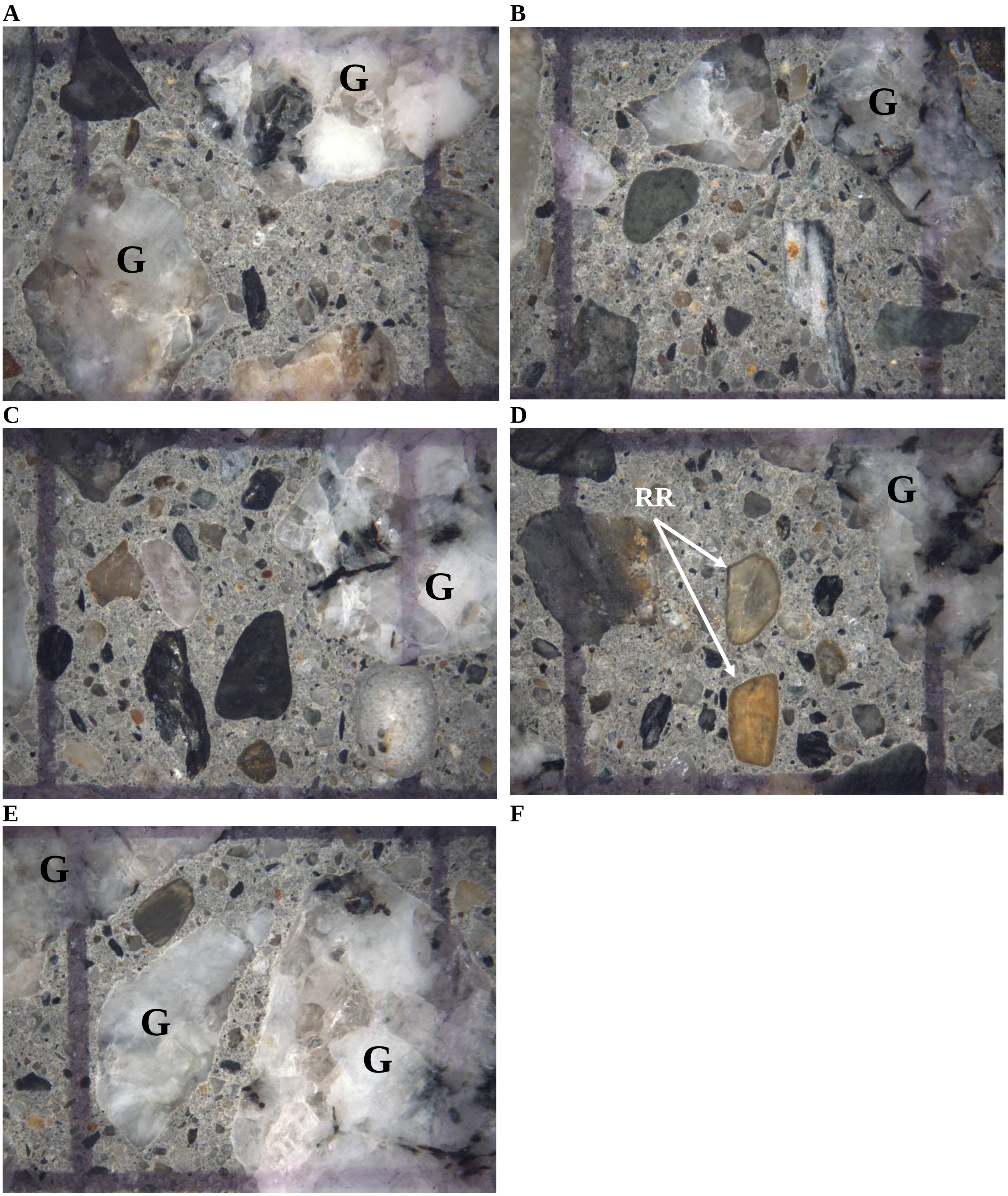
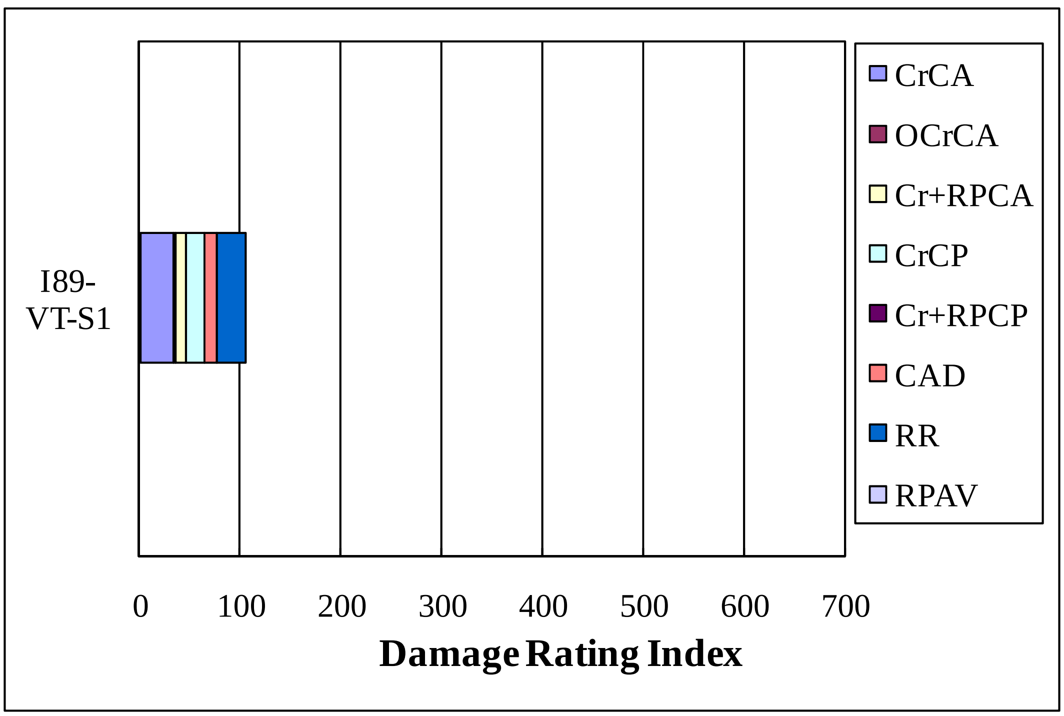


Figure A6. Micrographs of the polished core section I89-VT-N3 (distance between vertical lines = 1 cm). The micrographs show particles of the coarse aggregate, a grayish granitic-type rock (G). A few particles of the fine aggregate (e.g. schist, microquartzite, sandstone, and argilite) show dark/reaction rims (RR) with limited internal cracking. There is no noticeable cracking in the cement paste in this core (at the 15x magnification used in the test).

CORE: I89-VT-S1



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
I89-VT-S1	33	2	11	17	0	12	28	0	**104**

Figure A7. Polished I89-VT-S1 core section and DRI results

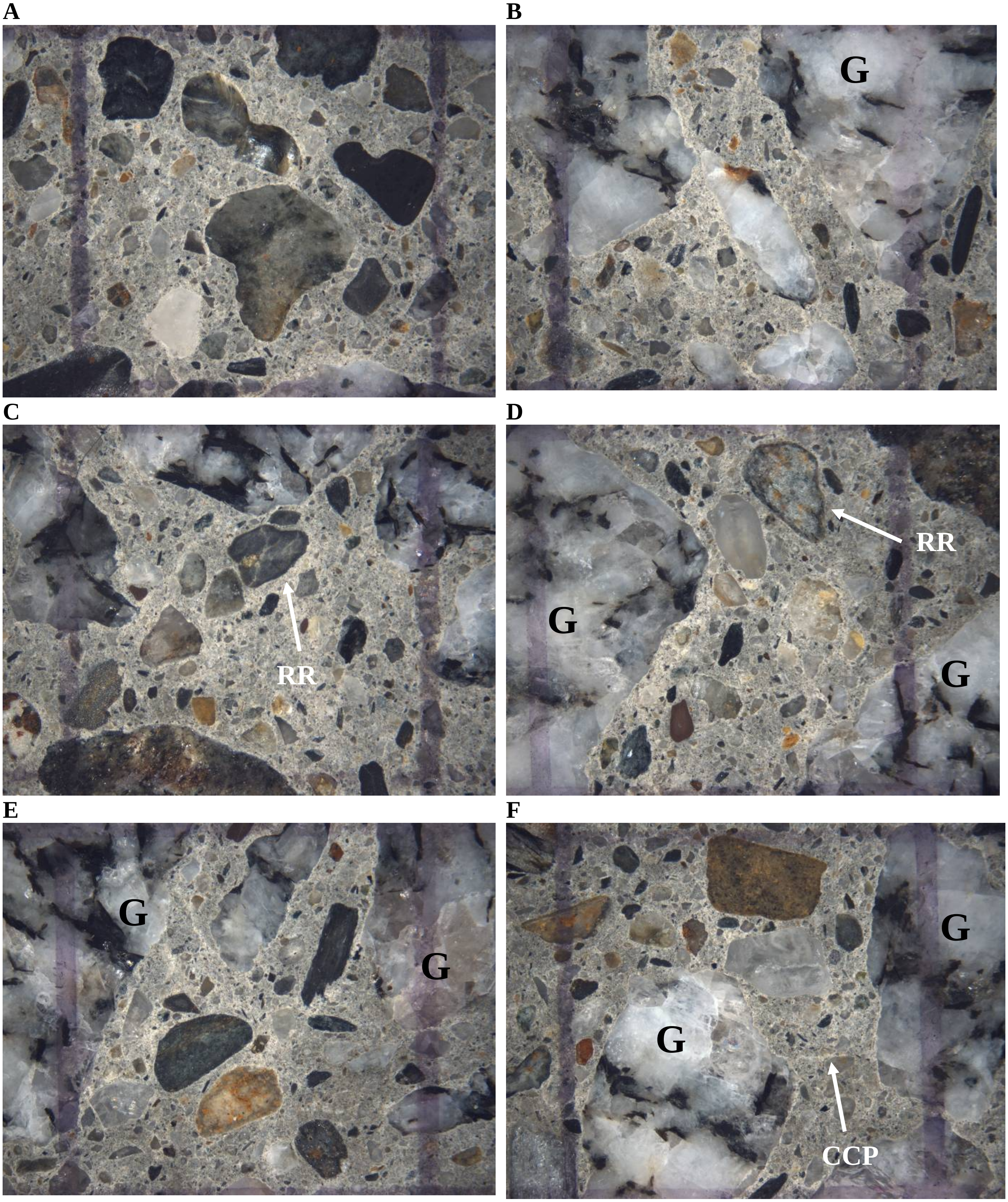
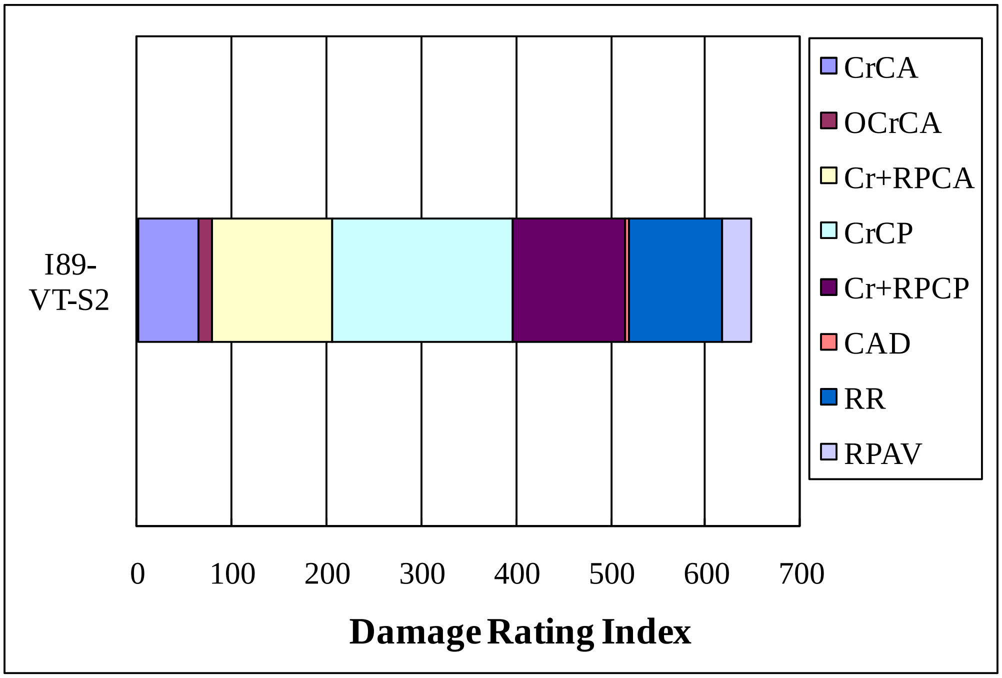


Figure A8. Micrographs of the polished core section I89-VT-S1 (distance between vertical lines = 1 cm). The micrographs show particles of the coarse aggregate, a grayish granitic-type rock (G). A few particles of the fine aggregate, composed of different rock types (e.g. schist, microquartzite, sandstone, and argilite) show dark/reaction rims (RR), but limited internal cracking. There is limited very fine cracking in the cement paste (CCP – micrograph F), in a few cases appearing at the interface between coarse aggregate particles and the cement paste.

CORE: I89-VT-S2



Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
I89-VT-S2	65	14	128	189	119	6	98	29	**647**

Figure A9. Polished I89-VT-S2 core section and DRI results

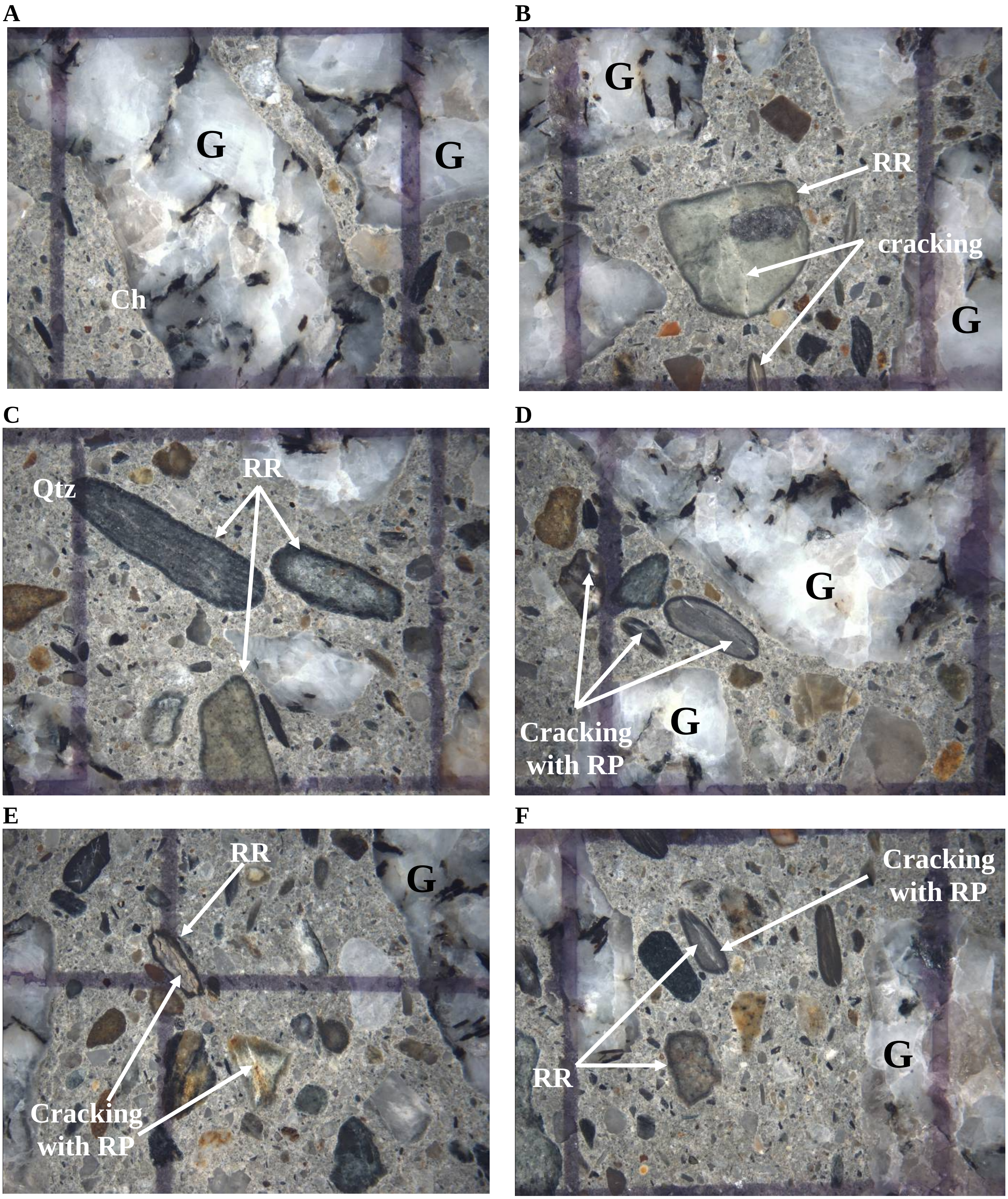
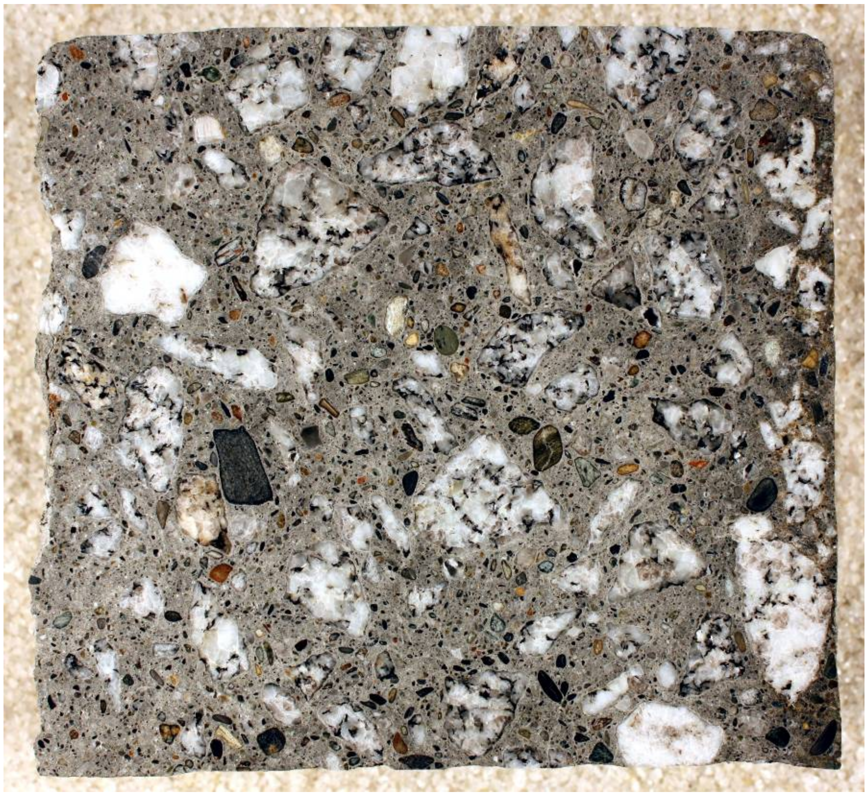
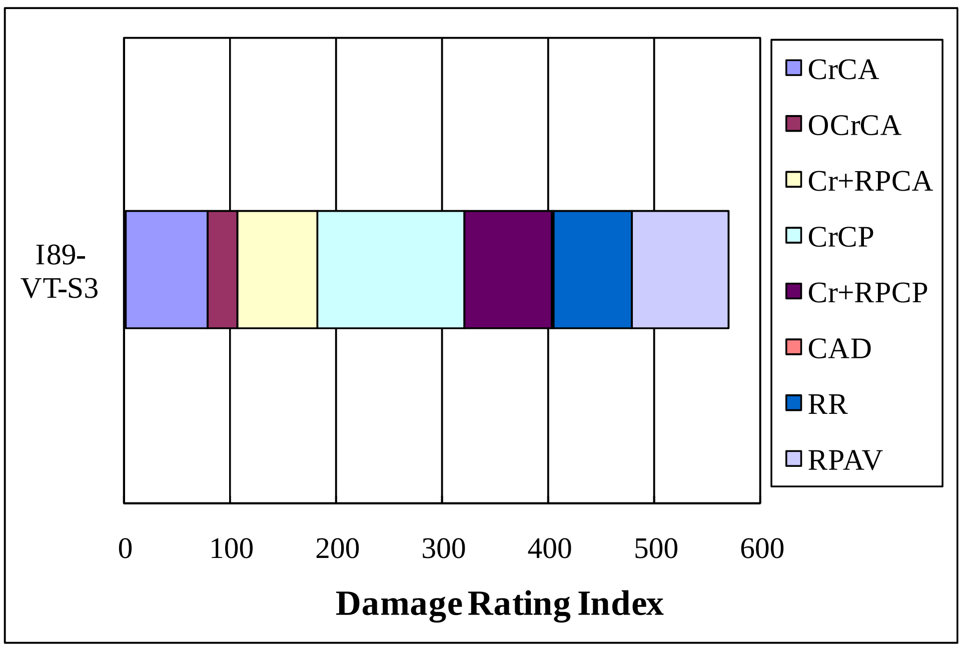


Figure A10. Micrographs of the polished core section I89-VT-S2 (distance between vertical lines = 1 cm)
The micrographs show particles of the coarse aggregate, a grayish granitic-type rock (G). Numerous particles of the fine aggregate show dark/reaction rims (RR) with significant internal cracking (with/without reaction products) that often extends into the cement paste (*cracking with RP* in micrographs B, D, E & F). There is significant cracking in the cement paste, with/without reaction products, associated to the reactivity in the fine aggregate.

CORE: I89-VT-S3





Sample	CrCA	OCrCA	Cr+RPCA	CrCP	Cr+RPCP	CAD	RR	RPAV	**DRI**
I89-VT-S3	78	29	75	138	83	2	74	90	**568**

Figure A11. Polished I89-VT-S3 core section and DRI results

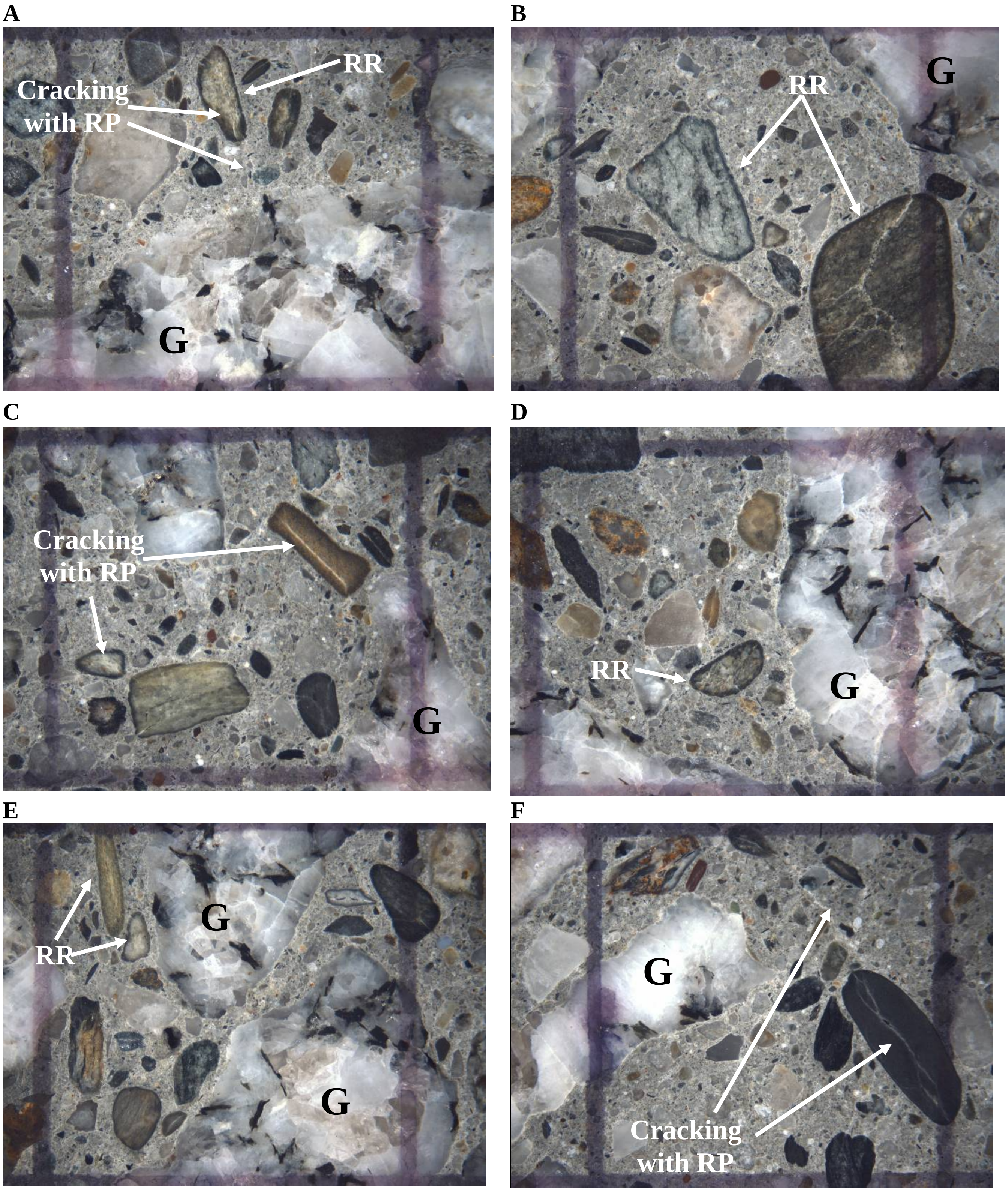


Figure A12. Micrographs of the polished core section I89-VT-S3 (distance between vertical lines = 1 cm). The micrographs show particles of the coarse aggregate, a grayish granitic-type rock (G). Numerous particles of the fine aggregate show dark/reaction rims (RR) with significant internal cracking (with/without reaction products) that often extends into the cement paste (*cracking with RP* in micrographs A & F). There is significant cracking in the cement paste, with/without reaction products, associated to the reactivity in the fine aggregate.

Appendix B

Details of Site Visit May 12, 2010

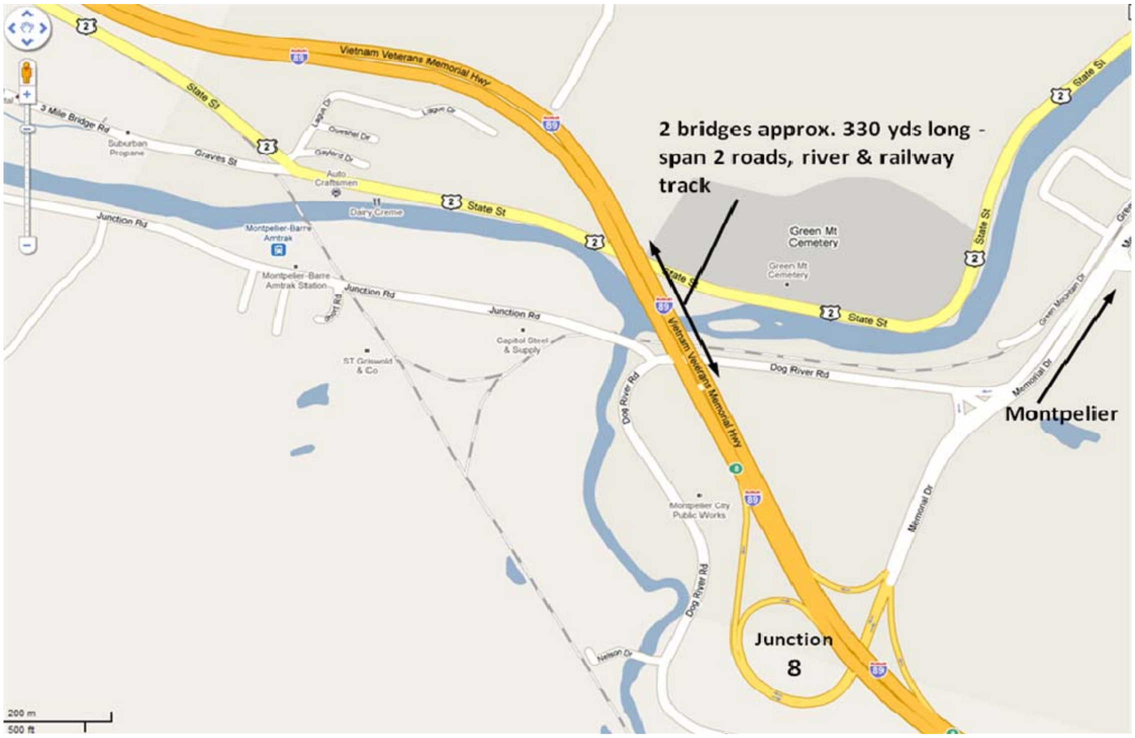


Figure B1. Location of Bridge (modified from Google Maps)

Figure B2. General View of Bridge from South Abutment on Northbound Lanes

Figure B3. Typical View of Map Cracking

Figure B4. Location of Core N1

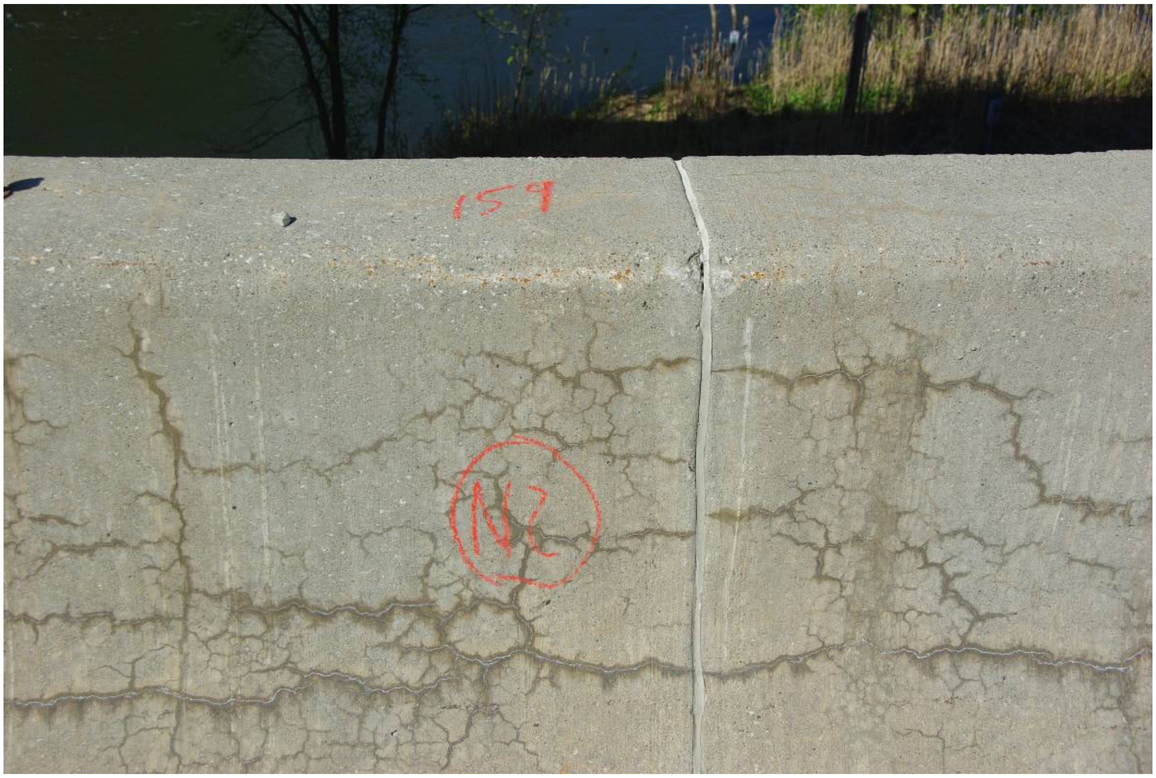


Figure B5. Location of Core N2

Figure B6. Location of Core S1

Figure B7. Location of Core S2

Figure B8. Location of Core S3