

**MICHIGAN DEPARTMENT OF TRANSPORTATION  
M•DOT**

**Investigation of Calcium Hydroxide Depletion as  
a Cause of Concrete Pavement Deterioration**

**R. W. Muethel**

**Research Laboratory Section  
Construction and Technology Division  
Research Project 94 B-0108  
Research Report No. R-1353**

**Michigan Transportation Commission  
Barton W. LaBelle, Chairman;  
Jack L. Gingrass, Vice-Chairman;  
Robert M. Andrews, Ted B. Wahby  
John C. Kennedy, Betty Jean Awrey  
James R. DeSana, Director  
Lansing, November 1997**

The information contained in this report was compiled exclusively for the use of the Michigan Department of Transportation. Recommendations contained herein are based upon the research data obtained and the expertise of the researchers, and are not necessarily to be construed as Department policy. No material contained herein is to be reproduced--wholly or in part--without the expressed permission of the Engineer of Construction and Technology.

## **PREFACE**

This investigation was conducted by the Michigan Department of Transportation Research Laboratory as a research project in the State Planning and Research program. The purpose of this project was to investigate the relationship of calcium hydroxide depletion to the deterioration of pavement concrete. Laboratory specimens and pavement core samples were analyzed using physical and chemical tests and procedures.

Principal Investigator for the project was Robert W. Muethel, staff geologist at the Michigan Department of Transportation Research Laboratory.

Scanning electron microscope analysis was conducted by Larry Sutter, instructor/petrographer at Michigan Technological University.

## TABLE OF CONTENTS

List of Figures .....	i
Executive Summary .....	1
Action Plan .....	3
Introduction .....	4
Samples .....	7
Laboratory Specimens .....	7
Pavement Cores .....	7
Tests and Procedures .....	8
Results of Examinations and Tests .....	9
Examination of Laboratory Specimens .....	9
Examination of Pavement Cores .....	9
Chloride Permeability Tests .....	11
Chemical Determination of Calcium Hydroxide Content .....	12
Scanning Electron Microscope Analysis .....	12
Conclusions .....	14
Recommendations for Existing Concrete .....	14
Recommendations for New Construction .....	14
References .....	16
Appendix A: Tests and Procedures .....	18
Appendix B: Pavement Core Locations .....	20
Appendix C: Pavement Core Examinations .....	23

## LIST OF FIGURES

Figure 1	Calcium carbonate deposits on underside of bridge deck . . . . .	6
Figure 2	Corroded reinforcing steel from zones of carbonated concrete at cracks and a joint . . . . .	7
Figure 3	Zones of carbonation along the face of an open pavement crack . . . . .	10
Figure 4	Deteriorated concrete at the base of an open, spalled pavement crack . . . . .	11
Figure 5	SEM micrograph of unleached concrete . . . . .	13
Figure 6	SEM micrograph of concrete after boiling to simulate leaching . . . . .	13

## EXECUTIVE SUMMARY

The purpose of this investigation was to determine, by chemical and physical testing, the significance of calcium hydroxide depletion as a contributor to the deterioration of concrete mortar in pavements.

The deterioration of concrete pavements at cracks and joints has been associated with freeze-thaw failure of the coarse aggregate, often referred to as D-cracking. However, in many cases concrete pavements containing coarse aggregate that is not recognized as being susceptible to D-cracking failure eventually develop the characteristic crack patterns commonly associated with D-cracking. Such distress may be the result of carbonation and the leaching of calcium hydroxide from the concrete by the action of carbonic acid and other acids that are often present in the pavement environment.

Calcium hydroxide depletion was investigated by examination and testing of laboratory-made concrete specimens and sets of concrete cores taken at pavement crack locations on three major state trunklines. Procedures included petrographic examination, phenolphthalein staining to identify zones of reduced pH, rapid chloride permeability tests, chemical tests to determine calcium hydroxide content, and examination of specimens by scanning electron microscope.

Petrographic examination of pavement cores, using the phenolphthalein staining procedure, revealed progressive deterioration related to the openness of the cracks. Little or no carbonation was noted at tight cracks. Considerable carbonation and leaching was noted at open cracks. Horizontal delaminations and deterioration of the concrete at the pavement base were noted at open, spalled cracks. Severe corrosion of reinforcing steel also was noted in the zones of reduced pH.

Rapid chloride permeability tests conducted on concrete specimens prepared to simulate a leached condition showed increased permeability due to the leaching process.

Chemical tests conducted on concrete removed from carbonated, leached zones along open cracks in the pavement cores showed greatly reduced calcium hydroxide content.

Scanning electron microscope examination of concrete that was boiled to simulate leaching revealed that the boiling process removed the very fine grained cementitious mortar constituents including calcium hydroxide from the surface of the concrete, resulting in a leached appearance, with exposures of isolated large calcium hydroxide crystals. Unboiled concrete examined by scanning electron microscope showed no evidence of leaching.

Calcium hydroxide depletion by carbonation and leaching appears to be strongly associated with deterioration of concrete at cracks. Weakening of the concrete due to loss of the calcium hydroxide material, and disruption of the concrete due to volume increase of the corroded reinforcing steel were shown to be significant contributors to concrete deterioration at cracks.

For existing concrete, restoration of the high alkalinity environment at pavement cracks should be investigated. Application of calcium hydroxide followed by sealing to prevent recurrent leaching should be considered as a part of the remediation and repair of distressed concrete.

For new construction, prevention of concrete deterioration associated with calcium hydroxide depletion may be accomplished by the use of alternate cement types and pozzolanic additives such as ground granulated blast furnace slag that combine with calcium hydroxide to form unleachable compounds. The use of corrosion-resistant reinforcement such as stainless steel, steel with copper cladding, or steel with epoxy coating should be considered. Investigation into the use of fiberglass or other polymeric reinforcement as an alternative to steel is also recommended.

## **ACTION PLAN**

1. Pavement Selection Review Committee (PSRC)
  - a. Submit report to PSRC for comment and review.
  - b. PSRC to provide acceptance or modification of report's recommendations.
    1. PSRC accepted the report as written without modification at their August 28, 1997, meeting.
2. Engineering Operations Committee
  - a. Accept report
  - b. Approve the development of a research proposal to investigate possible mitigation and prevention measures for the distress resulting from calcium hydroxide depletion in concrete pavement.



## INTRODUCTION

Much of the deterioration of portland cement concrete pavements has been attributed to the failure of the coarse aggregate when subjected to freezing and thawing, often referred to as D-cracking distress. However, many pavements containing coarse aggregates that are not considered to be susceptible to the D-cracking process develop staining and crescent-shaped crack patterns at transverse cracks and joints similar to those that are commonly attributed to D-cracking deterioration.

It has become increasingly evident that such deterioration of portland cement concrete can be due to other causes in addition to the freeze-thaw failure of the coarse aggregate. One particular cause of concrete distress is carbonation. Carbonation has been recognized for many years to be a commonly identified result of the attack of carbon dioxide upon exposed concrete surfaces. Although carbonation has been considered to be a cause of surface defects, it can also contribute to deeper distress in concrete at cracks and at joints due to the pH reduction that occurs when calcium hydroxide is replaced by calcium carbonate. Reduced pH can provide a corrosive environment for reinforcing steel, resulting in expansive cracking generated by the volume increase that occurs as steel converts to iron oxides.

Another cause of deterioration that can work in conjunction with carbonation is the continual long-term leaching of calcium hydroxide, an important constituent of concrete. Leaching is a process that is present in the pavement environment wherever moisture is present at open cracks, and may be a more significant cause of deterioration than D-cracking. The leaching process is exacerbated by the presence of carbonic acid and other acids that may be present in water that interacts with the concrete.

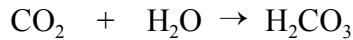
The leaching process is progressive, resulting in greater and greater permeability as calcium hydroxide is removed from the concrete at the crack surfaces. The increase in permeability makes the concrete more vulnerable to the process of freezing and thawing, and the loss of solid mass results in physical weakening of the concrete at the crack locations. Increased permeability allows moisture to access coarse aggregate particles that are susceptible to freeze-thaw deterioration, resulting in additional distress during periods of freezing and thawing.

A major type of deterioration of portland cement concrete pavements in Michigan is breakdown of the concrete at joints and cracks. Virtually all concrete pavements eventually develop such distress, regardless of the type of coarse aggregate. Advanced deterioration has been found at cracks and joints, whereas adjacent concrete appears to be in excellent condition. Such localization of distress suggests that much of the deterioration attributed to the breakdown of the coarse aggregate may be due to the deterioration of the concrete mortar. Breakdown of the concrete mortar requires the presence of agents that can react with constituents within the concrete to cause deterioration. One such agent that is abundantly present in Michigan's pavement environment is water. Water, by itself, is capable of dissolving leachable constituents from the concrete.

However, water in the pavement environment most often contains varying amounts of another agent, carbonic acid, that is being formed continually as a natural process by the reaction of atmospheric carbon dioxide and moisture, and as emissions from vehicles and other sources of combustion.

Carbonic acid forms according to the following formula:

Carbon Dioxide + Water → Carbonic Acid



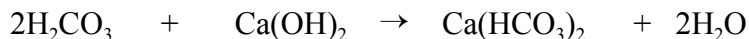
According to Terzaghi<sup>[1]</sup>, carbonic acid has been found to aggressively attack concrete in the high salinity environment of seawater, particularly at alkalinity conditions below pH 7. Water that permeates pavement cracks and joints can also be highly saline due to the presence of deicing salt residues, and would be expected to accelerate the leaching due to carbonic acid attack.

One of the most leachable and chemically reactive constituents in concrete is calcium hydroxide formed when calcium oxide in the cement combines with water during hydration. Kosmatka and Panarese<sup>[2]</sup> found that calcium hydroxide can comprise as much as 25 percent of the paste. Loss of this component due to leaching causes increased permeability and physical weakening of the concrete. According to Tremper<sup>[3]</sup>, a 16 percent loss of lime from portland cement concrete due to leaching resulted in a 20 percent loss of compressive strength.

The deterioration caused by leaching loss is progressive, advancing into the concrete from the surface of the cracks and joint faces. The concrete from which the calcium hydroxide has been removed is weakened and becomes increasingly more permeable as leaching proceeds.

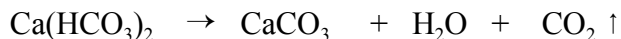
Reaction of carbonic acid with calcium hydroxide produces highly soluble calcium bicarbonate that forms as follows:

Carbonic Acid + Calcium Hydroxide → Calcium Bicarbonate + Water



The calcium bicarbonate solution then forms calcium carbonate and water after evaporation of carbon dioxide, as follows:

Calcium Bicarbonate → Calcium Carbonate + Water + Carbon Dioxide



Calcium bicarbonate leachate may form calcium carbonate deposits in relatively tight cracks if the leachate becomes trapped. Leachate from open cracks will migrate to form calcium carbonate deposits on surfaces exposed to atmospheric carbon dioxide.

Figure 1 shows an example of the deterioration of portland cement of a structure caused by the leaching of calcium hydroxide from the deck concrete. The calcium hydroxide leachate has migrated through cracks to form calcium carbonate deposits on the underside of the bridge deck.



Figure 1 . Calcium carbonate deposits on underside of bridge deck.

Such deposits, similar to calcite dripstone deposits in caves, also are common at cracks on concrete bridge piers, railings, and barrier walls. Similar deposits are found in pavement subbase material beneath cracks, as incrustations on drainage discharge pipes, and on geotextile filter fabrics in pavement drainage systems.

Reinforcing steel in portland cement concrete is considered to be protected from corrosion by the high alkalinity attributed to calcium hydroxide. However, according to Lea [4], if loss of calcium hydroxide causes alkalinity to drop below pH 10, corrosion of steel can occur. Severe corrosion of steel has been observed within very localized zones at cracks.

Figure 2 shows an example of severely corroded welded wire reinforcing steel obtained at one of the open cracks on the I-69 roadway and an example of corroded longitudinal reinforcing steel removed from a repair site on the I-196 roadway (see Appendix B/C). The figure also includes a deeply corroded load transfer dowel bar from a reconstruction site on US 23 in Monroe County as an example of the severity of corrosion that can occur at pavement joints.

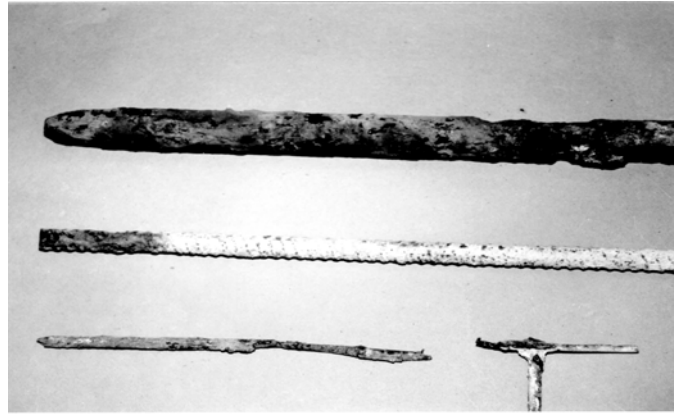


Figure 2. Corroded reinforcing steel and dowel bar from zones of carbonated concrete at cracks and at a joint.

Corroding steel undergoes a considerable volume increase as the iron converts from a metallic form to an oxide. The volume increase can readily cause disruption of the adjacent concrete that has already been weakened by loss of calcium hydroxide.

Failure of the steel at cracks and joints also contributes to loss of load transfer, resulting in pumping and faulting of the pavement slab by large, heavy vehicles, causing further deterioration due to displacement of the supporting base material beneath the pavement.

## SAMPLES

### Laboratory Specimens

A set of six 150 mm by 300 mm concrete cylinders were prepared using a conventional MDOT Grade 35P mix design typical of concrete used in pavements. The concrete contained natural gravel 6AA coarse aggregate with 25mm as the largest size. The cylinders were cured for 28 days before testing. After curing, the cylinders were sliced into 50 mm specimens for rapid chloride permeability testing.

### Pavement Cores

Pavements that have been in service for at least 10 years, and showing staining, cracking, and spalling were selected for examination of the condition of the concrete. Sets of cores were obtained from crack locations on three major state trunklines, as follows:

1. I-96 Westbound Traffic Lane, East of M66, Ionia Co.  
(Jointed Pavement With Welded Wire Reinforcement)
2. I-69 Southbound Passing Lane, Olivet vic., Eaton Co.  
(Jointed Pavement With Welded Wire Reinforcement)
3. I-196 Eastbound Traffic Lane, Hudsonville vic., Ottawa Co.  
(Unjointed, Continually Reinforced Pavement)

The cores were obtained to determine the amount of calcium hydroxide content in the concrete at cracks versus the amount of calcium hydroxide in the concrete away from cracks.

For the investigation, cracks were rated as tight, with no evidence of surface deterioration, and open, with discoloration or spalling present on the pavement surface. A standard sampling plan was set up to obtain three cores at each selected crack location -- a core through the crack, a core approximately 150 mm from the crack, and a core approximately 900 mm from the crack to monitor the degree of lateral deterioration due to the leaching process.

From examination of the set of cores obtained from the I-96 test pavement, it became apparent that the open cracks were strongly associated with the leaching process. Subsequent samplings from the remaining test pavements included predominantly open cracks. A total of 36 cores were obtained for this project. Appendix B contains a detailed list of the core locations.

## **TESTS AND PROCEDURES**

The calcium hydroxide leaching process was investigated using both physical and chemical test methods and procedures, including visual examination and tests for permeability and content of calcium hydroxide in concrete.

Microscopical examination was conducted to determine the visual condition of the laboratory-prepared concrete specimens and core specimens taken from in-service pavements.

A staining procedure using phenolphthalein was used to identify carbonated concrete in the laboratory-prepared specimens and the pavement core specimens, based upon alkalinity. According to the procedure, concrete with alkalinity greater than pH 9.5 acquires a purple stain when treated with phenolphthalein, whereas concrete with alkalinity below pH 9.5 does not become stained. Concrete that does not become stained is considered to be either carbonated or depleted of calcium hydroxide.

The ASTM C642 procedure, "Standard Test Method for Specific Gravity, Absorption and Voids in Hardened Concrete," contains a process of boiling the specimens to determine the permeable voids. The boiling process was used to simulate the effects of long-term leaching in the pavement

environment. Laboratory-prepared concrete cylinders were prepared for comparative rapid chloride permeability tests of boiled versus unboiled specimens.

The AASHTO T277 procedure, "Standard Method of Test for Rapid Determination of the Chloride Permeability of Concrete, was conducted to measure the comparative permeability of the boiled versus unboiled specimens prepared in the laboratory, as indicated by the coulombs of electricity passed during a six hour period.

The ASTM C25 procedure, "Standard Test Methods for Chemical Analysis of Limestone, Quicklime, and Hydrated Lime," contains a rapid sugar test to determine the available lime index. The available lime index test was conducted to measure the comparative calcium hydroxide content of the leached versus unleached specimens obtained from pavement cores.

Examination by scanning electron microscope (SEM) was conducted to compare the calcium hydroxide content of boiled versus unboiled concrete specimens prepared in the laboratory.

The tests and procedures used for this investigation are listed in Appendix A.

## **RESULTS OF EXAMINATIONS AND LABORATORY TESTS**

### Examination of Laboratory Specimens

The laboratory specimens were examined microscopically before slicing to check for visible cracking that would cause anomalous results in the rapid chloride permeability tests. Portions of the boiled specimens that were prepared to simulate leached concrete were treated with phenolphthalein and then examined for visual evidence of leaching.

The unleached concrete was noted to become stained purple after treatment with phenolphthalein, indicating alkalinity with pH greater than 9.5. The leached concrete did not become stained after treatment with phenolphthalein, indicating that the alkalinity had become reduced to below pH 9.5. The interior of the leached concrete, however, was noted to acquire a purple stain, indicating that the effect of the boiling was most severe on the exposed surface, similar to the actual leaching environment at pavement cracks.

### Examination of Pavement Cores

The pavement cores were examined after treatment with phenolphthalein to detect zones of lowered alkalinity. After treatment with phenolphthalein, the top surfaces of all cores remained unstained, indicating carbonation. Microscopical examination revealed the presence of calcium carbonate on the surfaces. The carbonation was noted to extend to a shallow depth, less than two mm, as measured on the core sides. As with the top surfaces, the core bottoms remained unstained after treatment with

phenolphthalein. Microscopical examination of the concrete on the core bottoms revealed the presence of calcium carbonate deposits.

Cores with relatively tight cracks acquired a purple stain along the crack face when treated with phenolphthalein, indicating no evidence of leaching. The concrete at the base showed no evidence of deterioration.

Cores through cracks that evidence of leaching along with phenolphthalein, as shown in Figure 3. zones was noted to be corrosive environment pH due to the removal of leaching. Delaminations in at such cracks, indicating deterioration had occurred.



were more open showed the crack face when treated apparent as unstained zones, Reinforcing steel in such rusted, indicating a associated with the lowered calcium hydroxide by the concrete were also noted that increased freeze-thaw

Figure 3. Zones of carbonation along the face of an open pavement crack.

Cores obtained through deterioration of the pavement, as shown in spalls had been repaired with hot-pour crack sealers.



spalled cracks showed severe concrete at the base of the Figure 4. In most cases, the with bituminous cold patch or

Figure 4. Deteriorated concrete at the base of an open, spalled pavement crack.

The reinforcing steel at such locations was often rusted through, resulting in loss of load transfer. The crack faces often displayed an abraded appearance due to the loss of mortar by leaching and scouring as water moved through the crack.

Because of the considerable amount of crack sealer material present on the surfaces of the spalled cracks, the phenolphthalein stain process could not be used.



The original work plan for the investigation called for sectioning of the cores to determine the comparative amounts of calcium hydroxide at various levels in the pavement. After examination of the cores using the phenolphthalein staining test procedure, it became evident that the leaching process was occurring at the crack faces, progressing inwardly. Based upon that finding, the sampling of the concrete for chemical analysis for calcium hydroxide content was changed. To obtain a sampling of the leached concrete, the unstained zones of concrete along the crack faces were carefully removed from the cores by selective chipping. A sampling of unleached concrete also was prepared from concrete that stained purple. Detailed descriptions of the pavement core examinations are included in Appendix C.

### Chloride Permeability Tests

Four cylinder slices prepared by saturation with boiling to simulate leached concrete, and four cylinder slices prepared without boiling, were tested for comparative permeability by the AASHTO T227 Rapid Chloride Permeability Test. The sets of specimens were placed in test cells and subjected to an electrical current of 60 volts d.c. for six hours to determine the electrical charge passed, measured in coulombs.

The set of simulated leached specimens recorded a higher average permeability than the set of unleached specimens, as follows:

<u>Specimen Type</u>	<u>Permeability, as Coulombs Passed</u>
Boiled Concrete	5806
Unboiled Concrete	4888

Guidelines issued with the AASHTO T277 test procedure indicate that the coulomb values for both the boiled and unboiled concrete specimens are both in the >4000 coulomb category considered to show high chloride permeability. The relatively high chloride permeability of the unboiled concrete was found to be typical of conventional Michigan pavement and bridge deck concrete.

According to Hodgman [5], calcium hydroxide is most soluble at a temperature just above freezing, becoming less soluble as temperature increases. Leaching of calcium hydroxide in the pavement environment would be expected to be greater than that demonstrated by the boiled laboratory specimens, with the most severe leaching occurring during periods of precipitation combined with cold temperatures.

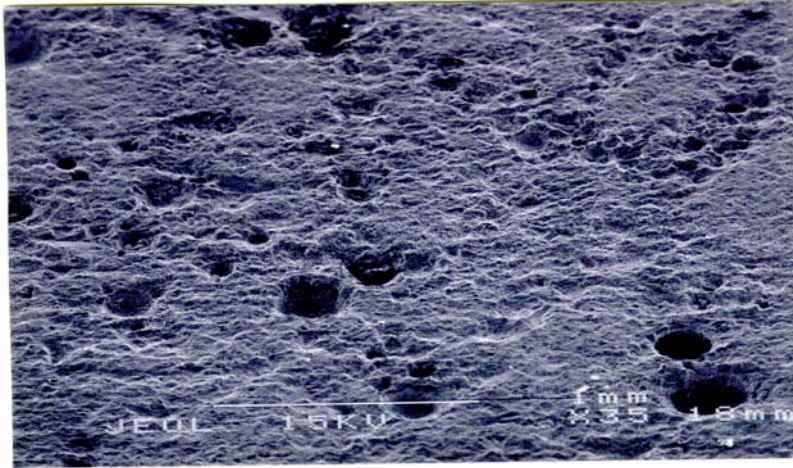
### Chemical Determination of Calcium Hydroxide Content

The chemical determinations of calcium hydroxide content using the ASTM C25 sucrose test procedure indicated that the concrete from carbonated zones at cracks contained considerably less calcium hydroxide than noncarbonated concrete, as follows:

<u>Specimen Type</u>	<u>Calcium Hydroxide, percent</u>
----------------------	-----------------------------------

Carbonated Concrete	1.5
Noncarbonated Concrete	8.3

The calcium of the concrete was considerably maximum percent common in concrete. For concrete, leaching would reduce the pH associated with The results of indicated that phenolphthalein



hydroxide content noncarbonated noted to be less than the amount of 25 considered to be portland cement this particular considerably less be necessary to to a level that is corrosion of steel. the sucrose test the staining

procedure correctly indicated the leached and unleached zones.

#### Examination by Scanning Electron Microscope

Specimens of unleached concrete and simulated leached concrete, prepared by the boiling procedure included in the ASTM C642 test method were submitted to the Michigan Technological University laboratory for examination by scanning electron microscope.

Examination of the unleached specimen revealed no evident loss of material from the surface, with no mortar constituents exposed. The SEM micrograph in Figure 5. shows the unleached surface of the specimen, with numerous air void exposures.

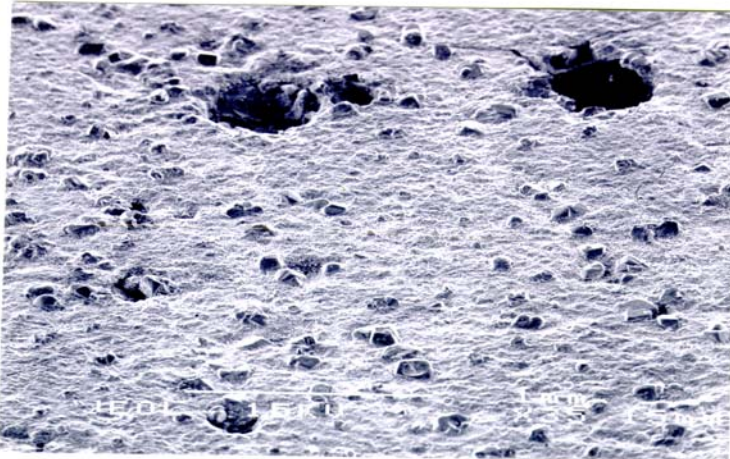
Figure 5. SEM micrograph of unboiled concrete.

Examination of the boiled specimen revealed that the very fine grained calcium hydroxide, more readily dissolved due to small size, had been removed during the boiling process, leaving large isolated crystals of calcium hydroxide exposed.

The SEM micrograph in Figure 6. shows the relict large calcium hydroxide crystals remaining on the surface of the specimen after the boiling procedure. Also shown in the micrograph are several entrained air void exposures.

Figure 6. SEM micrograph of concrete after boiling to simulate leaching.

The results of the SEM examinations indicates that some, but not all, of the calcium hydroxide was removed during the boiling process. This is consistent with the reduction in solubility of calcium hydroxide at higher temperatures discussed earlier.



the boiling process. with the reduction in calcium hydroxide temperatures

### CONCLUSION

The examinations on the laboratory-specimens and taken from in-service pavements showed that calcium hydroxide can cause

S

and tests conducted prepared concrete core specimens leaching at cracks considerable loss of

from the mortar, resulting in increased permeability of the concrete.

The loss of calcium hydroxide from the concrete at cracks appears to be a significant contributor to the disintegration of concrete at cracks. The increase in voids resulting from loss of calcium hydroxide due to the leaching process would be expected to result in both reduced strength and increased permeability of the mortar at cracks.

Reduced alkalinity due to carbonation or removal of calcium hydroxide by leaching was noted to be associated with severe rusting of the reinforcing steel at cracks. The reinforcing steel in all of the cores obtained through open cracks was noted to be rusted through due to corrosion in the zones of lowered pH. The volume increase of the rusted reinforcing steel appears to be a significant contributor to the disintegration of concrete.

### **RECOMMENDATIONS FOR EXISTING CONCRETE**

For existing concrete, the sealing of cracks before extended leaching occurs would be expected to deter the loss of calcium hydroxide and other leachable constituents of the concrete. Also, improved drainage to prevent accumulation of water in the concrete at cracks would be expected to reduce the leaching process.

Restoration of the high alkalinity environment at pavement cracks would be expected to deter the corrosion of reinforcing steel. The development of an application process to restore calcium hydroxide to concrete at cracks, followed by sealing to prevent recurrent leaching, should be investigated as a part of the remediation and repair of existing concrete.

### **RECOMMENDATIONS FOR NEW CONSTRUCTION**

For new construction, the loss of mass due to leaching of calcium hydroxide could be greatly reduced by use of concrete mixtures that do not contain substantial amounts of calcium hydroxide. Such mixtures would require the use of alternate cement types and pozzolanic components such as ground granulated blast furnace slag that would combine with the calcium hydroxide to form unleachable compounds and concrete with lower permeability. The development of such concrete mix designs should be pursued.

The use of noncorroding reinforcement, such as stainless steel, copper-clad steel, or epoxy-coated steel should be investigated to eliminate the expansive distress caused by rusting of the reinforcing steel at cracks. Investigation into the use of fiberglass or other polymeric reinforcement materials is also recommended.

## REFERENCES

1. R. D. Terzaghi, Proceedings, *American Concrete Institute*, 44, 977 (1948).
2. S. H. Kosmatka and W. C. Panarese, *Design and Control of Concrete Mixtures*, Thirteenth Edition, Third Printing (rev.) 1992, p 20.
3. B. Tremper, *Proceedings, American Concrete, Institute*, 28, 1 (1932).
4. F. M. Lea, *The Chemistry of Cement and Concrete*, Third Edition, Chemical Publishing Company, Inc., New York, N. Y., 1970, p 553.
5. C. D. Hodgman, *Handbook of Chemistry and Physics*, Chemical Rubber Publishing Co., Cleveland, Ohio

## **APPENDIX A**

## **Tests and Procedures**

Standard Practice for Petrographic Examination of Hardened Concrete. ASTM Designation: C 856 - 83 (Reapproved 1988)

Phenolphthalein Staining Procedure. The Chemistry of Cement and Concrete. Third Edition, 1971 p 543

Standard Test Method for Specific Gravity, Absorption, and Voids in Hardened Concrete. ASTM Designation C 642 - 90

Standard Method of Test for Rapid Determination of the Chloride Permeability of Concrete. AASHTO Designation: T 277-83

Standard Test Methods for Chemical Analysis of Limestone, Quicklime, and Hydrated Lime. ASTM Designation: C 25 - 93a

## **APPENDIX B**



### Pavement Core Locations

1. I-96 Westbound Traffic Lane, East of M66, Ionia Co.  
Cores were obtained approximately 1.7 meters from the outside edge of the pavement.

<u>Core No.</u>	<u>Station + m</u>	<u>Crack Type</u>
1A	920+27.4	Open
1B	920+27.6	
1C	920+27.7	
1D	920+28.3	
2A	921+ 7.6	Open
2B	921+ 7.8	
2C	921+ 7.9	
2D	921+ 8.5	
3A	922+ 0.0	Open
3B	922+ 0.2	
3C	922+ 0.3	
3D	922+ 0.9	

2. I-69 Southbound Passing Lane, Olivet vic., Eaton Co.  
Cores were obtained approximately 0.2 to 0.5 meters from the outside edge of the pavement.

<u>Core No.</u>	<u>Station + m</u>	<u>Crack Type</u>
1A	2846+ 4.6	Tight
1B	2846+ 4.4	
1C	2846+ 4.3	
1D	2846+ 3.7	
2A	2838+19.2	Open
2B	2838+19.1	
2C	2838+18.9	
2D	2838+18.3	
3A	2838+12.8	Open
3B	2838+12.6	
3C	2838+12.5	
3D	2838+11.9	
4A	2837+20.3	Open

3. I-196 Eastbound Traffic Lane, Hudsonville vic., Ottawa Co.  
Cores were obtained approximately 0.2 meters from the outside edge of the pavement.

<u>Core No.</u>	<u>Station + m</u>	<u>Crack Type</u>
1	1114+ 1.2	Tight
2	1114+ 0.6	
NA	1114+ 0.8	
3	1113+30.3	
4	1114+10.7	Open
5	1114+10.5	
6	1114+10.4	
7	1114+ 9.6	
8	1116+ 6.4	Open
9	1116+ 6.2	
10	1116+ 5.9	
11	1116+ 5.5	

## **APPENDIX C**

## Pavement Core Examinations

1. I-96 Westbound Traffic Lane, East of M-66, Ionia Co.  
Cores were obtained approximately 1.7 meters from the outside edge of the pavement.

### Sample

Identification: Core No. 1A  
Dimensions: Diameter = 100 mm, Length = 250 mm.  
Top Surface: Tined  
Bottom Surface: Gravel base material attached.  
Cracks: Roughly vertical, open, full-depth crack parallel to surface tining.  
Reinforcement: Welded wire steel at 75 mm depth.

#### Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

#### Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 1 mm.  
Carbonation along crack face extends from 1 mm to 5 mm into paste.  
Core bottom is partly carbonated.

### Sample

Identification: Core No. 1B  
Dimensions: Diameter = 100 mm, Length = 245 mm.  
Top Surface: Tined. Small spalled area.  
Bottom Surface: Gravel base material attached.  
Cracks: None  
Reinforcement: Welded wire steel at 75 mm depth.

#### Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand

#### Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Core bottom is partly carbonated.

Sample

Identification: Core No. 1C  
Dimensions: Diameter = 100 mm, Length = 245 mm.  
Top Surface: Tined  
Bottom Surface: Gravel base material attached.  
Cracks: None  
Reinforcement: Welded wire steel at 75 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 1 mm.  
Core bottom is partly carbonated.

Sample

Identification: Core No. 1D  
Dimensions: Diameter = 100 mm, Length = 245 mm.  
Top Surface: Tined  
Bottom Surface: Gravel base material attached.  
Cracks: None  
Reinforcement: Welded wire steel at 75 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 1 mm.  
Core bottom is partly carbonated.

### Sample

Identification: Core No. 2A  
Dimensions: Diameter = 100 mm, Length = 245 mm.  
Top Surface: Tined  
Bottom Surface: Gravel base material attached.  
Cracks: Roughly vertical, open, full-depth crack parallel to surface tining.  
Core broke at delamination crack at depth of steel.  
Reinforcement: Welded wire steel, rusted, at 100 mm depth.

#### Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand

#### Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 1 mm.  
Carbonation along crack face extends from 1 mm to 3 mm into paste.  
Core bottom is carbonated.

### Sample

Identification: Core No. 2B  
Dimensions: Diameter = 100 mm, Length = 250 mm.  
Top Surface: Tined  
Bottom Surface: Gravel base material attached.  
Cracks: None  
Reinforcement: Welded wire steel at 100 mm depth.

#### Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand

#### Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 1 mm. Core bottom is carbonated.

Sample

Identification: Core No. 2C  
Dimensions: Diameter = 100 mm, Length = 245 mm.  
Top Surface: Tined  
Bottom Surface: Gravel base material attached.  
Cracks: None  
Reinforcement: Welded wire steel at 100 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 1 mm.  
Core bottom is predominantly carbonated.

Sample

Identification: Core No. 2D  
Dimensions: Diameter = 100 mm, Length = 245 mm.  
Top Surface: Tined  
Bottom Surface: Gravel base material attached.  
Cracks: None  
Reinforcement: Welded wire steel at 100 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 1 mm.  
Core bottom is not carbonated.

Sample

Identification: Core No. 3A  
Dimensions: Diameter = 100 mm, Length = 250 mm.  
Top Surface: Tined  
Bottom Surface: Gravel base material attached.  
Cracks: Roughly vertical, open, full-depth crack parallel to surface tining.  
Reinforcement: Welded wire steel at 90 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Crack is filled with calcium carbonate deposit. Core bottom is partly carbonated.

Sample

Identification: Core No. 3B  
Dimensions: Diameter = 100 mm, Length = 245 mm.  
Top Surface: Tined.  
Bottom Surface: Gravel base material attached.  
Cracks: None.  
Reinforcement: Welded wire steel at 90 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Core bottom is partly carbonated.

Sample

Identification: Core No. 3C  
Dimensions: Diameter = 100 mm, Length = 245 mm.  
Top Surface: Tined.  
Bottom Surface: Gravel base material attached.  
Cracks: None.  
Reinforcement: Welded wire steel at 90 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.



Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 1 mm.  
Core bottom is predominantly carbonated.

Sample

Identification: Core No. 3D  
Dimensions: Diameter = 100 mm, Length = 250 mm.  
Top Surface: Tined.  
Bottom Surface: Gravel base material attached.  
Cracks: None.  
Reinforcement: Welded wire steel at 90 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 1 mm.  
Core bottom is predominantly carbonated.

2. I-69 Southbound Passing Lane, Olivet vic., Eaton Co.  
Cores were obtained approximately 0.2 to 0.5 meters from the outside edge of the pavement.

Sample

Identification: Core No. 1A  
Dimensions: Diameter = 100 mm, Length = 230 mm.  
Top Surface: Untextured.  
Bottom Surface: Sand base material attached.  
Cracks: Roughly vertical, tight, transverse crack extends to depth of 175 mm  
Reinforcement: Welded wire steel at 90 mm depth, rusted through.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Crack is carbonated to depth of 50 mm. Core bottom is carbonated.

Sample

Identification: Core No. 1B  
Dimensions: Diameter = 100 mm, Length = 230 mm.  
Top Surface: Untextured.  
Bottom Surface: Sand base material attached.  
Cracks: None.  
Reinforcement: Welded wire steel at 80 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Crack is carbonated to depth of 50 mm. Core bottom is carbonated.

Sample

Identification: Core No. 1C  
Dimensions: Diameter = 100 mm, Length = 230 mm.  
Top Surface: Untextured.  
Bottom Surface: Sand base material attached.  
Cracks: None.  
Reinforcement: Welded wire steel at 90 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Crack is carbonated to depth of 50 mm. Core bottom is carbonated.

Sample

Identification: Core No. 1D  
Dimensions: Diameter = 100 mm, Length = 230 mm.  
Top Surface: Untextured.  
Bottom Surface: Sand base material attached.  
Cracks: None.  
Reinforcement: Welded wire steel at 90 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Crack is carbonated to depth of 50 mm. Core bottom is carbonated.

Sample

Identification: Core No. 2A  
Dimensions: Diameter = 100 mm, Length = 230 mm.  
Top Surface: Untextured.  
Bottom Surface: Sand base material attached.  
Cracks: Roughly vertical, open, transverse crack extends full-depth. Black bituminous sealer attached to depth of 25 mm. Crack face appears scoured.  
Reinforcement: Welded wire steel at 90 mm depth, rusted through.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 1 mm.  
Carbonation along crack face extends up to 15 mm into paste, increasing at core bottom.

Sample

Identification: Core No. 2B  
Dimensions: Diameter = 100 mm, Length = 230 mm.  
Top Surface: Untextured.  
Bottom Surface: Sand base material attached.  
Cracks: None.  
Reinforcement: No steel present.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Core bottom is carbonated.

Sample

Identification: Core No. 2C  
Dimensions: Diameter = 100 mm, Length = 230 mm.  
Top Surface: Untextured.  
Bottom Surface: Sand base material attached.  
Cracks: No cracks.  
Reinforcement: Welded wire steel at 95 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Core bottom is carbonated.

Sample

Identification: Core No. 2D  
Dimensions: Diameter = 100 mm, Length = 230 mm.  
Top Surface: Untextured.  
Bottom Surface: Sand base material attached.  
Cracks: None.  
Reinforcement: Welded wire steel at 100 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Core bottom is carbonated.

Sample

Identification: Core No. 3A  
Dimensions: Diameter = 100 mm, Length = 220 mm.  
Top Surface: Untextured, coated with black, bituminous sealer used to fill crack.  
Bottom Surface: Concrete rubble.  
Cracks: Roughly vertical, open, transverse crack extending full-depth, filled with black bituminous sealer to depth of 115 mm. Crack face appears scoured. Horizontal delamination crack at 95 mm depth.  
Reinforcement: Welded wire steel at 95 mm depth, rusted through.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 1 mm.  
Shallow carbonation extends along crack face.

Sample

Identification: Core No. 3B  
Dimensions: Diameter = 100 mm, Length = 250 mm.  
Top Surface: Untextured, partly coated with black bituminous sealer.  
Bottom Surface: Sand base material attached.  
Cracks: Horizontal delamination cracks at 175 mm and 200 mm.  
Reinforcement: Welded wire steel at 100 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Core bottom is carbonated.

Sample

Identification: Core No. 3C  
Dimensions: Diameter = 100 mm, Length = 250 mm.  
Top Surface: Untextured.  
Bottom Surface: Sand base material attached.  
Cracks: None.  
Reinforcement: Welded wire steel at 95 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm. 100 mm  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Core bottom is carbonated.

Sample

Identification: Core No. 3D  
Dimensions: Diameter = 100 mm, Length = 250 mm.  
Top Surface: Untextured.  
Bottom Surface: Sand base material attached.  
Cracks: None.  
Reinforcement: Welded wire steel at 95 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 2 mm.  
Core bottom is carbonated.

Sample

Identification: Core No. 4A  
Dimensions: Diameter = 100 mm, Length = 225mm.  
Top Surface: Untextured.  
Bottom Surface: Concrete rubble.  
Cracks: Roughly vertical, open, transverse crack extending full-depth. Black bituminous sealer attached to crack face to depth of 19 mm. Delamination cracks at 200 and 224 mm depths.  
Reinforcement: Welded wire steel at 95 mm depth, rusted through.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Gray  
Carbonation: Surface of core is carbonated to approximate depth of 1 mm. Carbonation along crack face is variable, extending to 10 mm into paste near surface. Core bottom is carbonated.

3. I-196 Eastbound Traffic Lane, Hudsonville vic., Ottawa Co.  
Cores were obtained approximately 0.2 meter from the outside edge of the pavement.

Sample

Identification: Core No. 1  
Dimensions: Diameter = 150 mm, Length = 230 mm.  
Top Surface: Untextured. Gray stain.  
Bottom Surface: Gravel base material attached.  
Cracks: Tight transverse crack extends full-depth.  
Reinforcement: Deformed longitudinal steel bar, approximate. 15 mm dia. at 100 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Tan to 175 mm depth, then Gray  
Carbonation: Surface of core is carbonated. Tan paste noted to be less intensely stained by phenolphthalein than gray paste. Core bottom is carbonated.

Sample

Identification: Core No. 2

Dimensions: Diameter = 150 mm, Length = 230 mm.  
Top Surface: Untextured. Gray stain.  
Bottom Surface: Gravel base material attached.  
Cracks: None.  
Reinforcement: Deformed longitudinal steel bars, approximate 150 mm dia. at 90 mm to 115 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Tan to 175 mm depth, then Gray  
Carbonation: Surface of core is carbonated. Tan paste noted to be less intensely stained by phenolphthalein than gray paste. Core bottom is carbonated.

Sample

Identification: Core No. 3  
Dimensions: Diameter = 150 mm, Length = 225 mm.  
Top Surface: Untextured. Gray stain.  
Bottom Surface: Gravel base material attached.  
Cracks: Horizontal delamination crack at top of steel.  
Reinforcement: Deformed longitudinal steel bar, approximate. 15 mm dia at 80 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 mm to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Tan to 175 mm depth, then Gray  
Carbonation: Surface of core is carbonated. Tan paste noted to be less intensely stained by phenolphthalein than gray paste. Core bottom is carbonated.



Sample

Identification: Core No. 4  
Dimensions: Diameter = 150 mm, Depth = 230 mm.  
Top Surface: Untextured. Gray stain.  
Bottom Surface: Gravel base material attached.  
Cracks: Open full-depth crack and horizontal crack at steel. Crack face appears scoured, with coarse aggregate exposed in high relief. Concrete above delamination has many faint horizontal cracks.  
Reinforcement: Deformed longitudinal steel bar, approximate. 15 mm dia. at 90 mm depth, partly rusted.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm. Many carbonates below delamination show extensive freeze-thaw cracks with secondary calcium carbonate deposits.  
Fine Aggregate: Natural Sand.

Paste:

Color: Tan to 175 mm depth, then Gray  
Carbonation: Surface of core is carbonated. Paste on vertical crack is variably carbonated. Paste on delamination crack surface is carbonated. Tan paste is noted to be less intensely stained by phenolphthalein than gray paste. Core bottom is carbonated.

Sample

Identification: Core No. 5  
Dimensions: Diameter = 150 mm, Length = 230 mm.  
Top Surface: Untextured. Gray stain.  
Bottom Surface: Gravel base material attached.  
Cracks: None.  
Reinforcement: Deformed longitudinal steel bar, approximate. 15 mm dia. at 90 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Tan to 175 mm depth, then Gray  
Carbonation: Not determined. Core was saved as untreated specimen.

Sample

Identification: Core No. 6  
Dimensions: Diameter = 150 mm, Length = 230 mm.  
Top Surface: Untextured. Gray stain.  
Bottom Surface: Gravel base material attached.  
Cracks: None.  
Reinforcement: Deformed longitudinal steel bar, approximate. 15 mm dia. at 90 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Tan to 175 mm depth, then Gray  
Carbonation: Surface of core is carbonated. Tan paste noted to be less intensely stained by phenolphthalein than gray paste. Core bottom is carbonated.

Sample

Identification: Core No. 7  
Dimensions: Diameter = 150 mm, Length = 230 mm.  
Top Surface: Untextured. Gray stain.  
Bottom Surface: Gravel base material attached.  
Cracks: None.  
Reinforcement: Deformed longitudinal steel bar, approximate. 15 mm dia. at 90 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Tan to 175 mm depth, then Gray  
Carbonation: Surface of core is carbonated. Tan paste noted to be less intensely stained by phenolphthalein than gray paste. Core bottom is carbonated.

Sample

Identification: Core No. 8  
Dimensions: Diameter = 150 mm, Length = 230 mm.  
Top Surface: Untextured. Deep spall location with bituminous patch. Gray stain.  
Bottom Surface: Concrete rubble.  
Cracks: Open, full-depth crack. Horizontal delamination crack at steel depth.  
Reinforcement: Two deformed longitudinal steel bars, approximate. 15 mm dia. at 90 mm depth, partly rusted.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm. Many carbonates show extensive freeze-thaw cracks secondary calcium carbonate deposits.  
Fine Aggregate: Natural Sand.

Paste:

Color: Tan to 175 mm depth, then Gray  
Carbonation: Surface of core is carbonated. Tan paste noted to be less intensely stained by phenolphthalein than gray paste. Core bottom is carbonated.

Sample

Identification: Core No. 9  
Dimensions: Diameter = 150 mm, Length = 230 mm.  
Top Surface: Untextured. Gray stain.  
Bottom Surface: Gravel base material attached.  
Cracks: Horizontal delamination crack at steel depth.  
Reinforcement: Two deformed longitudinal steel bars, approximate. 15 mm dia. at 90 mm depth.

Aggregates:

Coarse Aggregate: Gravel.  
Fine Aggregate: Natural Sand.

Paste:

Color: Tan to 175 mm depth, then Gray  
Carbonation: Surface of core is carbonated. Paste on surface of delamination crack broken for examination is partly carbonated. Tan paste noted to be less intensely stained by phenolphthalein than gray paste. Core bottom is carbonated.

Sample

Identification: Core No. 10  
Dimensions: Diameter = 150 mm, Length = 230 mm.  
Top Surface: Untextured. Gray stain.  
Bottom Surface: Gravel base material attached.  
Cracks: None.  
Reinforcement: Two deformed longitudinal steel bars, approximate. 15 mm dia. at 90 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Tan to 175 mm depth, then Gray  
Carbonation: Surface of core is carbonated. Surface is carbonated. Tan paste noted to be less intensely stained by phenolphthalein than gray paste. Core bottom is carbonated.

Sample

Identification: Core No. 11  
Dimensions: Diameter = 150 mm, Length = 230 mm.  
Top Surface: Untextured. Gray stain.  
Bottom Surface: Gravel base material attached.  
Cracks: None.  
Reinforcement: Two deformed longitudinal steel bars, approximate 15 mm dia. at 90 to 100 mm depth.

Aggregates:

Coarse Aggregate: Gravel. Top size 19 to 25 mm.  
Fine Aggregate: Natural Sand.

Paste:

Color: Tan to 175 mm depth, then Gray  
Carbonation: Surface of core is carbonated. Surface is carbonated. Tan paste noted to be less intensely stained by phenolphthalein than gray paste. Core bottom is carbonated.