

Research Report – UCD-ITS-RR-16-19

---

Results from Visual Inspection and Laboratory Testing  
for ASR in Existing Concrete Cores from Bridges and  
Pavements in California

May 2016

Hui Li  
John T. Harvey  
Jon Asselanis  
Junwen Zhou  
Irwin M. Guada  
Venkata N. Kannekanti  
Rongzong Wu

# Results from Visual Inspection and Laboratory Testing for ASR in Existing Concrete Cores from Bridges and Pavements in California

**Authors:**

H. Li, J. Harvey, J. Asselanis, J. Zhou, I. Guada, V. Kannekanti, and R. Wu

Partnered Pavement Research Center (PPRC) Strategic Plan Project Task 3.34:  
Improved Screening Tests for ASR

---

**PREPARED FOR:**

California Department of Transportation  
Division of Research, Innovation and System Information  
and Materials Engineering and Testing Services, Office of  
Structural Materials

**PREPARED BY:**

University of California  
Pavement Research Center  
UC Davis, UC Berkeley





## TECHNICAL REPORT DOCUMENTATION PAGE

|  |                                     |   |
|--|-------------------------------------|---|
| 1. REPORT NUMBER<br>UCPRC-RR-2015-07   | 2. GOVERNMENT ASSOCIATION<br>NUMBER | 3. RECIPIENT'S CATALOG NUMBER   |
| 4. TITLE AND SUBTITLE<br>Results from Visual Inspection and Laboratory Testing for ASR in Existing Concrete Cores from Bridges and Pavements in California   |                                     | 5. REPORT PUBLICATION DATE<br>March 2017  |
|  |                                     | 6. PERFORMING ORGANIZATION CODE   |
| 7. AUTHOR(S)<br>H. Li, J. Harvey, J. Asselanis, J. Zhou, I. Guada, V. Kannekanti, and R. Wu  |                                     | 8. PERFORMING ORGANIZATION<br>REPORT NO.  |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>University of California Pavement Research Center<br>Department of Civil and Environmental Engineering, UC Davis<br>1 Shields Avenue<br>Davis, CA 95616   |                                     | 10. WORK UNIT NUMBER  |
|  |                                     | 11. CONTRACT OR GRANT NUMBER<br>65A0542   |
| 12. SPONSORING AGENCY AND ADDRESS<br>California Department of Transportation<br>Division of Research, Innovation, and System Information<br>P.O. Box 942873<br>Sacramento, CA 94273-0001   |                                     | 13. TYPE OF REPORT AND PERIOD<br>COVERED<br>Research Report<br>June 2015 – June 2016  |
|  |                                     | 14. SPONSORING AGENCY CODE<br>RPMD Task ID: 2693  |
| 15. SUPPLEMENTAL NOTES   |                                     |   |
| 16. ABSTRACT<br><p>The overall goal of this project was to evaluate with available cores the presence of alkali-silica reaction (ASR) in California bridges and pavements, to develop procedures for evaluation of ASR by Caltrans staff, and, potentially, to investigate several locations suspected of having ASR damage. This report summarizes the creation of an inventory for cores taken from bridges and pavements in previous projects, the results of visual inspection and strength testing to identify the potential presence of ASR, and the development of a draft approach for Caltrans staff to evaluate the potential for ASR in bridges and pavements. A spreadsheet database was prepared for storing inventory data for 265 pavement cores with four inch (100 mm) diameter and 311 bridge cores with two inch (50 mm) diameter. Most of the bridge cores were from the San Francisco Bay Area, while the pavement cores were collected from across the state. Visual inspection was performed on 259 of the pavement cores (including multiple samples from some of the pavement cores) and 80 of the bridge cores (those with lengths greater than the three-inch minimum required for evaluation of ASR) using the Damage Rating Index (DRI) method. None of the cores showed the likelihood of an ASR issue, as defined by a DRI greater than 2,000, although a few cores showed a small number of ASR features. Comparison of the ages of the bridges and the ASR damage rating index for the cores showed almost no trend, and showed no apparent differences between cores from bridges built before and after 1995, approximately when Caltrans changed specifications to reduce the risk of ASR.</p> <p>Most of the pavement cores tested had unconfined compressive strength (UCS) less than 8,700 psi (60 MPa) and the median of the UCS of the pavement cores was approximately 6,100 psi (42 MPa). Most of the pavement cores tested had densities less than 156 pcf (2,500 kg/m<sup>3</sup>) and the median of the UCS of the pavement cores was approximately 147 pcf (2,350 kg/m<sup>3</sup>). No significant correlation was found between the UCS and the density of the pavement cores tested, although the UCS strengths generally increased with increased density. The bridge cores were too small in diameter for strength and density testing. An integrated spreadsheet database was prepared for storing all relevant data for all cores, including test results from all tasks (DRI, UCS, and density).</p> <p>A draft guideline was developed for visual inspection of concrete cores to identify signs of potential ASR-related distresses and to support decisions regarding the need for a further detailed investigation for ASR. The guideline describes step-by-step inspection procedures and selection criteria for a further detailed examination, with relevant example pictures showing different severity levels of potential ASR distresses.</p> |                                     |   |
| 17. KEY WORDS<br>bridge decks, concrete pavements, ASR, damage, strength, visual inspection, petrographic examination  |                                     | 18. DISTRIBUTION STATEMENT<br>No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161 |
| 19. SECURITY CLASSIFICATION (of this report)<br><br>Unclassified   | 20. NUMBER OF PAGES<br>57           | 21. PRICE<br>None   |

Reproduction of completed page authorized

## UCPRC ADDITIONAL INFORMATION

|                               |   |
|-------------------------------|---|
| DRAFT STAGE<br>Stage 6, final | PARTNERED PAVEMENT RESEARCH CENTER STRATEGIC<br>PLAN ELEMENT NUMBER<br>3.34 |
| FHWA NUMBER<br>CA172702A      | VERSION NUMBER<br>1   |

CALTRANS TECHNICAL LEAD AND REVIEWER(S)  
 Keith Hoffman, and Vijay Jain, James Sagar, and Jacquelyn Wong

### PROPOSALS FOR IMPLEMENTATION

It is proposed that the Draft Test Procedures for Screening And Examining Concrete Core Samples for Alkali-Silica Reactivity included in this report be considered for use by Caltrans.

### RELATED DOCUMENTS

None

### SIGNATURES

|                              |  |                             |  |  |   |
|------------------------------|--|-----------------------------|--|--|---|
| H. Li<br><b>FIRST AUTHOR</b> | J.T. Harvey<br><b>TECHNICAL REVIEW</b> | D. Spinner<br><b>EDITOR</b> | J.T. Harvey<br><b>PRINCIPAL INVESTIGATOR</b> | K. Hoffman<br><b>CALTRANS TECH. LEAD</b> | T. Joseph Holland<br><b>CALTRANS CONTRACT MANAGER</b> |
|------------------------------|--|-----------------------------|--|--|---|

Reproduction of completed page authorized

## **DISCLAIMER STATEMENT**

---

This document is disseminated in the interest of information exchange. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This publication does not constitute a standard, specification or regulation. This report does not constitute an endorsement by the Department of any product described herein.

For individuals with sensory disabilities, this document is available in alternate formats. For information, call (916) 654-8899, TTY 711, or write to California Department of Transportation, Division of Research, Innovation and System Information, MS-83, P.O. Box 942873, Sacramento, CA 94273-0001.

## **ACKNOWLEDGMENTS**

---

The authors would like to thank Caltrans staff, including Christopher Glasscock, Vijay Jain, Keith Hoffman, James Sagar, Deepak Maskey, David Lim, Flor Bautista, and Jacquelyn Wong for help in developing the project work plan, reviewing the results, and providing technical direction, and T. Joe Holland and Nick Burmas for providing research management and direction.

## **PROJECT OBJECTIVES/GOALS**

---

The overall goals of this project were to evaluate the presence of alkali-silica reaction (ASR) in California bridges and pavements by using an already-existing collection of available pavement section and bridge cores taken from locations around the state, to develop procedures for evaluation of ASR by Caltrans staff, and, potentially, to investigate several locations suspected of having ASR damage. The cores, which had been taken from bridge decks and concrete pavements throughout California, had been collected for other research studies but they were determined to be suitable for this study's statewide assessment of the presence of ASR in Caltrans pavements and bridges. The primary objective of the project was to inventory and then use these cores to provide an overall high-level assessment of the presence of ASR in the state's pavements and bridge decks. The project's secondary objective was to see if there was any difference in the ASR detection rates for concrete placed before and after Caltrans changed its ASR-mitigation practices in the 1990s. Creation of a procedure for evaluating ASR that can be used by Caltrans staff was added as a third objective during execution of the project.

Before this study began, it was understood that the likelihood of finding ASR in any one of these samples might be low because the cores had not been taken from bridges and pavements where ASR was suspected or where there was visible damage from ASR. It was also understood that the sampling and laboratory practices to be used in this study differed from those that would be used on a typical forensic investigation where ASR is suspected because of the need to perform rapid, low-cost evaluation of a large number of cores.

This report summarizes the results of the inventory and testing of the cores made available at the beginning of the study, which completes the three objectives of the project. Some additional sampling and testing of locations with suspected ASR may be performed in the project.

## EXECUTIVE SUMMARY

---

Alkali-aggregate reaction (AAR) refers to the reaction between the hydroxyl ions in the alkaline cement pore solution in portland cement concrete (PCC) and reactive aggregates in the concrete. Alkali-silica reaction (ASR) is the most common form of alkali-aggregate reaction found in concrete. This reaction produces a composite called *alkali-silica gel* that will increase in volume and crack the aggregates and the surrounding cement paste if the latter lacks sufficient strength to resist the expansive pressure.

Caltrans has spent significant resources over several decades attempting to mitigate the impact of ASR on bridges and pavements. In 2000, Caltrans finalized a general specification it had developed to reduce ASR's impact. However, to date no study has been conducted to evaluate the service-life impact of ASR on the California highway network or to compare the results of studies on concrete materials placed before and after the final specifications changes.

The first indication of ASR in a pavement is a characteristic cracking pattern. Once a determination is made that ASR is present or that further examination is desired, cores are extracted from the area where cracking occurred. The cores are then cut into thin and/or polished sections.

The most common technique used for the identifying ASR is the examination of thin sections of concrete using a petrographic microscope. Scanning electron microscopy (SEM) is an alternative technique; it is used to examine polished sections of concrete. Of the two techniques, SEM gives a more definitive result about the presence of alkali-silica gel because the process uses x-ray microanalysis to confirm the identification of ASR reaction products.

Compressive strengths from areas suspected of having ASR can be an indicator of ASR-related microcracking, although low compressive strengths can occur for a number of other reasons.

A survey to determine the extent of ASR on the California highway network would require extensive condition surveying and field sampling. However, having existing concrete cores collected by three earlier Caltrans studies provided an opportunity to initiate an ASR survey study on the cores.

More than 300 bridge deck cores had been obtained from various structures throughout the state as part of a Caltrans Bridge Deck Preservation Committee initiative. A second set of cores was obtained from those collected by a ground-penetrating radar (GPR) study that had been conducted to determine the existing



pavement structural cross-sections on California's highway network. A third group of cores was obtained from an evaluation of coefficient of thermal expansion (CTE). A total of 265 pavement cores and 311 bridge cores were available from the three studies. Of the bridge cores, 102 had lengths greater than 75 mm (3 inches), the minimum length required to provide sufficient cross-sectional area for ASR examination based on advice from the petrographer subcontracted for the study and approved by the UCPRC and the Caltrans steering committee. The preferred length was 100 mm (4 inches) to provide more cross-sectional area. Because the pavement cores had a larger diameter and were all longer than 3 inches, all of them were potentially useable for petrographic examination.

The overall goals of this project were to evaluate the presence of alkali-silica reaction (ASR) in California bridges and pavements by using an already-existing collection of available pavement section cores and bridge cores taken from locations around the state, to develop procedures for evaluation of ASR by Caltrans staff, and, potentially, to investigate several locations suspected of having ASR damage. The primary objective of the project was to inventory and then use these cores to provide an overall high-level assessment of the presence of ASR in the state's pavements and bridge decks. The project's secondary objective was to see if there was any difference in the ASR detection rates for concrete placed before and after Caltrans changed its ASR-mitigation practices in the 1990s. A third objective added during the project was the creation an ASR evaluation procedure for use by Caltrans staff.

Before this study began, it was understood that the likelihood of finding ASR in any one of these samples might be low because the cores had not been taken from bridges and pavements where ASR was suspected or where there was visible damage from ASR. It was also understood that the sampling and laboratory practices to be used in this study differed from those that would be used on a typical forensic investigation where ASR is suspected because of the need to perform rapid, low-cost evaluation of a large number of cores.

This research report summarizes the creation of an inventory of the bridge and pavement cores from the earlier studies, lays out the criteria for visual inspection and assessment of the cores, and presents the results of strength and density testing on the cores to identify potential issues pertaining to ASR in California roadways.

Among the results from the testing were the following:

- Most of the pavement cores inspected showed Damage Rating Index (DRI) for Concrete (following ASTM C 856-14) values of less than 1,000 (ASR not likely, according to the criteria shown in Section 3.2), with a DRI value of roughly 200 being the approximate median. A few cores had DRI results between 1,000 and 2,000 (ASR possible). None of the pavement cores inspected showed DRI results larger than 2,000 (ASR probable).

- Most of the bridge cores inspected had DRI results less than 1,000 (ASR not likely, according to the criteria listed previously), and the median DRI result was approximately 500. Very few of the bridge cores had DRI results between 1,000 and 2,000 (ASR possible), and none of them had DRI results greater than 2,000 (ASR probable).

As-built data for the bridge cores were obtained for 259 of the 311 bridge cores. All of the cores came from bridges that were built before the year 2000. Comparison with the year of construction and the DRI data showed almost no trend between the age of the cores and DRI, with bridge ages ranging from 17 to 69 years old at time of visual inspection. Even the youngest cores should have had enough time to begin to manifest ASR if the reaction was occurring. There was no apparent difference in DRI values for the 46 cores taken from bridges built after 1995, when changes to specifications were made, compared with bridges built before 1995.

- Approximately 90 percent of the unconfined compressive strength (UCS) results were between 4,400 and 8,800 psi (30 and 61 MPa) and the median value was approximately 6,090 psi (42 MPa). These results were considered to be within the range of long-term strengths expected of PCC pavements by experienced Caltrans materials engineers.
- Approximately 90 percent of the density results were between 140 and 155 pcf (2,243 and 2,483 kg/m<sup>3</sup>) and the median value was approximately 147 pcf (2,350 kg/m<sup>3</sup>). These results were considered to be within the range of densities expected of PCC pavements by experienced Caltrans materials engineers.
- There was no significant correlation found between the UCS and density of the pavements core tested, although UCS strength generally increased with density.
- A draft guideline was developed for the visual inspection of concrete cores to identify signs of potential ASR-related distresses; this guideline can to be used in the future by Caltrans staff to determine the need for further, more detailed examinations. The guideline describes step-by-step inspection procedures and selection criteria for further detailed examinations, and uses photographic examples that show different severity levels of potential ASR distresses.
- An integrated spreadsheet database was prepared for storing all relevant data for all cores, including test results from all tasks (DRI, UCS, and density).

The second objective of evaluating the effects on ASR of specification changes in the 1990s could not be completed because of the very low detection of ASR in the cores examined, regardless of whether the concrete was placed before or after 1995.

Based on the results of the study, which showed very low detection of ASR, it is recommended that no further work be performed on this project, except that Caltrans may choose to select a few locations suspected of having ASR for sampling and evaluation.

# TABLE OF CONTENTS

---

|  |            |
|--|------------|
| <b>PROJECT OBJECTIVES/GOALS</b> .....  | <b>iv</b>  |
| <b>EXECUTIVE SUMMARY</b> .....   | <b>v</b>   |
| <b>LIST OF FIGURES</b> .....   | <b>x</b>   |
| <b>LIST OF ABBREVIATIONS</b> .....   | <b>xi</b>  |
| <b>LIST OF TEST METHODS AND STANDARDS</b> .....  | <b>xi</b>  |
| <b>CONVERSION FACTORS</b> .....  | <b>xii</b> |
| <b>1. INTRODUCTION</b> .....   | <b>1</b>   |
| 1.1 Background.....  | 1          |
| 1.2 Study Objective/Goal .....   | 2          |
| <b>2. COMPILATION OF INVENTORY DATA ON EXISTING CORES AND PREPARATION OF SAMPLES</b> ..... | <b>5</b>   |
| 2.1 Compiling Data on the Existing Bridge and Pavement Cores.....                          | 5          |
| 2.2 Sample Preparation.....  | 10         |
| <b>3. VISUAL INSPECTION AND ASSESSMENT OF CORES</b> .....                                  | <b>15</b>  |
| 3.1 Overview .....   | 15         |
| 3.2 Damage Rating Index Method.....  | 16         |
| 3.3 Results of Visual Inspection of Pavement Cores.....                                    | 20         |
| 3.4 Results of Visual Inspection of Bridge Cores.....                                      | 22         |
| 3.5 Comparison of Bridge Core DRI and Year of Construction .....                           | 24         |
| 3.6 Guidelines for Visual Inspection .....   | 25         |
| <b>4. COMPRESSIVE STRENGTH TESTING OF PAVEMENT CORES</b> .....                             | <b>27</b>  |
| 4.1 Overview .....   | 27         |
| 4.2 Compressive Strength Testing Method .....  | 28         |
| 4.3 Results of Compressive Strength Testing.....   | 29         |
| 4.4 Results of Density Measurements .....  | 31         |
| 4.5 Compressive Strength versus Density .....  | 32         |
| <b>5. SUMMARY, CONCLUSIONS, AND RECOMMENDED NEXT TASKS</b> .....                           | <b>33</b>  |
| 5.1 Summary.....   | 33         |
| 5.2 Conclusions .....  | 33         |
| 5.3 Next Steps.....  | 34         |
| <b>REFERENCES</b> .....  | <b>35</b>  |
| <b>APPENDIX</b> .....  | <b>36</b>  |
| Field Survey and Taking and Processing of Cores .....                                      | 36         |
| Measuring Damage Rating Index .....  | 36         |

## LIST OF FIGURES

---

|   |    |
|---|----|
| Figure 2.1: Pavement cores, including 150 cores that had been soaked in lime water for CTE testing. ....                                | 6  |
| Figure 2.2: Bridge cores; cores equal to or longer than 3 inches were used for ASR visual inspection. ....                              | 7  |
| Figure 2.3: Inventory of bridge cores. ....   | 7  |
| Figure 2.4: Inventory of pavement cores. ....   | 8  |
| Figure 2.5: Map showing original locations of bridge cores. ....  | 9  |
| Figure 2.6: Map showing original locations of pavement cores. ....  | 10 |
| Figure 2.7: J-slot continuous diamond blades for concrete core cutting. ....  | 11 |
| Figure 2.8: Cutting plan for pavement cores. ....   | 12 |
| Figure 2.9: Concrete cores for visual inspection. ....  | 13 |
| Figure 2.10: Concrete pavement cores after cutting and leveling for strength testing. ....  | 13 |
| Figure 3.1: Pavement and bridge cores after cutting for visual inspection. ....   | 15 |
| Figure 3.2: Example of the Damage Rating Index (DRI) worksheet. ....  | 17 |
| Figure 3.3: Example scans of the cut surfaces of three pavement cores. ....   | 18 |
| Figure 3.4: Example scans of the cut surfaces of three bridge cores. ....   | 19 |
| Figure 3.5: Project steering committee meeting on visual inspection at the UC Berkeley Richmond Field<br>Station on June 19, 2015. .... | 20 |
| Figure 3.6: DRI of pavement cores, by core number. ....   | 21 |
| Figure 3.7: DRI of pavement cores, frequency chart. ....  | 21 |
| Figure 3.8: DRI of pavement cores, cumulative distribution chart. ....  | 22 |
| Figure 3.9: DRI of bridge cores, by core number. ....   | 23 |
| Figure 3.10: DRI of bridge cores, frequency chart. ....   | 23 |
| Figure 3.11: DRI of bridge cores, cumulative distribution chart. ....   | 24 |
| Figure 3.12: Damage Rating Index versus year of construction for bridge cores. ....   | 25 |
| Figure 4.1: Pavement cores and strength testing. ....   | 27 |
| Figure 4.2: Frequency of length-to-diameter ratio (LDR) of pavement cores. ....   | 28 |
| Figure 4.3: Length-to-diameter ratio (LDR) correction factor. ....  | 28 |
| Figure 4.4: Corrected unconfined compressive strength of pavement cores, organized by core number. ....                                 | 29 |
| Figure 4.5: Corrected unconfined compressive strength of pavement cores, histogram chart (metric and US<br>units). ....                 | 30 |
| Figure 4.6: Density of pavement cores, histogram chart (metric and US units). ....  | 31 |
| Figure 4.7: Strength versus density of pavement cores (metric and US units). ....   | 32 |
| Figure A.1: Example of the procedures and decision making criteria for the petrographic examination and<br>Damage Index Rating. ....    | 40 |
| Figure A.2: Example photos showing some of the common petrographic features of ASR. ....  | 41 |

## **LIST OF ABBREVIATIONS**

---

|       |   |
|-------|---|
| AAR   | Alkali-aggregate reaction                         |
| AME   | Applied Materials & Engineering                   |
| ASR   | Alkali-silica reaction                            |
| DES   | Division of Engineering Services                  |
| GPR   | Ground-penetrating radar                          |
| LDR   | Length-to-diameter ratio                          |
| METS  | Materials Engineering and Testing Services        |
| OSM   | Office of Structural Materials                    |
| PLM   | Polarized light microscopy                        |
| PPRC  | Partnered Pavement Research Center                |
| SEM   | Scanning electron microscopy                      |
| UCPRC | University of California Pavement Research Center |
| UCS   | Unconfined compressive strength                   |
| XRD   | X-ray diffraction                                 |
| ASTM  | American Society for Testing and Materials        |
| FTIR  | Fourier transform infrared spectroscopy           |
| PCC   | Portland cement concrete                          |
| RFS   | Richmond Field Station                            |

## **LIST OF TEST METHODS AND STANDARDS**

---

|                   |   |
|-------------------|---|
| ASTM C39/C39M-14a | Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens |
| ASTM C294-12      | Standard Descriptive Nomenclature for Constituents of Concrete Aggregates       |
| ASTM C642-13      | Standard Test Method for Density, Absorption, and Voids in Hardened Concrete    |
| ASTM C856-14      | Standard Practice for Petrographic Examination of Hardened Concrete             |

# CONVERSION FACTORS

| <b>SI* (MODERN METRIC) CONVERSION FACTORS</b>                      |                             |                             |                             |                     |
|--|-----------------------------|-----------------------------|-----------------------------|---------------------|
| <b>APPROXIMATE CONVERSIONS TO SI UNITS</b>                         |                             |                             |                             |                     |
| Symbol   | When You Know               | Multiply By                 | To Find                     | Symbol              |
| <b>LENGTH</b>  |                             |                             |                             |                     |
| in   | inches                      | 25.4                        | Millimeters                 | mm                  |
| ft   | feet                        | 0.305                       | Meters                      | m                   |
| yd   | yards                       | 0.914                       | Meters                      | m                   |
| mi   | miles                       | 1.61                        | Kilometers                  | Km                  |
| <b>AREA</b>  |                             |                             |                             |                     |
| in <sup>2</sup>  | square inches               | 645.2                       | Square millimeters          | mm <sup>2</sup>     |
| ft <sup>2</sup>  | square feet                 | 0.093                       | Square meters               | m <sup>2</sup>      |
| yd <sup>2</sup>  | square yard                 | 0.836                       | Square meters               | m <sup>2</sup>      |
| ac   | acres                       | 0.405                       | Hectares                    | ha                  |
| mi <sup>2</sup>  | square miles                | 2.59                        | Square kilometers           | km <sup>2</sup>     |
| <b>VOLUME</b>  |                             |                             |                             |                     |
| fl oz  | fluid ounces                | 29.57                       | Milliliters                 | mL                  |
| gal  | gallons                     | 3.785                       | Liters                      | L                   |
| ft <sup>3</sup>  | cubic feet                  | 0.028                       | cubic meters                | m <sup>3</sup>      |
| yd <sup>3</sup>  | cubic yards                 | 0.765                       | cubic meters                | m <sup>3</sup>      |
| NOTE: volumes greater than 1000 L shall be shown in m <sup>3</sup> |                             |                             |                             |                     |
| <b>MASS</b>  |                             |                             |                             |                     |
| oz   | ounces                      | 28.35                       | Grams                       | g                   |
| lb   | pounds                      | 0.454                       | Kilograms                   | kg                  |
| T  | short tons (2000 lb)        | 0.907                       | megagrams (or "metric ton") | Mg (or "t")         |
| <b>TEMPERATURE (exact degrees)</b>                                 |                             |                             |                             |                     |
| °F   | Fahrenheit                  | 5 (F-32)/9<br>or (F-32)/1.8 | Celsius                     | °C                  |
| <b>ILLUMINATION</b>  |                             |                             |                             |                     |
| fc   | foot-candles                | 10.76                       | Lux                         | lx                  |
| fl   | foot-Lamberts               | 3.426                       | candela/m <sup>2</sup>      | cd/m <sup>2</sup>   |
| <b>FORCE and PRESSURE or STRESS</b>                                |                             |                             |                             |                     |
| lbf  | poundforce                  | 4.45                        | Newtons                     | N                   |
| lbf/in <sup>2</sup>  | poundforce per square inch  | 6.89                        | Kilopascals                 | kPa                 |
| <b>APPROXIMATE CONVERSIONS FROM SI UNITS</b>                       |                             |                             |                             |                     |
| Symbol   | When You Know               | Multiply By                 | To Find                     | Symbol              |
| <b>LENGTH</b>  |                             |                             |                             |                     |
| mm   | millimeters                 | 0.039                       | Inches                      | in                  |
| m  | meters                      | 3.28                        | Feet                        | ft                  |
| m  | meters                      | 1.09                        | Yards                       | yd                  |
| km   | kilometers                  | 0.621                       | Miles                       | mi                  |
| <b>AREA</b>  |                             |                             |                             |                     |
| mm <sup>2</sup>  | square millimeters          | 0.0016                      | square inches               | in <sup>2</sup>     |
| m <sup>2</sup>   | square meters               | 10.764                      | square feet                 | ft <sup>2</sup>     |
| m <sup>2</sup>   | square meters               | 1.195                       | square yards                | yd <sup>2</sup>     |
| ha   | Hectares                    | 2.47                        | Acres                       | ac                  |
| km <sup>2</sup>  | square kilometers           | 0.386                       | square miles                | mi <sup>2</sup>     |
| <b>VOLUME</b>  |                             |                             |                             |                     |
| mL   | Milliliters                 | 0.034                       | fluid ounces                | fl oz               |
| L  | liters                      | 0.264                       | Gallons                     | gal                 |
| m <sup>3</sup>   | cubic meters                | 35.314                      | cubic feet                  | ft <sup>3</sup>     |
| m <sup>3</sup>   | cubic meters                | 1.307                       | cubic yards                 | yd <sup>3</sup>     |
| <b>MASS</b>  |                             |                             |                             |                     |
| g  | grams                       | 0.035                       | Ounces                      | oz                  |
| kg   | kilograms                   | 2.202                       | Pounds                      | lb                  |
| Mg (or "t")  | megagrams (or "metric ton") | 1.103                       | short tons (2000 lb)        | T                   |
| <b>TEMPERATURE (exact degrees)</b>                                 |                             |                             |                             |                     |
| °C   | Celsius                     | 1.8C+32                     | Fahrenheit                  | °F                  |
| <b>ILLUMINATION</b>  |                             |                             |                             |                     |
| lx   | lux                         | 0.0929                      | foot-candles                | fc                  |
| cd/m <sup>2</sup>  | candela/m <sup>2</sup>      | 0.2919                      | foot-Lamberts               | fl                  |
| <b>FORCE and PRESSURE or STRESS</b>                                |                             |                             |                             |                     |
| N  | newtons                     | 0.225                       | Poundforce                  | lbf                 |
| kPa  | kilopascals                 | 0.145                       | poundforce per square inch  | lbf/in <sup>2</sup> |

# 1. INTRODUCTION

---

## 1.1 Background

Alkali-aggregate reaction (AAR) refers to the reaction between the hydroxyl ions in the alkaline cement pore solution in portland cement concrete (PCC) and reactive aggregates in the concrete. Alkali-silica reaction (ASR) is the most common form of alkali-aggregate reaction found in concrete. This reaction produces a composite called *alkali-silica gel* that will increase in volume and crack the aggregates and the surrounding cement paste if the latter lacks sufficient strength to resist the expansive pressure.

Caltrans has spent significant resources over several decades attempting to mitigate the impact of ASR on bridges and pavements. In 2000, Caltrans finalized a general specification it had developed to reduce ASR's impact. However, to date no study has been conducted to evaluate the service-life impact of ASR on the California highway network or to compare the results of studies on concrete materials placed before and after the final specifications changes.

The first indication of ASR in a pavement is a characteristic cracking pattern. Once a determination is made that ASR is present or that further examination is desired, cores are extracted from the area where cracking occurred. The cores are then cut into thin and/or polished sections.

The most common technique used for the identifying ASR is the examination of thin sections of concrete using a petrographic microscope. Scanning electron microscopy (SEM) is an alternative technique; it is used to examine polished sections of concrete. Of the two techniques, SEM gives a more definitive result about the presence of alkali-silica gel because the process uses x-ray microanalysis to confirm the identification of ASR reaction products.

Compressive strengths from areas suspected of having ASR can be an indicator of ASR-related microcracking, although low compressive strengths can occur for a number of other reasons.

A survey to determine the extent of ASR on the California highway network would require extensive condition surveying and field sampling. However, having existing concrete cores collected by three earlier Caltrans studies provided an opportunity to initiate an ASR survey study on the cores.

The first of these earlier studies, a Caltrans Bridge Deck Preservation Committee initiative, collected 311 bridge deck cores from various structures throughout the state as part of quality assurance testing. The cores were identified as being of use for ASR research and were obtained for this study from the Caltrans Transportation Laboratory.



A second set of cores was obtained from those remaining from a ground-penetrating radar (GPR) study completed in 2012. The goal of the study for which the cores had been collected was to develop better information regarding the existing pavement structures on California's state highway system. The cores, many of which were taken from concrete pavements, had been used to calibrate the GPR. Some of the cores were from pavements with PCC surfaces and others had been overlaid with asphalt prior to coring. Although most of the GPR pavement cores were discarded after completion of the thickness measurements, cores from 134 sites had been saved and were still available.

A third study, from which 131 cores were obtained, had used nondestructive testing to measure the coefficient of thermal expansion (CTE) on concrete pavement projects. Although the cores from the CTE study had been subjected to a brief period of soaking, it was determined that the soaking would not compromise the results of the ASR study.

Altogether, a total of 265 pavement cores and 311 bridge cores were available from the three studies. Of the bridge cores, 102 had lengths greater than 75 mm (3 inches), the minimum length required to provide sufficient cross-sectional area for ASR examination based on advice from the petrographer subcontracted for the study and approved by the UCPRC and the Caltrans steering committee (which consisted of selected staff from the Office of Structural Materials [OSM] and members of the Pavement Program). The preferred length was 100 mm (4 inches) to provide more cross-sectional area. Because the pavement cores had a larger diameter and were all longer than 3 inches, all of them were potentially useable for petrographic examination.

## **1.2 Study Objective/Goal**

The overall goals of this project were to evaluate the presence of alkali-silica reaction (ASR) in California bridges and pavements by using an already-existing collection of available pavement section cores and bridge cores taken from locations around the state, to develop procedures for evaluation of ASR by Caltrans staff, and, potentially, to investigate several locations suspected of having ASR damage. The cores, which had been removed from bridge decks and concrete pavements throughout California, had been collected for other research studies but they were determined to be suitable for this study's statewide assessment of the presence of ASR in Caltrans pavements and bridges. The primary objective of the project was to inventory and then use these cores to provide an overall high-level assessment of the presence of ASR in the state's pavements and bridge decks. The project's secondary objective was to see if there was any difference in the ASR detection rates for concrete placed before and after Caltrans changed its ASR-mitigation practices in the 1990s. Creation of a procedure for evaluating ASR that can be used by Caltrans staff was added as a third objective during execution of the project.

Before this study began, it was understood that the likelihood of finding ASR in any one of these samples might be low because the cores had not been taken from bridges and pavements where ASR was suspected or where there was visible damage from ASR. It was also understood that the sampling and laboratory practices to be used in this study differed from those that would be used on a typical forensic investigation where ASR is suspected because of the need to perform rapid, low-cost evaluation of a large number of cores.

This report summarizes the results of the inventory and testing of the cores made available at the beginning of the study, which completes the three objectives of the project, except that the second objective of evaluating detection rates of ASR in concrete placed before and after specification changes in the 1990s showed no differences because of very low detection rates across all cores.

*(This page left blank)*

## **2. COMPILATION OF INVENTORY DATA ON EXISTING CORES AND PREPARATION OF SAMPLES**

---

The first task of the project had three parts: inventory the pavement and bridge cores, create a database from the inventory, and prepare the cores for further evaluation and testing. Once the inventory data was collected it was to be used for the following, if possible:

- To create a final database that can be utilized by various Caltrans units in the future,
- To determine the adequacy of current specifications, and
- To correlate the prevalence of ASR in concrete to site conditions and service life.

### **2.1 Compiling Data on the Existing Bridge and Pavement Cores**

All the bridge and pavement section cores were collected from Caltrans and UCPRC storage facilities and brought to the UCPRC's laboratory at Richmond Field Station (see Figure 2.1 and Figure 2.2). Once there, UCPRC staff—using identification data provided by staff of the Caltrans Division of Engineering Services (DES) Materials Engineering and Testing Services (METS)—processed and inventoried the bridge cores, measured their dimensions, and organized all the cores for use in this study.

Spreadsheet data files (shown in Figure 2.3 for the bridge cores and in Figure 2.4 for the pavement cores) were generated to archive the available information. Data available for the bridge cores, including bridge ID/name and location, coring date, core size and core location on bridge, and any historical data (bridge age, mix design, strength, stiffness, etc.), came from METS staff, while information for the pavement cores came from UCPRC records.

Figure 2.5 and Figure 2.6 show that most of the bridge cores were from the San Francisco Bay Area and northern California, and that the pavement cores came from across the state. Figure 2.6 also shows where cores were taken from the surface of PCC pavements and from PCC under asphalt surfaces.



**Figure 2.1: Pavement cores, including 150 cores that had been soaked in lime water for CTE testing.**

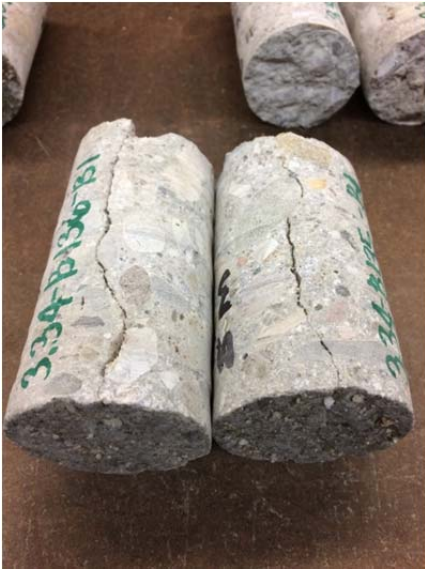


Figure 2.2: Bridge cores; cores equal to or longer than 3 inches were used for ASR visual inspection.

| CoreID | District | County       | Route  | CoreLocation         | BridgeNumber | PM     | Lane | Abutto | TransDist | Shoulder    | Note4Loc         | CoreID     | CoringDate | CoreType | Latitude | Longitude | Elevation | WaterBodyName | WaterBodyType | DistanceWB | CoreDiam | CoreLength | Notes       |           |
|--------|----------|--------------|--------|----------------------|--------------|--------|------|--------|-----------|-------------|------------------|------------|------------|----------|----------|-----------|-----------|---------------|---------------|------------|----------|------------|-------------|-----------|
| 1      | 4        | Contra Costa | NB 680 | Jane 3, BR#28-0161   | 28-0161      | 13.93  | 3    | 1      | 53'       | 106"        | ic Blvd. o/s     | 1          | 8/12/08    | Bridge   | 37.8938  | -122.067  | 254       | Reservoir     | Fresh         | 20,000     | 2        | 3          | D4-2A7204   |           |
| 2      | 4        | Contra Costa | NB 680 | 3, BR#28-0161 A91    | 28-0161      | 13.93  | 3    | 1      | 52'       | 105"        | ic Blvd. o/s     | 2          | 8/12/08    | Bridge   | 37.8938  | -122.067  | 254       | Reservoir     | Fresh         | 20,000     | 2        | 3          | D4-2A7204   |           |
| 3      | 4        | Contra Costa | NB 680 | 3, BR#28-0161 BNT    | 28-0161      | 13.93  | 3    | 2      | 15'       | 18"         | ic Blvd. o/s     | 3          | 8/12/08    | Bridge   | 37.8938  | -122.067  | 254       | Reservoir     | Fresh         | 20,000     | 2        | 2          | D4-2A7204   |           |
| 4      | 4        | Contra Costa | NB 680 | 3, BR#28-0161 BN     | 28-0161      | 13.93  | 3    | 2      | 9'        | 18"         | ic Blvd. o/s     | 4          | 8/12/08    | Bridge   | 37.8938  | -122.067  | 254       | Reservoir     | Fresh         | 20,000     | 2        | 3          | D4-2A7204   |           |
| 5      | 4        | San Mateo    | 380    | BR#35-0253, 7R       | 35-0253      | 5.73   |      |        |           |             | 7R               | 1/5        | Unknown    | Bridge   | 37.6344  | -122.415  | 20        | SF Bay        | Ocean Bay     | 8,000      | 2        | 2          | Core broker |           |
| 6      | 4        | San Mateo    | 380    | BR#35-0253, 9K       | 35-0253      | 5.73   |      |        |           |             | 9K               |            | Unknown    | Bridge   | 37.6344  | -122.415  | 20        | SF Bay        | Ocean Bay     | 8,000      | 2        | 2          | D4-0E5304   |           |
| 7      | 4        | San Mateo    | 380    | BR#35-0253, 9R       | 35-0253      | 5.73   |      |        |           |             | 9R               |            | Unknown    | Bridge   | 37.6344  | -122.415  | 20        | SF Bay        | Ocean Bay     | 8,000      | 2        | 3          | D4-0E5304   |           |
| 8      | 4        | San Mateo    | 380    | BR#35-0253, 11L      | 35-0253      | 5.73   |      |        |           |             | 11L              | 1/3        | Unknown    | Bridge   | 37.6344  | -122.415  | 20        | SF Bay        | Ocean Bay     | 8,000      | 2        | 5          | D4-0E5304   |           |
| 9      | 3        | Placer       | NB 65  | R12.67, BR#19-017    | 19-0176      | R12.67 | 2    | 1      | 13'       | 163"        | am Slough        | 1          | 6/30/09    | Bridge   | 38.8619  | -121.3    | 158       | Mill Pond     | Fresh         | 6,231      | 2        | 3          | D3-2E8804   |           |
| 10     | 3        | Placer       | NB 65  | R12.67, BR#19-017    | 19-0176      | R12.67 | 2    | 1      | 228'      | 116"        | am Slough        | 2          | 6/30/09    | Bridge   | 38.8619  | -121.3    | 158       | Mill Pond     | Fresh         | 6,231      | 2        | 2          | D3-2E8804   |           |
| 11     | 3        | Placer       | NB 65  | R12.67, BR#19-017    | 19-0176      | R12.67 | 2    | 1      | 664'      | 91"         | am Slough        | 3          | 6/30/09    | Bridge   | 38.8619  | -121.3    | 158       | Mill Pond     | Fresh         | 6,231      | 2        | 3          | D3-2E8804   |           |
| 12     | 3        | Placer       | NB 65  | R12.67, BR#19-017    | 19-0176      | R12.67 | 2    | 1      | 10210'    | 711"        | am Slough        | 4          | 6/30/09    | Bridge   | 38.8619  | -121.3    | 158       | Mill Pond     | Fresh         | 6,231      | 2        | 3          | D3-2E8804   |           |
| 13     | 3        | Placer       | NB 65  | R12.67, BR#19-017    | 19-0176      | R12.67 | 2    | 2      | 236'      | 81"         | am Slough        | 5          | 6/30/09    | Bridge   | 38.8619  | -121.3    | 158       | Mill Pond     | Fresh         | 6,231      | 2        | 3          | D3-2E8804   |           |
| 14     | 3        | Placer       | NB 65  | R12.67, BR#19-017    | 19-0176      | R12.67 | 2    | 2      | 1011'     | 105"        | am Slough        | 6          | 6/30/09    | Bridge   | 38.8619  | -121.3    | 158       | Mill Pond     | Fresh         | 6,231      | 2        | 3          | D3-2E8804   |           |
| 15     | 3        | Placer       | 65     | M 8.02, BR#19-017    | 19-0174      | M8.02  | 2    | 1      | 67'       | 108"        | Oaks Blvd        | 1          | 6/30/09    | Bridge   | 38.7951  | -121.297  | 122       | hitney Por    | Fresh         | 20,000     | 2        | 3          | D3-2E8804   |           |
| 16     | 3        | Placer       | 65     | M8.02, BR#19-017     | 19-0174      | M8.02  | 2    | 1      | 15611'    | 105"        | Oaks Blvd        | 2          | 6/30/09    | Bridge   | 38.7951  | -121.297  | 122       | hitney Por    | Fresh         | 20,000     | 2        | 3          | D3-2E8804   |           |
| 17     | 3        | Placer       | 65     | M8.02, BR#19-017     | 19-0174      | M8.02  | 2    | 1      | 1289'     | 104"        | Oaks Blvd        | 3          | 6/30/09    | Bridge   | 38.7951  | -121.297  | 122       | hitney Por    | Fresh         | 20,000     | 2        | 3          | D3-2E8804   |           |
| 18     | 3        | Placer       | 65     | M8.02, BR#19-017     | 19-0174      | M8.02  | 2    | 1      | 1437'     | 66"         | Oaks Blvd        | 4          | 6/30/09    | Bridge   | 38.7951  | -121.297  | 122       | hitney Por    | Fresh         | 20,000     | 2        | 3          | D3-2E8804   |           |
| 19     | 3        | Placer       | 65     | PM R11.92, BR#19-0   | 19-0173      | R11.92 | 1    | 1      | 952'      | 60"         | Bridges          | 1          | 6/30/09    | Bridge   | 38.8511  | -121.3    | 133       | hitney Por    | Fresh         | 2,104      | 2        | 3          | D3-2E8804   |           |
| 20     | 3        | Placer       | 65     | PM R11.92, BR#19-0   | 19-0173      | R11.92 | 1    | 1      | 1256'     | 60"         | Bridges          | 2          | 6/30/09    | Bridge   | 38.8511  | -121.3    | 133       | hitney Por    | Fresh         | 2,104      | 2        | 2          | D3-2E8804   |           |
| 21     | 3        | Placer       | 65     | PM R11.92, BR#19-0   | 19-0173      | R11.92 | 1    | 1      | 1532'     | 60"         | Bridges          | 3          | 6/30/09    | Bridge   | 38.8511  | -121.3    | 133       | hitney Por    | Fresh         | 2,104      | 2        | 3          | D3-2E8804   |           |
| 22     | 3        | Placer       | 65     | PM R11.92, BR#19-0   | 19-0173      | R11.92 | 1    | 3      | 290'      | 102"        | Bridges          | 4          | 6/30/09    | Bridge   | 38.8511  | -121.3    | 133       | hitney Por    | Fresh         | 2,104      | 2        | 3          | D3-2E8804   |           |
| 23     | 3        | Placer       | 65     | R8.20, BR#19-015     | 19-0154S     | R8.20  | 3    | 3      | 347'      | 111"        | s Blvd. Off      | 1          | 6/30/09    | Bridge   | 38.7973  | -121.299  | 118       | olsom Lak     | Fresh         | 47,933     | 2        | 3          | D3-2E8804   |           |
| 24     | 3        | Placer       | 65     | R8.20, BR#19-015     | 19-0154S     | R8.20  | 3    | 82'    | 153"      | s Blvd. Off | 2                | 6/30/09    | Bridge     | 38.7973  | -121.299 | 118       | olsom Lak | Fresh         | 47,933        | 2          | 3        | D3-2E8804  |             |           |
| 25     | 3        | Placer       | 65     | R8.20, BR#19-015     | 19-0154S     | R8.20  | 3    | 67'    | 911"      | s Blvd. Off | 3                | 6/30/09    | Bridge     | 38.7973  | -121.299 | 118       | olsom Lak | Fresh         | 47,933        | 2          | 2.5      | D3-2E8804  |             |           |
| 26     | 3        | Placer       | 65     | R8.20, BR#19-015     | 19-0154S     | R8.20  | 3    | 101'   | 111"      | s Blvd. Off | 4                | 6/30/09    | Bridge     | 38.7973  | -121.299 | 118       | olsom Lak | Fresh         | 47,933        | 2          | 2.5      | D3-2E8804  |             |           |
| 27     | 3        | Placer       | 65     | PM 12.60, BR#19-0    | 19-0179R     | 12.6   | 2    | 4      | 432'      | 96"         | Pkwy BOH         | 1          | 6/30/09    | Bridge   | 38.8609  | -121.3    | 147       | olsom Lak     | Fresh         | 60,000     | 2        | 2          | D3-2E8804   |           |
| 28     | 3        | Placer       | 65     | PM 12.60, BR#19-0    | 19-0179R     | 12.6   | 2    | 4      | 1328'     | 91"         | Pkwy BOH         | 2          | 6/30/09    | Bridge   | 38.8609  | -121.3    | 147       | olsom Lak     | Fresh         | 60,000     | 2        | 3          | D3-2E8804   |           |
| 29     | 3        | Placer       | 65     | PM 12.60, BR#19-0    | 19-0179R     | 12.6   | 2    | 4      | 1401'     | 31"         | Pkwy BOH         | 3          | 6/30/09    | Bridge   | 38.8609  | -121.3    | 147       | olsom Lak     | Fresh         | 60,000     | 2        | 3          | D3-2E8804   |           |
| 30     | 3        | Placer       | 65     | PM 12.60, BR#19-0    | 19-0179R     | 12.6   | 2    | 4      | 25311'    | 710"        | Pkwy BOH         | 4          | 6/30/09    | Bridge   | 38.8609  | -121.3    | 147       | olsom Lak     | Fresh         | 60,000     | 2        | 3          | D3-2E8804   |           |
| 31     | 3        | Placer       | 65     | PM 12.60, BR#19-0    | 19-0179R     | 12.6   | 2    | 4      | 2823'     | 27"         | Pkwy BOH         | 5          | 6/30/09    | Bridge   | 38.8609  | -121.3    | 147       | olsom Lak     | Fresh         | 60,000     | 2        | 3          | D3-2E8804   |           |
| 32     | 3        | Placer       | 65     | PM 12.60, BR#19-0    | 19-0179R     | 12.6   | 2    | 1      | 54'       | 95"         | Pkwy BOH         | 6          | 6/30/09    | Bridge   | 38.8609  | -121.3    | 147       | olsom Lak     | Fresh         | 60,000     | 2        | 3          | D3-2E8804   |           |
| 33     | 3        | Placer       | 65     | PM 12.60, BR#19-0    | 19-0179L     | 12.6   | 2    | 1      | 124'      | 95"         | Pkwy BOH         | 1          | 6/30/09    | Bridge   | 38.8609  | -121.3    | 147       | olsom Lak     | Fresh         | 60,000     | 2        | 2          | D3-2E8804   |           |
| 34     | 3        | Placer       | 65     | PM 12.60, BR#19-0    | 19-0179L     | 12.6   | 2    | 1      | 700'      | 86"         | Pkwy BOH         | 2          | 6/30/09    | Bridge   | 38.8609  | -121.3    | 147       | olsom Lak     | Fresh         | 60,000     | 2        | 2          | D3-2E8804   |           |
| 35     | 3        | Placer       | 65     | PM 12.60, BR#19-0    | 19-0179L     | 12.6   | 2    | 1      | 1625'     | 137"        | Pkwy BOH         | 3          | 6/30/09    | Bridge   | 38.8609  | -121.3    | 147       | olsom Lak     | Fresh         | 60,000     | 2        | 3          | D3-2E8804   |           |
| 36     | 3        | Placer       | 65     | PM 12.60, BR#19-0    | 19-0179L     | 12.6   | 2    | 1      | 2004'     | 101"        | Pkwy BOH         | 4          | 6/30/09    | Bridge   | 38.8609  | -121.3    | 147       | olsom Lak     | Fresh         | 60,000     | 2        | 3          | D3-2E8804   |           |
| 37     | 3        | Placer       | 65     | PM 12.60, BR#19-0    | 19-0179L     | 12.6   | 2    | 1      | 2527'     | 76"         | Pkwy BOH         | 5          | 6/30/09    | Bridge   | 38.8609  | -121.3    | 147       | olsom Lak     | Fresh         | 60,000     | 2        | 3          | D3-2E8804   |           |
| 38     | 3        | Placer       | 65     | PM 12.60, BR#19-0    | 19-0179L     | 12.6   | 2    | 1      | 2662'     | 59"         | Pkwy BOH         | 6          | 6/30/09    | Bridge   | 38.8609  | -121.3    | 147       | olsom Lak     | Fresh         | 60,000     | 2        | 3          | D3-2E8804   |           |
| 39     | 4        | Solano       | 80     | CR Bridge, Lane 1, F | 23-29L       | R5.2   | 1    |        |           |             | 505 South Sweeny | Sample 1/2 | 8/10/08    | Bridge   | 38.1333  | -122.224  | 104       | lake Chab     | Fresh         | 2,158      | 2        | 5          | D4-0E8104   |           |
| 40     | 4        | Solano       | 80     | CR Bridge, Lane 1, F | 23-29L       | R5.2   | 1    |        |           |             | 505 South Sweeny | Sample 2/2 | 8/10/08    | Bridge   | 38.1333  | -122.224  | 104       | lake Chab     | Fresh         | 2,158      | 2        | 6          | D4-0E8104   |           |
| 41     | 4        | Solano       | 80     | CR Bridge, Lane 1, F | 23-29R       | R5.2   | 1    |        |           |             | 505 North Sweeny | Sample 1/2 | 8/10/08    | Bridge   | 38.1333  | -122.224  | 104       | lake Chab     | Fresh         | 2,158      | 2        | 5          | D4-0E8104   |           |
| 42     | 4        | Solano       | 80     | uth, Lane 1, PM R5.4 | 23-0169L     | R5.57  | 1    |        |           |             | Allendale 505 S  | 3/3        | 8/10/08    | Bridge   | 38.1382  | -122.221  | 279       | lake Chab     | Fresh         | 2,200      | 2        | 4          | D4-0E8104   |           |
| 43     | 4        | Solano       | 80     | uth, Lane 1, PM R5.4 | 23-169R      | R5.57  | 1    |        |           |             | 505 North Allen  | 2/2 Sample | 8/10/08    | Bridge   | 38.1382  | -122.221  | 279       | lake Chab     | Fresh         | 2,200      | 2        | 5          | D4-0E8104   |           |
| 44     | 4        | Solano       | 80     | uth, Lane 1, PM R5.4 | 23-169R      | R5.57  | 1    |        |           |             | 505 North Allen  | 2/2 Sample | 8/10/08    | Bridge   | 38.1382  | -122.221  | 279       | lake Chab     | Fresh         | 2,200      | 2        | 5          | D4-0E8104   |           |
| 45     | 4        | Solano       | 80     | Lane 1, PM R26.46    | 23-0051L     | R26.46 | 1    |        |           |             | 80W Mason        | 2/2 Sample | 8/10/08    | Bridge   | 38.3542  | -121.979  | 163       | Illatis Cree  | Fresh         | 400        | 2        | 4          | D4-0E8104   |           |
| 46     | 4        | Solano       | 80     | Lane 1, PM R26.46    | 23-0051L     | R26.46 | 1    |        |           |             | 80W Mason        | 2/2        | 8/10/08    | Bridge   | 38.3542  | -121.979  | 163       | Illatis Cree  | Fresh         | 400        | 2        | 2          | Core broker |           |
| 47     | 4        | Alameda      | SB 880 | low, Lane 3, BR#33-4 | 33-0273      | 10.66  | 3    | 1      | 143'      |             | Crandall Creek   | 8          | 25/1       | 11/20/08 | Bridge   | 37.5675   | -122.043  | 32            | landall Cre   | Creek      | 6,336    | 2          | 5           | D4-0E7804 |

Figure 2.3: Inventory of bridge cores.

| PRC3.34 - ASR PAVEMENT CORE INVENTORY |            |            |             | LOCATION: ATIRC, ROOM 132 STORAGE |          |        |        |           |           |           |            |          |      |        |       |     |           |         |        |                |          |             |
|---------------------------------------|------------|------------|-------------|-----------------------------------|----------|--------|--------|-----------|-----------|-----------|------------|----------|------|--------|-------|-----|-----------|---------|--------|----------------|----------|-------------|
| Core#                                 | Site       | CoreName   | Core Tested | LayerNumber                       | Material | H(Min) | H(Max) | Latitude  | Longitude | Elevation | Date       | District | Lane | County | Route | Dir | NumLayers | Missing | Choice | 4.18 PCC Crate | Crate 23 | Left Behind |
| 1                                     | 03G0AY00_3 | 03G0AY00_3 |             | 4                                 | PCC      | 201    | 201    | 33.503712 | -122.2023 | 11.74     | 11/13/2010 | 3        | 2    | GLE    | 5     | S   | 6         | 0       |        |                |          | x           |
| 2                                     | 03G0FY00_2 | 03G0FY00_2 |             | 5                                 | PCC      | 203    | 203    | 33.507391 | -122.205  | 11.95     | 11/13/2010 | 3        | 2    | GLE    | 5     | N   | 7         | 0       |        |                |          | x           |
| 3                                     | 03G0FY00_3 | 03G0FY00_3 |             | 4                                 | PCC      | 224    | 224    | 33.677706 | -122.2044 | 19.62     | 11/13/2010 | 3        | 2    | GLE    | 5     | N   | 6         | 0       |        |                |          | x           |
| 4                                     | 0306Y00_1  | 0306Y00_1  |             | 4                                 | PCC      | 211    | 211    | 38.673837 | -121.707  | 2.69      | 3/8/2011   | 3        | 2    | YOL    | 5     | N   | 5         | 1       |        |                |          |             |
| 5                                     | 0306Y00_1  | 0306Y00_1  |             | 5                                 | PCC      | 213    | 213    | 38.941911 | -122.0074 | 12.93     | 2/8/2011   | 3        | 2    | COL    | 5     | N   | 7         | 0       |        |                |          | x           |
| 6                                     | 0306Y00_3  | 0306Y00_3  |             | 4                                 | PCC      | 220    | 220    | 33.982839 | -122.1508 | 7.14      | 1/12/2011  | 3        | 2    | COL    | 5     | N   | 6         | 0       |        |                |          | x           |
| 7                                     | 0306Y00_5  | 0306Y00_5  |             | 5                                 | PCC      | 209    | 209    | 33.371958 | -122.1327 | 8.47      | 1/12/2011  | 3        | 2    | COL    | 5     | N   | 6         | 0       |        |                |          | x           |
| 8                                     | 0306Y00_1  | 0306Y00_1  |             | 4                                 | PCC      | 210    | 210    | 33.342126 | -122.1951 | 9.85      | 1/12/2011  | 3        | 2    | COL    | 5     | S   | 6         | 0       |        |                |          | x           |
| 9                                     | 0309Y01_1  | 0309Y01_1  |             | 5                                 | PCC      | 196    | 196    | 38.880394 | -121.9733 | 6.73      | 2/8/2011   | 3        | 2    | YOL    | 5     | S   | 6         | 0       |        |                |          | x           |
| 10                                    | 0309Y01_2  | 0309Y01_2  |             | 5                                 | PCC      | 213    | 213    | 38.809357 | -121.8965 | 4.77      | 2/8/2011   | 3        | 2    | YOL    | 5     | S   | 7         | 0       |        |                |          | x           |
| 11                                    | 0400Y00_2  | 0400Y00_2  |             | 5                                 | PCC      | 209    | 209    | 38.561602 | -121.6493 | 1.92      | 4/14/2011  | 3        | 1    | YOL    | 80    | W   | 7         | 0       |        |                |          | x           |
| 12                                    | 0430AY00_1 | 0430AY00_1 |             | 2                                 | PCC      | 233    | 233    | 38.566485 | -121.6224 | 2.96      | 3/30/2011  | 3        | 3    | YOL    | 80    | W   | 4         | 0       |        |                |          | x           |
| 13                                    | 0430AY00_2 | 0430AY00_2 |             | 2                                 | PCC      | 240    | 240    | 38.566833 | -121.6189 | 2.71      | 3/18/2011  | 3        | 3    | YOL    | 80    | E   | 3         | 0       |        |                |          | x           |
| 14                                    | 0430AY00_1 | 0430AY00_1 |             | 1                                 | PCC      | 219    | 219    | 38.696833 | -121.3216 | 13.66     | 3/23/2011  | 3        | 4    | SAC    | 80    | W   | 2         | 0       |        |                |          | x           |
| 15                                    | 0430AY00_1 | 0430AY00_1 |             | 1                                 | PCC      | 219    | 219    | 38.697057 | -121.3213 | 13.41     | 3/23/2011  | 3        | 5    | SAC    | 80    | W   | 2         | 1       |        |                |          | x           |
| 16                                    | 0440Y00_2  | 0440Y00_2  |             | 4                                 | PCC      | 230    | 230    | 38.657768 | -121.5394 | 1.98      | 2/8/2011   | 3        | 3    | SAC    | 5     | N   | 6         | 0       |        |                |          | x           |
| 17                                    | 0440Y00_1  | 0440Y00_1  |             | 5                                 | PCC      | 237    | 237    | 38.614021 | -121.5117 | 1.55      | 3/8/2011   | 3        | 4    | SAC    | 5     | N   | 7         | 0       |        |                |          | x           |
| 18                                    | 0450Y00_2  | 0450Y00_2  |             | 2                                 | PCC      | 203    | 203    | 38.609706 | -121.4285 | 4.23      | 4/14/2011  | 3        | 1    | SAC    | 51    | S   | 4         | 0       |        |                |          | x           |
| 19                                    | 04E0Y00_1  | 04E0Y00_1  |             | 3                                 | PCC      | 203    | 203    | 38.318056 | -121.324  | 3.93      | 4/12/2011  | 3        | 2    | SAC    | 99    | N   | 5         | 0       |        |                |          | x           |
| 20                                    | 04E0Y00_2  | 04E0Y00_2  |             | 4                                 | PCC      | 211    | 211    | 38.391028 | -121.3664 | 4.3       | 3/16/2011  | 3        | 2    | SAC    | 99    | N   | 6         | 1       |        |                |          | x           |
| 21                                    | 04F0Y00_1  | 04F0Y00_1  |             | 4                                 | PCC      | 216    | 216    | 38.839138 | -121.1622 | 42.53     | 1/26/2011  | 3        | 3    | PLA    | 80    | E   | 5         | 0       |        |                |          | x           |
| 22                                    | 04F0Y00_2  | 04F0Y00_2  |             | 3                                 | PCC      | 200    | 200    | 38.870087 | -121.1322 | 15.143    | 1/14/2010  | 3        | 3    | PLA    | 80    | W   | 4         | 0       |        |                |          | x           |
| 23                                    | 04G0Y00_2  | 04G0Y00_2  |             | 4                                 | PCC      | 203    | 203    | 33.10686  | -120.9472 | 220.98    | 11/3/2010  | 3        | 2    | PLA    | 80    | E   | 7         | 0       |        |                |          | x           |
| 24                                    | 04G0Y00_4  | 04G0Y00_4  |             | 1                                 | PCC      | 375    | 375    | 33.232046 | -120.6813 | 500.16    | 11/4/2010  | 3        | 2    | PLA    | 80    | E   | 4         | 0       |        |                |          | x           |
| 25                                    | 04G0Y00_1  | 04G0Y00_1  |             | 4                                 | PCC      | 217    | 217    | 33.313313 | -120.512  | 541.36    | 11/3/2010  | 3        | 2    | PLA    | 80    | E   | 5         | 0       |        |                |          | x           |
| 26                                    | 04G0Y00_2  | 04G0Y00_2  |             | 2                                 | PCC      | 262    | 262    | 33.370956 | -120.0389 | 519.96    | 11/4/2010  | 3        | 2    | NEV    | 80    | W   | 5         | 0       |        |                |          | x           |
| 27                                    | 04G0Y00_3  | 04G0Y00_3  |             | 3                                 | PCC      | 206    | 206    | 33.324178 | -120.1969 | 551.53    | 11/4/2010  | 3        | 2    | NEV    | 80    | W   | 5         | 0       |        |                |          | x           |
| 28                                    | 04G0Y00_1  | 04G0Y00_1  |             | 3                                 | PCC      | 133    | 133    | 33.239734 | -120.6728 | 492.54    | 11/4/2010  | 3        | 2    | PLA    | 80    | W   | 6         | 0       |        |                |          | x           |
| 29                                    | 04G0Y00_2  | 04G0Y00_2  |             | 4                                 | PCC      | 224    | 224    | 33.32544  | -120.818  | 317.14    | 11/4/2010  | 3        | 2    | PLA    | 80    | W   | 5         | 0       |        |                |          | x           |
| 30                                    | 04G0Y00_5  | 04G0Y00_5  |             | 5                                 | PCC      | 190    | 190    | 33.329165 | -120.5914 | 511.71    | 11/4/2010  | 3        | 2    | NEV    | 80    | W   | 6         | 0       |        |                |          | x           |
| 31                                    | 04H0Y00_1  | 04H0Y00_1  |             | 4                                 | PCC      | 203    | 203    | 38.574391 | -121.5549 | 1.47      | 2/10/2011  | 3        | 1    | YOL    | 50    | E   | 6         | 0       |        |                |          | x           |
| 32                                    | 04H0Y00_1  | 04H0Y00_1  |             | 2                                 | PCC      | 191    | 191    | 38.574391 | -121.5549 | 1.47      | 2/10/2011  | 3        | 1    | YOL    | 50    | E   | 6         | 0       |        |                |          | x           |
| 33                                    | 04H0Y00_3  | 04H0Y00_3  |             | 1                                 | PCC      | 191    | 191    | 38.583927 | -121.2896 | 8.95      | 3/8/2011   | 3        | 1    | SAC    | 50    | E   | 3         | 0       |        |                |          | x           |
| 34                                    | 04H0Y00_5  | 04H0Y00_5  |             | 1                                 | PCC      | 211    | 211    | 38.555666 | -121.4004 | 4.01      | 2/10/2011  | 3        | 1    | SAC    | 50    | E   | 3         | 0       |        |                |          | x           |
| 35                                    | 04H0Y00_3  | 04H0Y00_3  |             | 1                                 | PCC      | 203    | 203    | 38.608665 | -121.2718 | 10.27     | 3/23/2011  | 3        | 3    | SAC    | 50    | W   | 3         | 0       |        |                |          | x           |
| 36                                    | 04H0Y00_1  | 04H0Y00_1  |             | 1                                 | PCC      | 228    | 228    | 38.575176 | -121.5599 | 1.63      | 3/18/2011  | 3        | 3    | YOL    | 50    | E   | 3         | 0       |        |                |          | x           |
| 37                                    | 0400Y00_1  | 0400Y00_1  |             | 2                                 | PCC      | 214    | 214    | 38.526455 | -121.4697 | 2.53      | 3/5/2011   | 3        | 4    | SAC    | 99    | S   | 4         | 1       |        |                |          | x           |
| 38                                    | 0400Y00_2  | 0400Y00_2  |             | 2                                 | PCC      | 205    | 205    | 38.526238 | -121.4696 | 2.62      | 4/12/2011  | 3        | 4    | SAC    | 99    | S   | 4         | 1       |        |                |          | x           |
| 39                                    | 0405Y00_1  | 0405Y00_1  |             | 5                                 | PCC      | 201    | 201    | 38.410626 | -121.3993 | 3.51      | 3/17/2011  | 3        | 3    | SAC    | 99    | N   | 6         | 1       |        |                |          | x           |
| 40                                    | 0405Y00_2  | 0405Y00_2  |             | 4                                 | PCC      | 211    | 211    | 38.487241 | -121.4364 | 2.47      | 3/17/2011  | 3        | 3    | SAC    | 99    | N   | 5         | 1       |        |                |          | x           |
| 41                                    | 0405Y00_3  | 0405Y00_3  |             | 2                                 | PCC      | 204    | 204    | 38.584931 | -121.4546 | 2.72      | 4/12/2011  | 3        | 3    | SAC    | 51    | N   | 4         | 1       |        |                |          | x           |
| 42                                    | 04J0Y00_1  | 04J0Y00_1  |             | 1                                 | PCC      | 305    | 305    | 33.335716 | -120.3552 | 665.94    | 11/4/2010  | 3        | 3    | NEV    | 80    | W   | 2         | 0       |        |                |          | x           |
| 43                                    | 0550Y00_1  | 0550Y00_1  |             | 1                                 | PCC      | 217    | 217    | 38.549195 | -121.7678 | 3.21      | 3/7/2011   | 3        | 2    | YOL    | 113   | N   | 3         | 1       |        |                |          | x           |
| 44                                    | 0550Y00_2  | 0550Y00_2  |             | 1                                 | PCC      | 250    | 250    | 38.586088 | -121.7668 | 4.71      | 1/10/2011  | 3        | 2    | YOL    | 113   | N   | 4         | 0       |        |                |          | x           |
| 45                                    | 0550Y00_3  | 0550Y00_3  |             | 1                                 | PCC      | 213    | 213    | 38.559791 | -121.7668 | 2.86      | 1/10/2011  | 3        | 2    | YOL    | 113   | S   | 3         | 0       |        |                |          | x           |
| 46                                    | 0550Y00_2  | 0550Y00_2  |             | 5                                 | PCC      | 205    | 205    | 38.708885 | -121.9568 | 14.84     | 12/15/2010 | 3        | 2    | YOL    | 505   | N   | 6         | 0       |        |                |          | x           |
| 47                                    | 0AG0M00_1  | 0AG0M00_1  |             | 1                                 | PCC      | 208    | 208    | 33.054422 | -121.439  | 6.52      | 4/12/2011  | 3        | 2    | YUB    | 65    | S   | 3         | 0       |        |                |          | x           |
| 48                                    | BV51       | BV51-2-30  |             | 2                                 | PCC      | 203    | 207    | 38.742931 | -122.9536 | 16.42     | 6/11/2009  | 4        | 2    | SON    | 101   | N   | 0         | 0       |        |                |          | x           |
| 49                                    | BV51       | BV51-4-90  |             | 1                                 | PCC      | 205    | 207    | 38.743206 | -122.9532 | 16.36     | 6/11/2009  | 4        | 2    | SON    | 101   | N   | 0         | 0       |        |                |          | x           |
| 50                                    | BV51       | BV51-6-150 |             | 1                                 | PCC      | 199    | 204    | 38.743501 | -122.9537 | 16.19     | 6/11/2009  | 4        | 2    | SON    | 101   | N   | 0         | 0       |        |                |          | x           |
| 51                                    | BV55       | BV55-2-30  |             | 5                                 | PCC      | 281    | 327    | 40.885786 | -122.3838 | 101.69    | 6/25/2009  | 2        | 2    | SHA    | 5     | S   | 0         | 0       |        |                |          | x           |

Figure 2.4: Inventory of pavement cores.

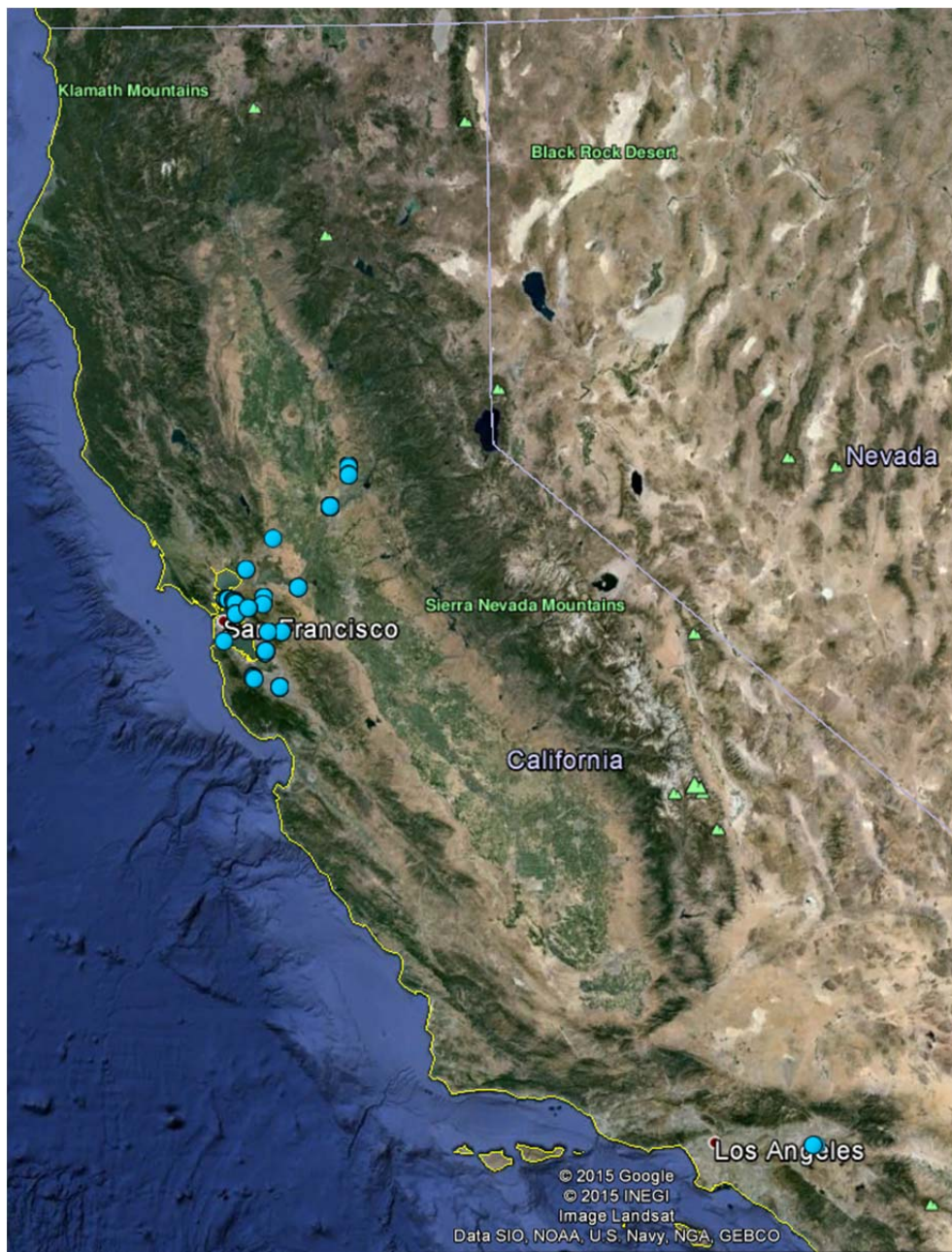
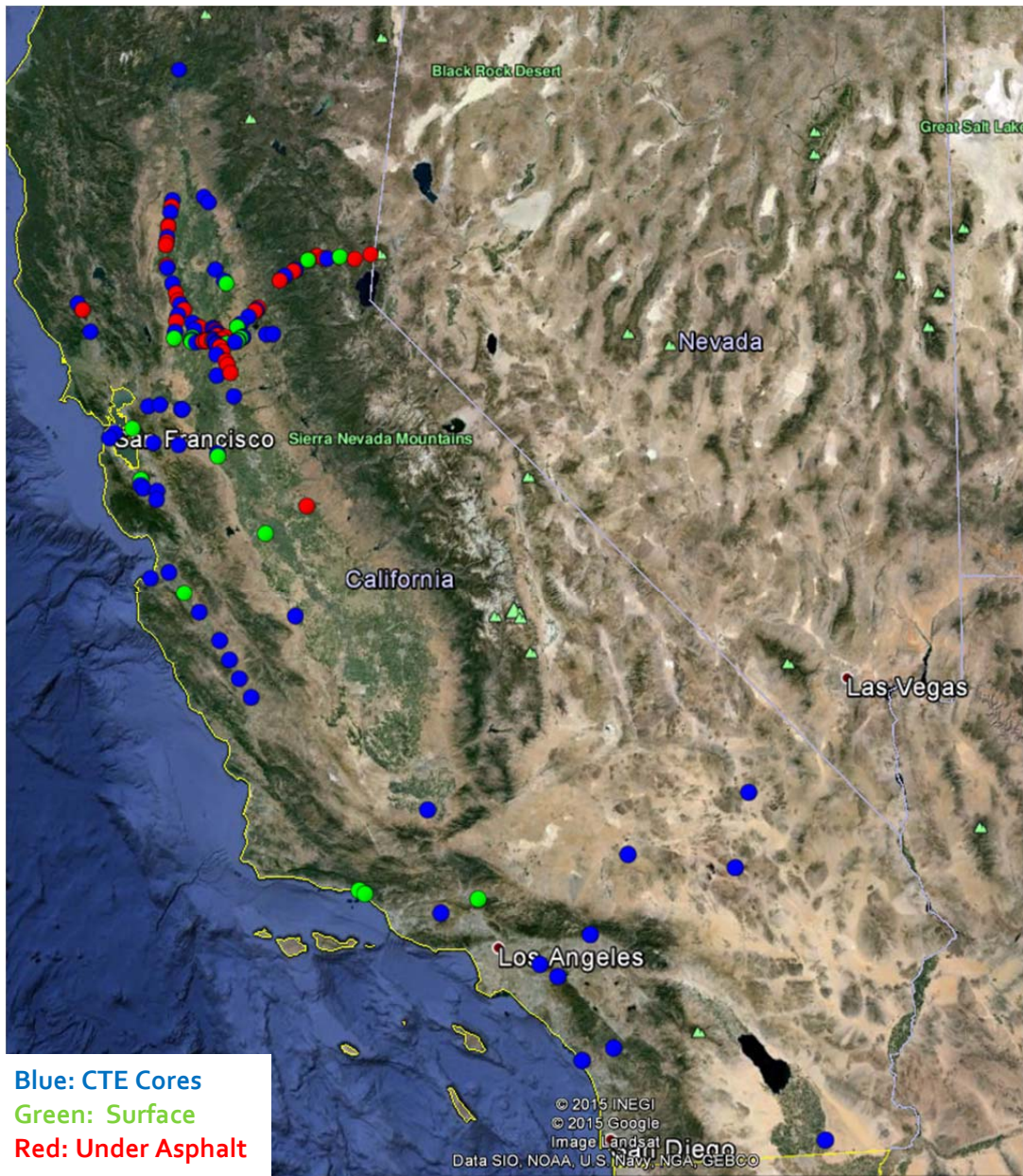


Figure 2.5: Map showing original locations of bridge cores.





.6: Map showing original locations of pavement cores.

## 2.2 Sample Preparation

The 265 pavement cores (Figure 2.1), of which 131 had been soaked briefly in lime water for the CTE testing, and 311 bridge cores were prepared for examination for ASR. For this investigation the petrographic consultant advised selecting bridge cores that had a minimum length of 3 inches (75 mm), so that the required amount of surface area for the examination on each would be available, and a preferred length of 4 inches (100 mm); this resulted in the selection of 102 cores to process before the examination (Figure 2.2). The pavement cores had sufficient surface area for examination because of their greater width (4 inches [102 mm]) and length.

After the cores were inventoried and measured, they were cut for testing and examination. As shown in Figure 2.7, the cores were cut using J-slot continuous diamond blades, which are commonly used to cut marble and tile.

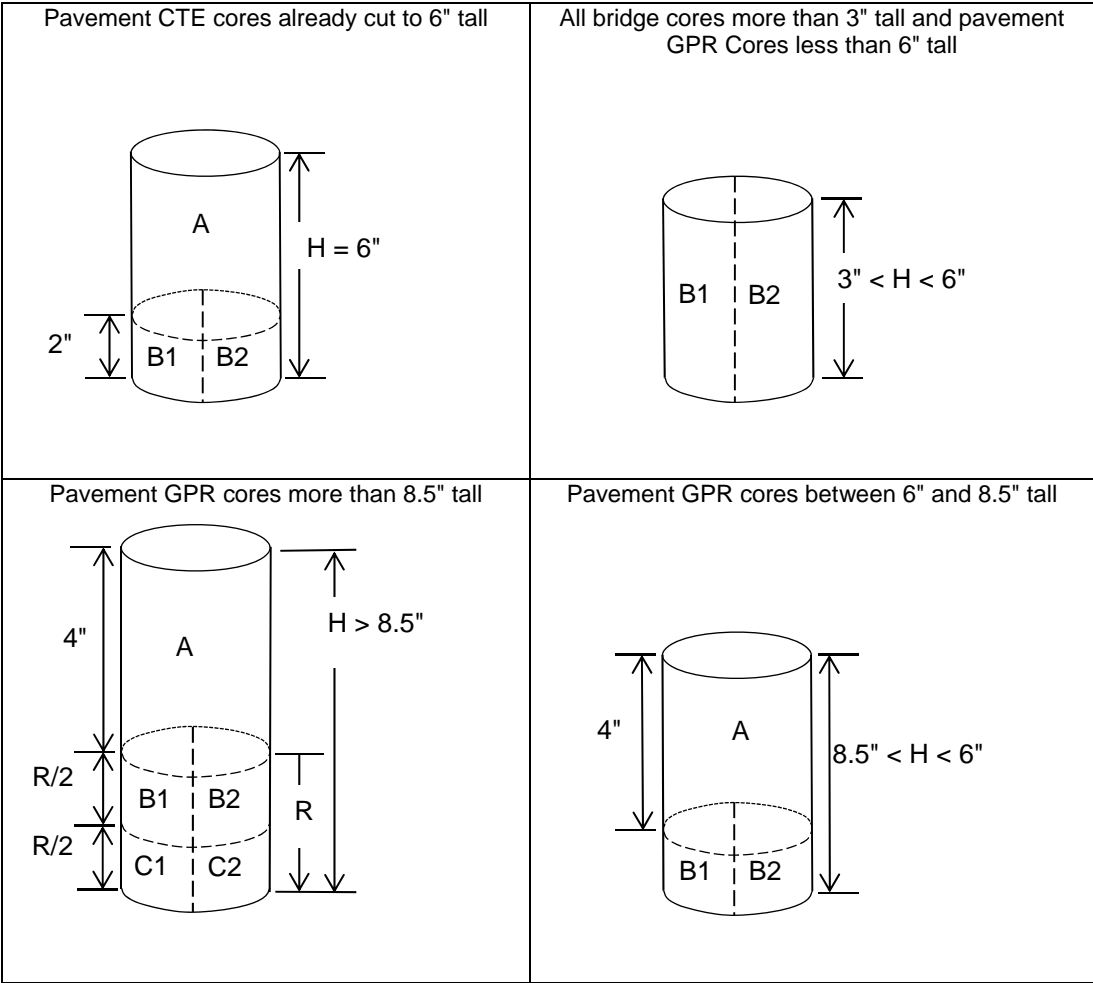


**Figure 2.7: J-slot continuous diamond blades for concrete core cutting.**

All the pavement cores used for CTE testing had been cut to a length of 6 inches (152 mm), but the pavement cores and bridge cores from the GPR study were of varying lengths. For this study, bridge cores that were equal to or longer than 3 inches were cut vertically into two parts for the ASR visual inspection (Figure 2.8 and Figure 2.9).

Pavement cores shorter than 6 inches (152 mm) were cut vertically, splitting them into two parts for visual inspection for ASR. Pavement cores between 6 inches (152 mm) and 8.5 inches (216 mm) long were cut twice, once for strength testing and once for visual inspection. First, a horizontal cut was made 4 inches (102 mm) from the top of the core, and this 4 inch core was used for strength testing; on pavement cores that had been less than 8.5 inches long, the remaining bottom piece of the original core (if it was not less than 2 inches long) was then cut down the middle vertically for ASR visual inspection. On pavement cores longer than 8.5 inches (216 mm), the bottom piece was cut horizontally again into two short cylinders not less than 2 inches (51 mm) long; each of these was then cut vertically in half for ASR visual inspection.

Pavement core pieces cut for strength testing were ground to ensure that the top and bottom surfaces were parallel to each other and perpendicular to the core sides (Figure 2.10). All the bridge cores were too small for strength testing.



Notes:

- Pavement CTE cores were 6 inches tall exactly, cut for previous testing.
- Bridge cores and pavement cores from the GPR study were separated by height to determine how to cut them: between 3 and 6 inches, between 6 and 8.5 inches, and greater than 8.5 inches.

**Figure 2.8: Cutting plan for pavement cores.**



**Figure 2.9: Concrete cores for visual inspection.**



**Figure 2.10: Concrete pavement cores after cutting and leveling for strength testing.**

*(This page left blank.)*

### 3. VISUAL INSPECTION AND ASSESSMENT OF CORES

---

#### 3.1 Overview

In Task 2 of this study, the cores inventoried and prepared for Task 1 were next examined visually and assessed for traces of ASR or ASR-related distress. Photos were taken and scans were made of the cut surfaces of the cores. The task of ASR visual inspection was contracted out to a primary petrographer (Jon Asselanis of Applied Materials Engineering Inc., Oakland, California) and a secondary petrographer (Derek Cong of WJE Associates Inc., Austin, Texas), both of whom the Caltrans steering committee had selected for this project based on their qualifications and their unit prices for the inspection.

A total of 259 pavement core samples (multiple pieces for most pavement cores) and 80 bridge core samples (Figure 3.1) were visually inspected by the primary petrographer.



Figure 3.1: Pavement and bridge cores after cutting for visual inspection.

### 3.2 Damage Rating Index Method

A descriptive rating method for ASR using the Damage Rating Index (DRI) for Concrete following ASTM C856-14 (Standard Practice for the Petrographic Examination of Hardened Concrete) and ASTM C294-12 (Standard Descriptive Nomenclature for Constituents of Concrete Aggregates) was used for the visual inspection of the cut surfaces that were scanned. The method also considers work documented in FHWA reports (References 1, 2, and 3). Figure 3.2 shows an example DRI rating sheet, and Figure 3.3 and Figure 3.4 show examples of the scans of cut faces of cores used for the petrographic examination. The detailed steps for this DRI method for ASR visual inspection are presented in the appendix.

The following values were used as criteria for the extent of ASR found:

- DRI = 0, No ASR
- DRI < 500, ASR very unlikely
- $500 \leq \text{DRI} < 1,000$ , ASR not likely
- $1,000 \leq \text{DRI} < 2,000$ , ASR possible
- DRI > 2,000, ASR probable

| <b>Sample Identification</b>         |                        |
|--------------------------------------|------------------------|
| <b>Petrographic Feature</b>          | <b>Weighing Factor</b> |
| Coarse aggregate with cracks         | 0.25                   |
| Coarse aggregate with cracks and gel | 2.00                   |
| Coarse aggregate debonded            | 3.00                   |
| Reaction rims around aggregate       | 0.50                   |
| Cement paste with cracks             | 2.00                   |
| Cement paste with cracks and gel     | 4.00                   |
| Air voids lined or filled with gel   | 0.50                   |

Sum

Area (cm<sup>2</sup>)

Normalized area (cm<sup>2</sup>)

**Damage Rating Index (DRI)**

| Sample 111 |         | Sample 112 |         |
|------------|---------|------------|---------|
| Feature    | Weighed | Feature    | Weighed |
| 0          | 0       | 0          | 0       |
| 0          | 0       | 0          | 0       |
| 0          | 0       | 0          | 0       |
| 0          | 0       | 9          | 4.5     |
| 0          | 0       | 0          | 0       |
| 0          | 0       | 0          | 0       |
| 0          | 0       | 0          | 0       |
| 0          | 0       | 0          | 0       |
| 0          | 0       | 9          | 4.5     |
| 76.3       |         | 112.7      |         |
| 0.76       |         | 1.13       |         |
| <b>0</b>   |         | <b>399</b> |         |

**Area Calculations**

Length (in.)

Width (in.)

Area (in.<sup>2</sup>)

Area (cm<sup>2</sup>)

|      |       |
|------|-------|
| 2.81 | 4.16  |
| 4.21 | 4.20  |
| 11.8 | 17.5  |
| 76.3 | 112.7 |

**Figure 3.2: Example of the Damage Rating Index (DRI) worksheet.**



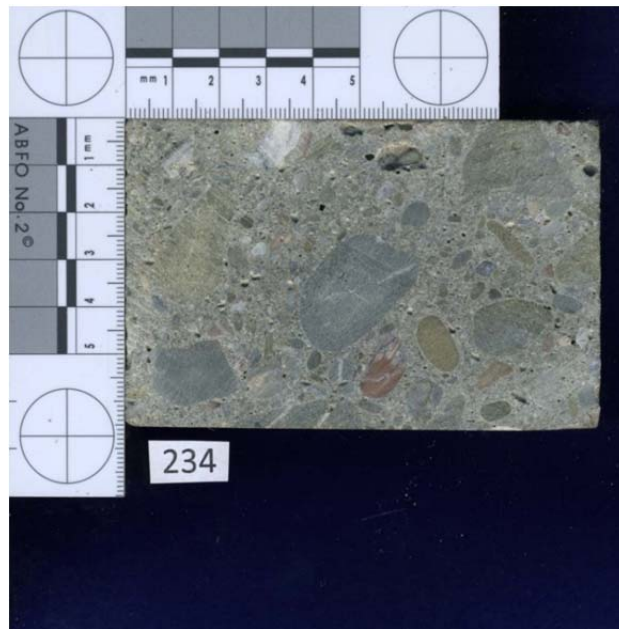
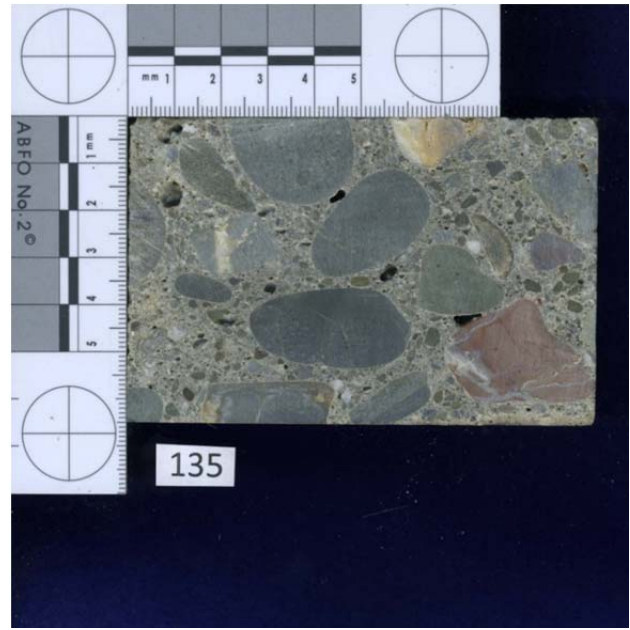
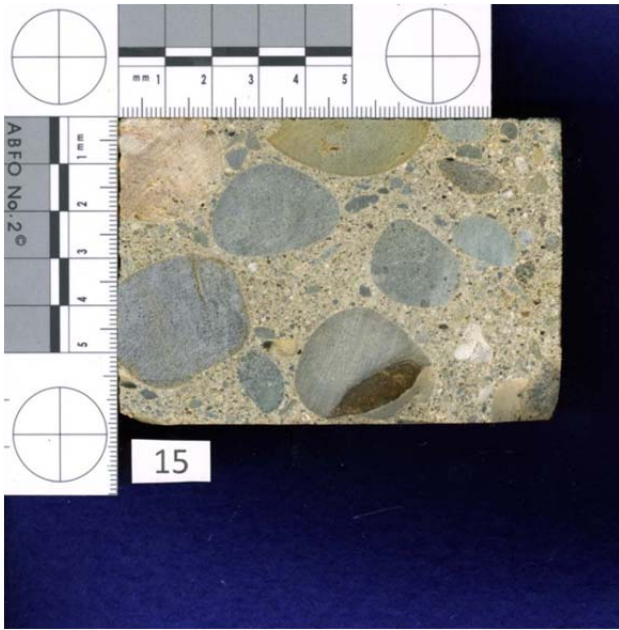


Figure 3.3: Example scans of the cut surfaces of three pavement cores.



Figure 3.4: Example scans of the cut surfaces of three bridge cores.

### 3.3 Results of Visual Inspection of Pavement Cores

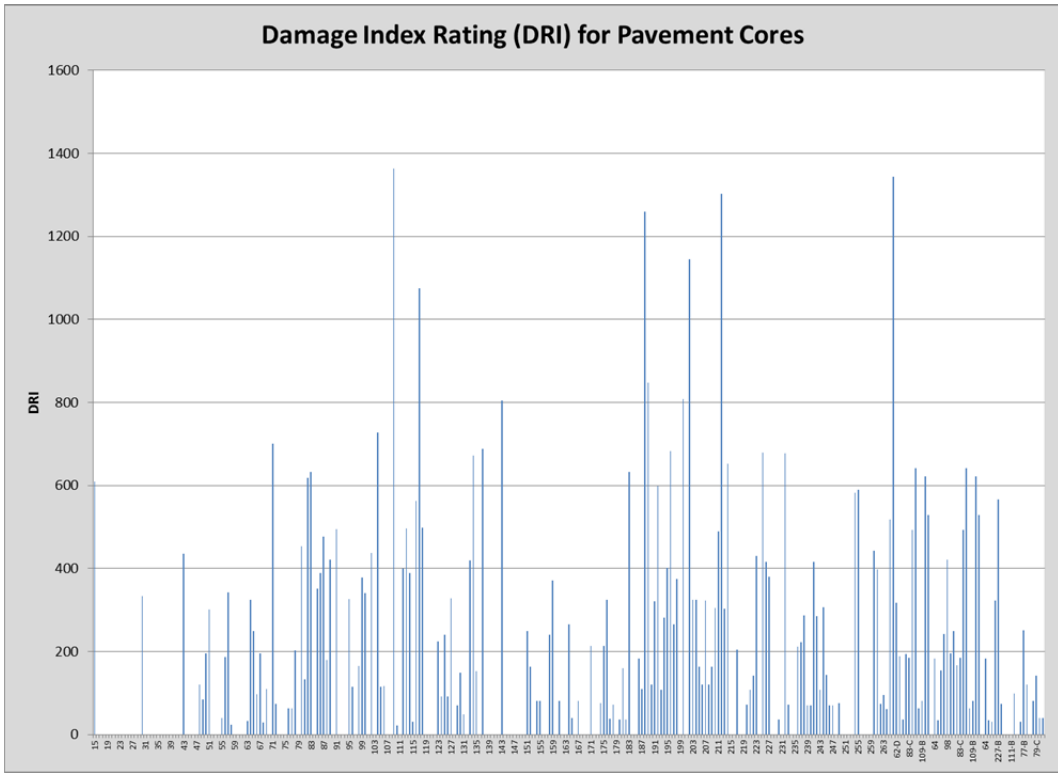
The cores used for the petrographic examinations were reviewed by the steering committee, and the petrographic examination process was explained by the petrographer at a meeting held at the UCPRC Richmond laboratory on June 19, 2015 (Figure 3.5).

Almost none of the pavement core samples presented any ASR issue, as defined by the Damage Rating Index; that is, none of the core samples had a DRI value greater than 2,000. Consequently, the UCPRC was directed to not send selected cores to the secondary petrographer for cross-checking of the results at this time, but it was agreed that this decision would be revisited after it was determined whether or not additional cores could be obtained from structures or pavements suspected of having ASR.

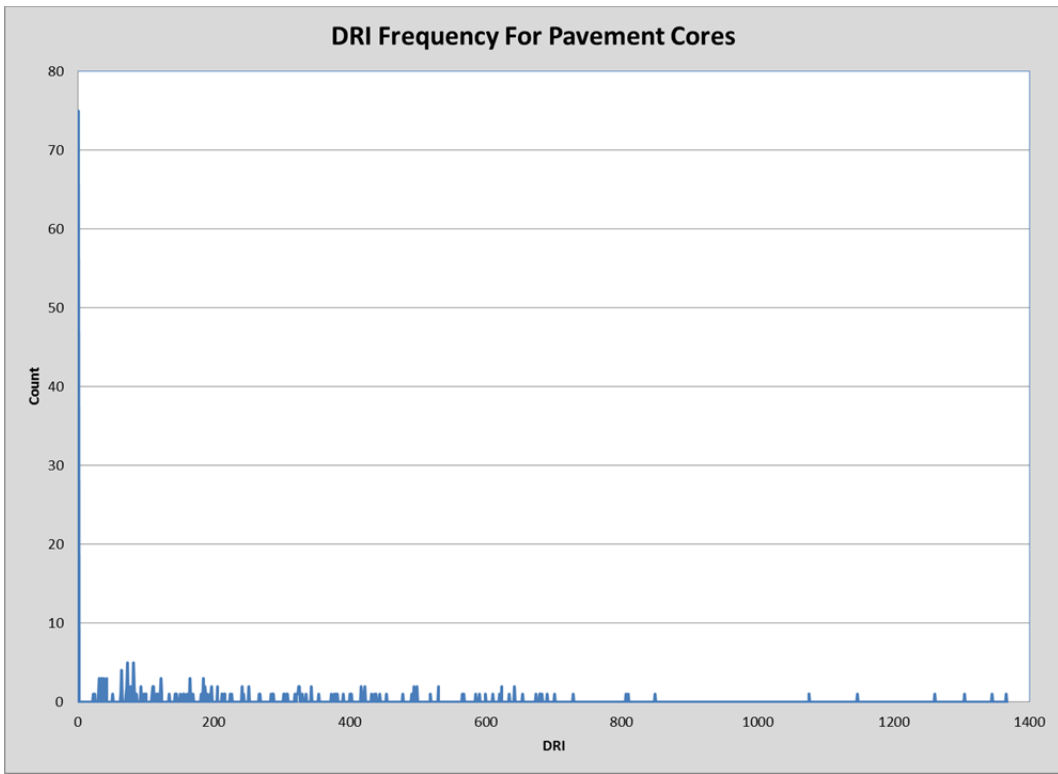


**Figure 3.5: Project steering committee meeting on visual inspection at the UC Berkeley Richmond Field Station on June 19, 2015.**

The results of the visual inspection for pavement cores using the DRI method are presented in Figure 3.6 through Figure 3.8, organized respectively by core number, frequency of DRI result, and DRI cumulative distribution. Most of the pavement cores inspected showed DRI numbers less than 1,000 (ASR not likely according to the criteria shown in Section 3.2), with a DRI around 200 being the approximate median, as can be seen in Figure 3.8. A few cores had DRI values between 1,000 and 2,000 (ASR possible) but, as noted, none of the pavement cores inspected showed DRI results larger than 2,000 (ASR probable).



**Figure 3.6: DRI of pavement cores, by core number.**



**Figure 3.7: DRI of pavement cores, frequency chart.**

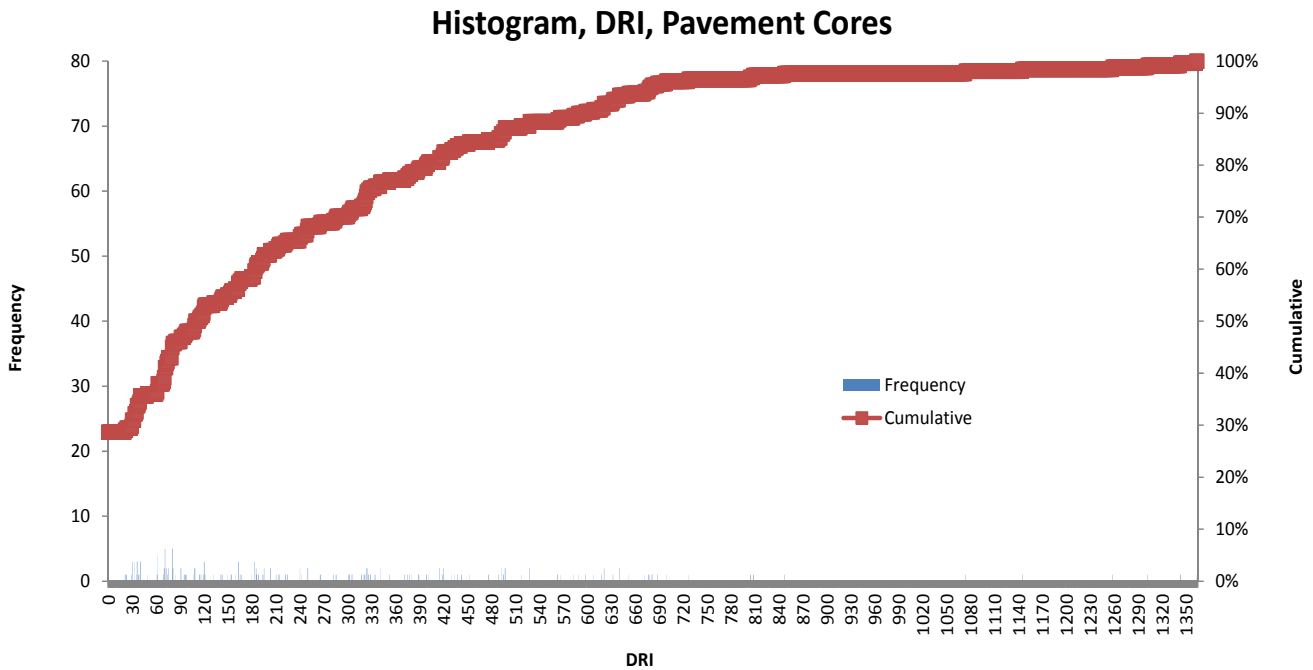


Figure 3.8: DRI of pavement cores, cumulative distribution chart.

### 3.4 Results of Visual Inspection of Bridge Cores

The results of visual inspection for the bridge cores using the DRI method are presented in Figure 3.9 through Figure 3.11, organized respectively by core number, frequency of DRI result, and DRI cumulative distribution. As with the pavement cores, most of the bridge cores inspected had DRI results less than 1,000 (ASR not likely, according to the established criteria), and the median DRI result was approximately 500, as shown in Figure 3.11. Very few of the bridge cores had DRI results between 1,000 and 2,000 (ASR possible), and none of them had DRI results greater than 2,000 (ASR probable).

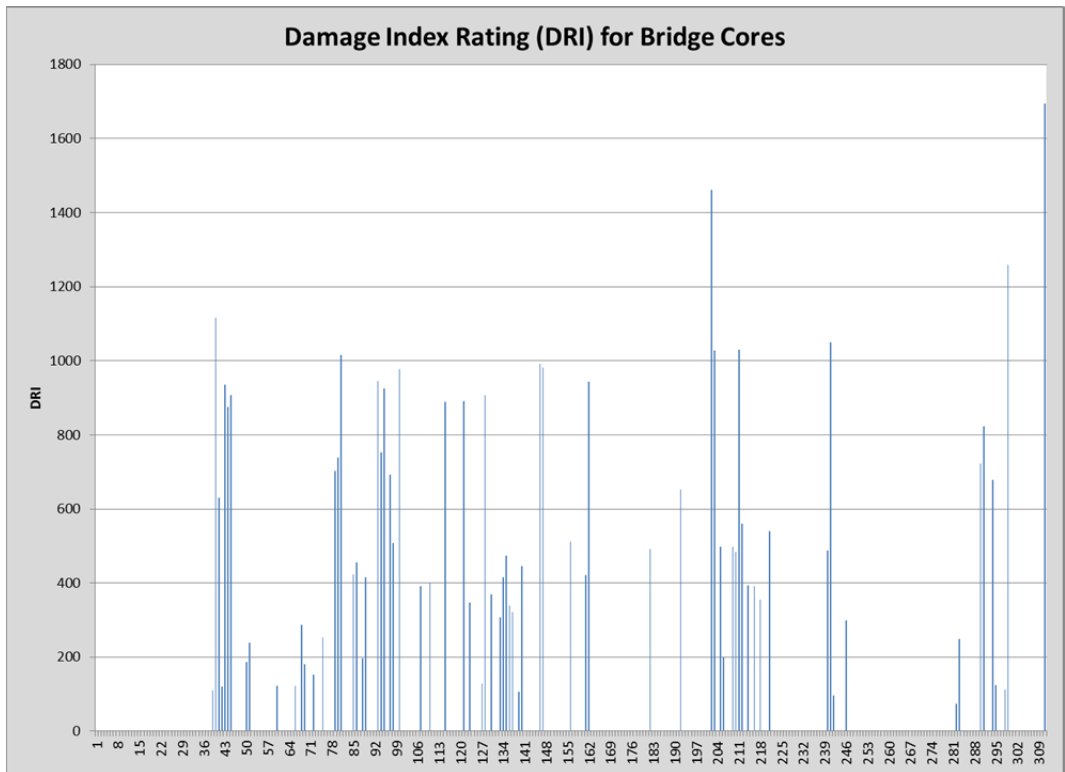


Figure 3.9: DRI of bridge cores, by core number.

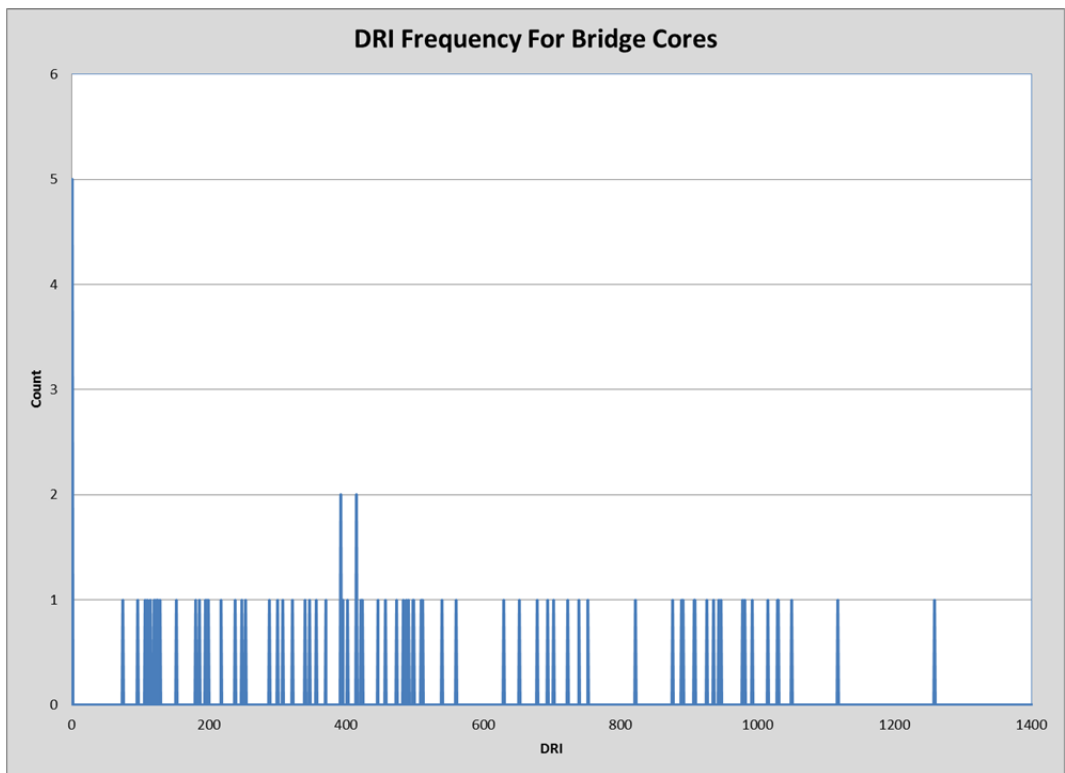
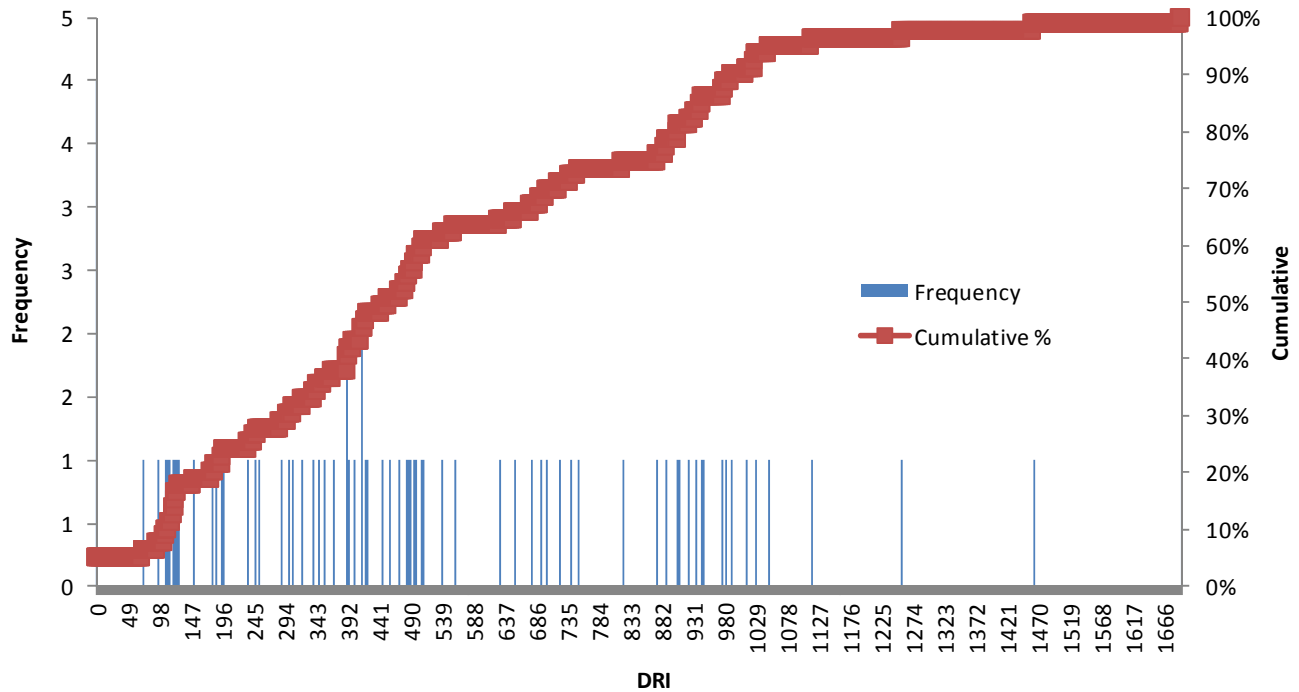


Figure 3.10: DRI of bridge cores, frequency chart.

## Histogram, DRI, Bridge Cores

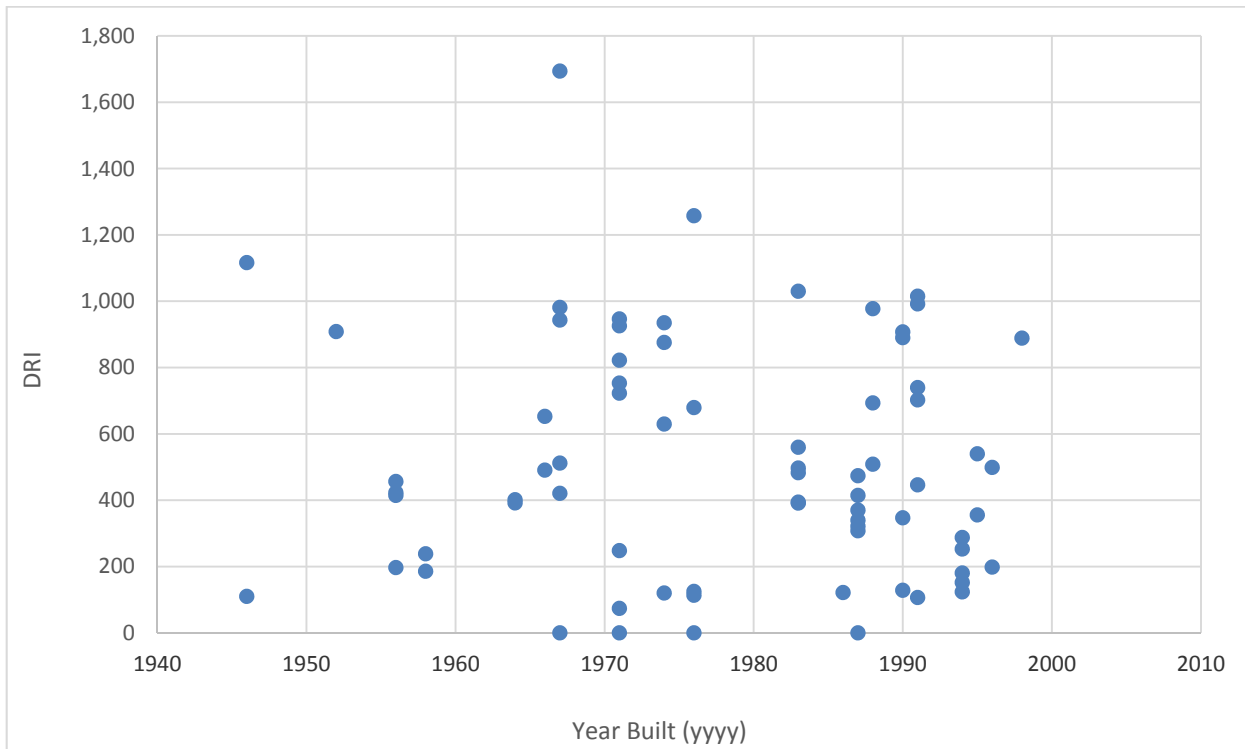


**Figure 3.11: DRI of bridge cores, cumulative distribution chart.**

### 3.5 Comparison of Bridge Core DRI and Year of Construction

The year of construction of each of the bridge cores was compared with the Damage Rating Index for each of the 259 cores for which a construction year was found in the bridge logs, as shown in Figure 3.12. The data indicate that there is almost no trend between the ages of the cores, which ranged from 17 to 69 years old at time of visual inspection, and DRI. This should have been sufficient time for even the youngest cores to begin to manifest ASR if the reaction was occurring.

There were 26 cores taken from bridges built after 1995, approximately the time when changes in specifications to reduce the risk of ASR were implemented. There was no apparent difference in DRI values for bridges built before and after 1995.



**Figure 3.12: Damage Rating Index versus year of construction for bridge cores.**

### 3.6 Guidelines for Visual Inspection

One result of performing this visual inspection procedure was the creation of a draft guideline for evaluating concrete pavement cores for evidence of ASR and ASR-related distresses for future use by Caltrans staff to determine the need for further, more detailed examinations. A draft version of this guideline, which includes both a step-by-step description of the inspection process and the selection criteria required to conduct further detailed examinations, as well as sample photographs showing gradations of ASR distress, appears in the appendix.



*(This page left blank)*

## 4. COMPRESSIVE STRENGTH TESTING OF PAVEMENT CORES

### 4.1 Overview

In Task 3 of this project, 206 of the pavement cores were subjected to compressive strength testing (Figure 4.1) following ASTM C39/C39M-14a (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens) to help assess the condition of the concrete. Low strength due to microcracking is a potential indicator of ASR damage. The density of the pavement cores used for strength testing was also measured following ASTM C642-13 (Standard Test Method for Density, Absorption, and Voids in Hardened Concrete) to help determine whether any low strength values were attributable to low-density aggregate or high voids contents. The compressive strengths were also compared with those expected for concrete pavement strength based on data provided by the Caltrans Office of Structural Materials.



Figure 4.1: Pavement cores and strength testing.

The spreadsheet database created for this current project was also updated with results from the DRI, strength, and density testing.

## 4.2 Compressive Strength Testing Method

The length-to-diameter ratio (LDR) of the pavement cores in ASTM C39/C39M was used to adjust the strength values from cores of different lengths in order to produce approximately comparable values. The LDR values are presented in Figure 4.2. Most of the LDR values for the pavement cores ranged from 1.0 to 1.2, smaller than the standard LDR of 2.0. The correction factor curve of LDR for the pavement cores is shown in Figure 4.3, using a four-step linear interpretation from the LDR correction factor given in ASTM C39/C39M. The density of the pavement cores for strength testing was measured using the total air mass and the total volume of each core.

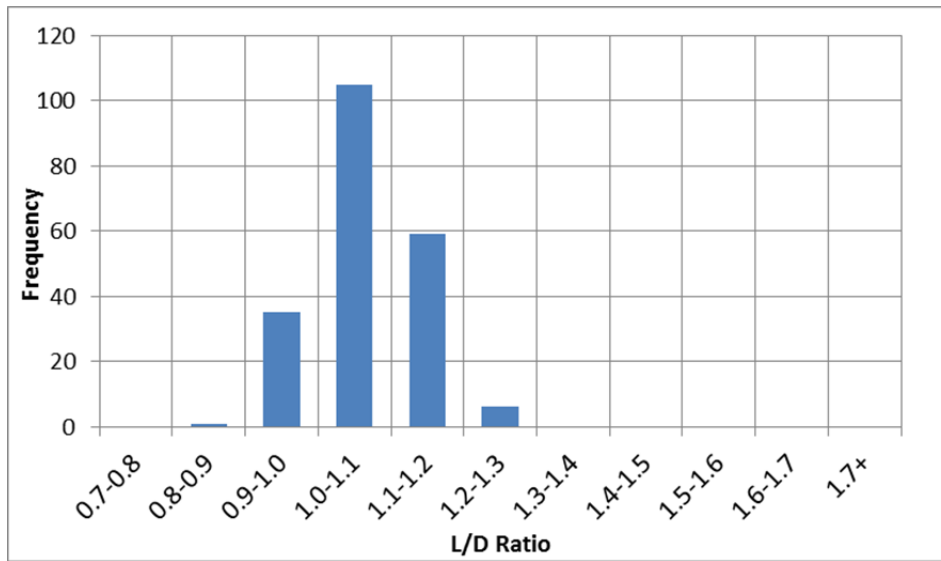


Figure 4.2: Frequency of length-to-diameter ratio (LDR) of pavement cores.

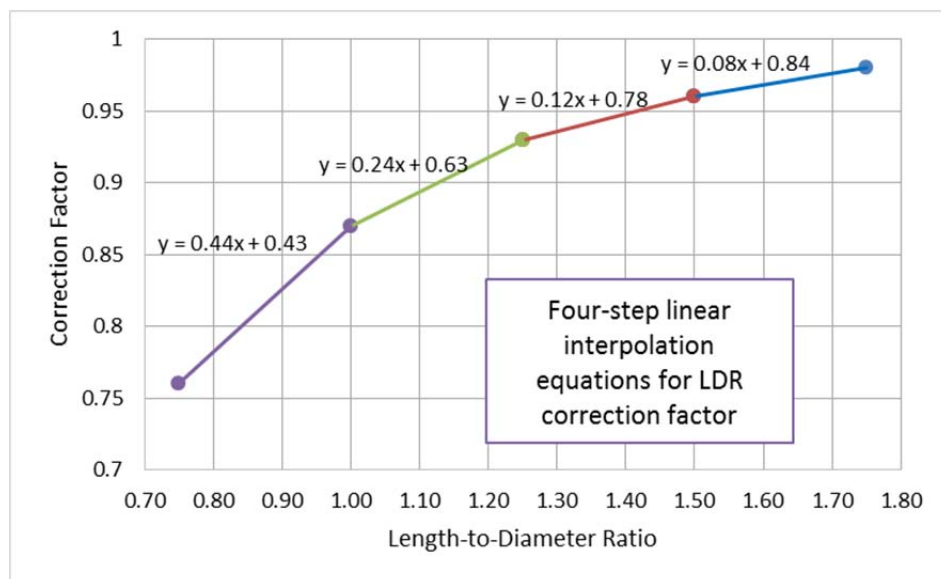


Figure 4.3: Length-to-diameter ratio (LDR) correction factor.

### 4.3 Results of Compressive Strength Testing

The LDR corrected unconfined compressive strengths (UCS) of the pavement cores are presented in Figure 4.4 and Figure 4.5, plotted by core number and grouped into a histogram, respectively. Most of the pavement cores tested had UCS results less than 8,700 psi (60 MPa) while a small number had results between 8,700 and 11,600 psi (60 MPa and 80 MPa). None of the pavement cores tested had UCS results greater than 11,600 psi. The median UCS result was approximately 6,090 psi (42 MPa). These results were considered to be within the range of long-term strengths expected of PCC pavements by experienced Caltrans materials engineers.

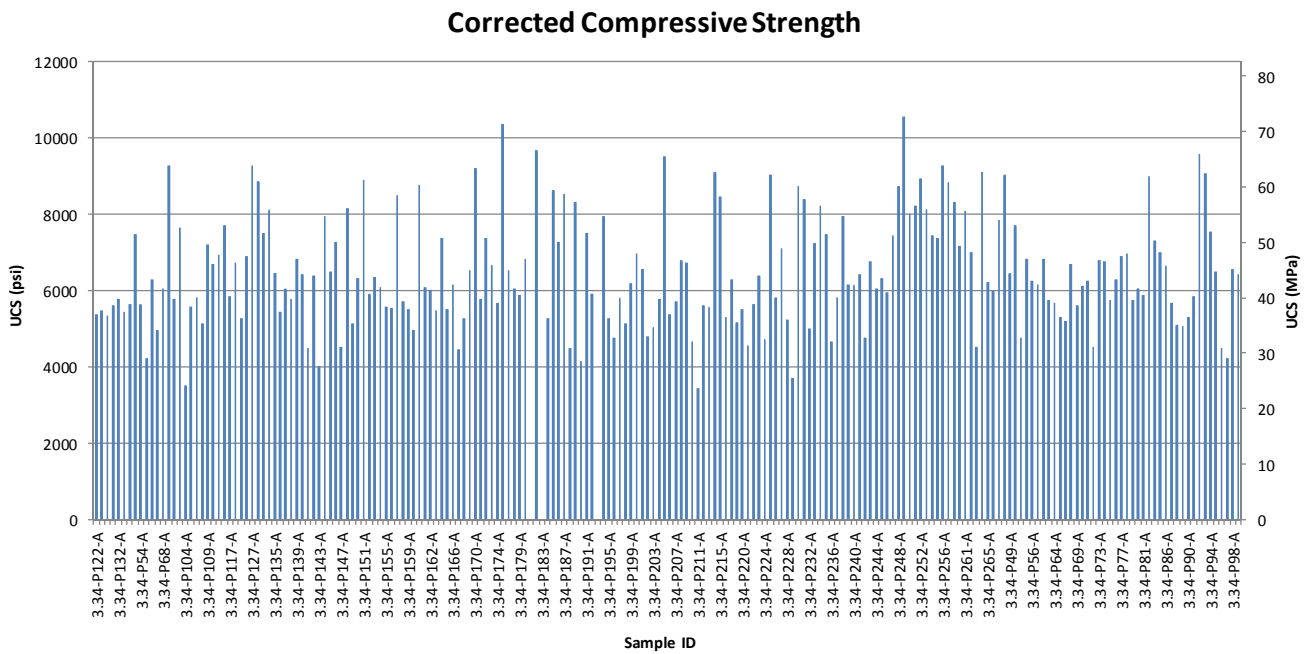


Figure 4.4: Corrected unconfined compressive strength of pavement cores, organized by core number.

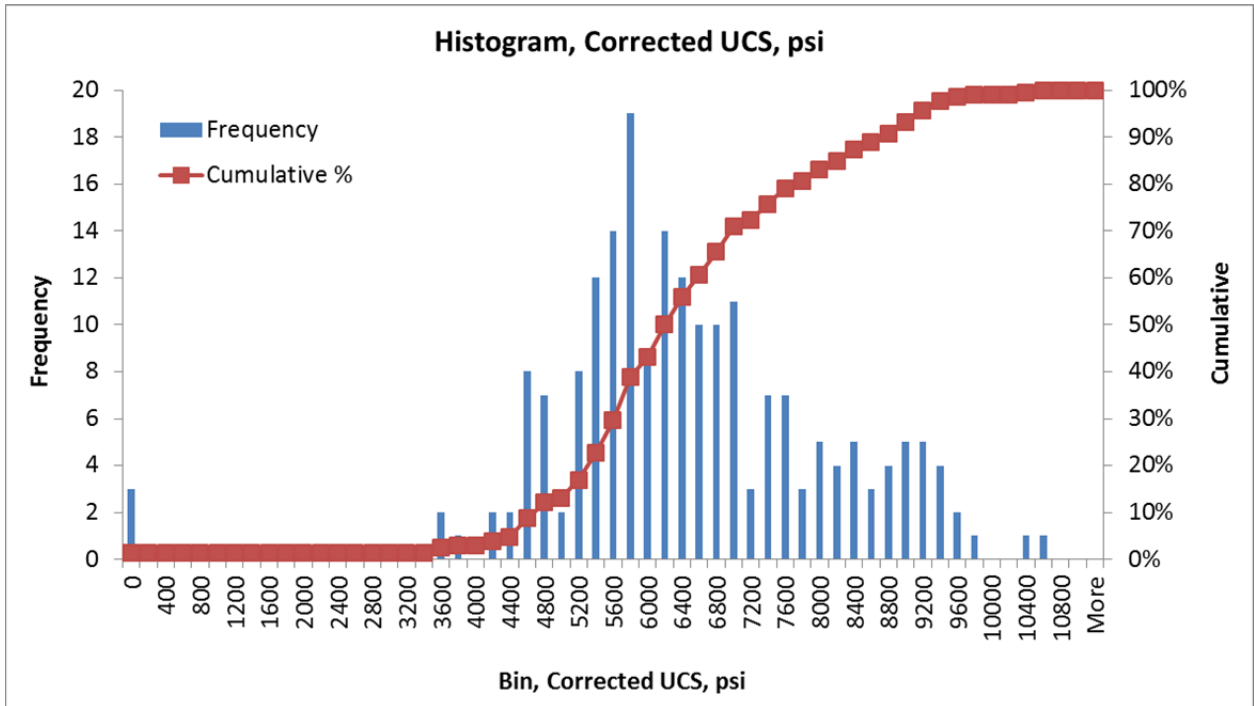
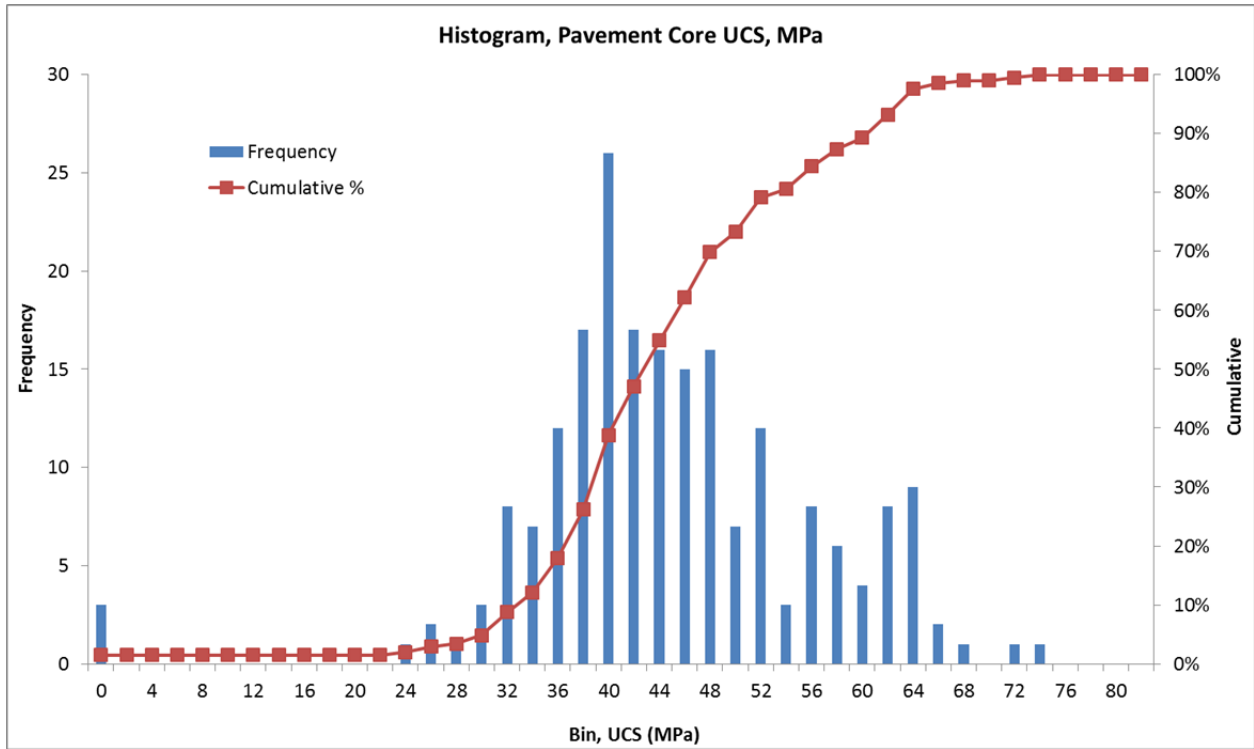


Figure 4.5: Corrected unconfined compressive strength of pavement cores, histogram chart (metric and US units).

#### 4.4 Results of Density Measurements

The densities (air mass/volume) of the pavement cores tested are presented in Figure 4.6 with histogram plots. Most of the pavement cores tested had densities less than 156 pcf (2,500 kg/m<sup>3</sup>) and the median UCS result was approximately 147 pcf (2,350 kg/m<sup>3</sup>). Density is primarily controlled by the density of the aggregates used in the concrete. These results were considered to be within the range of densities expected of PCC pavements by experienced Caltrans materials engineers.

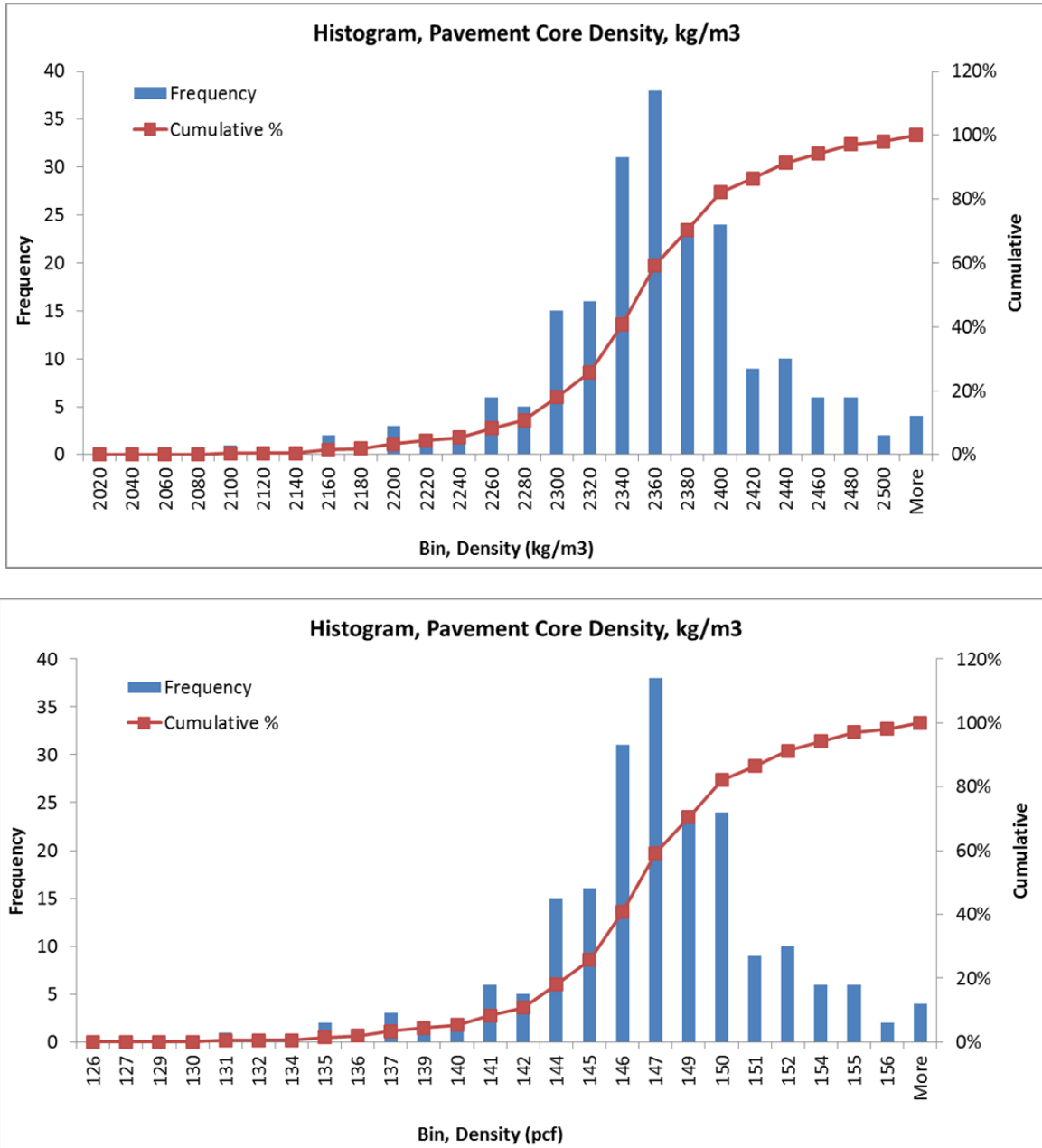


Figure 4.6: Density of pavement cores, histogram chart (metric and US units).

#### 4.5 Compressive Strength versus Density

Comparison of the results of the UCS and density tests for the pavement cores are presented in Figure 4.7. It can be seen that there is no significant correlation between the UCS values and densities of the pavement cores tested, although the UCS strengths generally increase with the density.

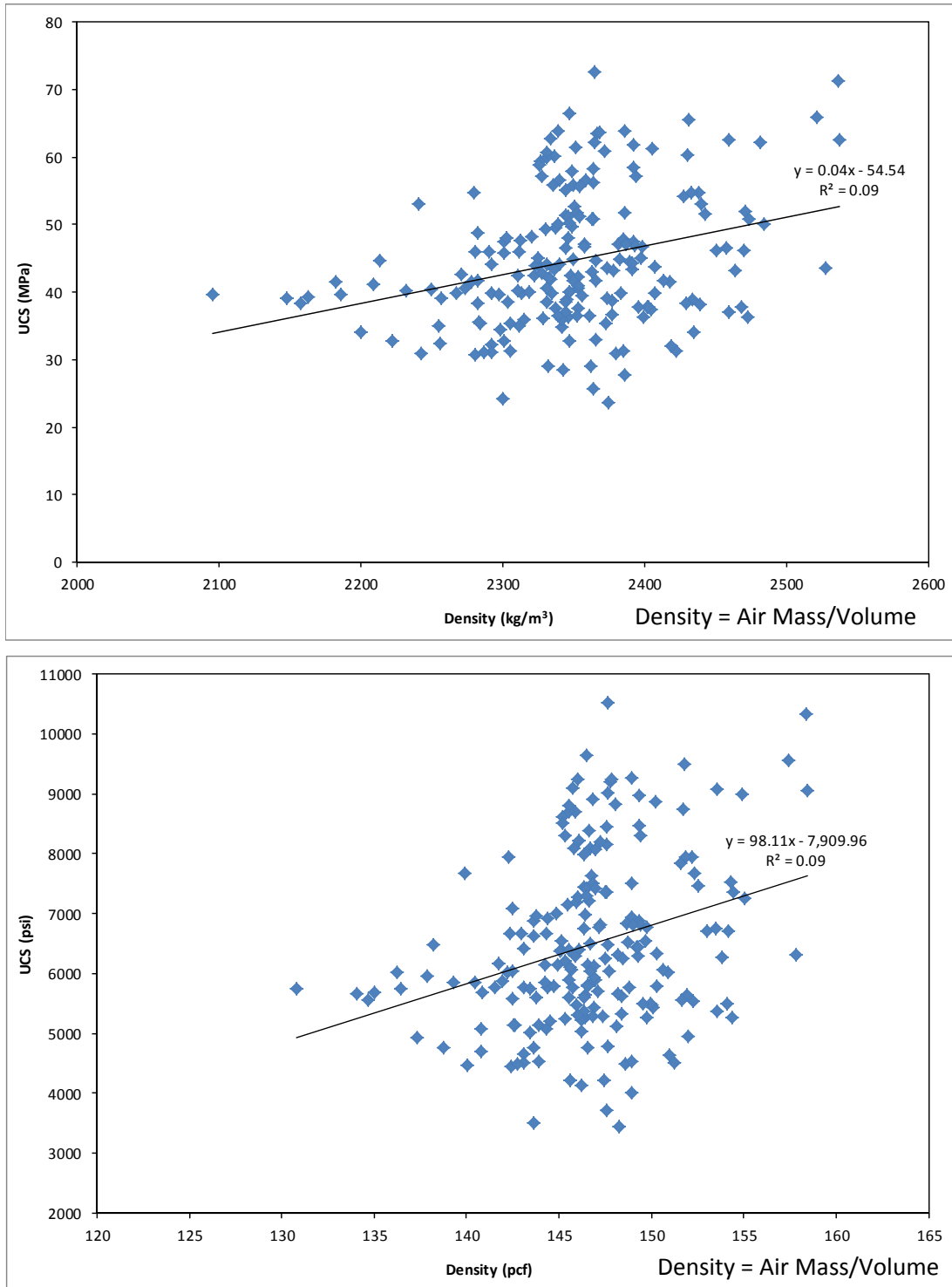


Figure 4.7: Strength versus density of pavement cores (metric and US units).

## **5. SUMMARY, CONCLUSIONS, AND RECOMMENDED NEXT TASKS**

### **5.1 Summary**

This report summarizes the creation of an inventory for cores taken from bridges and pavements as part of previous projects, the results of visual inspection and strength testing to identify the potential presence of ASR, and the development of a draft approach for Caltrans staff to evaluate the potential for ASR in bridges and pavements. A spreadsheet database was prepared for storing inventory data for 265 pavement cores and 311 bridge cores. Most of the bridge cores were from the San Francisco Bay Area while the pavement cores were collected from across the state. Visual inspection was performed on 259 of the pavement cores (including multiple specimens cut from some of the pavement cores) and 80 bridge cores (those with lengths greater than 3 inches) using the Damage Rating Index (DRI) method.

A draft guideline for investigation of ASR for future use by Caltrans staff was prepared using the DRI method adopted for this project.

Unconfined compressive strength (UCS) and density tests were performed on portions of 206 cores. The density and strength test results were compared to see if there was a correlation, and the results were also compared with values expected by experienced Caltrans materials engineers.

The second objective, to evaluate the effects on ASR of specification changes that occurred around 1995, could not be completed because of the very low detection of ASR in all of the cores examined, regardless of whether they were constructed before or after 1995.

### **5.2 Conclusions**

Among the results from the testing were the following:

- Most of the pavement cores inspected showed Damage Rating Index (DRI) for Concrete values of less than 1,000 (ASR not likely, according to the criteria shown in Section 3.2), with a DRI value of roughly 200 being the approximate median. A few cores had DRI results between 1,000 and 2,000 (ASR possible). None of the pavement cores inspected showed DRI results larger than 2,000 (ASR probable).
- Most of the bridge cores inspected had DRI results less than 1,000 (ASR not likely, according to the criteria listed previously), and the median DRI result was approximately 500. Very few of the bridge cores had DRI results between 1,000 and 2,000 (ASR possible), and none of them had DRI results greater than 2,000 (ASR probable).



- As-built data for the bridge cores were obtained for 259 of the 311 bridge cores. All of the cores came from bridges that were built before the year 2000. Comparison with the year of construction and the DRI data showed almost no trend between the age of the cores and DRI, with bridge ages ranging from 17 to 69 years old at time of visual inspection. Even the youngest cores should have had enough time to begin to manifest ASR if the reaction was occurring. There was no apparent difference in DRI values for the 46 cores taken from bridges built after 1995, when changes to specifications were made, compared with bridges built before 1995.
- Approximately 90 percent of the unconfined compressive strength (UCS) results were between 4,400 and 8,800 psi (30 and 61 MPa) and the median value was approximately 6,090 psi (42 MPa). These results were considered to be within the range of long-term strengths expected of PCC pavements by experienced Caltrans materials engineers.
- Approximately 90 percent of the density results were between 140 and 155 pcf (2,243 and 2,483 kg/m<sup>3</sup>) and the median value was approximately 147 pcf (2,350 kg/m<sup>3</sup>). These results were considered to be within the range of densities expected of PCC pavements by experienced Caltrans materials engineers.
- There was no significant correlation found between the UCS and density of the pavement cores tested, although UCS strength generally increased with density.
- A draft guideline was developed for the visual inspection of concrete cores to identify signs of potential ASR-related distresses; this guideline can to be used in the future by Caltrans staff to determine the need for further, more detailed examinations. The guideline describes step-by-step inspection procedures and selection criteria for further detailed examinations, and uses photographic examples that show different severity levels of potential ASR distresses.
- An integrated spreadsheet database was prepared for storing all relevant data for all cores, including test results from all tasks (DRI, UCS, and density).

### **5.3 Next Steps**

Based on the results of the study, which showed very low detection of ASR, it is recommended that no further work be performed on this project, except that Caltrans may choose to select a few locations suspected of having ASR for sampling and evaluation.

## REFERENCES

---

1. FHWA-HIF-09-004. Fournier, B., M.-A. Berube, and K.J. Folliard. Report on the Diagnosis, Prognosis, and Mitigation of Alkali-Silica Reaction (ASR) in Transportation Structures, Federal Highway Administration (FHWA), January 2010.
2. FHWA-HIF-09-001. Thomas, M.D.A., B. Fournier, and K.J. Folliard. Report on Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction, Federal Highway Administration (FHWA), April 2008.
3. FHWA-RD-01-164. Van Dam, T.J., L.L. Sutter, K.D. Smith, M.J. Wade, and K.R. Peterson. Guidelines for Detection, Analysis, and Treatment of Materials-related Distress in Concrete Pavements – Volume 2: Appendix B: Laboratory Methods, Federal Highway Administration (FHWA), August 2002.

## **APPENDIX**

---

### **A. Draft Test Procedures for Screening And Examining Concrete Core Samples for Alkali-Silica Reactivity**

#### **Procedures for ASR Visual Inspection, Draft**

The following test methods shall be used:

- ASTM C856, “Standard Practice for the Petrographic Examination of Hardened Concrete,” including descriptive rating of Alkali-Silica Reactivity (ASR) using the Damage Rating Index for Concrete (DRI)
- ASTM C294, “Standard Descriptive Nomenclature for Concrete Aggregates”

The procedures used for screening and examining concrete for alkali-silica reactivity (ASR) are as follows:

#### **Field Survey and Taking and Processing of Cores**

In the field, the concrete structure or structures suspected of having alkali-silica reactivity (ASR) should be surveyed to determine the extent of the potential damage. Surveys should include photographic documentation of the structures and any deleterious features, such as cracking, efflorescence, and exudations. Surveys should also include layouts of the steel reinforcement and detailed mapping of the crack pattern. Concrete cores should be photographed in the field, examined for unusual features, cataloged, and categorized. An example of the procedures and decision-making criteria for the petrographic examination and Damage Index Rating is shown in Figure A.1.

Three cores with a diameter of 4 inches, or with a minimum diameter of 3 inches if 4 inches is too large, should be taken from the structure showing possible ASR cracking and sent to a laboratory for visual examination. This examination should be conducted on whole (uncut) cores, saw-cut longitudinally, with overlapping cross-sectional slices. Also, any loose or water-soluble materials, either from the field before coring or from the cores delivered to the lab, should be taken to the lab and held for later analysis. All samples (cores and other materials) should be photographed and logged when delivered to the laboratory.

#### **Measuring Damage Rating Index**

The lapped slice faces should be measured to determine the area of examination and the area of the face should be visually examined to determine the number of physical features typically associated with ASR. These features include coarse aggregate with cracks, coarse aggregate with cracks filled with gel, debonded coarse aggregate, aggregate with reaction rims, cement (cementitious) paste with cracks, paste with cracks filled with

gel, and voids lined or filled with gel. Each feature should be given a weighing factor based on its association to ASR. Photos in Figure A.2 show some of the common petrographic features of ASR. The weighted features should be summed and normalized to the area examined, which will give a Damage Rating Index (DRI) value for the core slice. Additional information should be gathered regarding the presence of reacted aggregate (but not showing signs of distress), the presence of secondary mineral deposits other than ASR gel, and the physical characteristics of the concrete, such as consolidation and segregation.

Cores with DRI values greater than 1,500 should be separated and prepared for further examination utilizing polarized light microscopy (PLM) techniques, including thin-section analysis, powder grain mount analysis, and stereoscopic examinations (reflected light) at high magnifications. Analysis of accessory materials, including efflorescence, exudations, loose aggregate and loose altered paste and mortar include thin-section analysis of vacuum-impregnated, epoxy-mounted samples, X-Ray Diffraction (XRD) analysis, Fourier Transform Infrared Spectroscopy (FTIR), and Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM/EDX).

The following is an outline of the screening and examining procedures, including specialized or recommended equipment necessary to perform the tasks (accessory equipment and consumables are included):

## 1) Sampling from Structure

### a. Photodocumentation and identification of structure

*Location of steel reinforcement, structure geometry, crack pattern*

#### i. Equipment

1. Digital camera
2. Tape measure, measuring wheel, or other distance measuring devices

### b. Collection of accessory materials

*Identification of ASR reaction products*

#### i. Equipment

1. Collection containers
2. Picks, brushes, and various collection handtools
3. Digital camera

c. Core drilling

*Recovery of concrete core samples*

i. Equipment

1. Coring rig
2. Diamond-bonded coring drill bits (preferred sizes are 3 inch and 4 inch diameter)
3. Gas-powered electrical generator

2) **Examination of Concrete Core Longitudinal Cross-Sections**

a. Photodocumentation and logging of core samples

*Correlation of core samples to location within structure(s)*

i. Equipment

1. Digital camera
2. Photomacrographic scales or rulers

b. Collection of accessory materials (loose materials, mineral or mineraloid deposits, or water-soluble deposits of question)

*Identification of ASR reaction products*

i. Equipment

1. Dental picks
2. Collection containers

c. Longitudinal cross sections with smooth cut and lapped surfaces

*Determination of DRI*

i. Equipment

1. Water-cooled concrete saw with continuous-rim diamond-bonded saw blade (minimum 14" diameter blade)
2. Trim saw or tile saw
3. Polishing/lapping wheel (capable of lapping 4 inch by 6 inch cross section with either loose grit or diamond-bonded pads)

d. Examination of lapped cross sections at low magnification

*Determination of DRI*

i. Equipment

1. Variable zoom stereoscope with magnifications from 5x to at least 50x
2. Hand-held or table-mounted magnifiers (typically 2x to 10x magnification)
3. Hardness testing kit (Mohs hardness or standardized hardness picks)

e. Measurement of cross-sections

*Determination of DRI*

i. Equipment

1. Calibrated digital micrometer or scales

f. Photodocumentation

*Correlation of concrete core DRI to location within structure*

i. Equipment

1. Flat-bed scanner or digital camera
2. Photomacrographic scale or ruler

g. Sum of physical features common to ASR

*DRI Report (see Figure A.1)*

i. Equipment

1. Damage Rating Index (DRI) worksheet with weighing factors (*Excel* spreadsheet)

## REFERENCES

- 1) FHWA-HIF-09-004. Fournier, B., M.A. Berube, and K.J. Folliard. Report on the Diagnosis, Prognosis, and Mitigation of Alkali-Silica Reaction (ASR) in Transportation Structures, Federal Highway Administration (FHWA), January 2010.
- 2) FHWA-HIF-09-001. Thomas, M.D.A., B. Fournier, and K.J. Folliard. Report on Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction, Federal Highway Administration (FHWA), April 2008.
- 3) FHWA-RD-01-164. Van Dam, T.J., L.L. Sutter, K.D. Smith, M.J. Wade, and, K.R. Peterson. Guidelines for Detection, Analysis, and Treatment of Materials-related Distress in Concrete Pavements – Volume 2: Appendix B: Laboratory Methods, Federal Highway Administration (FHWA), August 2002.

**Sample Identification**

**Petrographic Feature**

|                                      | Weighing Factor |
|--------------------------------------|-----------------|
| Coarse aggregate with cracks         | 0.25            |
| Coarse aggregate with cracks and gel | 2.00            |
| Coarse aggregate debonded            | 3.00            |
| Reaction rims around aggregate       | 0.50            |
| Cement paste with cracks             | 2.00            |
| Cement paste with cracks and gel     | 4.00            |
| Air voids lined or filled with gel   | 0.50            |

Sum

Area (cm<sup>2</sup>)

Normalized Area (cm<sup>2</sup>)

**Damage Rating Index (DRI)**

**Area Calculations**

Length (in.)

Width (in.)

Area (in.<sup>2</sup>)

Area (cm<sup>2</sup>)

| Sample 1 |         | Sample 2   |         |
|----------|---------|------------|---------|
| Feature  | Weighed | Feature    | Weighed |
| 0        | 0       | 0          | 0       |
| 0        | 0       | 0          | 0       |
| 0        | 0       | 0          | 0       |
| 0        | 0       | 9          | 4.5     |
| 0        | 0       | 0          | 0       |
| 0        | 0       | 0          | 0       |
| 0        | 0       | 0          | 0       |
|          |         |            |         |
| 0        | 0       | 9          | 4.5     |
|          |         |            |         |
| 76.3     |         | 112.7      |         |
| 0.76     |         | 1.13       |         |
| <b>0</b> |         | <b>399</b> |         |

|      |       |
|------|-------|
| 2.81 | 4.16  |
| 4.21 | 4.20  |
| 11.8 | 17.5  |
| 76.3 | 112.7 |

The criteria used for ASR for this study were:

- DRI = 0, No ASR;
- DRI < 500, ASR very unlikely;
- 500 ≤ DRI < 1000, ASR not likely;
- 1000 ≤ DRI < 2000, ASR possible;
- DRI > 2000, ASR probable.

**Figure A.1: Example of the procedures and decision making criteria for the petrographic examination and Damage Index Rating.**

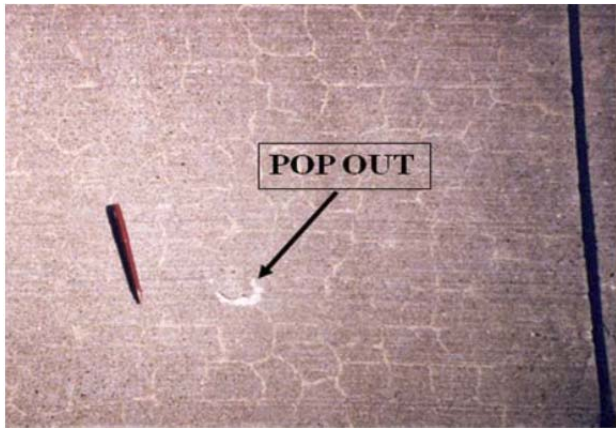


**Figure A.2: Example photos showing some of the common petrographic features of ASR.**





**Figure A.2: Example photos showing some of the common petrographic features of ASR (*cont'd*).**



**Figure A.2. Example photos showing some of the common petrographic features of ASR (cont'd).**  
(Some of the photos are from the reference: Thomas, M.D.A., B. Fournier, and K.J. Folliard. *Alkali-aggregate Reactivity (AAR) Facts Book*. No. FHWA-HIF-13-019. 2013.)