

1. REPORT NUMBER CA15-2702	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
4. TITLE AND SUBTITLE Results from Visual Inspection and Laboratory Testing for ASR in Existing Concrete Cores from Bridges and Pavements in California.		5. REPORT DATE March 2017
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR H. Li, J. Asselanis, J. Zhou, I. Guada, V. Kanekanti, and R. Wu		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of California Pavement Research Center Department of Civil and Environmental Engineering, UC Davis 1 Shields Avenue Davis, CA 95616		10. WORK UNIT NUMBER
		11. CONTRACT OR GRANT NUMBER 65A0542
12. SPONSORING AGENCY AND ADDRESS California Department of Transportation Division of Research, Innovation, and Systems Information P.O. Box 942873 Sacramento, CA 94273-0001		13. TYPE OF REPORT AND PERIOD COVERED Research Report June 2015-June 2016
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

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 pavement 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.

Refer to Final Report for rest of Abstract.

17. KEY WORDS Bridge Decks, concrete pavements, ASR, damage, strength, visual inspection, petrographic examination	18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161	
19. SECURITY CLASSIFICATION (of this report) Unclassified	20. NUMBER OF PAGES 58	21. COST OF REPORT CHARGED None

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

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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

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TECHNICAL REPORT DOCUMENTATION PAGE

1. REPORT NUMBER UCPRC-RR-2015-07	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
4. TITLE AND SUBTITLE Results from Visual Inspection and Laboratory Testing for ASR in Existing Concrete Cores from Bridges and Pavements in California		5. REPORT PUBLICATION DATE March 2017
		6. PERFORMING ORGANIZATION CODE
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		11. CONTRACT OR GRANT NUMBER 65A0542
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		14. SPONSORING AGENCY CODE RPMD Task ID: 2702
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19. SECURITY CLASSIFICATION (of this report) Unclassified	20. NUMBER OF PAGES 57	21. PRICE None

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UCPRC ADDITIONAL INFORMATION

DRAFT STAGE Stage 6, final	PARTNERED PAVEMENT RESEARCH CENTER STRATEGIC PLAN ELEMENT NUMBER 3.34
FHWA NUMBER CA172702A	VERSION NUMBER 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

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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/m³) and the median value was approximately 147 pcf (2,350 kg/m³). 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.

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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

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

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.

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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.

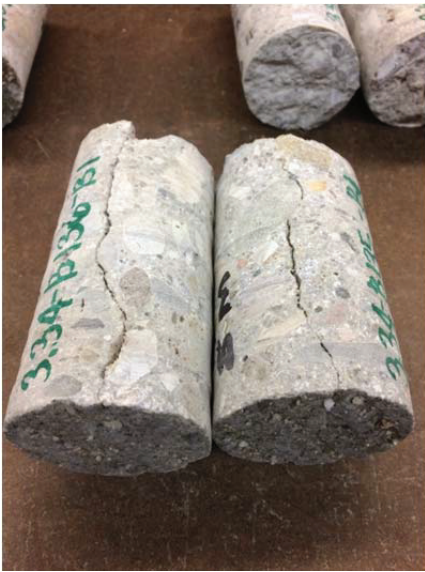


Figure 2.2: Bridge cores; cores equal to or longer than 3 inches were used for ASR visual inspection.

CoreID	District	County	Route	CoreLocation	BridgeNumber	PM	Lane	Abutto	TransDist	Shoulder	Note4Loc	CoreID	CoringDate	CoreType	Latitude	Longitude	Elevation	WaterBody Name	WaterBody Type	Distance WB	CoreDiam	CoreLength	Notes
1	4	Contra Costa	NB 680	ane 3, BR#28-0161	28-0161	13.93	3	1	53'	10'6"	ic Blvd o/s	1	8/12/08	Bridge	37.8938	-122.067	254	Senovir Res	Fresh	20.000	2	3	04-2A7204
2	4	Contra Costa	NB 680	3, BR#28-0161 AS1	28-0161	13.93	3	1	52'	10'6"	ic Blvd o/s	2	8/12/08	Bridge	37.8938	-122.067	254	Senovir Res	Fresh	20.000	2	3	04-2A7204
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	Senovir Res	Fresh	20.000	2	2	04-2A7204
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	Senovir Res	Fresh	20.000	2	3	04-2A7204
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	04-0E5304
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	04-0E5304
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	04-0E5304
9	3	Placer	NB 65	R12.67, BR#19-017	19-0176	R12.67	2	1	13'	16'3"	am Slough	1	6/30/09	Bridge	38.8619	-121.3	158	Mill Pond	Fresh	6.231	2	3	03-2E8804
10	3	Placer	NB 65	R12.67, BR#19-017	19-0176	R12.67	2	1	22'8"	11'6"	am Slough	2	6/30/09	Bridge	38.8619	-121.3	158	Mill Pond	Fresh	6.231	2	2	03-2E8804
11	3	Placer	NB 65	R12.67, BR#19-017	19-0176	R12.67	2	1	66'4"	9'1"	am Slough	3	6/30/09	Bridge	38.8619	-121.3	158	Mill Pond	Fresh	6.231	2	3	03-2E8804
12	3	Placer	NB 65	R12.67, BR#19-017	19-0176	R12.67	2	1	102'10"	7'11"	am Slough	4	6/30/09	Bridge	38.8619	-121.3	158	Mill Pond	Fresh	6.231	2	3	03-2E8804
13	3	Placer	NB 65	R12.67, BR#19-017	19-0176	R12.67	2	2	23'6"	8'1"	am Slough	5	6/30/09	Bridge	38.8619	-121.3	158	Mill Pond	Fresh	6.231	2	3	03-2E8804
14	3	Placer	NB 65	R12.67, BR#19-017	19-0176	R12.67	2	2	10'1"	10'5"	am Slough	6	6/30/09	Bridge	38.8619	-121.3	158	Mill Pond	Fresh	6.231	2	3	03-2E8804
15	3	Placer	65	M 08.02, BR#19-017	19-0174	M8.02	2	1	67'	10'8"	Oaks Blvd	1	6/30/09	Bridge	38.7951	-121.297	122	hitney Por	Fresh	20.000	2	3	03-2E8804
16	3	Placer	65	M8.02, BR#19-017	19-0174	M8.02	2	1	156'11"	10'5"	Oaks Blvd	2	6/30/09	Bridge	38.7951	-121.297	122	hitney Por	Fresh	20.000	2	3	03-2E8804
17	3	Placer	65	M8.02, BR#19-017	19-0174	M8.02	2	1	128'9"	10'4"	Oaks Blvd	3	6/30/09	Bridge	38.7951	-121.297	122	hitney Por	Fresh	20.000	2	3	03-2E8804
18	3	Placer	65	M8.02, BR#19-017	19-0174	M8.02	2	1	143'7"	6'6"	Oaks Blvd	4	6/30/09	Bridge	38.7951	-121.297	122	hitney Por	Fresh	20.000	2	3	03-2E8804
19	3	Placer	65	M 11.92, BR#19-0	19-0173	R11.92	1	1	95'2"	6'0"	Bridges C	1	6/30/09	Bridge	38.8511	-121.3	133	hitney Por	Fresh	2.104	2	3	03-2E8804
20	3	Placer	65	M 11.92, BR#19-0	19-0173	R11.92	1	1	126'6"	6'4"	Bridges C	2	6/30/09	Bridge	38.8511	-121.3	133	hitney Por	Fresh	2.104	2	2	03-2E8804
21	3	Placer	65	M 11.92, BR#19-0	19-0173	R11.92	1	1	153'2"	6'4"	Bridges C	3	6/30/09	Bridge	38.8511	-121.3	133	hitney Por	Fresh	2.104	2	3	03-2E8804
22	3	Placer	65	M 11.92, BR#19-0	19-0173	R11.92	1	3	29'0"	10'2"	Bridges C	4	6/30/09	Bridge	38.8511	-121.3	133	hitney Por	Fresh	2.104	2	3	03-2E8804
23	3	Placer	65	M 18.20, BR#19-015	19-0154S	R8.20	3	3	34'7"	11'1"	is Blvd. Off	1	6/30/09	Bridge	38.7973	-121.299	118	olsom Lak	Fresh	47.933	2	3	03-2E8804
24	3	Placer	65	M 18.20, BR#19-015	19-0154S	R8.20	3	3	8'2"	15'3"	is Blvd. Off	2	6/30/09	Bridge	38.7973	-121.299	118	olsom Lak	Fresh	47.933	2	3	03-2E8804
25	3	Placer	65	M 18.20, BR#19-015	19-0154S	R8.20	3	3	6'7"	9'11"	is Blvd. Off	3	6/30/09	Bridge	38.7973	-121.299	118	olsom Lak	Fresh	47.933	2	2.5	03-2E8804
26	3	Placer	65	M 18.20, BR#19-015	19-0154S	R8.20	3	3	10'1"	11'1"	is Blvd. Off	4	6/30/09	Bridge	38.7973	-121.299	118	olsom Lak	Fresh	47.933	2	2.5	03-2E8804
27	3	Placer	65	M 12.60, BR#19-0	19-0179R	12.6	2	4	43'2"	9'6"	Pkwy BOH	1	6/30/09	Bridge	38.8609	-121.3	147	olsom Lak	Fresh	60.000	2	2	03-2E8804
28	3	Placer	65	M 12.60, BR#19-0	19-0179R	12.6	2	4	132'8"	9'1"	Pkwy BOH	2	6/30/09	Bridge	38.8609	-121.3	147	olsom Lak	Fresh	60.000	2	3	03-2E8804
29	3	Placer	65	M 12.60, BR#19-0	19-0179R	12.6	2	4	140'1"	3'1"	Pkwy BOH	3	6/30/09	Bridge	38.8609	-121.3	147	olsom Lak	Fresh	60.000	2	3	03-2E8804
30	3	Placer	65	M 12.60, BR#19-0	19-0179R	12.6	2	4	253'11"	7'10"	Pkwy BOH	4	6/30/09	Bridge	38.8609	-121.3	147	olsom Lak	Fresh	60.000	2	3	03-2E8804
31	3	Placer	65	M 12.60, BR#19-0	19-0179R	12.6	2	4	282'3"	2'7"	Pkwy BOH	5	6/30/09	Bridge	38.8609	-121.3	147	olsom Lak	Fresh	60.000	2	3	03-2E8804
32	3	Placer	65	M 12.60, BR#19-0	19-0179R	12.6	2	1	54'	9'5"	Pkwy BOH	6	6/30/09	Bridge	38.8609	-121.3	147	olsom Lak	Fresh	60.000	2	3	03-2E8804
33	3	Placer	65	M 12.60, BR#19-0	19-0179L	12.6	2	1	12'4"	9'5"	Pkwy BOH	1	6/30/09	Bridge	38.8609	-121.3	147	olsom Lak	Fresh	60.000	2	2	03-2E8804
34	3	Placer	65	M 12.60, BR#19-0	19-0179L	12.6	2	1	70'0"	8'6"	Pkwy BOH	2	6/30/09	Bridge	38.8609	-121.3	147	olsom Lak	Fresh	60.000	2	2	03-2E8804
35	3	Placer	65	M 12.60, BR#19-0	19-0179L	12.6	2	1	162'5"	13'7"	Pkwy BOH	3	6/30/09	Bridge	38.8609	-121.3	147	olsom Lak	Fresh	60.000	2	2	03-2E8804
36	3	Placer	65	M 12.60, BR#19-0	19-0179L	12.6	2	1	200'4"	10'1"	Pkwy BOH	4	6/30/09	Bridge	38.8609	-121.3	147	olsom Lak	Fresh	60.000	2	3	03-2E8804
37	3	Placer	65	M 12.60, BR#19-0	19-0179L	12.6	2	1	252'7"	7'6"	Pkwy BOH	5	6/30/09	Bridge	38.8609	-121.3	147	olsom Lak	Fresh	60.000	2	3	03-2E8804
38	3	Placer	65	M 12.60, BR#19-0	19-0179L	12.6	2	1	266'2"	5'9"	Pkwy BOH	6	6/30/09	Bridge	38.8609	-121.3	147	olsom Lak	Fresh	60.000	2	3	03-2E8804
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	ake Chab	Fresh	2.158	2	5	04-0E8104	
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	ake Chab	Fresh	2.158	2	6	04-0E8104	
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	ake Chab	Fresh	2.158	2	5	04-0E8104	
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	ake Chab	Fresh	2.200	2	4	04-0E8104
43	4	Solano	80	ake, Lane 1, PM R5.1	23-169R	R5.57	1				505 North Allen/22 Sample	8/10/08	Bridge	38.1382	-122.221	279	ake Chab	Fresh	2.200	2	5	04-0E8104	
44	4	Solano	80	ake, Lane 1, PM R5.1	23-169R	R5.57	1				505 North Allen/22 Sample	8/10/08	Bridge	38.1382	-122.221	279	ake Chab	Fresh	2.200	2	5	04-0E8104	
45	4	Solano	80	Lane 1, PM R26.46, L	23-0051L	R26.46	1				80W Masco/2 Sample	8/10/08	Bridge	38.3542	-121.979	163	ittis Cree	Fresh	400	2	4	04-0E8104	
46	4	Solano	80	Lane 1, PM R26.46, L	23-0051L	R26.46	1				80W Masco/2	2/2	8/10/08	Bridge	38.3542	-121.979	163	ittis Cree	Fresh	400	2	2	Core broker
47	4	Alameda	SB 880	oe, Lane 3, BR#33-4	33-0273	10.66	3	1	14'3"		Crandall Creek	25/1	11/20/08	Bridge	37.5675	-122.043	32	landall Cre	Creek	6.336	2	5	04-0E7804

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	13.62	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	12.33	2/8/2011	3	2	COL	5	N	7	0					x
6	0306Y00_3	0306Y00_3		4	PCC	220	220	33.98239	-122.1508	7.14	1/12/2011	3	2	COL	5	N	6	0					x
7	0306Y00_5	0306Y00_5		5	PCC	209	209	33.37158	-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	38.880384	-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	1.32	4/15/2011	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	-121.534	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	11/4/2010	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	519.56	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	33.182544	-120.818	317.34	11/4/2010	3	2	PLA	80	W	5	0					x
30	04G0Y00_5	04G0Y00_5		5	PCC	190	190	33.239165	-120.5314	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	38.583527	-121.2386	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	-121.5539	1.63	3/18/2011	3	3	YOL	50	E	3	0					x
37	04H0Y00_1	04H0Y00_1		2	PCC	214	214	38.526455	-121.4687	2.59	3/10/2011	3	4	SAC	99	S	4	1					x
38	04H0Y00_2	04H0Y00_2		2	PCC	205	205	38.526298	-121.4686	2.62	4/12/2011	3	4	SAC	99	S	4	1					x
39	04O5Y00_1	04O5Y00_1		5	PCC	201	201	38.410626	-121.3933	3.51	3/17/2011	3	3	SAC	99	N	6	1					x
40	04O5Y00_2	04O5Y00_2		4	PCC	211	211	38.487241	-121.4364	2.47	3/17/2011	3	3	SAC	99	N	5	1					x
41	04O5Y00_3	04O5Y00_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	3/10/2011	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	-121.768	2.86	1/10/2011	3	2	YOL	113	S	3	0					x
46	0550Y00_2	0550Y00_2		5	PCC	205	205	38.70885	-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	-122.9526	26.42	6/11/2009	4	2	SON	101	N	0	0					
49	BV51	BV51-4-90		1	PCC	205	207	38.743206	-122.9532	26.36	6/11/2009	4	2	SON	101	N	0	0					
50	BV51	BV51-6-150		1	PCC	199	204	38.743501	-122.9537	26.19	6/11/2009	4	2	SON	101	N	0	0					
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					

Figure 2.4: Inventory of pavement cores.

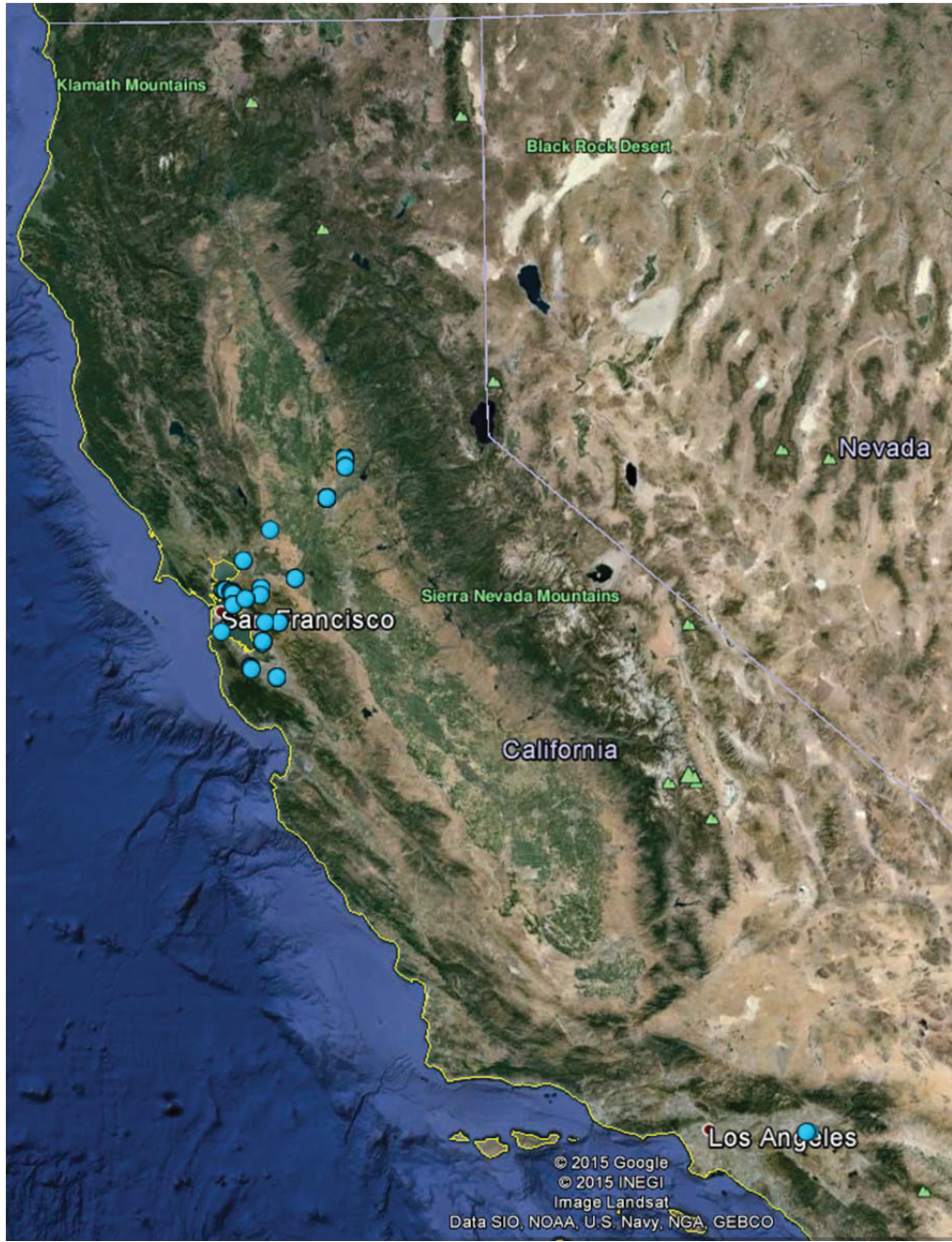
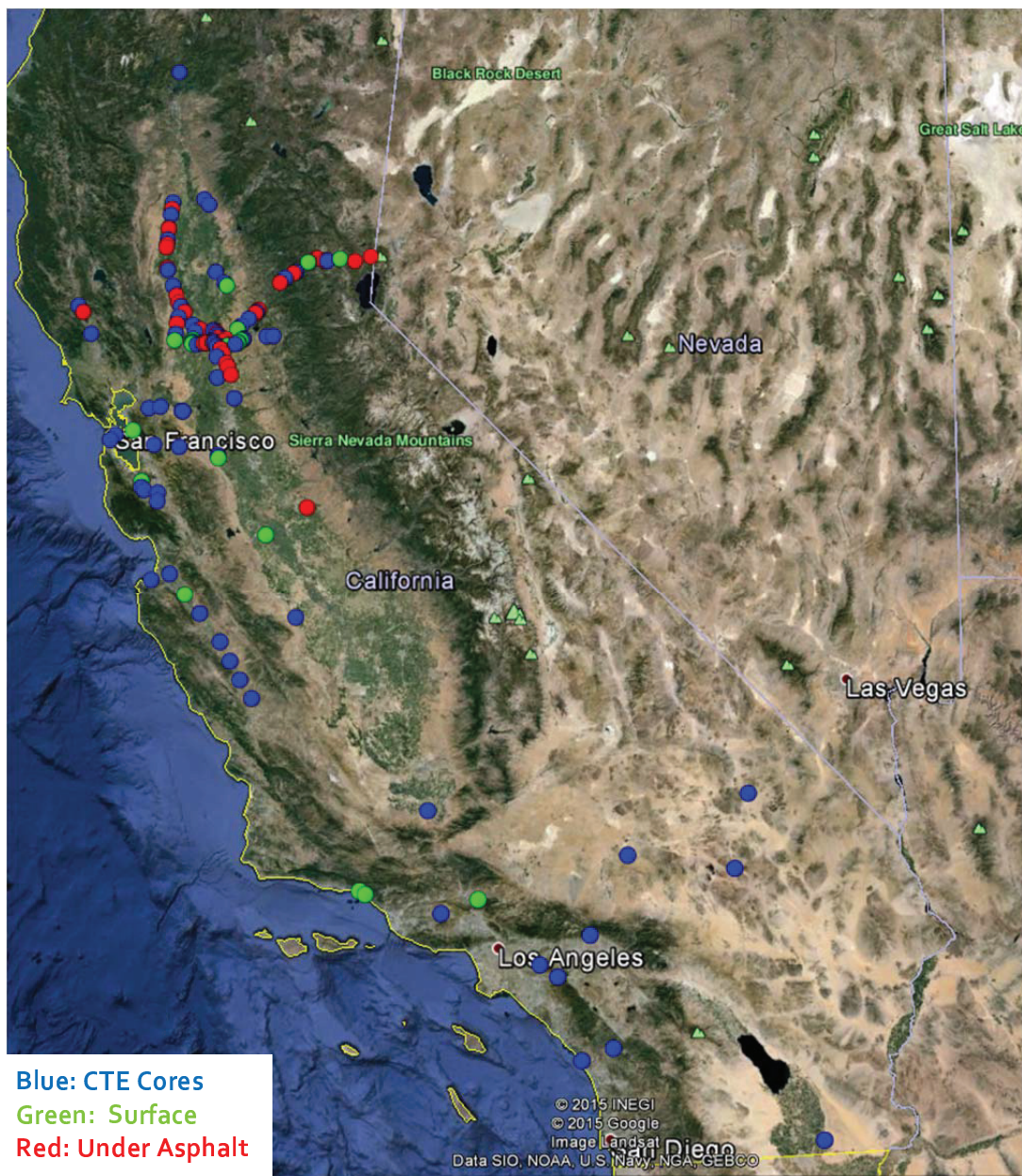


Figure 2.5: Map showing original locations of bridge cores.



.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.

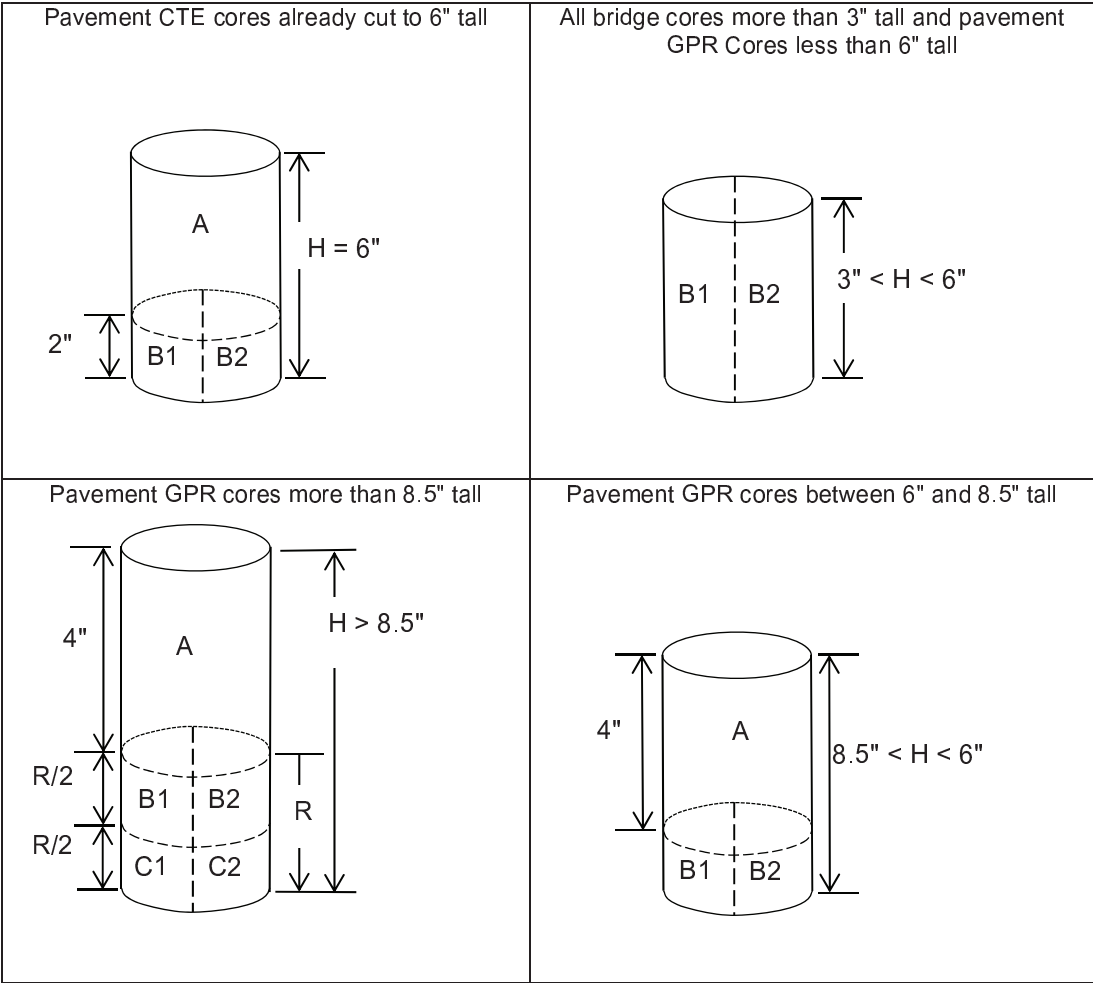


Figure 2.7: J-slot continuous diamond blades for concrete core cutting.

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 (22 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.

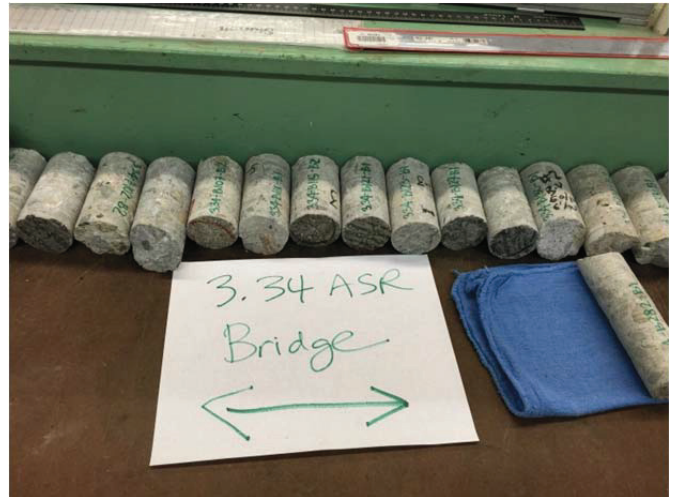
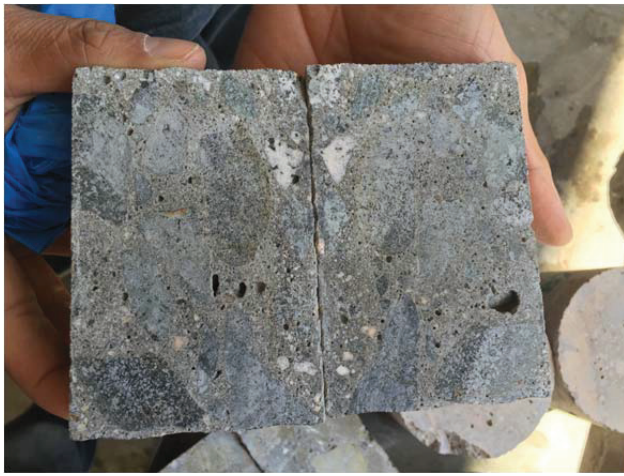


Figure 2.9: Concrete cores for visual inspection.



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

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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

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 (cm²)

Normalized area (cm²)

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	
0		399	

Area Calculations

Length (in.)

Width (in.)

Area (in.²)

Area (cm²)

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.

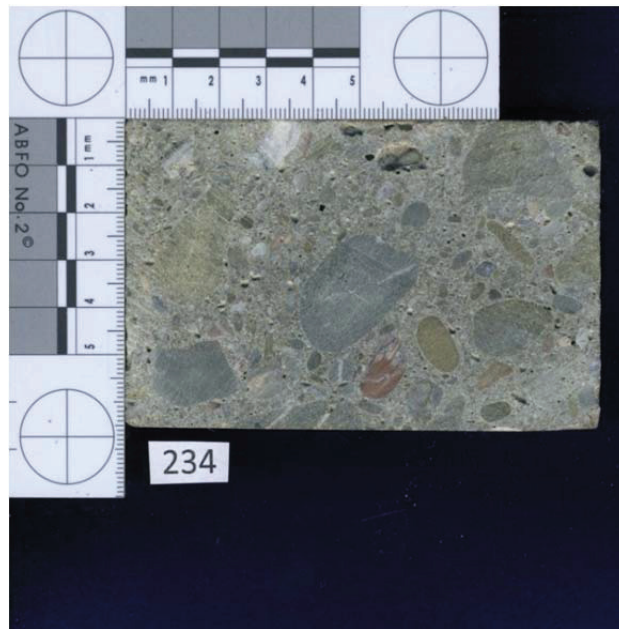
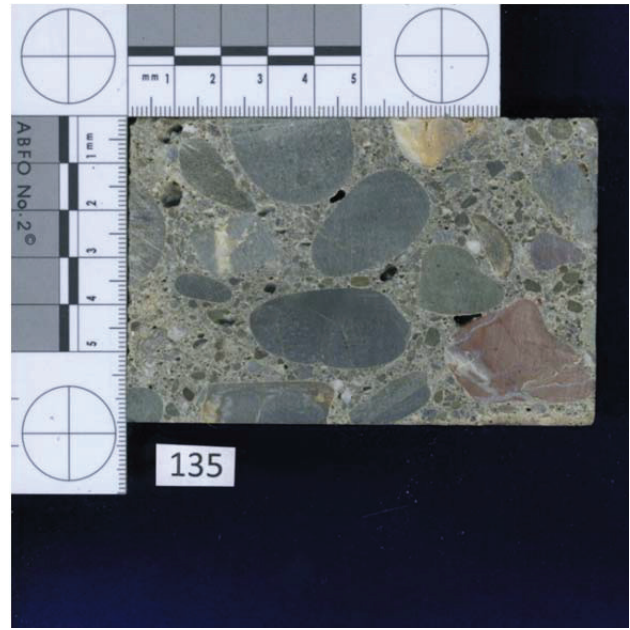
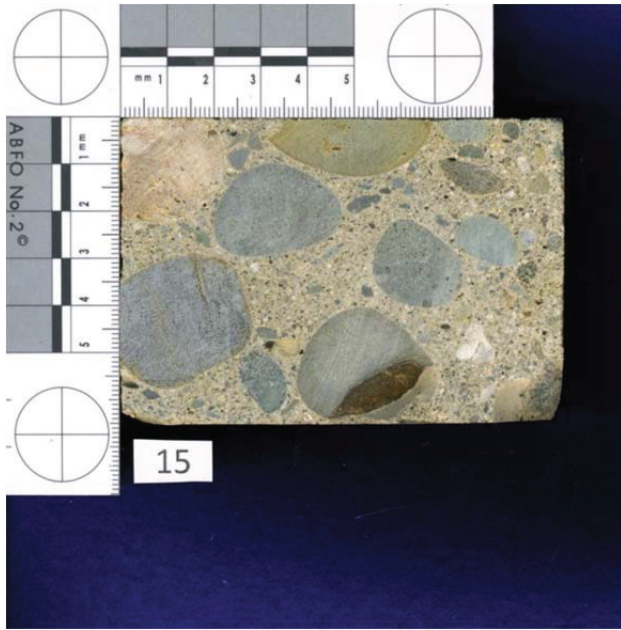


Figure 3.3: Example scans of the cut surfaces of three pavement cores.

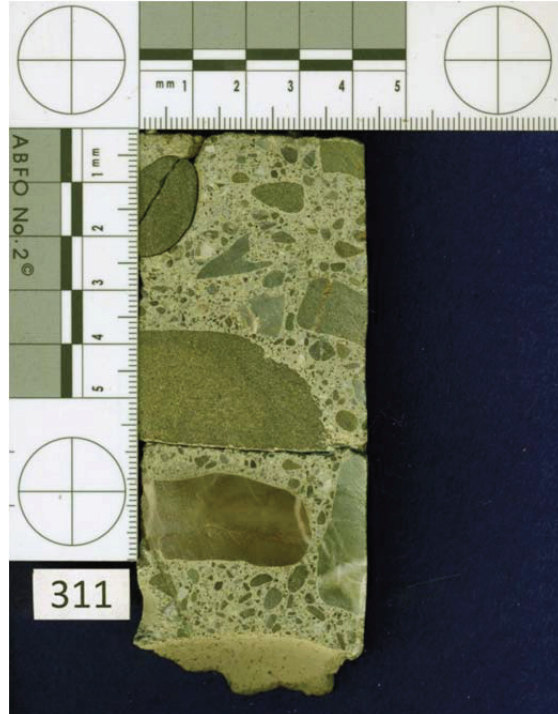
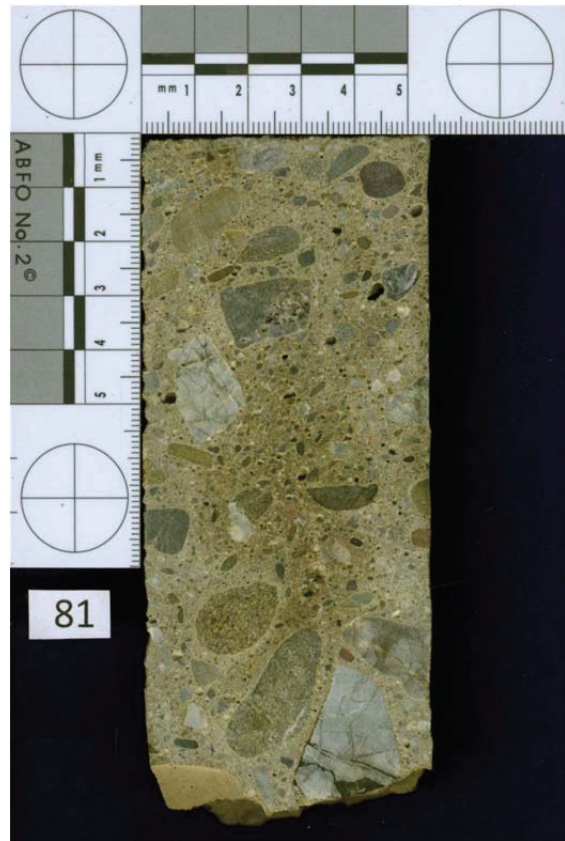


Figure 3.4: Example scans of the cut surfaces of three bridge cores.

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).

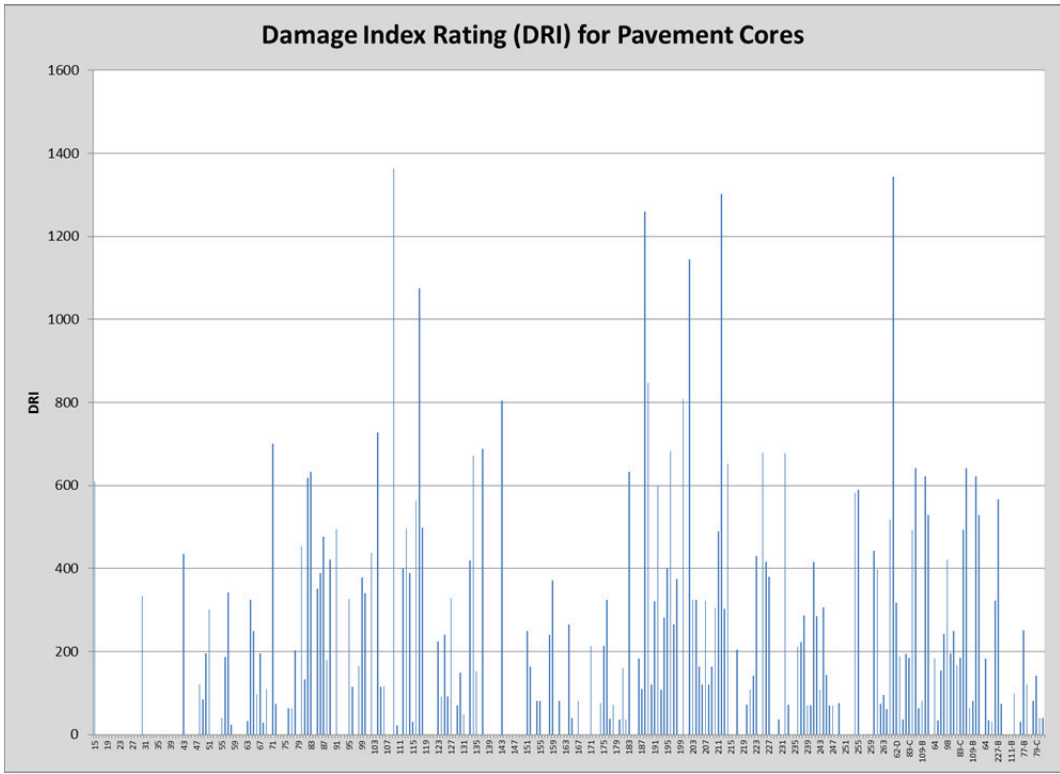


Figure 3.6: DRI of pavement cores, by core number.

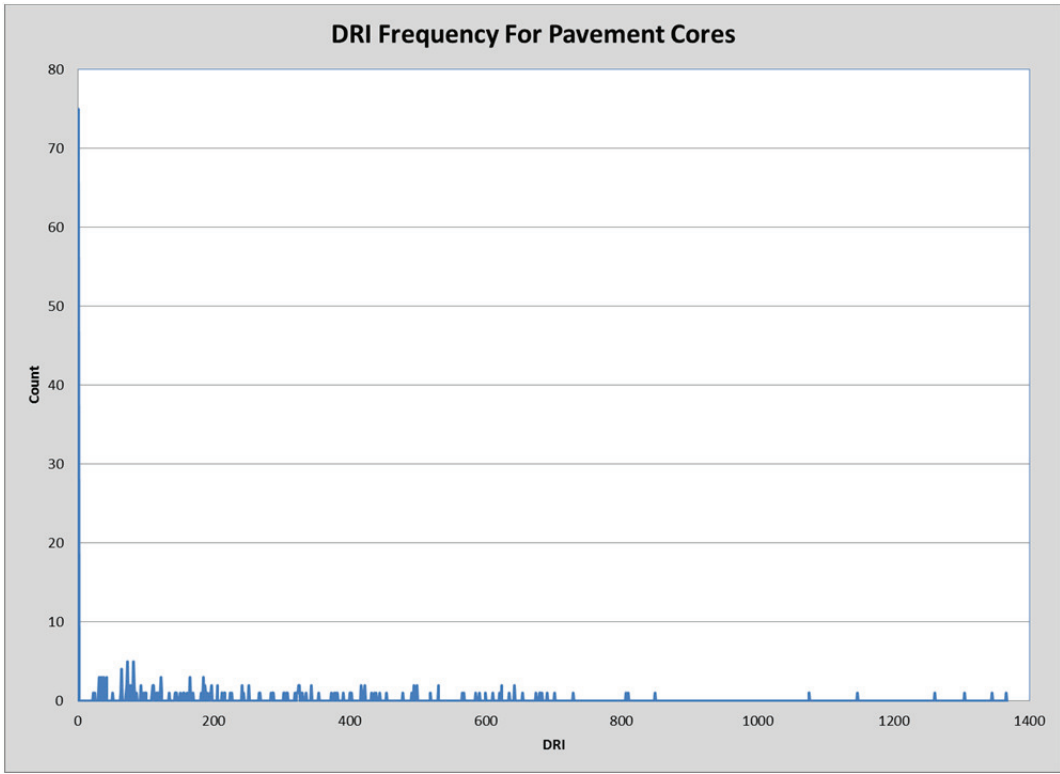


Figure 3.7: DRI of pavement cores, frequency chart.

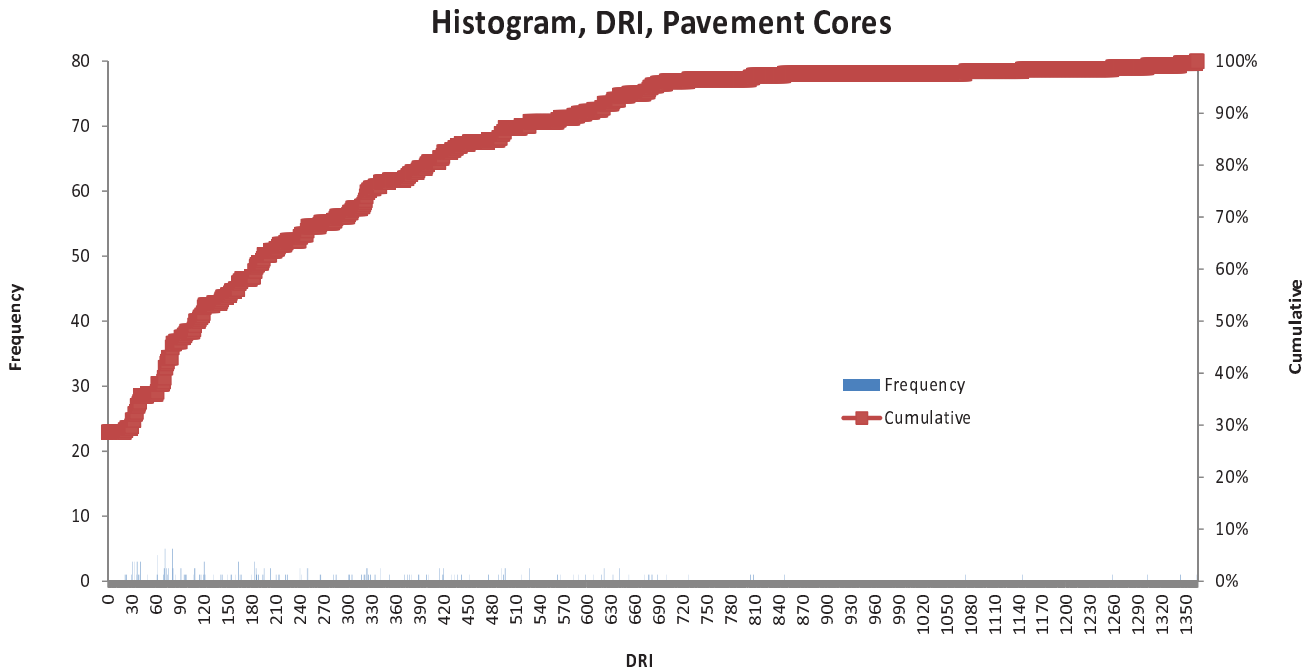


Figure 3.8: DRI of pavement cores, cumulative distribution chart.

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).

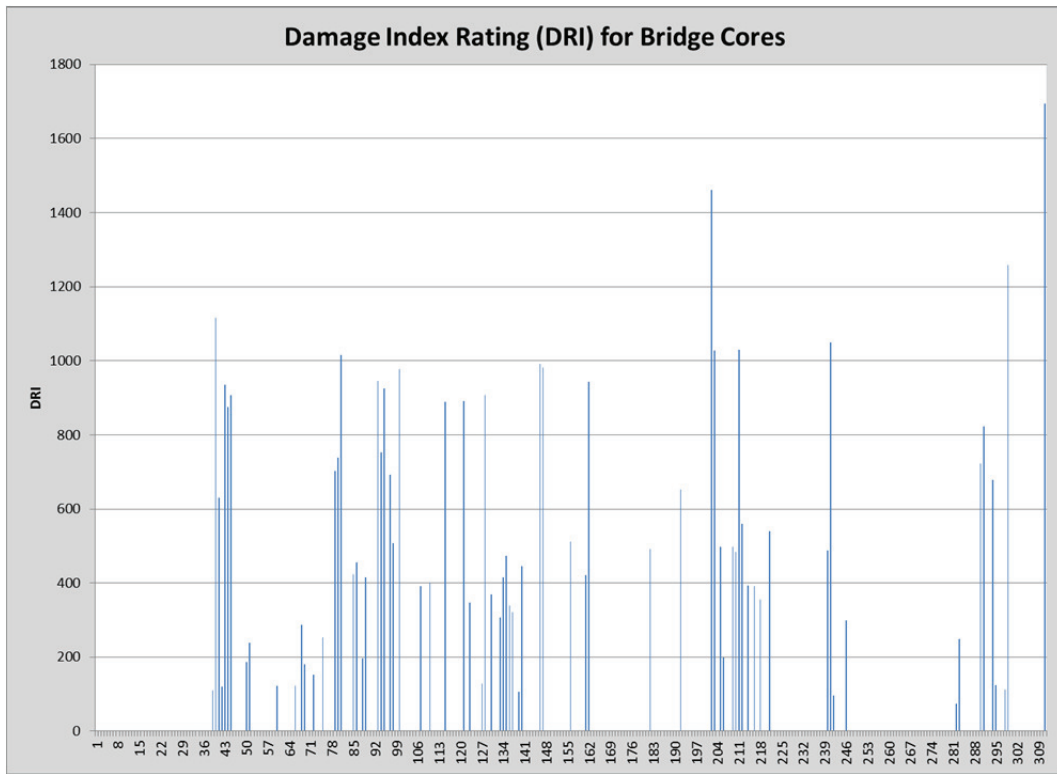


Figure 3.9: DRI of bridge cores, by core number.

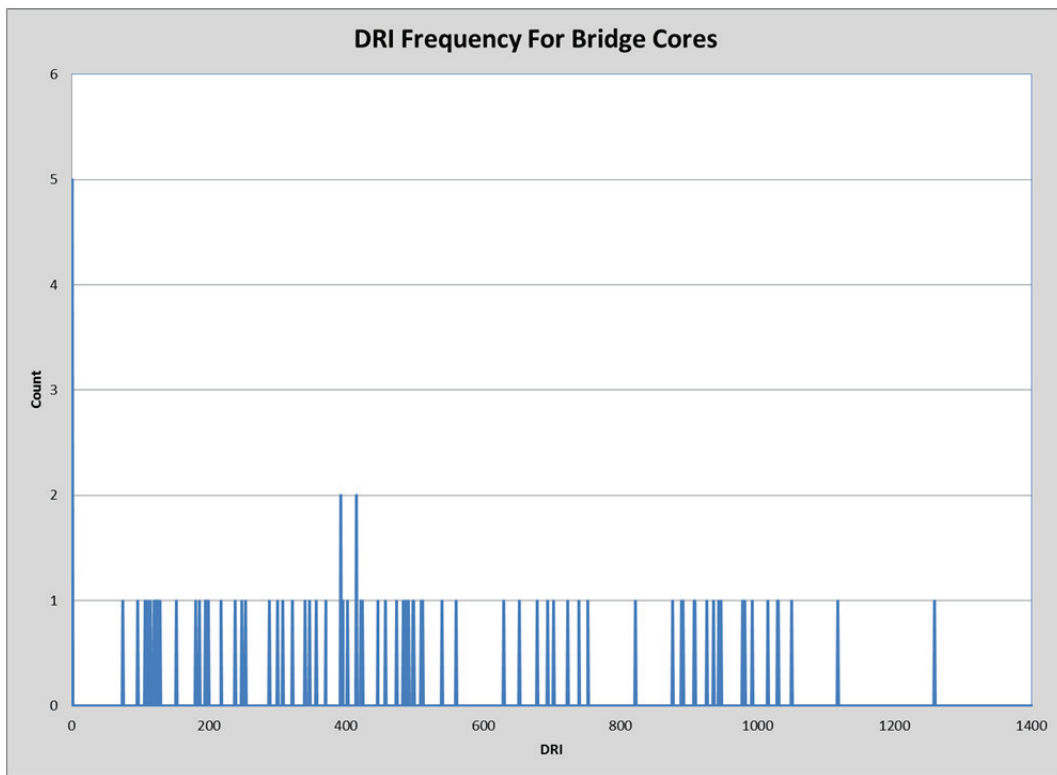


Figure 3.10: DRI of bridge cores, frequency chart.

Histogram, DRI, Bridge Cores

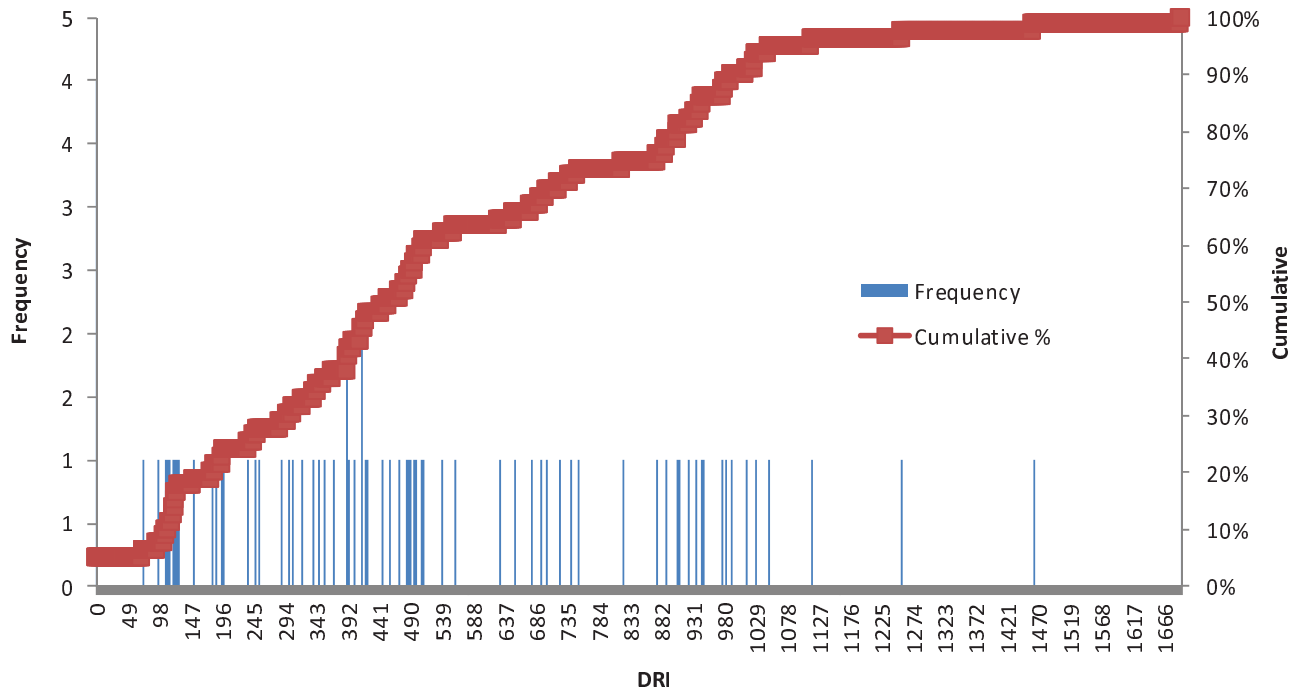


Figure 3.11: DRI of bridge cores, cumulative distribution chart.

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.

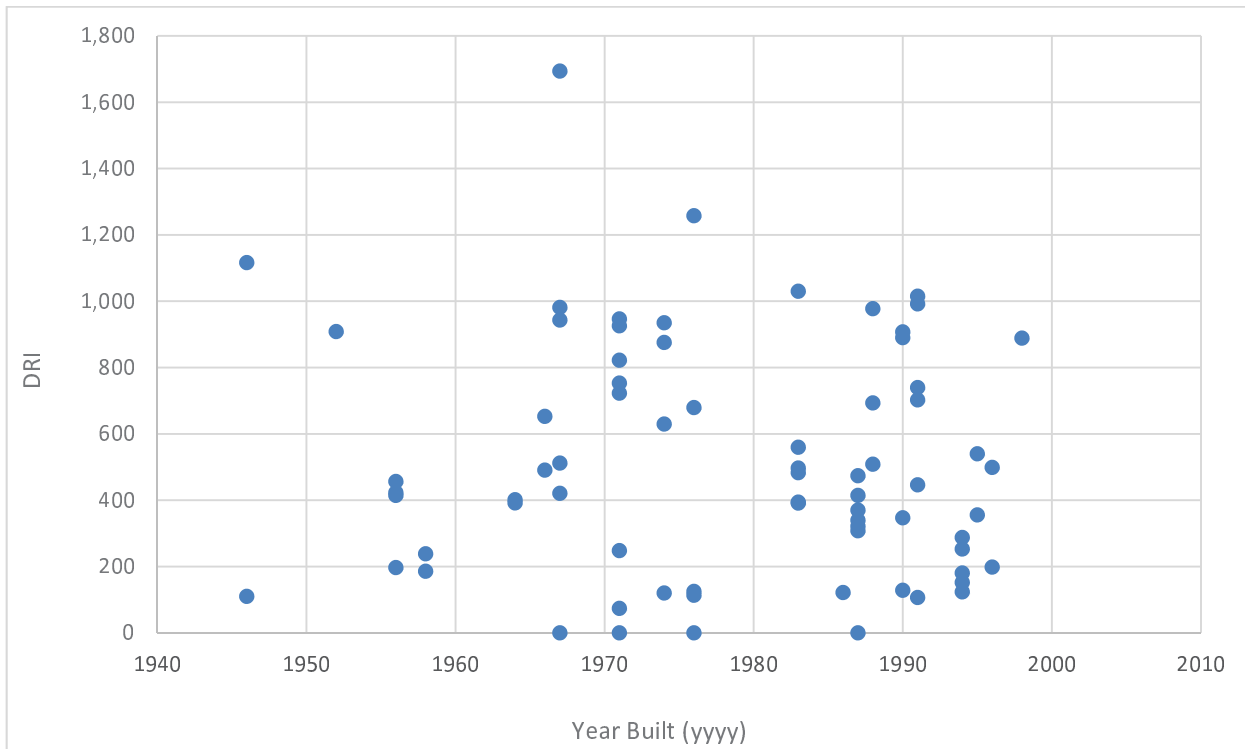


Figure 3.12: Damage Rating Index versus year of construction for bridge cores.

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.

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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.

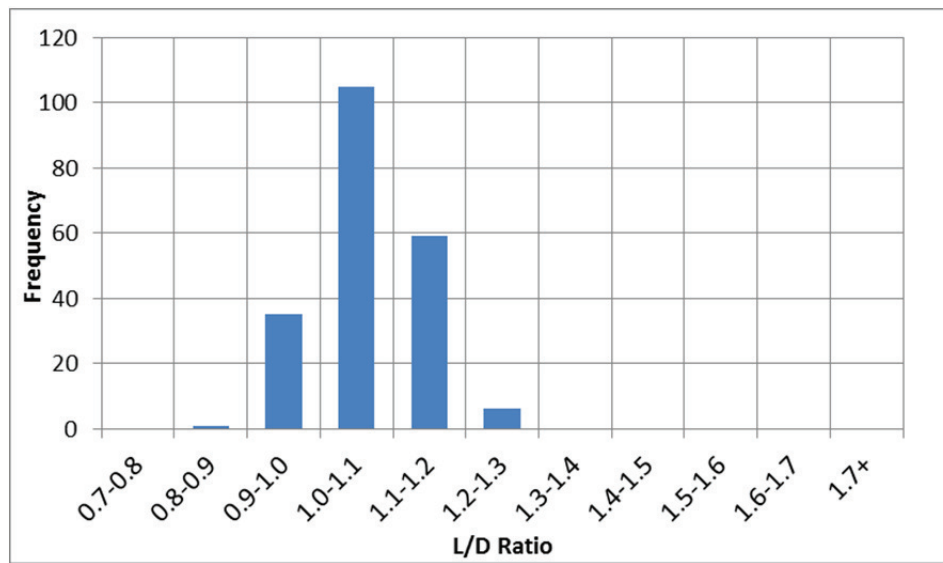


Figure 4.2: Frequency of length-to-diameter ratio (LDR) of pavement cores.

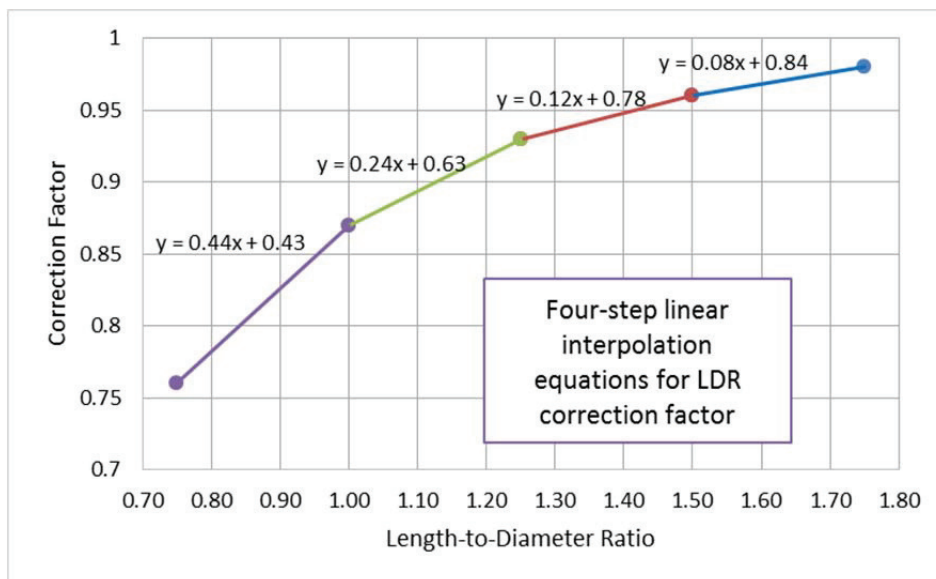


Figure 4.3: Length-to-diameter ratio (LDR) correction factor.

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.

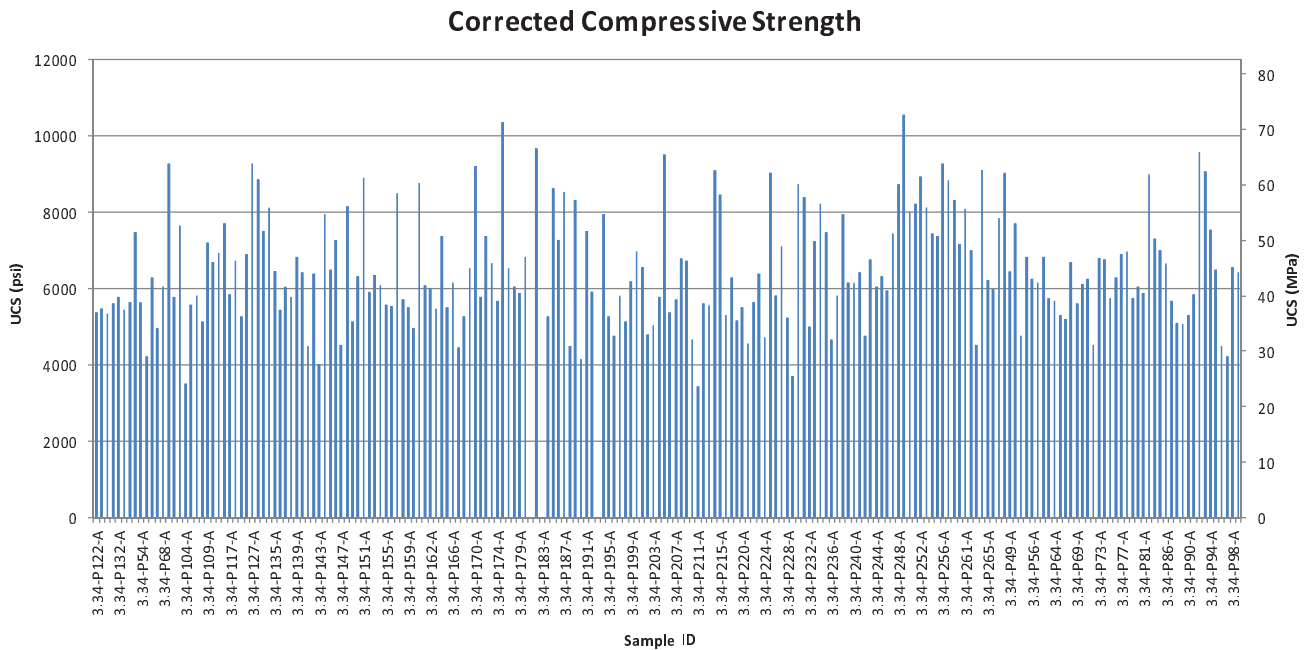


Figure 4.4: Corrected unconfined compressive strength of pavement cores, organized by core number.

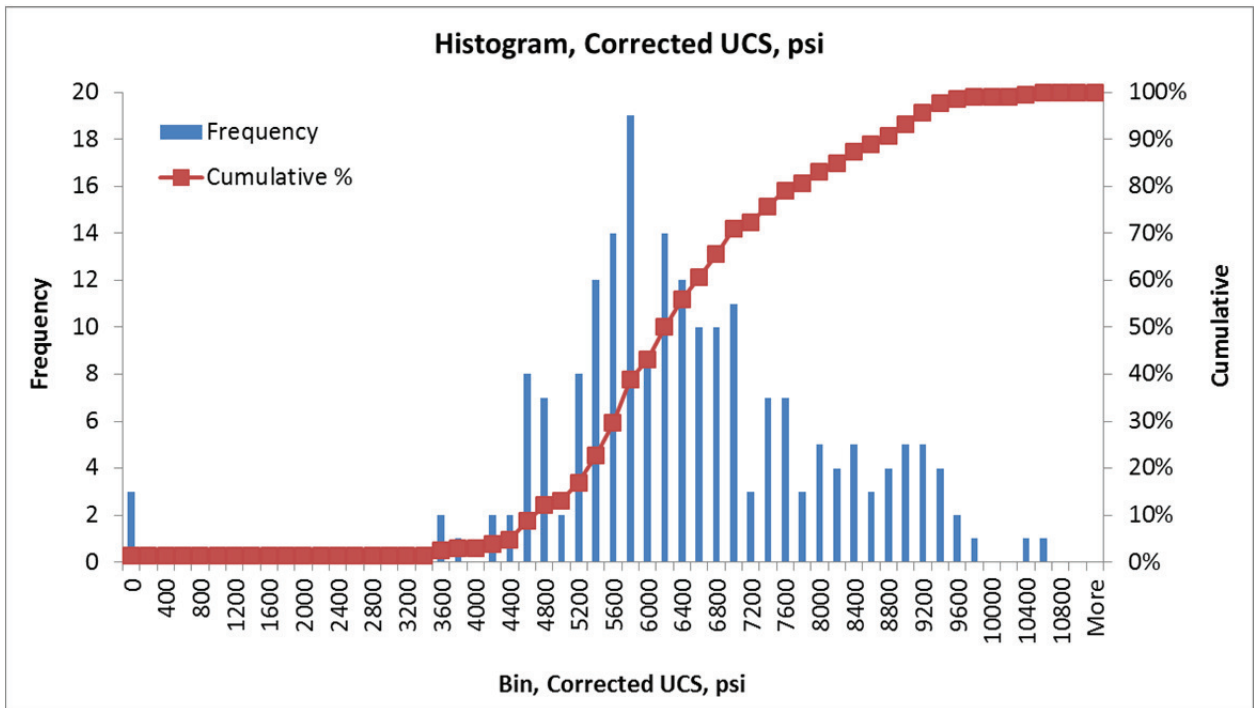
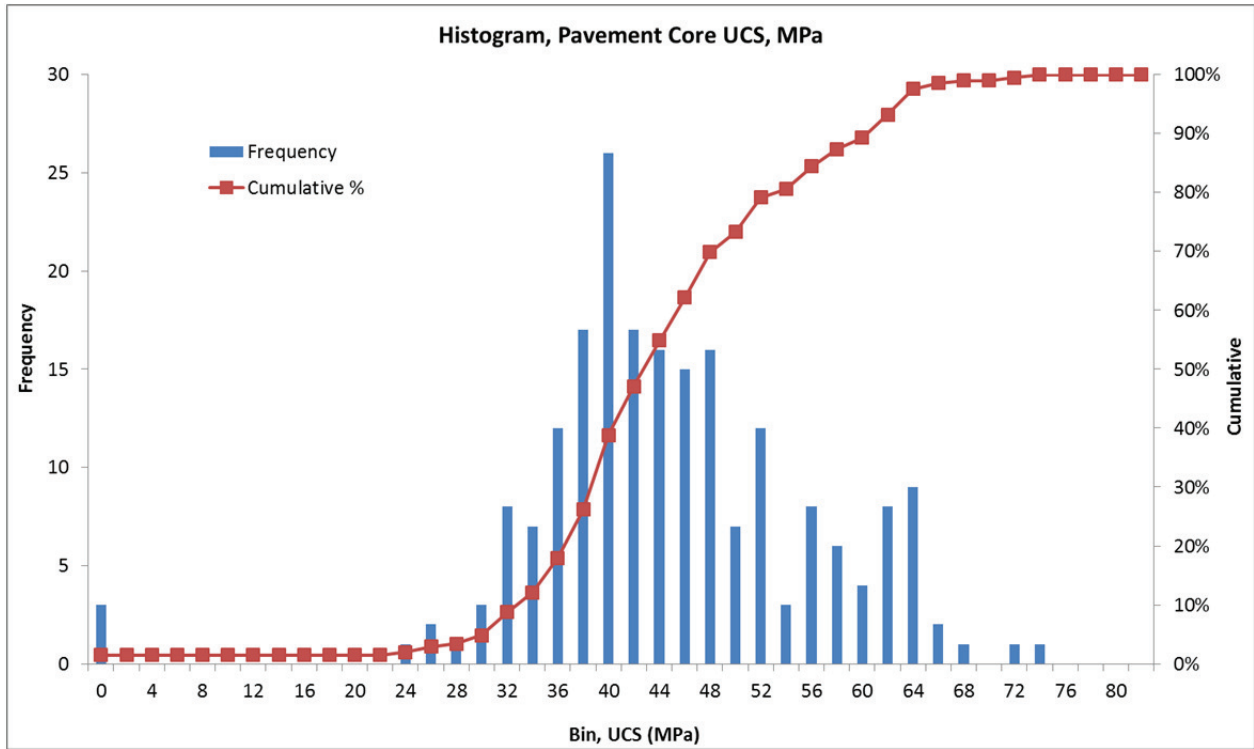


Figure 4.5: Corrected unconfined compressive strength of pavement cores, histogram chart (metric and US units).

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/m³) and the median UCS result was approximately 147 pcf (2,350 kg/m³). 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.

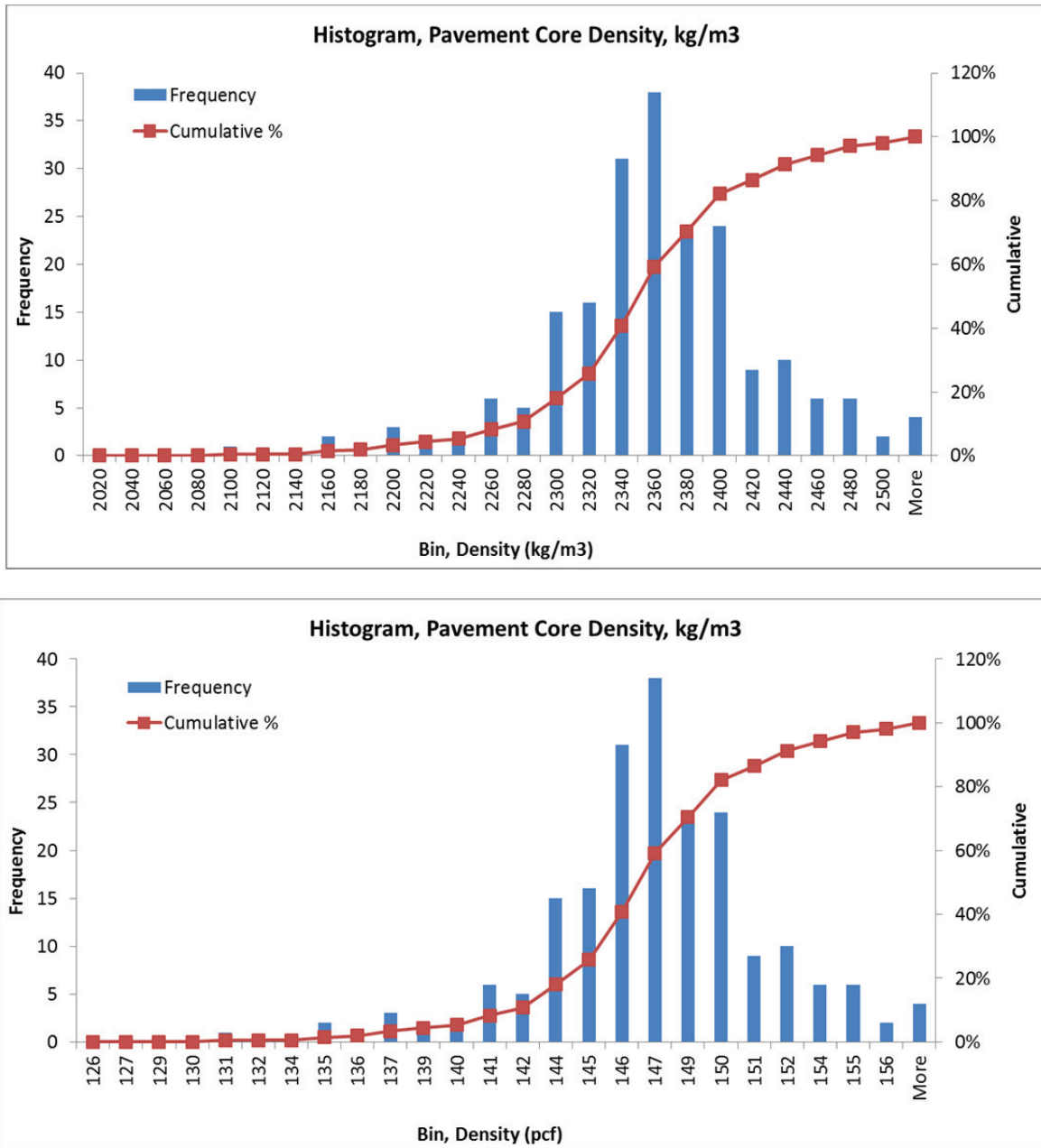


Figure 4.6: Density of pavement cores, histogram chart (metric and US units).

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.

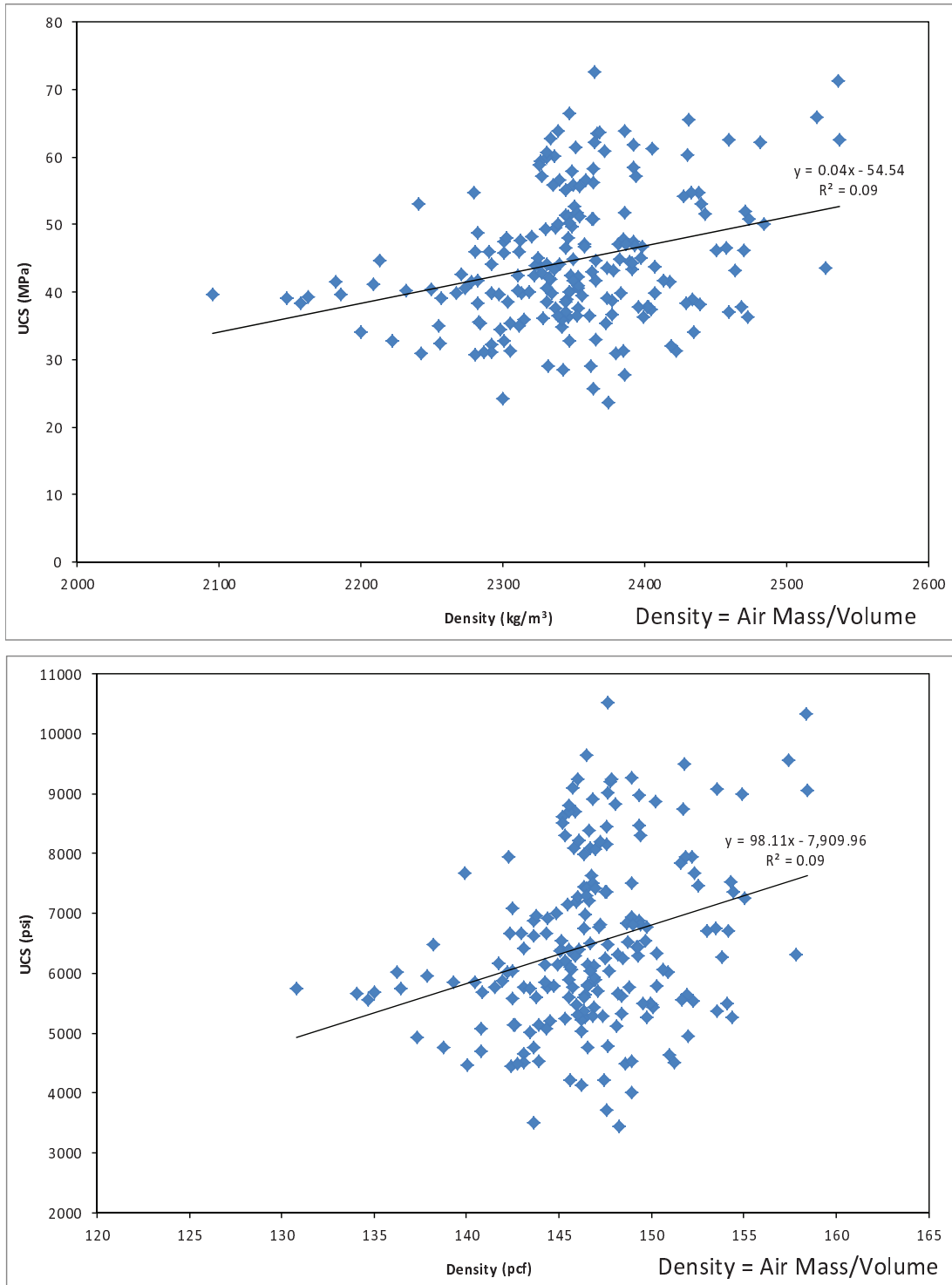


Figure 4.7: Strength versus density of pavement cores (metric and US units).

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/m³) and the median value was approximately 147 pcf (2,350 kg/m³). 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 (cm²)

Normalized Area (cm²)

Damage Rating Index (DRI)

Area Calculations

Length (in.)

Width (in.)

Area (in.²)

Area (cm²)

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	
0		399	

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*).

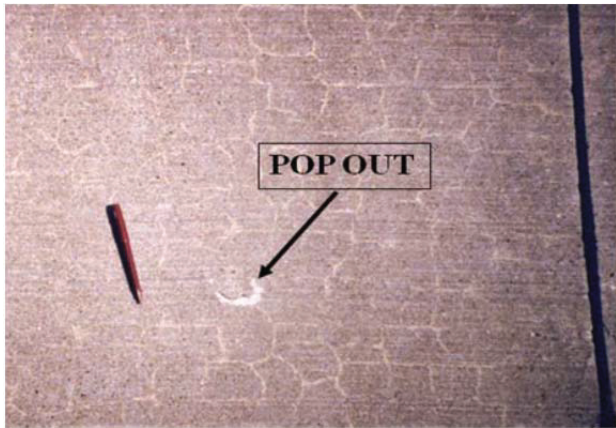


Figure A.2. Example photos showing some of the common petrographic features of ASR (cont'd).
(Some of the photos are from the reference: Thomas, M.D.A., B. Fournier, and K.J. Folliard. *Alkali-aggregate Reactivity (AAR) Facts Book*. No. FHWA-HIF-13-019. 2013.)