Performance Evaluation of Concrete Pavement Granular Subbase—Pavement Surface Condition Evaluation

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16. Abstract

This research project covered a wide range of activities that allowed researchers to understand the relationship between stability, pavement distress, and recycled portland cement concrete (RPCC) subbase aggregate materials. Detailed laboratory and field tests, including pavement distress surveys, were conducted at 26 sites in Iowa were conducted.

Findings show that specific gravities of RPCC are lower than those of crushed limestone. RPCC aggregate material varies from poorly or well-graded sand to gravel. A modified Micro-Deval test procedure showed that abrasion losses of virgin aggregate materials were within the maximum Micro-Deval abrasion loss of 30% recommended by ASTM D6028-06. Micro-Deval abrasion loss of RPCC aggregate materials, however were much higher than those of virgin materials and exceeded 30% loss. Modulus of elasticity of RPCC subbase materials is high but variable. RPCC subbase layers normally have low permeability.

The pavement surfaces for both virgin and RPCC subbase across Iowa were evaluated to fulfill the objectives of this study related to field evaluation. Visual distress surveys were conducted to gather the detailed current pavement condition information including the type, extent, and severity of the pavement distresses. The historical pavement condition information for the surveyed field sections was extracted from the Iowa DOT's Pavement Management Information System (PMIS). The current surface condition of existing field pavements with RPCC subbase was compared with the virgin aggregate subbase sections using two different approaches. The changes in pavement condition indices (PCI and IRI) with time for both types of pavements (subbases) were compared.

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PERFORMANCE EVALUATION OF CONCRETE PAVEMENT GRANULAR SUBBASE – PAVEMENT SURFACE CONDITION EVALUATION

IHRB Project TR-554
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EXECUTIVE SUMMARY

This research project covered a wide range of activities that allowed researchers to understand the relationship between stability, pavement distress, and recycled portland cement concrete (RPCC) subbase aggregate materials. Laboratory and field tests and distress surveys at 26 sites in Iowa were conducted.

Results show that specific gravities of RPCC are lower than those of virgin crushed limestone. RPCC aggregate material varies from either poorly or well-graded sand to gravel. A modified Micro-Deval test procedure was created to conduct tests on virgin and RPCC aggregate materials. Abrasion losses of virgin aggregate materials were within the maximum Micro-Deval abrasion loss of 30% recommended by ASTM D6028-06. Micro-Deval abrasion loss of RPCC aggregate materials was much higher than those of virgin materials exceeding 30% loss. Modulus of elasticity of RPCC subbase materials is generally high, but variable from one project to another. RPCC subbase layers normally have low permeability.

The pavement surface condition of existing concrete pavements on both virgin and RPCC subbase across Iowa was evaluated to fulfill the objectives of this study related to field evaluation. Visual distress surveys were conducted to gather the detailed current pavement condition information including the type, extent, and severity of the pavement distresses. The historical pavement condition information for the surveyed field sections was extracted from the Iowa DOT's Pavement Management Information System (PMIS). The current surface condition of existing field pavements with RPCC subbase was compared with the virgin aggregate subbase sections using two different approaches. The changes in pavement condition indices (PCI and IRI) with time for both types of pavements (subbases) were compared.

1. INTRODUCTION

Newly-built and/or reconstructed pavements require significant quantities of aggregate material for the subbase layer. Traditional use of virgin material creates a high impact economically and environmentally. At the same time, it is very expensive to deposit waste concrete material from reconstructed pavement due to the transportation and environmental expenses. Using recycled Portland cement concrete (RPCC) aggregate for road construction is currently a widely used option for subbase layers. Re-use RPCC reduces the need for natural aggregates, preserves the environment, and does not occupy landfill space. However, RPCC aggregate can reportedly experience reduced permeability, clog drainage systems, and produce a leachate with high pH that can corrode metal drainage pipes and damage vegetation. These engineering properties could potentially result in reduced durability of pavement bases, affecting long-term performance of pavement. The Iowa Department of Transportation (DOT) currently uses the same specifications for natural and recycled concrete aggregates, even though these aggregates have different physical, chemical, and mechanical properties. Based on these potential problems, this research was aimed at developing special guidelines and specifications for using RPCC in pavement subbase as needed based on the results of a comprehensive field test program.

1.1 Research Objectives

The main objectives of this study were to

- Determine if RPCC pavement subbase is performing adequately by evaluating representative pavement sections with comparisons to virgin aggregate subbase sections.
- Evaluate the spatial variation in subbase stiffness and permeability by performing multiple tests within a given test section using semi non-destructive methods.
- Determine the gradation of the subbase materials.
- Evaluate the pavement drainage system at each test section site by inspecting the subdrain outlets.
- Develop suggested material guidelines and specifications for construction of pavements using RPCC aggregate for subbase as needed.

1.2 Research Plan

This research project included in situ testing of full-scale test sections of subbase materials on constructed pavements. Dynamic cone penetration (DCP), Clegg impact hammer, and light weight deflectometer (LWD) tests were conducted on the subbase and/or subgrade surface to analyze stability. The results were used to develop comparisons and correlations. Permeability testing was conducted at each site using a permeameter developed for field applications by the Minnesota Department of Transportation (Mn/DOT).

Twenty-six test locations, including 21 sites with RPCC subbase materials and six test sites with virgin subbase materials were investigated (Table 1). A testing plan with the described testing methods was implemented at each site. Subbase aggregate samples were collected and tested in the laboratory for gradation, abrasion and other index properties. The results were analyzed to evaluate the relationship of stability and permeability among the virgin and RPCC subbases.

Table 1. General information of project sites with assigned identification numbers

Site I.D.	Project location	Direction	Type of subbase	Pavement thickness (in.)	Subbase thickness (in.)	Construction year	Test date
1	Knapp Street, Ames, Iowa (first visit)	West	RPCC	9.3	6.2	1991	14 Mar 2007
3	US-20 in Webster County: Mile Post No. 116.80–121.06	West	Virgin	10.2	10.2	2005	23 Apr 2007
4	US-30 in Tama County: Mile Post No. 194.35–194.40	East	Virgin	10.0	N/A*	2005	1 May 2007
5	I-235 in Polk County (Guthrie Ave): Mile Post No. 10.9–11.0	South	Virgin	13.0	N/A	2004	17 May 2007
6	IA-330 in Marshall County: Mile Post No. 20.05–20.10	South	RPCC	12.0	5.0	2006	14 Jun 2007
7	I-35 in Story County: Mile Post No. 119.95–120.05	South	RPCC	12.0	6.0	1999	19 Jun 2007
8	I-35 in Hamilton County: Mile Post No. 140.75–140.80	North	RPCC	10.5	8.0	2003	19 Jun 2007
9	I-80 in Jasper County: Mile Post No. 165.0–165.05	East	RPCC	13.0	5.0	1996	21 Jun 2007
10	I-80 in Jasper County: Mile Post No. 165.20–165.25	East	RPCC	13.0	7.0	1994	21 Jun 2007
11	I-35 in Hamilton County: Mile Post No. 131.40–131.45	North	RPCC	10.5	8.0	1983	27 Jun 2007
12	IA-92 in Warren County: Mile Post No. 132.16–133.80	East	Virgin	10.0	12.0	1993	7 Aug 2007
13	I-80 in Pottawattamie County: Mile Post No. 10.55–10.60	West	RPCC	13.0	11.0	1999	9 Aug 2007
14	I-80 in Pottawattamie County: Mile Post No. 10.55–10.65	East	RPCC	12.0	N/A	2003	11 Sep 2007

15	I-80 in Cass County: Mile Post No. 65.10–65.20	East	RPCC	12.0	N/A	1988	25 Sep 2007
16	I-80 in Cass County: Mile Post No. 65.80–65.90	West	RPCC	12.0	N/A	1987	3 Oct 2007
17	Knapp Street, Ames, Iowa (second visit)	West	RPCC	9.4	6.7	N/A*	9 Oct 2007
18	I-80 in Cedar County: Mile Post No. 269.00–269.10	East	RPCC	13.0	6.0	Aug. 1991	16 Oct 2007
19	I-80 in Cedar County: Mile Post No. 272.30– to 272.40	East	RPCC	13.0	9.0	Sep. 1991	23 Oct 2007
20	I-80 in Cedar County: Mile Post No. 272.55–272.65	East	RPCC	13.0	9.0	May 1992	23 Oct 2007
21	I-80 in Cedar County: Mile Post No. 269.30–269.40	West	RPCC	12.5	8.5	Sep. 1992	30 Oct 2007
22	I-80 in Cedar County: Mile Post No. 269.10–269.20	West	RPCC	13.0	8.0	May 1992	30 Oct 2007
23	I-80 in Polk County: Mile Post No. 128.50–128.55 – Travel	East	RPCC	14.0	9.0	1994	1 Nov 2007
24	I-80 in Cedar County: Mile Post No. 275.70–275.75	West	RPCC	13.0	8.0	Jul. 1992	6 Nov 2007
25	I-80 in Cedar County: Mile Post No. 275.90–275.95	West	RPCC	13.0	8.0	Aug. 1992	6 Nov 2007
26	I-80 in Polk County: Mile Post No. 128.50–128.60 – Passing	East	Virgin	13.5	9.0	1994	9 Nov 2007
27	I-80 in Cedar County: Mile Post No. 276.60–276.70	East	RPCC	13.5	9.0	Oct. 1991	13 Nov 2007

* not available

2. LITERATURE REVIEW

The requirements and specifications for the physical, chemical, and mechanical properties of natural aggregates for use as pavement subbases are well developed. However, limited sources of virgin materials and disposal space for demolished pavements have increased the need for using RPCC aggregates in pavement subbases. More than 3 million tons of recycled concrete are being produced in the United States annually (Collins et al. 1994). Therefore, it is necessary to develop specifications for using RPCC aggregates in pavement subbase construction projects.

2.1 RPCC as a Replacement Material

Highway construction consumes large quantities of aggregate materials for subbase/base course and pavement. The production of crushed stone in the United States was about 2.2 billion tons in 1996 (Grogan 1996). The study showed that the consumption of the aggregate for the U.S. highway system was over 40% of the total aggregate production.

The National Cooperative Highway Research Program (NCHRP) summarized the use of waste materials in highway construction. The study estimated that approximately 3 million tons of removed concrete pavements are being produced in the United States annually (Collins et al. 1994). As the volume of waste and the cost of disposal continue to rise, landfilling of waste material has become less favorable. In some areas of the United States, a limited supply of virgin aggregate makes RPCC a viable economic solution (Burke et al. 1992). Natural sources in the local area may not available near some projects, or the quality of the aggregate simply does not meet the project requirements. Limited sources of virgin materials and increased cost of transportation of virgin aggregate materials to the construction sites are additional concerns that show the need for using RPCC as replaced aggregate materials for pavement subbase/base courses.

2.2 Current Use of RPCC Materials

RPCC has been used in many states at different stages. Several states have already applied RPCC to highway construction projects, but other states are still at the stages of experimental research, testing, and development (Vukov 2003). A comprehensive survey of state highway and environmental agencies on recycling and use of waste materials and by-products in highway applications was conducted by FHWA in 1991. The findings were published in the "NCHRP Synthesis of Highway Practice Report No. 199" (Collins et al. 1994) and in the "Guidance Document for Reclaimed Portland Cement Concrete" (Vukov 2003). As a part of the NCHRP survey, Table 2 provides an overview of research, specifications, and use of RPCC materials that are derived from three main sources: concrete pavement, construction and demolition (C&D) debris and broken concrete. According to the study, C&D debris and concrete pavement generated 25 million tons and 3 million tons of RPCC per year, respectively. Within the focus of this research, the RPCC material reclaimed from old PCC for the subbase layer was studied.

Table 2. Overview of state research, use, and available specification on various RPCC materials (adapted from Collins et al. 1994 and Vukov 2003)

State	Paving and building debris		
	Reclaimed concrete pavement	Broken concrete	Construction and demolition debris
Arizona	Aggregate base coarse (R,U) Concrete aggregate (R,U)		
California		Aggregate base coarse (R,U) Concrete aggregate (R,U)	
Colorado		Aggregate base coarse (R,U,S) Rip-rap/slope protection (R,U)	
Connecticut		Aggregate base coarse (R,U) Concrete aggregate (R,U,S)	Aggregate base coarse (R,U) Concrete aggregate (R,U,S)
Delaware		Embankment borrow (R,U)	Embankment borrow (R,U)
Iowa	Aggregate base coarse (R,U) Concrete aggregate (R,U) Subbase materials (R,U,S) (*)	Embankment borrow (R,U)	
Kansas	Aggregate base coarse (R,U,S) Stabilized base course (R,U)	Embankment borrow (R,U) Rip-rap/slope protection (R,U)	
Louisiana	Aggregate base coarse (R,U) Concrete aggregate (R,U,S)		
Maryland	Subbase materials (R,U)		
Massachusetts		Subbase materials (U)	
Michigan	Aggregate base course (R) Recycled pavement (U) Concrete aggregate (R,S)		
Minnesota	Concrete aggregate (S)		
Missouri	Aggregate base coarse (R,U) Rip-rap/slope protection (R,U)	Rip-rap/slope protection (R,U)	Embankment borrow (R,U)
Montana	Concrete aggregate (S)		
Nebraska	Aggregate base coarse		

	(R,U)		
New Jersey		Aggregate base course (R,U) Concrete aggregate (R)	
New York	Recycled pavement (R) Subbase materials (U)		
North Dakota	Stabilized base course (R) Aggregate base coarse (U) Recycled pavement (U,S)	Rip-rap/slope protection (R,U)	Embankment borrow (R,U)
Ohio	Aggregate base coarse (U) Subbase materials (U)		
Oklahoma	Concrete aggregate (S)		
Pennsylvania	Concrete aggregate (R,U) Subbase materials (R,U,S)	Subbase materials (R)	
Rhode Island	Subbase materials (U)		
South Carolina		Aggregate base course	
South Dakota	Recycled pavement (U)	Embankment borrow (U)	
Texas		Aggregate base course (R,U)	
Wyoming	Concrete aggregate (R,U,S)		

Note: This table contains reclaimed concrete uses only

Legend: "R" - Research, "U" - Use, "S" - Specification, "PS" - Provisional Specification, “*” - This use was not listed in the original table.

In 1979, a progress report entitled “Recycled Portland Cement Concrete Pavement in Iowa” was published summarizing the use of RPCC in Iowa and project locations. The report listed seven main benefits of recycling PCC pavement that interested Iowa DOT. These benefits included the facts that RPCC would (1) provide aggregate where high-quality aggregate was not economically available; (2) eliminate the need for disposal landfills for large amounts of pavement ruble; (3) conserve the aggregate sources; (4) reduce the need for disrupting land for quarrying purposes; (5) save fuel and energy by reducing aggregate transportation; (6) reduce damage due to hauling for the pavement construction; and (7) reduce the construction cost (Marks 1979).

The first Iowa DOT project using RPCC as coarse aggregate in PCC was located in Lyon County in 1976. The second project was in Pottawattamie County in 1977, where RPCC aggregate was used in 4 inch econocrete bases and 6 inch PCC shoulders on one lane of I-680 (Marks 1979). The crushing operation produced approximately 65% coarse fraction and 35% fine fraction. The typical gradations of the two sizes are presented in Table 3. The RPCC aggregate was evaluated by using the conventional aggregate tests. The abrasion loss of 59% was slightly higher than the allowed abrasion loss of 50%, but the 42% “A” freeze and thaw loss was much higher than 6% for crushed stone in the current standard specification issued by Iowa DOT.

Table 3. Typical grain size distribution of coarse fraction and fine fraction

Coarse fraction		Fine fraction	
Sieve size	**Percent passing**	**Sieve size**	**Percent passing**
1 ½ in.	100	3/8 in.	100
1 in.	72	No. 4	76
¾ in.	39	No. 8	51
½ in.	21	No. 16	30
3/8 in.	9.3	No. 30	16
No. 4	2.9	No. 50	8.0
No. 8	2.0	No. 100	3.5
No. 200	0.7	No. 200	2.0

In the report for Indiana DOT, Burke et al. (1992) studied the use of RPCC for concrete. Workability for the mixtures of RPCC were found to be similar to mixtures using natural aggregates. RPCC used as fine aggregate required more cement and water. The frost resistance of the concrete made from RPCC aggregate was not reduced if the RPCC originated from the original concrete of good quality. However, RPCC could significantly affect the concrete in terms of strength and performance. Reductions of compressive strength and modulus of elasticity were 25% and 30%, respectively. Damping capacity increased by 30% and higher amounts of drying shrinkage and creep were measured for the concrete with RPCC aggregate.

2.3 The Effects on Pavement Stability and Permeability

Pavement bases and subbases are used to provide uniform support of pavement surface and adequate drainage during the lifetime of the pavement. To meet these requirements, the materials used in pavement subbases must meet specific size distributions with adequate stiffness, good durability, high permeability, and resistance to permanent deformation (e.g. particle crushing).

Pavements are divided into two types: rigid pavement and flexible pavement. The pavement structures normally consist of three main layers: subgrade, aggregate subbase/base course, and wearing surface. The subgrade layer is a compacted soil layer on the natural ground surface. The subbase course is a layer of aggregate material lying above the subgrade layer and usually consists of crushed aggregate or gravel or recycled materials (e.g. RPCC or recycled Asphaltic cement concrete [ACC]).

Aggregate base is the main structural element of pavement foundation that determines the success or failure of the pavement (AASHTO 1993). A such, the aggregate base has to have three principal functions: subgrade protection, supporting surface, and construction platform. In most cases pavement distress or rutting appears and develops because the stress reaches critical states (Dawson 1995) or failures (Loach 1987). Thus, the subbase layer should reduce and redistribute the stress on the subgrade soil to a level that is lower than the critical stress level, and the soil should be subject to less deformation. The base layer should also provide adequate support to the pavement layer and is a stable platform during pavement construction.

2.4 Material Properties

RPCC aggregates have been used for pavement subbase in many states, but the specifications followed by these state DOTs for this type of material are derived from previously developed specifications for natural aggregates. In fact, RPCC aggregates have different physical, chemical, and mechanical properties because cement is a constituent of to the aggregate particles. Table 1 compares the properties of natural and recycled concrete aggregates (Yrjanson 1989).

Table 4. Engineering properties of virgin and recycled PCC materials

Property	Natural aggregate	Recycled concrete aggregate
Specific Gravity	2.6–2.6	2.2–2.4
Absorption (%)	0.5–1.6	4.3–5.9
Loss in L.A. abrasion test (%)	20–30	20–45

In a previous study, White et al. (2004) evaluated material properties on a limited scale in the laboratory and in situ for natural and RPCC aggregates used in Iowa. The properties included gradation, specific gravity, minimum and maximum density, abrasion loss, California Bearing Ration (CBR), penetration index (PI) use of DCP, Clegg impact value, and in situ permeability. Results from Table 4 suggest that RPCC has similar properties to crushed limestone but that the RPCC has higher water absorption, percentage of fines and lower specific gravity, density, compressive strength, and modulus of elasticity when compared with natural limestone aggregates.

According to White et al. (2004), the hydraulic conductivity normally decreases with increasing compaction energy (i.e. density) for different types of aggregates. With increased compaction energy, hydraulic conductivity in RPCC can reduce up to 16 times. The affect of increased compaction energy on permeability is less for crushed limestone granular subbase.

Table 5. Measured laboratory and field properties of natural and recycled aggregates used in road bases in Iowa (White et al. 2004)

Test perform	Property	Crushed limestone	RPCC
		Laboratory tests	
Sieve analysis	**Classification**	**GP (ASTM) A-1-a (AASHTO)**	**GP-GM (ASTM) A-1-a (AASHTO)**
Sieve analysis	Percent fines	8%	8%
Specific gravity	G_s	2.75	2.54
Vibrating table	$\gamma_{d\ max}$, $\gamma_{d\ min}$	97 lb/ft^3, 91 lb/ft^3	88 lb/ft^3, 84 lb/ft^3
Abrasion	Percent loss	15.3%	22.5%
CBR	CBR at 0.4 in. penetration	52%	22%
In situ tests			
Geogauge	Modulus	1480 ksf	1000 ksf
DCP	Penetration index (PI)	PI = 1.1 in./blow	PI = 0.95 in./blow
	CBR*	CBR = 9%*	CBR = 10%*
Clegg hammer	Clegg Impact Value (CIV)	CIV = 13	CIV = 13
Air permeameter	Permeability	2.2 in./sec.	1.9 in./sec.
Gradation	% fines	4%–9%	4%–11%**

* estimated from DCP, ** due to breakage of particles under compaction

2.5 Reported Performance Problems

Under the compaction and traffic loading, RPCC aggregates can experience breakage of particles, which increases the fines content (Miyagawa 1991, Maher et al. 1997, Taha et al. 1999, Chini et al. 2001, Kuo et al. 2001, and White et al. 2004). Increasing the fines content can reduce the freeze-thaw resistance and permeability of pavement bases (Kasai 2004, White et al. 2004), which potentially results in pavement deterioration (Huang 2004). When temperatures are below freezing, water condenses and forms ice lenses at the interface between the pavement and base. These ice lenses melt during the thaw periods and can contribute to increases pore water pressure. In the RPCC pavement subbases with high percentages of fines and low permeability, the pore water pressures can develop under the pavement which reduce shear strength of base and subgrade layers (Eigenbrod and Knuttsson 1992). High pore water pressures can result in pavement deterioration (Eigenbrod and Knuttsson 1992).

Cement hydration in the RPCC matric can reduce void ratio and lead to the reduced permeability and freeze-thaw resistance (Snyder 1995 and Melton 2004). The non-hydrated cement particles can hydrate in the presence of water (Kuo et al. 2001, Miyagawa 1991).

2.6 Iowa DOT Specification Review

The following Iowa DOT specifications were reviewed for recent changes that would affect subbase design and maintenance. The review included the following sections:

2110, Soil Aggregate Subbase

2111, Granular Subbase

4109, Aggregate Gradation

4121, Granular Subbase Material

4123, Modified Subbase Material

Iowa DOT specifications are modified every six months, in October and April, with a general supplemental (GS) specification that is sequentially numbered, starting with 1001 on October 2, 2001. Previous specifications followed that same pattern; however, a new database approach to maintaining specifications was initiated at that time which has provided a more streamlined approach to tracking specification changes since that date.

RPCC was first used as coarse aggregate for the PCC pavement in Lyon County in 1976 (Marks 1979) and as aggregate material for granular subbase for Interstate I-35 in Hamilton County in 1983. A review of supplemental specification and general specification changes started from the supplemental specification SS-1070 (December 1988) to general specifications GS-01014 Revisions (April 2008) (http://www.erl.dot.state.ia.us/APR_2008/GS/frames.htm), is shown in Table 7. A timeline chart was created that shows when a supplemental specification was developed or incorporated in the general specifications (Figure 1).

The specifications were reviewed and analyzed for changes with remarks. Most of the changes were editorial changes that simplify construction contract administration by specifying the use of planned quantities for measurement and by streamlining wording in "basis of payment" sections. One of the more significant items was a change to reduce the percentage of wear in abrasion loss from 50% to 45%. This change would significantly reduce the number of fines in the subbase, which mainly cause the freeze-thaw deterioration and clog the drained capability in the subbase layers.

The gradations for both crushed stone and recycled material provided by GS-01014 is a significant item. An error was made in GS-01014 with the sieve size in Gradation number 12a. The second sieve size (3/8 in.) of the sieve set of this gradation in English Gradation does not match the second sieve size (12.5 mm) in Metric Gradation (Table 6).

Table 6. Gradation of granular subbase (adapted from Iowa DOT Standard Specifications with GS-01014 Revisions, Section 4109.02 and 4121.02)

Sieve size		Crushed stone	Recycled PCC
English gradation	**Metric gradation**		
1 1/2 in.	37.5 mm	100	100
3/8 in.	12.5 mm (*)	40-80	40-80
No. 8	2.36 mm	5-25	5-20
No. 200	0.075 mm	0-6	0-6

(*) – In Metric Gradation, the second sieve size should be 9.5 mm instead of 12.5 mm if it is 3/8 in. in English Gradation.

Table 7. Specification review

Section 2110 -- Soil aggregate subbase				
Article	**Specification**	**Date**	**Change**	**Remark**
2110.07, A	GS 01011	10/17/2006	Replace the entire article	Determine the quantity of soil aggregate subbase along with the centerline of the subbase, including approaches to railroad crossings, bridges, and similar structures
2110.08, A	GS 01011	10/17/2006	Replace the first sentence	Change unit length from kilometer into mile

Section 2111 -- granular subbase				
Article	**Specification**	**Date**	**Change**	**Remark**
2111.01	SS 5135	9/27/1994	Delete all of the section	The section is replaced by Supplemental Specifications for Granular Subbase
2111.02	SS 1070	12/20/1988	Replace the entire article	RPCC, reclaimed from an interstate or primary roadbed under the jurisdiction of the Iowa DOT and meeting the specified gradation is allowed to use for granular subbase. RPCC pavement, meeting the specified gradation and obtained from other sources may be used for granular subbase with the approval of the engineer.
2111.02	SS 5135	9/27/1994	Delete all of the section	The section is replaced by Supplemental Specifications for Granular Subbase
2111.02	GS 97007	4/25/2000	Replace the first sentence	Editorial
2111.02	GS 97008	10/03/2000	Replace the first sentence	Editorial
2111.03C	SS 1070	12/20/1988	Replace the entire paragraph	Editorial
2111.03	SS 5135	9/27/1994	Delete all of the section	The section is replaced by Supplemental Specifications for Granular Subbase
2111.04	SS 5105	8/03/1993	Replace the first five sentences in the first paragraph	Editorial

2111.04	SS 5110	2/08/1994	Replace the first five sentences of the first paragraph	Editorial
2111.04	SS 5135	9/27/1994	Delete all of the section	The section is replaced by Supplemental Specifications for Granular Subbase
2111.04	GS 97008	10/3/2000	Delete the last paragraph	Editorial (Basis of Payment)
2111.06	SS 1070	12/20/1988	Replace the fourth paragraph	Requirements for minimum compaction and procedure to obtain the target compaction
2111.06	SS 5105	8/03/1993	Replace the fourth paragraph, including items 1, 2 and 3	Editorial
2111.06	SS 5110	8/02/1994	Replace the fourth paragraph, including items 1, 2, and 3.	Construction method
2111.06	SS 5135	9/27/1994	Delete all of the section	The section is replaced by Supplemental Specifications for Granular Subbase
2111.06	GS 97008	10/03/2000	Add the last sentence to the seventh paragraph	Determine time frame for placing the granular subbase
2111.06	GS 01004	4/15/2003	Add as the second and third sentences of the last paragraph	Allow the granular placed for winter shutdown
2111.06	GS 01011	10/17/2006	Delete the fourth paragraph	Editorial
2111.06	GS 01011	10/17/2006	Add the last two sentences of the last paragraph	Indicate the suitable areas to place granular subbase for winter shutdown
2111.07	SS 5135	9/27/1994	Delete all of the section	The section is replaced by Supplemental Specifications for Granular Subbase
2111.07	GS 97008	10/03/2000	Replace the sentence	Restriction for the granular subbase material
2111.08	SS 5060	7/14/1992	Replace all the article	Change the method of measurement from tons to square yards
2111.08	SS 5105	8/3/1993	Replace all the article	Editorial
2111.08	SS 5110	2/08/1994	Replace all the article	Editorial
2111.08	SS 5135	9/27/1994	Delete all of the section	The section is replaced by Supplemental Specifications for Granular Subbase
2111.09	SS 1070	12/20/1988	Replace the entire article	Basis of payment–new guidelines for payment relating with RPCC materials
2111.09	SS 1090	12/5/1989	Replace the entire article	Editorial (Basis of payment)

2111.09	SS 5060	7/14/1992	Replace the first paragraph, including items 1, 2 and 3 with new paragraph	Editorial (Basis of Payment)
2111.09	SS 5105	8/03/1993	Replace the first paragraph, including items 1, 2 and 3 with new paragraph	Editorial (Basis of Payment)
2111.09	SS 5110	2/08/1994	Replace the first paragraph, including items 1, 2 and 3 with new paragraph	Editorial
2111.09	SS 5135	9/27/1994	Delete all of the section	The section is replaced by Supplemental Specifications for Granular Subbase
2111.09	GS 01002	4/30/2002	Add the second and third sentences of the first paragraph	Editorial (Basis of Payment)
2111.09	GS 01003	10/29/2002	Add the second and third sentences of the first paragraph	Editorial
2111.09	GS 01004	4/15/2003	Add the second and third sentences of the first paragraph	Editorial
2111.09	GS 01011	10/17/2006	Add the second and third sentences of the first paragraph	Editorial

Section 4109 -- Aggregate gradation

Article	**Specification**	**Date**	**Change**	**Remark**
4109.02	SS 5006	8/28/1990	Change the gradation range from 25 to 30 to 25 to 60 for the sieve size 30	Increase the range of fines at sieve No. 30 (0.6 mm)
4109.02	GS 97005	4/27/1999	Add two new paragraphs	Using sieves with openings of 1 in. and 0.500 in. in lieu of 1.06 in. and 0.530 in., respectively

Section 4121 -- Granular subbase material

Article	**Specification**	**Date**	**Change**	**Remark**
4121.01, A2	SS 5015	12/11/1990	Delete the sentence and add a new sentence	Plasticity index shall not exceed 3
4121.01, A	SS 5105	8/03/1993	Replace the first sentence	Abrasion and Freeze Thaw Loss does not exceed 45% and 25%, respectively
4121.01, B	SS 5105	8/03/1993	Replace the first sentence	Plasticity index shall not exceed 5

4121.01	SS 5105	8/03/1993	Add new paragraph	Allow to replace the bottom two in. of the specified subbase material with screened fines of RPCC that contain less than 15% of particles passing No. 200 sieve. This layer of fines is used as a working platform and should not adversely affect the longitudinal subdrains. The upper granular subbase material must be thicker than 4 in.
4121.01	SS 5110	2/08/1994	Add a sentence after the first sentence	Allow to blend up to 15% of sand by either volume or weight to either virgin or RPCC aggregate
4121.01, A	SS 5110	2/08/1994	Replace the first sentence	Editorial
4121.01, B	SS 5110	2/08/1994	Replace the first sentence	Editorial
4121.01	GS 97005	4/27/1999	Replace the last sentence of the second paragraph	Editorial
4121.01, A, B	GS 97005	4/27/1999	Replace the paragraph A, abrasion and clay content, and paragraph B, clay content of minus 40 material	Editorial
4121.01	GS 97007	4/25/2000	Replace all of the second paragraph	Editorial
4121.01	GS 97008	10/3/2000	Replace all of the second paragraph	Editorial
4121.01, A, B	GS 97008	10/3/2000	Replace paragraph A, delete all of paragraph B	Percentage of wear is reduced to 45%
4121.01, A	GS 01003	10/29/2002	Replace "45%" with "50%" in the first sentence	Change in abrasion loss of material
4121.01	GS 01010	4/18/2006	Replace the entire article	Description
4121.01	GS 01011	10/17/2006	Replace the entire article	Editorial
4121.02	GS 01010	4/18/2006	Replace the entire article	Editorial
4121.02	GS 01011	10/17/2006	Replace the entire article	Crushed material meets the requirements for Gradation No. 12a of the Gradation Table, Article 4109.02. Sieve number versus percent of passing: 1 1/2 in., 3/8 in., No. 8, and No. 200 vs. 100, 40–80, 5–25, and 0–6, respectively

4121.03	GS 01010	4/18/2006	Replace the entire article	Require planned quantity other change in method of measurement
4121.03	GS 01011	10/17/2006	Replace the entire article	Editorial

Section 4123 -- Modified subbase material

Article	Specification	Date	Change	Remark
4123	SS 97043	10/26/1999	Replace all of section 4123	These supplemental specifications replaced the standard specifications, series of 1997
4123.02	SS 97043	10/26/1999	Material for modified subbase consists solely or in combinations of RPCC, crushed composite pavement, crushed stone, sand, or gravel meeting the requirements of Gradation No. 14	Sieve number versus percent of passing: 1.5 in., 3/4 in., No. 8, and No. 200 vs. 100, 70–90, 10–40, and 3–10, respectively
4123.02,A	SS 97043	10/26/1999	Abrasion and Freeze Thaw Loss	Abrasion and Freeze Thaw Loss of aggregates, Grading A or B, does not exceed 45% and 15%, respectively

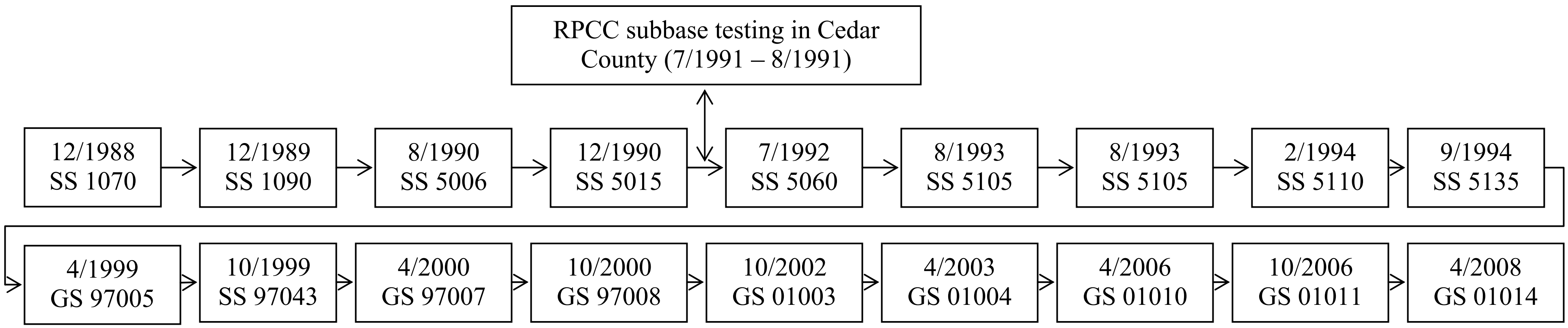


Figure 1. Timeline of Supplemental Specifications and General Specifications

2.7 Data and Steps used in Pavement Condition Assessment

This part of the research study was mainly conducted to determine if RPCC pavement subbase is performing adequately by evaluating representative pavement sections with comparisons to virgin aggregate subbase sections. For this purpose, a field evaluation plan was developed and an extensive field study was conducted to assess the representative PCC pavement sections with both RPCC subbase and virgin aggregate subbase.

The data and information required for the assessment of the pavement surface condition can be obtained directly from the agency's historical database or by conducting visual surveys. The detailed current pavement surface condition data for tested sites in this study were collected through the visual distress survey. The exiting pavement surface condition information was also extracted from the Iowa DOT's Pavement Management Information System (PMIS). The data collection methodologies used during the visual distress surveys and the study findings are described in this section. For the sake of completeness, the data and steps involved in conducting a detailed pavement condition assessment for selecting potential rehabilitation strategies are briefly reviewed.

The NCHPR 1-37 A report (2004), which contains comprehensive documentation for the Mechanistic-Empirical Pavement Design Guide (MEPDG) software, suggests that the overall pavement condition and problem definition can be determined by evaluating the following major aspects of the existing pavement:

- Structural adequacy (load related)
- Functional adequacy (user related)
- Subsurface drainage adequacy
- Material durability
- Shoulder condition
- Extent of maintenance activities performed in the past
- Variation of pavement condition or performance within a project
- Miscellaneous constraints (e.g., bridge and lateral clearance and traffic control restrictions)

The structural category relates to those properties and features that define the response of the pavement to traffic loads. The functional category relates to the surface and subsurface characteristics and properties that define the smoothness of the roadway, or to those surface characteristics that define the frictional resistance or other safety characteristics of the pavement's surface. The other aspects of the existing pavement should be informed because these may affect both structure and functional condition and the selecting of feasible rehabilitation alternatives. However, it should be noted that the data in the structural category, such as existing distress, and nondestructive and destructive testing, will be used in mechanistic-empirical design of rehabilitation alternatives.

The NCHRP 1-37 A report also suggests a comprehensive checklist of factors for the assessment of pavement condition considering those major aspects of the existing pavement as shown in Table 8. Even though this list should be modified to suit the project's specific needs, it is vital that the agencies develop procedures and guidelines for answering the questions on their list.

The data to be collected for conducting pavement assessment can be categorized into historic data and benchmark data (NCHRP 2004). Any data collected before pavement evaluation, regardless of type, is historic. It includes site-, design-, and construction-related data assembled from inventory, monitoring, and maintenance data tables established throughout the pavement life. Data collected during pavement evaluation, such as visual surveys, nondestructive, and destructive testing are described as benchmark data. The same data obtained from the files containing test data collected during construction is described as historic. A successful and thorough pavement evaluation program will require both benchmark and historic data, since some data by definition will always remain historic (e.g., traffic). However, in situations where the data can be obtained from both sources, benchmark data will tend to be more reliable.

The steps for determining an assessment of the pavement's current structural or functional condition are (APT 2001):

1. Historic data collection (records review)
2. First field survey
3. First data evaluation and determination of additional data requirements
4. Second field survey
5. Laboratory characterization
6. Second data evaluation
7. Final field evaluation report

2.7.1 Steps 1 and 2: Historic Data Collection and First Field Survey

The assessment of pavement should begin with an assembly of historic data and preferably some benchmark data. Steps 1 and 2 of the field collection and evaluation plan should, as a minimum, fulfill all the data requirements to perform an overall problem definition. The following activities should be performed:

- Review construction and maintenance files to recover and extract information and data pertinent to pavement performance and response.
- Review previous distress surveys and the pavement management records, if available, to establish performance trends and deterioration rates.
- Review previous deflection surveys.
- Review previous pavement borings and laboratory test results of pavement materials and subgrade soils.
- Perform a windshield survey or an initial surveillance of the roadway's surface, drainage features, and other related items.
- Identify roadway segments with similar or different surface and subsurface features using the idealized approach (discussed in the next section of this

chapter). In other words, isolate each unique factor that will influence pavement performance.

- Identify the field testing/materials sampling requirements for each segment and the associated traffic control requirements.
- Determine if the pavement performed better or worse than similar designs.

The information gathered in this step can be used to divide the pavement into units with similar design features, site conditions, and performance characteristics for a more detailed pavement evaluation.

2.7.2 Step 3: First Data Evaluation and Determination of Additional Data Requirements

Using the information and data gathered in steps 1 and 2, a preliminarily overall pavement condition analysis can be performed. If the information and data gathered is inadequate, then more detailed data will be required to determine the extent and severity of the pavement condition. Step 3 is very important since it helps agencies reduce considerably the list of additional data requirements, making the overall pavement assessment and problem definition process more cost-effective.

2.7.3 Steps 4 and 5: Second Field Survey and Laboratory Characterization

Steps 4 and 5 involve conducting detailed measuring and testing, such as coring and sampling, smoothness measurement, deflection testing, skid resistance measurement, drainage tests, and measuring vertical clearances on the project under evaluation. The data collected at this stage should be guided by the data needs determined at the end of the first evaluation phase in step 3. Steps 4 and 5 will also involve conducting tests such as material strength, resilient modulus, permeability, moisture content, composition, density, and gradations, using samples obtained from the second field survey. Field data collection, laboratory characterization, and data manipulation should be done according to established guidelines from test standards such as AASHTO, ASTM, LTPP, SHRP, and state and local highway agencies.

2.7.4 Steps 6 and 7: Second Data Evaluation and Final Field Evaluation Report

Using the data collected during steps 1–5, the final pavement evaluation and overall problem definition can be conducted. Step 7 documents the details of the pavement evaluation process, the data obtained specifying levels of input, and problems identified in a final evaluation report.

Table 8. Checklist of factors used in overall pavement condition assessment (NCHRP, 2004)

Facet	Factors	Description
Structural adequacy	Existing distress	1. Little or no load/fatigue-related distress 2. Moderate load/fatigue-related distress (possible deficiency in load-carrying capacity) 3. Major load/fatigue-related distress (obvious deficiency in current load-carrying capacity) 4. Load-carrying capacity deficiency: (yes or no)
	Nondestructive testing (deflection testing)	1. High deflections 2. Are backcalculated layer moduli reasonable? 3. Are joint load transfer efficiencies reasonable?
	Nondestructive testing (GPR testing)	1. Determine layer thickness
	Nondestructive testing (profile testing)	1. Determine joint/crack faulting
	Destructive testing	1. Are cores strengths and condition reasonable? 2. Are the layer thicknesses adequate?
	Previous maintenance performed	Minor, Normal, Major
	Has lack of maintenance contributed to structural deterioration?	Yes, No, Describe_________________
Functional adequacy	Smoothness	Measurement ______________ Very Good, Good, Fair, Poor, Very Poor
	Cause of smoothness deficiency	Foundation movement Localized distress or deterioration Other
	Noise	Measurement ______________ Satisfactory, Questionable, Unsatisfactory
	Friction resistance	Measurement ______________ Satisfactory, Questionable, Unsatisfactory
Subsurface drainage	Climate (moisture and temperature region)	Moisture throughout the year • Seasonal moisture • Very little moisture • Deep frost penetration • Freeze-thaw cycles • No frost problems
	Presence of moisture-accelerated distress	Yes, Possible, No
	Subsurface drainage facilities	Satisfactory, Marginal, Unsatisfactory
	Surface drainage facilities	Satisfactory, Marginal, Unsatisfactory
	Has lack of maintenance contributed to deterioration of drainage facilities?	Yes, No, Describe_________________
Materials durability	Presence of durability-related distress (surface layer)	1. Little or no durability-related distress 2. Moderate durability-related distress 3. Major durability-related distress
	Base erosion or stripping	1. Little or no base erosion or stripping 2. Moderate base erosion or stripping 3. Major base erosion or stripping
	Nondestructive testing (GPR testing)	1. Determine areas with material deterioration/moisture damage (stripping)

Table 8. Checklist of factors used in overall pavement condition assessment (continued)

Facet	Features	Description
Shoulder adequacy	Surface condition	1. Little or no load-associated/joint distress 2. Moderate load-associated/joint distress 3. Major load-associated/joint distress 4. Structural load-carrying capacity deficiency: (yes or no)
	Localized deteriorated areas	Yes, No Location:
Condition/ performance variability	Does the project section include significant deterioration of the following: • Bridge approaches • Intersections • Lane to lane • Cuts or fills	 Yes, No Yes, No Yes, No Yes, No
	Is there a systematic variation in pavement condition along project (localized variation)?	Yes, No
	Systematic lane to lane variation in pavement condition	Yes, No
Miscellaneous	PCC joint damage: • Is there adequate load transfer (transverse joints)? • Is there adequate load transfer (centerline joint)? • Is there excessive centerline joint width? • Is there adequate load transfer (lane-shoulder)? • Is there joint seal damage? • Is there excessive joint spalling (transverse)? • Is there excessive joint spalling (longitudinal)? • Has there been any blowups?	 Yes, No Yes, No Yes, No Yes, No Yes, No Yes, No Yes, No Yes, No
	Past maintenance • Patching • Joint resealing	 Yes, No Yes, No
	Traffic capacity and geometrics • Current capacity • Future capacity • Widening required now	 Adequate, Inadequate Adequate, Inadequate Yes, No
Constraints?	Are detours available for rehabilitation construction?	Yes, No
	Should construction be accomplished under traffic?	Yes, No
	Can construction be done during off-peak hours?	Yes, No, Describe________________
	Bridge clearance problems	Describe________________
	Lateral obstruction problems	Describe________________
	Utilities problems	Describe________________
	Other constraint problems	Describe________________

2.8 Methodology for Pavement Condition Assessment

The data and information required for the assessment of the pavement condition can be obtained directly from the agency's historical data tables (inventory or monitoring tables) or by conducting visual surveys, performing nondestructive testing, and performing destructive testing as part of pavement evaluation (NCHRP 2004).

The activities performed as part of assembling historic data from inventory or monitoring data files include a review of past construction and maintenance data files to recover and extract information and data pertinent to pavement design features, material properties, construction parameters, borings logs, and laboratory testing of layer materials and subgrade soils. The review should also include past pavement management records for information on past distress surveys and maintenance activities. A thorough review of past records could also yield information on pavement constraints such as bridge clearances and lateral obstruction. Two kinds of information that should be assembled as part of the historic data are traffic and climate-related data. The traffic data required include past and future traffic estimates that are required as input for determining current and future pavement structural adequacy. Climate variables such as precipitation and freeze-thaw cycles may also be required as inputs for rehabilitation design and structural adequacy analysis.

2.8.1 Visual Surveys

Visual surveys range from a casual windshield survey conducted from a moving vehicle to the more detailed survey that involves trained engineers and technicians walking the entire length of the project (or selected sample areas) and measuring and mapping out all distresses identified on the pavement surface, shoulders, and drainage systems (APT 2001). Recently, automated visual survey techniques have become more common and are being adopted for distress surveys and pavement condition evaluation.

Although pavement condition is defined in different ways by different agencies, it almost always requires the identification of several distress types, severities, and amounts through on-site visual survey. "Distress Identification Manual for the Long-Term Pavement Performance Project" (SHRP 1993) is the one distress manual that has broader applications and provides a common language for describing distress on different types of pavements.

2.8.2 Nondestructive Test

Nondestructive testing (NDT) is a term used to describe the examination of pavement structure and materials properties through means that do not induce damage or property changes to the structure (NCHRP 2004). NDT ranges from simple techniques such as using Ground Penetrating Radar (GPR) to determine in situ layer thickness and condition, profile testing to determine pavement surface smoothness, and friction testing to determine pavement surface-vehicle tire skid resistance, to the well-established method of deflection testing using a Falling Weight Deflectometer (FWD) (Shahin 1994).

NDT typically has the following advantages (AASHTO 1993; Shahin 1994):

- Reduces the occurrence of accidents due to lane closures
- Reduces costs
- Improves testing reliability
- Provides vital information for selecting between rehabilitation options
- Provides data for rehabilitation (overlay) design
- Enables data to be gathered quickly at several locations

Although NDT has many advantages, it also has the following limitations (FAA 1994):

- Requires other methods to evaluate the functional condition of the pavement such as visual condition, smoothness, and friction characteristics.
- Requires other important engineering properties of the pavement layers, such as

grain-size distribution of the subgrade to determine swelling and heaving potential.

- Gives different results at different measurement times in a year due to climatic variations.
- Needs some caution to evaluate the selected pavement types such as continuously reinforced concrete pavement, post-tensioned concrete, and pre-tensioned concrete due to the model dependencies of NDT software.

Nondestructive testing equipment includes both deflection and non-deflection testing equipment (FAA 1994). Deflection measuring equipment for nondestructive testing of pavements can be broadly classified as static or dynamic loading devices. Dynamic loading equipment can be further classified according to the type of forcing function used, i.e., vibratory or impulse devices. Non-deflection measuring equipment that can supplement deflection testing includes ground-penetrating radar, infrared thermography, and devices that measure surface waves.

2.8.3 Destructive Test

Destructive tests require the physical removal or damage of pavement layer material to obtain a sample (either disturbed or undisturbed) for laboratory characterization or to conduct an in situ DCP test (NCHRP 2004). Destructive testing ranges from simple tests such as coring (and determining the pavement layer thicknesses by measuring core lengths), to determining the elastic modulus and strength of PCC cores. Other forms of destructive testing that are less common include lifting of slabs of jointed concrete pavements (JCP) to determine subsurface material conditions.

Trenching consists of cutting a full depth, 4- to 6-in.-wide strip of pavement, the full width of a traffic lane, and removing it to observe the condition of the different pavement layers over time. If rutting is present, it allows the engineer to determine where the rutting is located and the cause of rutting (consolidation or plastic flow). Trenching also allows the engineer to determine if and where stripping-susceptible asphalt layers lie in the pavement section. Destructive tests such as trenching generally help improve evaluation of the causes of surface distresses.

Destructive testing has many limitations (e.g., risk to testing personnel), particularly when conducted on moderate to heavily trafficked highway systems. Practical restraints—in terms of time and money—severely limit the number and variety of destructive tests conducted on routine pavement evaluation studies (AASHTO 1993; Shahin 1994). Destructive testing also has some vital advantages, including the observation of subsurface conditions of pavement layers and bonding between layers.

3. LABORATORY INVESTIGATION

This section summarizes laboratory testing on the subbase aggregate materials for gradation, specific gravity, and Micro-Deval.

3.1 Specific Gravity

3.1.1 Test Procedure

Specific gravity was determined in accordance with ASTM C127-01, "Standard Tests Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate."

3.1.2 Test Result and Analysis

Oven-dry (OD) and saturated-surface-dry (SSD) specific gravities of the aggregate materials are shown in Table 9. Results from the table show that the specific gravities of RPCC are lower than those of crushed limestone.

Table 9. Oven-dry (OD) and saturated-surface-dry (SSD) specific gravities

Project I.D.	Specific gravity (oven dry)	Specific gravity (saturated surface dry)	Subbase material
1	-	-	RPCC
2	2.64	2.66	Crushed limestone
3	2.59	2.62	Crushed limestone
4	2.55	2.61	Crushed limestone
5	2.58	2.63	Crushed limestone
6	2.22	2.36	RPCC
7	2.24	2.38	RPCC
8	2.21	2.35	RPCC
9	2.20	2.37	RPCC
10	2.20	2.36	RPCC
11	2.18	2.36	RPCC
12	2.53	2.59	Crushed limestone
13	2.30	2.42	RPCC
14	2.26	2.41	RPCC
15	2.14	2.33	RPCC
16	2.22	2.37	RPCC
17	2.19	2.37	RPCC
18	2.23	2.37	RPCC
19	2.25	2.39	RPCC
20	2.22	2.37	RPCC
21	2.29	2.43	RPCC
22	2.29	2.43	RPCC
23	2.33	2.45	RPCC
24	2.24	2.39	RPCC
25	2.28	2.41	RPCC
26	2.39	2.49	Crushed limestone
27	2.25	2.40	RPCC

3.2 Sieve Analysis

3.2.1 Gradation Test Procedure

Sieve analyses were conducted in accordance with ASTM C136, "Standard Tests Method for Sieve Analysis of Fine and Coarse Aggregates." Particle size distribution curves were determined using air dry samples of about 2000 g and sieving over the 1.5, 1, 0.75, and 0.375 in., Nos. 4, 10, 20, 40, 60, 100, and 200 sieve sizes.

3.2.2 Gradation Test Result and Analysis

Grain-size distribution curves for all samples are shown in Figures 2 through 6. A summary of the gradation test results is presented in Tables 10 through 14. The current Iowa DOT gradation limits are provided for reference and indicate that several of the samples are outside the specification limits on the fine side.

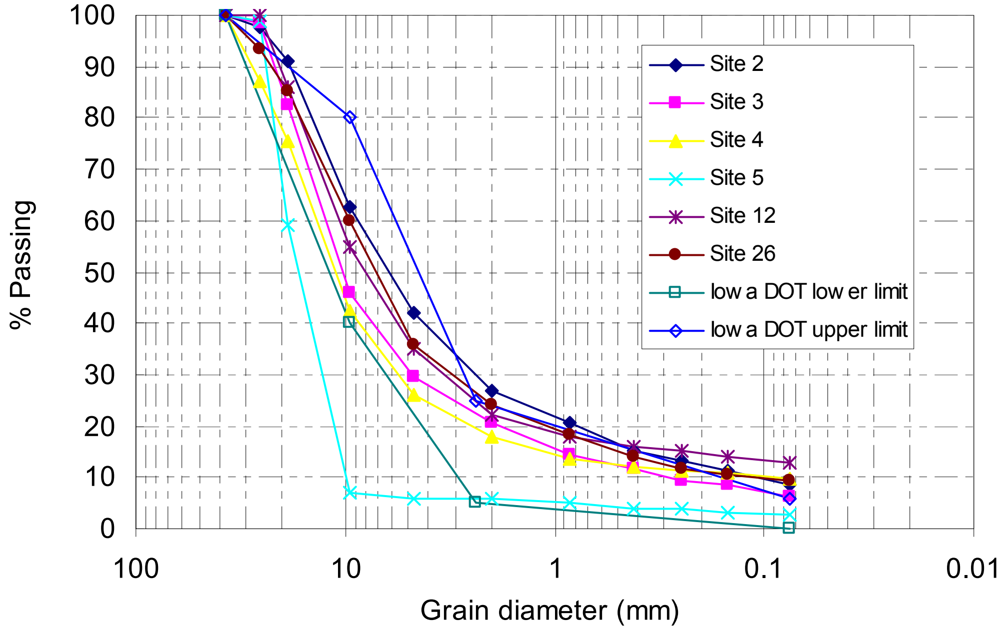


Figure 2. Gradation of virgin material samples

Table 10. Gradation of virgin material samples

Sieve		Percent of passing							
Sieve No.	**Size, mm.**	**Tested site 2**	**Tested site 3**	**Tested site 4**	**Tested site 5**	**Tested site 12**	**Tested site 26**	**Iowa DOT lower limit**	**Iowa DOT upper limit**
1 1/2 in.	37.50	100	100	100	100	100	100	100	100
1 in.	25.40	97	99	87	99	100	94	-	-
3/4 in.	19.00	91	83	75	59	86	85	-	-
1/2 in.	12.70	-	-	-	-	-	-	-	-
3/8 in.	9.510	63	46	42	7.0	55	60	40	80
4	4.760	42	30	26	6.0	35	36	-	-
8	2.360	-	-	-	-	-	-	5.0	25
10	2.000	27	21	18	6.0	22	24	-	-
20	0.850	21	15	14	5.0	18	18	-	-
40	0.420	15	12	12	4.0	16	14	-	-
60	0.250	13	10	11	4.0	15	12	-	-
100	0.149	11	9	11	3.0	14	10	-	-
200	0.075	8.7	6.2	9.7	2.7	13	9.4	0.0	6.0

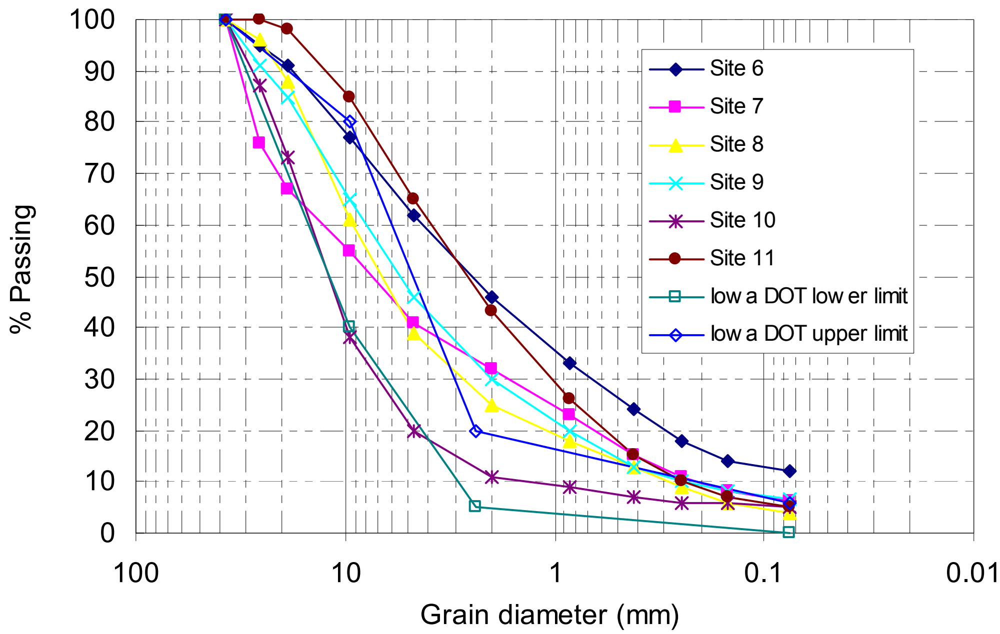


Figure 3. Gradation of RPCC samples obtained from test sites 6-11

Table 11. Gradation of RPCC samples obtained from test sites 6-11

Sieve		Percent of passing							
Sieve No.	**Size, mm.**	**Tested site 6**	**Tested site 7**	**Tested site 8**	**Tested site 9**	**Tested site 10**	**Tested site 11**	**Iowa DOT lower limit**	**Iowa DOT upper limit**
1 1/2 in.	37.50	100	100	100	100	100	100	100	100
1 in.	25.40	95	76	96	91	87	100	-	-
3/4 in.	19.00	91	67	88	85	73	98	-	-
1/2 in.	12.70	-	-	-	-	-	-	-	-
3/8 in.	9.510	77	55	61	65.0	38	85	40	80
4	4.760	62	41	39	46.0	20	65	-	-
8	2.360	-	-	-	-	-	-	5.0	20 (*)
10	2.000	46	32	25	30.0	11	43	-	-
20	0.850	33	23	18	20.0	9	26	-	-
40	0.420	24	15	13	13.0	7	15	-	-
60	0.250	18	11	9	10.0	6	10	-	-
100	0.149	14	8	6	8.0	6	7	-	-
200	0.075	12.0	6.3	4.0	6.6	5	5.2	0.0	6.0

(*)—The gradation requirement for the No. 8 sieve shall be 5% to 20% when recycled material is supplied.

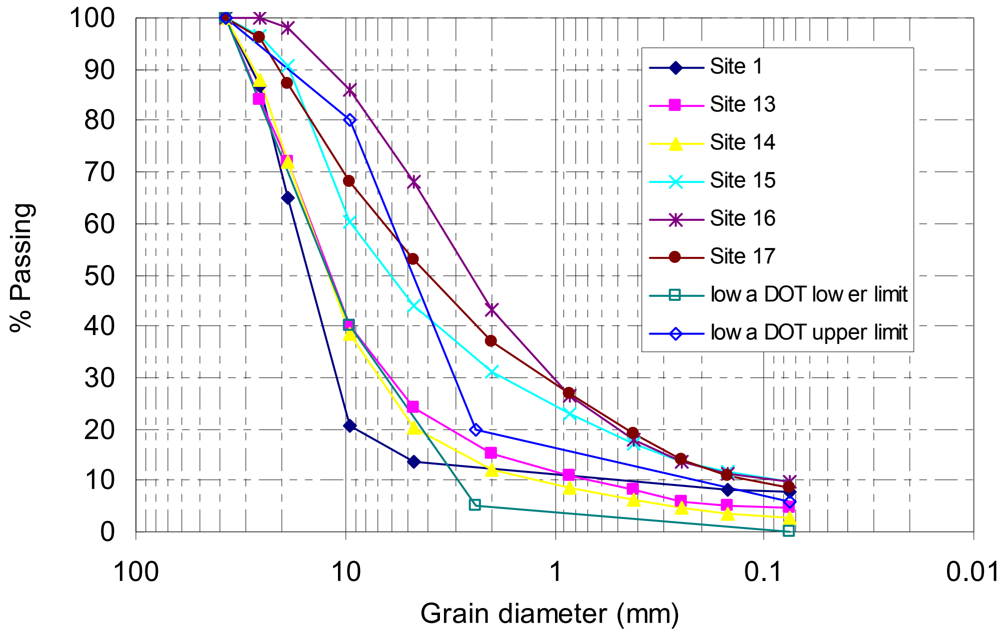


Figure 4. Gradation of RPCC samples obtained from test sites 1, 13-17

Table 12. Gradation of RPCC samples obtained from test sites 1, 13-17

Sieve		**Percent of passing**							
Sieve No.	**Size, mm.**	**Tested site 1**	**Tested site 13**	**Tested site 14**	**Tested site 15**	**Tested site 16**	**Tested site 17**	**Iowa DOT lower limit**	**Iowa DOT upper limit**
1 1/2 in.	37.50	100	100	100	100	100	100	100	100
1 in.	25.40	87	84	88	97	100	96	-	-
3/4 in.	19.00	65	72	72	91	98	87	-	-
1/2 in.	12.70	-	-	-	-	-	-	-	-
3/8 in.	9.510	21	40	38	60.1	86	68	40	80
4	4.760	14	24	20	43.9	68	53	-	-
8	2.360	-	-	-	-	-	-	5.0	20 (*)
10	2.000	-	15	12	31.0	43	37	-	-
20	0.850	-	11	8	22.8	26	27	-	-
40	0.420	-	8	6	17.2	18	19	-	-
60	0.250	-	6	5	13.7	14	14	-	-
100	0.149	8.1	5	4	11.7	11	11	-	-
200	0.075	7.9	4.5	2.7	9.6	10	8.4	0.0	6.0

(*)—The gradation requirement for the No. 8 sieve shall be 5% to 20% when recycled material is supplied.

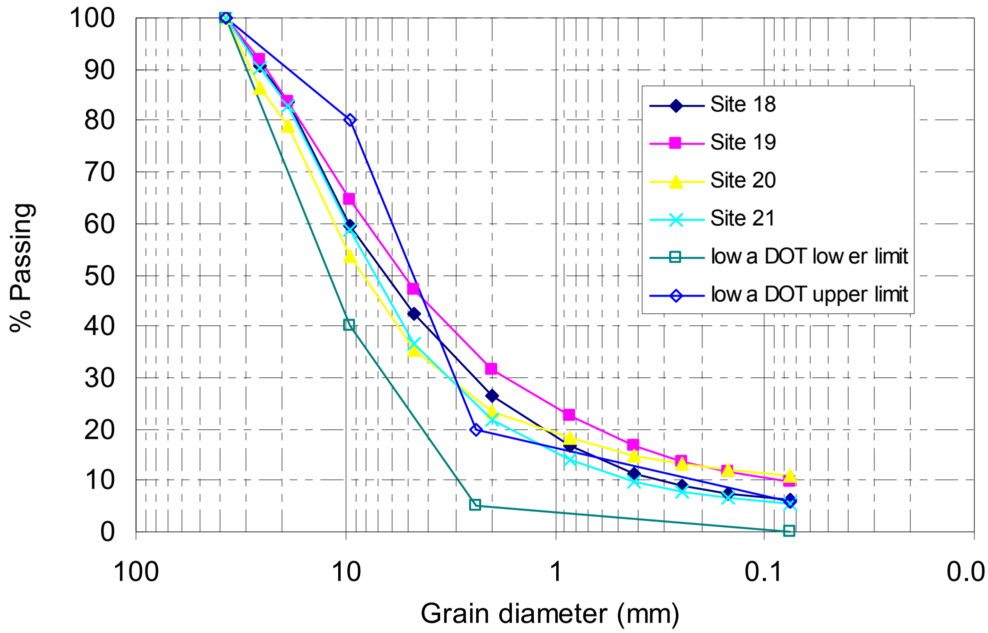


Figure 5. Gradation of RPCC samples obtained from test sites 18-21

Table 13. Gradation of RPCC samples obtained from test sites 18-21

Sieve		Percent of passing					
Sieve No.	**Size, mm.**	**Tested site 18**	**Tested site 19**	**Tested site 20**	**Tested site 21**	**Iowa DOT lower limit**	**Iowa DOT upper limit**
1 1/2 in.	37.50	100	100	100	100	100	100
1 in.	25.40	91	92	86	90	-	-
3/4 in.	19.00	84	84	79	83	-	-
1/2 in.	12.70	-	-	-	-	-	-
3/8 in.	9.510	60	64	54	58.9	40	80
4	4.760	42	47	35	36.7	-	-
8	2.360	-	-	-	-	5.0	20 (*)
10	2.000	26	31	23	21.8	-	-
20	0.850	17	23	18	13.9	-	-
40	0.420	11	17	15	9.7	-	-
60	0.250	8.8	14	13	7.7	-	-
100	0.149	7.4	12	12	6.5	-	-
200	0.075	6.1	9.6	10.8	5.3	0.0	6.0

(*)—The gradation requirement for the No. 8 sieve shall be 5% to 20% when recycled material is supplied.

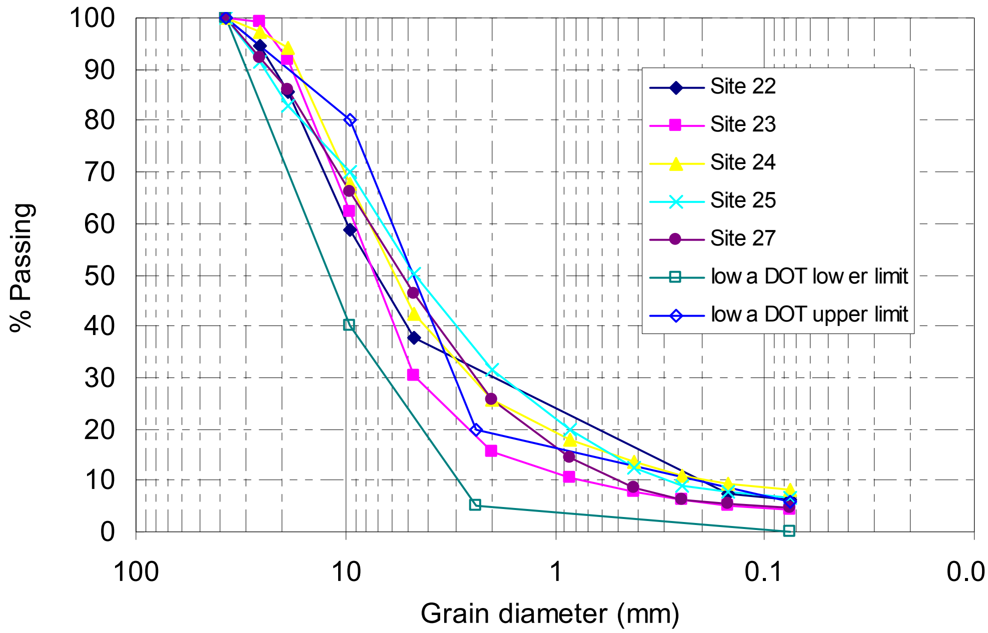


Figure 6. Gradation of RPCC samples obtained from test sites 22-25, 27

Table 14. Gradation of RPCC samples obtained from test sites 22-25, 27

Sieve		Percent of passing						
Sieve No.	**Size, mm.**	**Tested site 22**	**Tested site 23**	**Tested site 24**	**Tested site 25**	**Tested site 27**	**Iowa DOT lower limit**	**Iowa DOT upper limit**
1 1/2 in.	37.50	100	100	100	100	100	100	100
1 in.	25.40	94	99	97	91	92	-	-
3/4 in.	19.00	86	92	94	83	86	-	-
1/2 in.	12.70	-	-	-	-	-	-	-
3/8 in.	9.510	59	62	68	70.2	66	40	80
4	4.760	38	30	43	50.1	46	-	-
8	2.360	-	-	-	-	-	5.0	20 (*)
10	2.000	-	15	26	31.5	26	-	-
20	0.850	-	11	18	20.0	14	-	-
40	0.420	-	8	13	12.4	8	-	-
60	0.250	-	6	11	9.1	6	-	-
100	0.149	7.5	5	9	7.6	5	-	-
200	0.075	6.2	4.1	8.3	6.6	5	0.0	6.0

(*)—The gradation requirement for the No. 8 sieve shall be 5% to 20% when recycled material is supplied.

Table 15 shows that virgin aggregate materials from different projects classified as GP-GM. RPCC aggregate material vary from either poorly or well-graded sand to gravel.

Table 15. Summary of projects and engineering properties

I.D. No.	USCS	AASHTO	D_{10}	D_{30}	D_{60}	c_c	c_u
1	GP-GM	A-1-a	0.60	-	-	12.2	30.0
2*	GP-GM	A-1-a	0.14	3.05	10.28	6.5	74.1
3*	GP-GM	A-1-a	0.25	4.61	12.23	7.0	48.8
4*	GP-GM	A-1-a	0.06	4.78	12.91	31.4	228.8
5*	GP-GM	A-1-a	0.46	6.43	13.00	6.9	28.0
6	GW-GM	A-1-a	0.11	1.24	6.56	2.2	61.5
7	GP-GM	A-1-a	0.23	1.63	13.69	0.9	59.8
8	GP	A-1-a	0.30	3.05	9.30	3.3	31.1
9	GW-GM	A-1-a	0.27	2.00	8.16	1.8	30.3
10	GW-GM	A-1-a	1.46	7.56	15.09	2.6	10.3
11	SW-SM	A-1-a	0.26	1.06	3.95	1.1	15.2
12*	GP-GM	A-1-a	-	4.47	12.11	-	-
13	GP	A-1-a	0.69	6.72	14.90	4.4	21.8
14	GW	A-1-a	1.25	7.36	15.36	2.8	12.3
15	GP-GM	A-1-a	0.09	1.83	9.50	4.2	111.7
16	SP-SM	A-1-a	0.09	1.06	3.59	3.5	40.3
17	GW-GM	A-1-a	0.12	1.15	6.66	1.7	55.6
18	GW-GM	A-1-a	0.33	2.50	9.62	2.0	29.1
19	GP-GM	A-1-a	0.09	1.79	8.06	4.6	93.0
20	GP-GM	A-1-a	-	3.47	11.24	-	-
21	GW-GM	A-1-a	0.45	3.51	9.83	2.8	22.0
22	GP-GM	A-1-a	0.33	3.18	9.88	3.1	29.8
23	GP-GM	A-1-a	0.75	5.37	11.54	3.3	15.4
24	GP-GM	A-1-a	0.19	2.71	7.95	5.0	42.8
25	GW-GM	A-1-a	0.30	1.82	6.56	1.7	21.8
26*	GP-GM	A-1-a	0.12	3.53	9.59	11.2	82.6
27	GW	A-1-a	0.54	2.48	7.77	1.5	14.5

*: Projects with virgin aggregate materials

3.3 Micro-Deval Test for Material Abrasion

3.3.1 Test Procedure and Modification

Micro-Deval tests were conducted on three types of aggregate materials, including crushed limestone, RPCC, and gravel, using a modified testing method. The amount of collected sample from the field investigations was limited and did not meet the requirements of the standard both in total weight and each grain-size weight. Thus, a modified method was developed based on ASTM D6928-06, "Standard Tests Method for Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus" for the reduced sample sizes. In the modified method, the amount of material and steel ball were reduced to half the amount of those in the standard.

Figure 7. Micro-Deval testing machine in PCC laboratory, Iowa State University

3.3.2 Test Result and Analysis

The results of six model tests following the modified procedure and ASTM D6928-06 are shown in Table 16. The abrasion loss of the material conducted by the modified tests was determined to be 55% to 80% of the abrasion loss conducted following the standard procedures ASTM D6928-06. This was based on testing gravel and crushed limestone, respectively. An adjustment to the measured values was thus applied to report a possible range of values from the modified test procedure.

Table 16. Abrasion loss of modified and standard Micro-Deval model tests

Sample No	Material Type	Testing Type	Grading Group	Percent Loss:
1	Crushed Lime	ASTM	Group 2	35
2	Crushed Lime	Modified	–	25
3	Crushed Lime	ASTM	Group 1	31
4	Gravel	ASTM	Group 3	10
5	Gravel	Modified	–	5
6	Gravel	Modified	–	6

Modified Micro-Deval tests were conducted with subbase material aggregates collected from 26 projects. Results of the tests showed that the abrasion losses of RPCC are higher than those of crushed limestone aggregates. Based on the model tests, a range of abrasion loss for aggregate material of each project was calculated (Table 17).

Table 17. Abrasion loss of aggregate materials using modified Micro-Deval tests

Project I.D.	Measured % loss	Estimated range of percent loss[a] Minimum (%)	Maximum (%)
1	-	-	-
2*	10	13	19
3*	15	19	27
4*	14	17	25
5*	9	11	17
6	19	24	35
7	23	29	43
8	24	30	44
9	31	39	57
10	21	26	38
11	18	23	33
12*	18	22	32
13	13	16	23
14	15	19	27
15	36	45	65
16	27	34	49
17	24	29	43
18	26	32	47
19	26	32	47
20	32	41	59
21	20	25	36
22	25	31	45
23	20	25	36
24	31	39	57
25	20	25	36
26*	15	19	28
27	24	31	44
Average:	21	27	39
Standard deviation:	7	9	12

[a]: minimum and maximum percent loss is estimated based on the maximum and minimum loss of materials in modified tests – measured value/ 0.55 (max) and % and measured value/ 0.80 (min)

*: projects with virgin aggregate materials

Table 17 shows that the calculated minimum and maximum abrasion losses of virgin aggregate materials were lower than 30%, which is the maximum loss recommended by

ASTM D6928-06. Thus, virgin aggregate met the requirement of Micro-Deval abrasion loss. In contrast, there was only one RPCC sample from site No. 13 that had a calculated maximum abrasion loss lower than 30%. The maximum abrasion losses of 19 other RPCC samples exceeded 30%. Ten out of the 19 RPCC samples had calculated minimum abrasion losses exceeding 30%. The minimum losses of the other nine RPCC samples were lower than 30%. These values ranged from 18.7% to 29.5%. In general, abrasion losses of RPCC aggregate materials were normally higher than the maximum Micro-Deval abrasion loss suggested by the ASTM D 6928-06.

4. FIELD INVESTIGATION OF PAVEMENT SUBBASE

4.1 Introduction

The field investigation was the main focus of this research. A summary of all field investigation results are provided in the Appendix. Twenty-seven visits were made to twenty-six sites throughout 2007. A list of sites, including location, subbase types, construction date, etc. was created for reference. A field trip was normally arranged one week in advance. Local Iowa DOT offices were contacted to set up traffic control. Field tests were mostly conducted in the travel lanes.

A set of five core holes, including four 4-inch and one 10-inch core, was created for each test site. Test holes were cored every other pavement slab. In order to minimize damage to the patch by traffic, core holes were normally cut in the middle of the panels.

Figure 8. Coring and preparation for field tests

A series of field tests were conducted on the subbase and subgrade layers through core holes. One 4-in. hole was used to conduct a permeability test. DCP tests were conducted in the other three 4-in. holes. Subbase samples were collected from the 4-in. holes after the tests were completed. Lightweight deflectometer (LWD) and Clegg impact hammer tests were conducted on the surfaces of subbase and subgrade layers in the 10-inch core hole. Two or three DCP tests were also conducted in the 10-inch hole after the LWD and Clegg hammer tests. Thus, the DCPs in the 10-inch hole were tested from the subgrade surface.

After the 10-inch hole was cored, the subbase surface was leveled and kept to the original condition as much as possible for LWD and Clegg hammer tests. Silica sand was also used in many cases to increase the contact between the LWD and testing surface. The Clegg hammer tests were conducted after the LWD test on the subbase surface. Silica sand was not used for the Clegg hammer tests.

Figure 9. 10-in. core hole before and after sampling; 10-in. PCC core

Subbase aggregate material from the 10-inch core hole was collected after the LWD and Clegg hammer tests on the subbase surface were completed. Aggregate material samples were then used to conduct the laboratory index tests.

4.2 Test Methods

4.2.1 Dynamic Cone Penetrometer (DCP)

DCP tests (See Figure 10) were conducted in accordance with ASTM D6951, Standard Test Method for Use of Dynamic Cone Penetration in Shallow Pavement Applications. CBR values were estimated by using Penetration Index (PI) (mm/blow).

Figure 10. Dynamic cone penetrometer (DCP) test

4.2.2 Light Weight Deflectometer (LWD)

Keros LWD was used to measure the in situ elastic modulus. The loading plate diameter was 200 mm and the drop height was set at a constant height of 700 mm. Based on the force applied to the plate, its contact area and deflection, LWD elastic modulus (E_{LWD}) was calculated using elastic half-space theory. The LWD devices is shown in Figure 11.

Figure 11. Lightweight deflectometer (LWD) test

The application of a concentrated vertical load to a horizontal surface of the subbase layer produces vertical stresses in the layer. Pressure distribution of the stresses is represented by a bell- or dome- shaped space (Terzaghi and Peck 1967), depending on the plate type (rigid or flexible) and material type. Modulus of elasticity is calculated using the following equation:

$$E = \frac{f(1-\upsilon^2)\sigma_o a}{d_o}, \quad (1)$$

where: E = modulus of elasticity (MPa), d_o = deflection (mm), υ = Poisson's ratio, σ_o = applied stress at surface (MPa), a = radius of the plate (mm), f = shape factor depending on stress distribution

The shape factor f depends on type of plate (rigid or flexible) and soil type. The Keros LWD device used for the project was assumed rigid. Based on the study of Vennapusa and White (2008), shape factors for subgrade soils, which are elastic materials, and subbase aggregate materials are $\pi/2$ and 8/3, respectively. Poisson's ratio of 0.4 was applied for the calculations.

4.2.3 Clegg Impact Hammer

Clegg impact hammer tests were conducted in accordance with ASTM D5874-02, Standard Test Method for Determination of Impact Value (IV) of a Soil. The Clegg impact hammer uses a drop weight and an accelerometer to indirectly determine stiffness at the surface (see

Figure 12). This is a simple and rapid in situ test that can be conducted on base/subbase and subgrade materials. Clegg impact value (IV) is measured as the rebound of the fourth blow of a standard 4.5 kg hammer.

Different correlation between CBR and IV were proposed using empirical relationships depending on types of materials. Clegg (1986) proposed the relationship:

$$CBR = (0.24\ CIV+1)^2, \quad (2)$$

This relationship is suitable for evaluating CBR of soils. However, for coarse aggregates like crushed limestone or sand with non-plastic fines, this relationship seems to provide high value of CBR. Al-Amoudi et al. (2002) proposed alternative correlations between IV and CBR for GM and SM, respectively, as follows:

$$CBR = 0.861(CIV)^{1.136}, \quad (3)$$

$$CBR = 1.3577(CIV)^{1.011}, \quad (4)$$

In this study, equations (3) and (4) were used to calculate CBR values for subbase materials; and equation (2) was used to calculate CBR for subgrade layers.

Figure 12. Clegg impact hammer test

4.2.4 Permeability Test

In determining the permeability of the subbase layer, a unique permeameter was used to measure the saturated hydraulic conductivity. This apparatus allows water to infiltrates into a subsurface material under a constant head. The infiltration rate with time is converged to a steady value (Clyne et al. 2001).

At each site a 4-inch hole was cored through the PCC pavement to the surface of subbase layer. A hand auger was then used to excavate a hole in the subbase material to its mid-depth or at least 6 inches. The diameter of the hole is roughly 4 inches. The hole was filled with water and then monitored for a period of time to allow saturatation of the subbase material (see Clyne et al. 2001). After the saturation period, the remaining water in that hole was removed by cloth. The permeameter was then placed in the well hole and kept upright. The air tube of the permeameter was lifted allowing water to flow into the granular subbase layer. The water flowed out of the permeameter under a constant head. The flow rate was measured at regular time intervals until a steady condition was reached. This steady flow rate was then used to calculate the hydraulic conductivity (Clyne et al. 2001).

Figure 13. Permeability test using Mn/DOT permeameter

The permeability tests were conducted with two successive head measurements of 5 cm and 10 cm. Saturated hydraulic conductivity using the GP-L model was calculated by the following equation:

$$k_{fs} = \frac{CQ}{2\pi H^2 [1 + \frac{C}{2}\left(\frac{a}{H}\right)^2}, \quad (5)$$

where C is the shape factor. Optimum shape factor for use in the GP-L model, C, is

$$C = 0.0046\left[\frac{H}{a}\right]^2 + 0.0318\left[\frac{H}{a}\right] - 0.0087, \quad (6)$$

a is radius of well, a is roughly 5 cm, H is head measurement, Q is flow rate.

4.3 Test Results

Field test results of subbase and subgrade modulus of elasticity obtained from LWD tests, CIV, and CBR are summarized in Table 18. The modulus of elasticity was highly variable. Among RPCC materials, the maximum value of modulus of elasticity was up to 20 times greater than the minimum value.

Table 18. Summary of modulus of elasticity, Clegg impact and CBR values

Site	E_{LWD} (Mpa)		Subbase			Subgrade		
I.D.	Subbase	Subgrade	CIV	CBR[a]	CBR[b]	CIV	CBR[a]	CBR[b]
1	206	33	17	22	45	14	19	18
2*	108	-	30	41	25	-	-	9
3*	43	-	22	29	18	-	-	11
4*	131	-	38	54	51	-	-	14
5*	92	-	27	36	30	-	-	18
6	90	47	37	52	22	-	-	6.5
7	129	-	36	50	42	15	22	14
8	123	42	48	70	36	19	30	12
9	629	-	110	100**	100**	-	-	13
10	322	64	74	100**	85	33	80	14
11	186	34	53	75	62	14	19	15
12*	547	140	39	55	62	9	10	8
13	535	60	38	54	85	10	12	14
14	-	-	-	-	33	-	-	15
15	2126	-	125	100**	100**	-	-	8
16	1188	-	77	100**	100**	-	-	-
17	658	59	49	72	39	15	21	8
18	297	44	39	55	100	16	24	28
19	1188	-	163	100**	100**	-	-	9
20	1937	-	638	100**	100**	-	-	48
21	298	40	59	88	85	20	35	33
22	258	-	33	46	85	-	-	20
23	1185	-	93	100**	85	-	-	18
24	517	-	138	100**	62	-	-	22
25	391	150	115	100**	85	99	100	18
26*	442	-	143	100**	85	-	-	14
27	277	80	83	100**	85	98	100	22
Average:	535	66	89	73	67	30	39	16
Standard deviation:	554	39	119	27	28	32	34	9

*: subbase material is virgin aggregate; **: converted value is higher than 100; [a]: CBR is converted from CIV obtained from Clegg impact hammer tests; [b]: CBR is converted from PI obtained from DCP tests

For design purposes, the support of subgrade and subbase is defined in terms of subgrade reaction (*k*). It is the ratio of the stress in pounds per square inch on a loaded area and the deflection in inches for that load. The load area is a 30-in. diameter plate. The *k* values are normally expressed as pounds per cubic inch (pci) (PCA 1984). The LWD values provide a measurement of the dynamic k values. Results are summarized in Table 19. These values are much higher than typically used in design and are not considered reliable design values. More research is needed to understand why these values are so high.

Table 19. Estimated k-composite values from LWD measurements

Site	LWD measurements		Composite modulus k	
I.D.	Stress, kPa	Deflection, µm	MPa/m	pci
1	—	—	—	—
2	386	18	21093	77706
3	216	659	329	1210
4	238	168	1421	5234
5	224	467	481	1772
6	261	383	681	2510
7	267	247	1083	3988
8	261	252	1036	3816
9	267	56	4775	17591
10	273	101	2710	9983
11	261	185	1411	5197
12	261	63	4143	15262
13	267	66	4053	14931
14	—	—	—	—
15	257	16	16113	59358
16	261	29	9000	33156
17	264	53	4985	18364
18	245	109	2249	8284
19	261	29	9000	33156
20	264	18	14678	54072
21	257	114	2261	8331
22	264	135	1957	7210
23	251	28	8982	33090
24	254	65	3917	14430
25	261	88	2966	10926
26	254	76	3350	12341
27	257	123	2096	7721

Many CIV obtained from many Clegg hammer tests were significantly too high and out of range. Subbase layers in those projects were very stiff. CBR values converted from these CIV were much higher than the normal range of 40–80 and seemed to be unreasonable. In this study, the authors limited CBR values to 100, considering the maximum measured force to be equal to standard force. In general, CBR values obtained from a DCP test were lower than that of the Clegg hammer test.

A summary of the hydraulic conductivity values are provided in Table 20. Results show that the RPCC generally has low permeability at about 1 ft/day.

Table 20. Hydraulic conductivity of subbase layers

Site I.D.	Subbase material	$k_{1\ (5\ cm)}$ (ft/day)	$k_{2\ (10\ cm)}$ (ft/day)
4	Virgin	8.10	19.09
5	Virgin	0.01	0.01
6	RPCC	0.05	0.05
7	RPCC	1.33	1.21
8	RPCC	2.21	1.91
9	RPCC	0.26	0.23
10	RPCC	0.32	0.00
11	RPCC	0.44	0.34
14	RPCC	3.09	4.77
15	RPCC	0.02	0.02
16	RPCC	0.04	0.04
17	RPCC	1.51	0.39
18	RPCC	0.18	0.20
19	RPCC	0.03	0.13
20	RPCC	1.66	1.86
21	RPCC	0.37	0.31
22	RPCC	0.55	0.54
23	RPCC	0.17	0.20
24	RPCC	1.18	1.59
25	RPCC	3.31	5.14
26	Virgin	0.07	0.07
27	RPCC	0.46	0.73
Average:		1.15	1.77
Standard deviation:		1.84	4.13

5. INTERSTATE I-80 IN CEDARS COUNTY

5.1 Site Description

Interstate I-80 in Cedar County from mile marker 266 to 278.5 was divided into four sections and constructed in 1991 and 1992 using RPCC for the subbase layer. These sections were paved at the same time (oral communication between Dr. Chuck Jahren and Rodger Boulet). Paving sections, subbase tested areas during construction period with dates, and tested sites in recent field investigation are shown in Figure 14. This figure was drawn based on the "Permeability of Granular Subbase Materials" report and the communication between Dr. Chuck Jahren and Rodger Boulet regarding the Cedar County Project.

At the beginning of the project, an agreement was made between Iowa DOT and the contractor to make changes in the gradation of granular subbase material and to evaluate the effects on permeability (Miyagawa 1991). Five one-mile test areas were conducted on the subbase layer from mile marker 266 eastbound lanes (oral communication between Dr. Chuck Jahren and Rodger Boulet regarding the Cedar County Project). Experimental areas are as follows

Area 1–The first one-mile area of subbase applied the regular Iowa specification of 100% passing the 1 inch sieve and 10%–35% passing sieve No. 8. Field tests were conducted and showed that the material was draining very poorly.

Area 2–The second mile area of subbase involved changing the gradation so that 100% of the material was passing the 1.5 inch sieve and the maximum amount of 25% passing sieve No. 8. The permeability was slightly improved but still relatively low.

Area 3–In the third mile area, the roller pattern was changed to a maximum of four passes with static steel drum roller. This roller pattern was used on the rest of the project.

Area 4–In the fourth mile area, subbase material was produced with special care to avoid disturbing the old base material of the existing pavement. The material passing sieve No. 8 was controlled around 20%–23%. In place gradation tests showed that the amount of breakdown resulting from this new procedure was significantly decreased. The compacted subbase material had 25.7% passing sieve No. 8 (Miyagawa 1991).

Area 5–In the fifth mile, subbase material passing sieve No. 8 was controlled to less than 20%. This gradation was used on the rest of the project. This last change resulted in the production of fines or "fluff."

These experimental areas roughly cover the first two sections paved in 1991 from milepost 266.00 to milepost 272.50, in the eastbound lane. A letter dated on 10/17/1991 allows the use of screenings as a 2 in. blanket placed under the subbase. The first 2 in. blanket of fines was placed on 4/28/1992. This blanket was used on all the remaining sections of the project.

5.2 Analysis of Result

In 2007, the research team conducted tests at eight sites (Figure 14). Test results from site 18, which was conducted in area A4, were used to compare with results and corresponding specification of gradation obtained from area A4. Other test sites were conducted in the sections that applied the gradation used for area A5; their results were compared with specification gradation and test results of area A5.

A significant breakdown of RPCC subbase aggregate material due to compaction can be interpreted from Figure 15. The grain-size distribution of the material in the stockpile was close to the upper limit gradation applied for this area. Three in-place samples were tested after the subbase layer was compacted by a roller. The gradations of these samples varied through the gradation limits. The number of fines significantly increased. The gradation curve of the material obtained from site 18 was similar with the curve in place 1 and was close to the lower gradation limit. However, there is no clear indication that more RPCC aggregate material was broken down under the traffic loads (Figures 15 and 16).

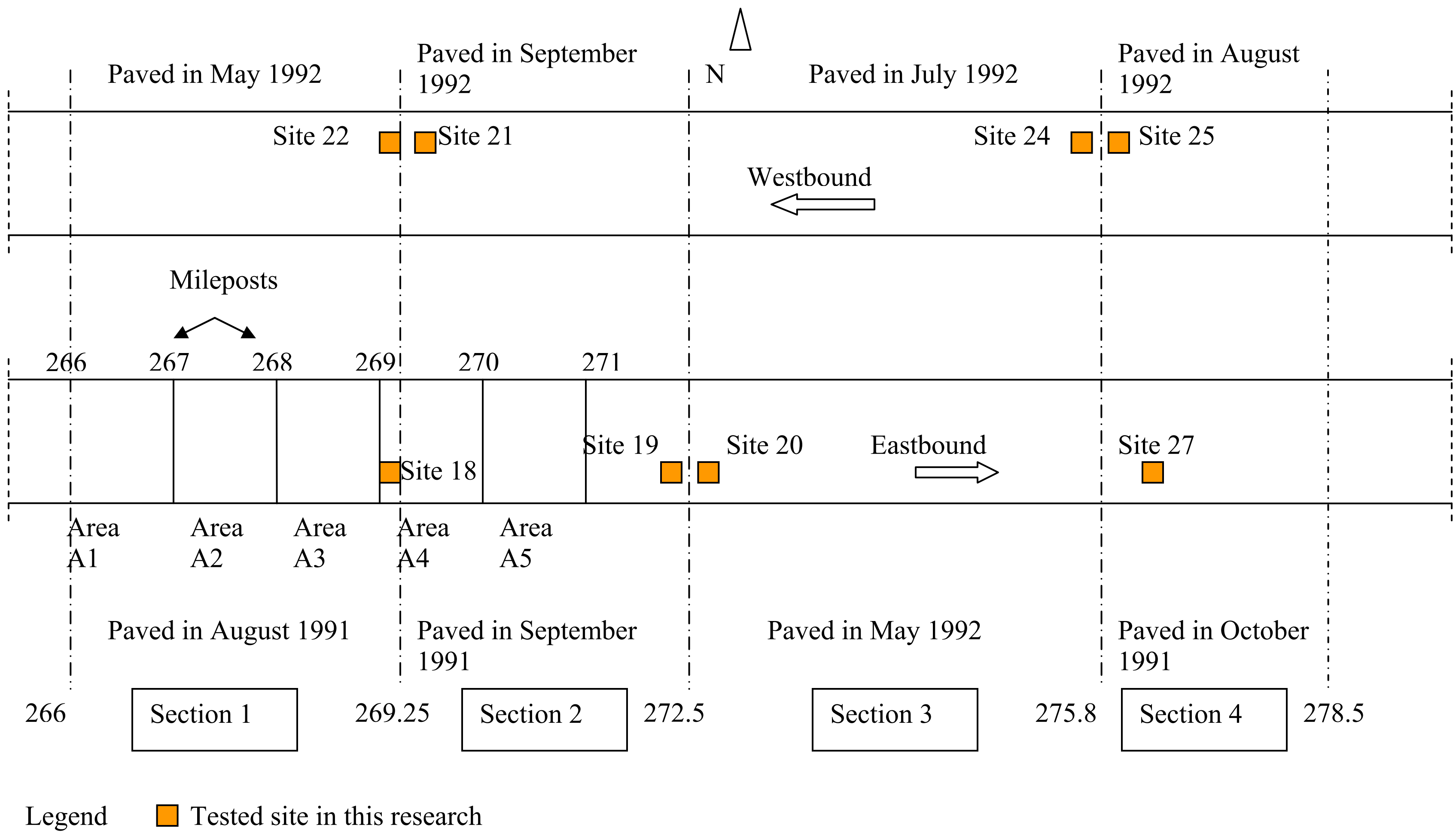


Figure 14. Experimental areas and paving sections during construction period; tested sites

Table 21. Grain-size distribution of samples from test site 18 and area A4

Sieve		Percent of passing						
Sieve no.	Size, mm.	Stockpile	In-place 1	In-place 2	In-place 3	Tested site 18	Iowa DOT lower limit	Iowa DOT upper limit
1 ½ in.	37.500	100	100	100	100	100	100	100
1 in.	25.400	88	94	96	94	91	-	-
3/4 in.	19.000	72	82	90	88	84	-	-
1/2 in.	12.700	54	71	83	77	-	-	-
3/8 in.	9.510	43	59	76	65	60	40	80
4	4.760	29	41	64	47	42	-	-
8	2.360	22	30	48	36	-	10 (*)	25
10	2.000	-	-	-	-	26	-	-
16	1.190	17	23	36	27	-	-	-
20	0.850	-	-	-	-	17	-	-
30	0.595	13	17	27	21	-	-	-
40	0.420	-	-	-	-	11	-	-
50	0.297	9.2	12	18	14	-	0	15
60	0.250	-	-	-	-	8.8	-	-
100	0.149	6.9	9.0	13	10	7.4	-	-
200	0.074	5.5	7.0	10	8.2	6.1	0	6.0

(*): The percent passing the No. 8 sieve was kept from 10% to 25%

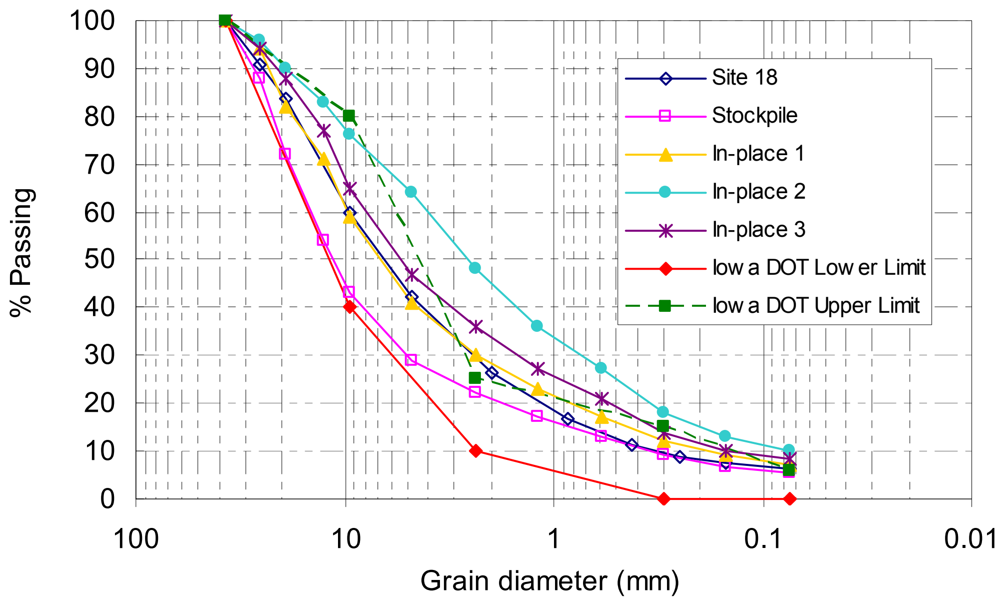


Figure 15. Gradation of materials from test site 18 and area A4

Table 22. Grain-size distribution of samples from test site 19 and area A5

Sieve		Percent of passing						
Sieve No.	Size, mm.	Stockpile	In-place 1	In-place 2	In-place 3	Tested site 19	Iowa DOT lower limit	Iowa DOT upper limit
1 ½ in.	37.500	100	100	100	100	100	100	100
1 in.	25.400	88	94	96	94	92	-	-
¾ in.	19.000	72	82	90	88	84	-	-
½ in.	12.700	54	71	83	77	-	-	-
3/8 in.	9.510	43	59	76	65	64	40	80
4	4.760	29	41	64	47	47	-	-
8	2.360	22	30	48	36	-	10	20 (*)
10	2.000	-	-	-	-	31	-	-
16	1.190	17	23	36	27	-	-	-
20	0.850	-	-	-	-	23	-	-
30	0.595	13	17	27	21	-	-	-
40	0.420	-	-	-	-	17	-	-
50	0.297	9.2	12	18	14	-	0	15
60	0.250	-	-	-	-	14	-	-
100	0.149	6.9	9.0	13	10	12	-	-
200	0.074	5.5	7.0	10	8.2	9.6	0	6.0

(*): The upper limit of percent passing the No. 8 sieve was reduced to 20%

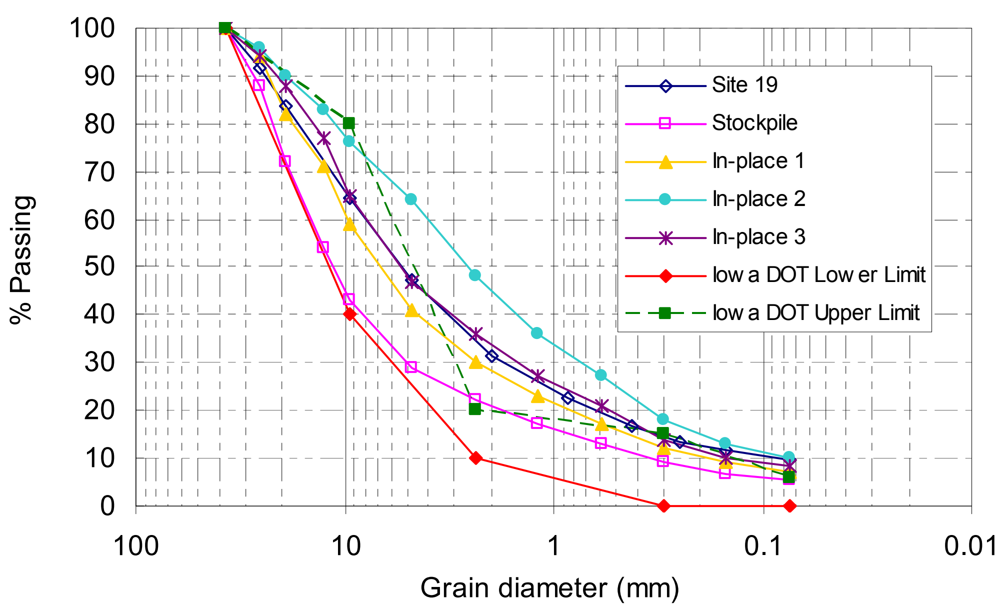


Figure 16. Gradation of materials from test site 19 and area A5

5.3 In situ Permeability

In situ testing of hydraulic conductivity was completed during the construction period and during the reported field investigations, although different methods were used. During the construction period, a hydraulic conductivity test was performed by filling water into a 4 in. diameter hole in the subbase layer and counting the infiltration rate. According to the report of Miyagawa (1994), the average hydraulic conductivity of the tests on August 8, 1991 on 1.5 inch crushed concrete (4 passes) was 20 ft/day. The report does not indicate which area these tests were conducted in, but it seems to be area A3 since it mentioned "4 passes." The tests on August 13, 1991 on crushed concrete 1.5 inch subbase material might have taken place on area A4 since there was a note of severe segregation of material. The results of hydraulic conductivity varied, but the average value might be around 50 ft/day.

The recent site investigation was made to eight different locations in four sections (two locations per section) on both directions of I-80 from mile marker 266.00 to 278.50 in Cedar County (Figure 14). The field permeameter described earlier was used to perform the hydraulic conductivity test in the subbase material layer. The test results showed that the subbase layer had comparatively very low permeability (Table 23).

Since there is no clear indication that more RPCC aggregate material was broken down under the traffic loads, it is unclear what led to reduction in the permeability of the subbase layer.

Table 23. Hydraulic conductivity of subbase material using Mn/DOT permeameter

Site No.	Subbase material	K_{5cm} (ft/day)	K_{10cm} (ft/day)
18	RPCC	0.2	0.2
19	RPCC	0.0	0.1
20	RPCC	1.7	1.9
21	RPCC	0.4	0.3
22	RPCC	0.6	0.5
24	RPCC	1.2	1.6
25	RPCC	3.3	5.1
27	RPCC	0.5	0.7
Average		1.0	1.3

6. INTERSTATE I-80 IN POLK COUNTY

6.1 Site Description

Interstate I-80 eastbound at mile marker 128.50-128.60 in Polk County has two traveling and one passing lanes. The subbase layer of traveling lanes was constructed in 1994 using RPCC aggregate subbase materials. The passing lane were constructed on virgin aggregate subbase material. Two field trips were conducted to evaluate the traveling and passing lanes (Figure 17).

Figure 17. Test sites 23 and 26 on I 80 eastbound traveling and passing lanes in Polk County

6.2 Test Results

Grain-size distribution of RPCC and virgin materials from sites 23 and 26 are presented in Figure 18 and Table 24. The gradation of RPCC and virgin materials are similar. The amount of fine particles for the virgin material is slightly higher than that of RPCC aggregate material. The amount of virgin particles passing No. 200 is also higher than the upper limit provided by Iowa Standard Specification. Permeability of the subbase layers from both sites were low, though the hydraulic conductivities of RPCC subbase layer were higher than those of virgin material subbase layer (Table 25).

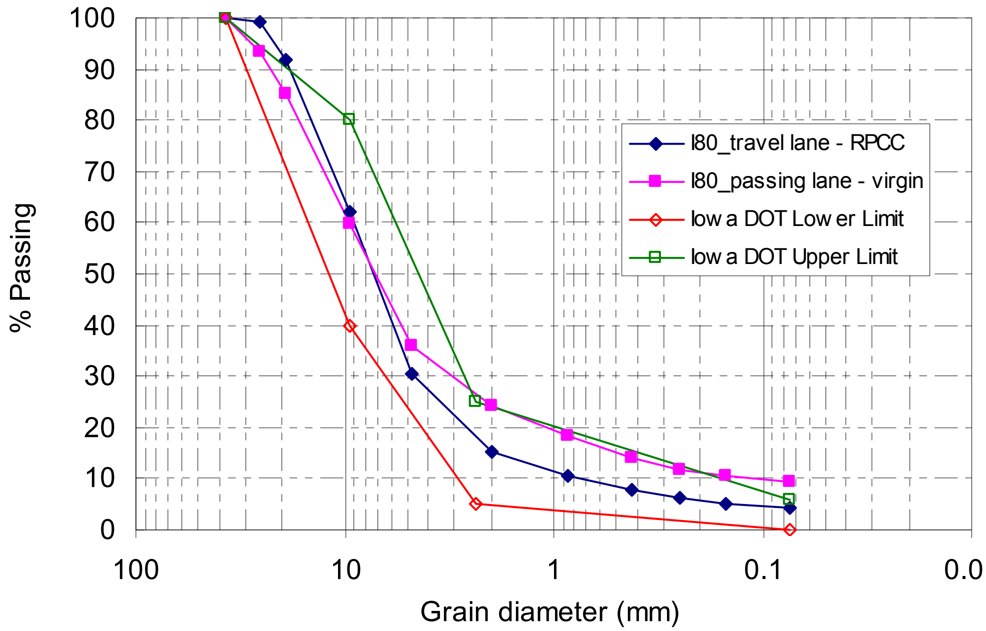


Figure 18. Gradation of aggregate materials from sites 23 and 26

Table 24. Gradation of aggregate materials from sites 23 and 26

Sieve		**Percent of passing**			
Sieve No.	**Size, mm.**	**Tested site 23**	**Tested site 26**	**Iowa DOT lower limit**	**Iowa DOT upper limit**
1 1/2"	37.5	100	100	100	100
1"	25.4	99	94	-	-
3/4"	19.0	92	85	-	-
3/8"	9.51	62	60	40	80
4	4.76	30	36	-	-
8	2.36	-	-	5	25
10	2.00	15	24	-	-
20	0.85	11	18	-	-
40	0.42	8	14	-	-
60	0.25	6	12	-	-
100	0.149	5	10	-	-
200	0.074	4.1	9.4	0	6.0

Table 25. Hydraulic conductivity of subbase material

Site No.	**Subbase material**	**K_{15cm} (ft/day)**	**K_{210cm} (ft/day)**
23	RPCC	0.2	0.2
26	Virgin	0.1	0.1

7. INVESTIGATION OF PAVEMENT SURFACE CONDITION

7.1 Visual Distress Surveys

For this research, visual distress surveys were conducted to gather detailed current pavement surface condition information including the extent and severity of the distress. The distress survey methodology used in this study followed the methodology described in the Strategic Highway Research Program's (SHRP) "Distress Identification Manual for the Long-Term Pavement Performance (LTPP) Project." (Miller and Bellinger 2003).The distress types and severity levels were identified using the Distress Identification Manual and recorded on the distress map sheets with the symbols. Symbols to be used for mapping distresses in test sections are shown in Figure 19, and an example mapped section is presented in Figure 20.

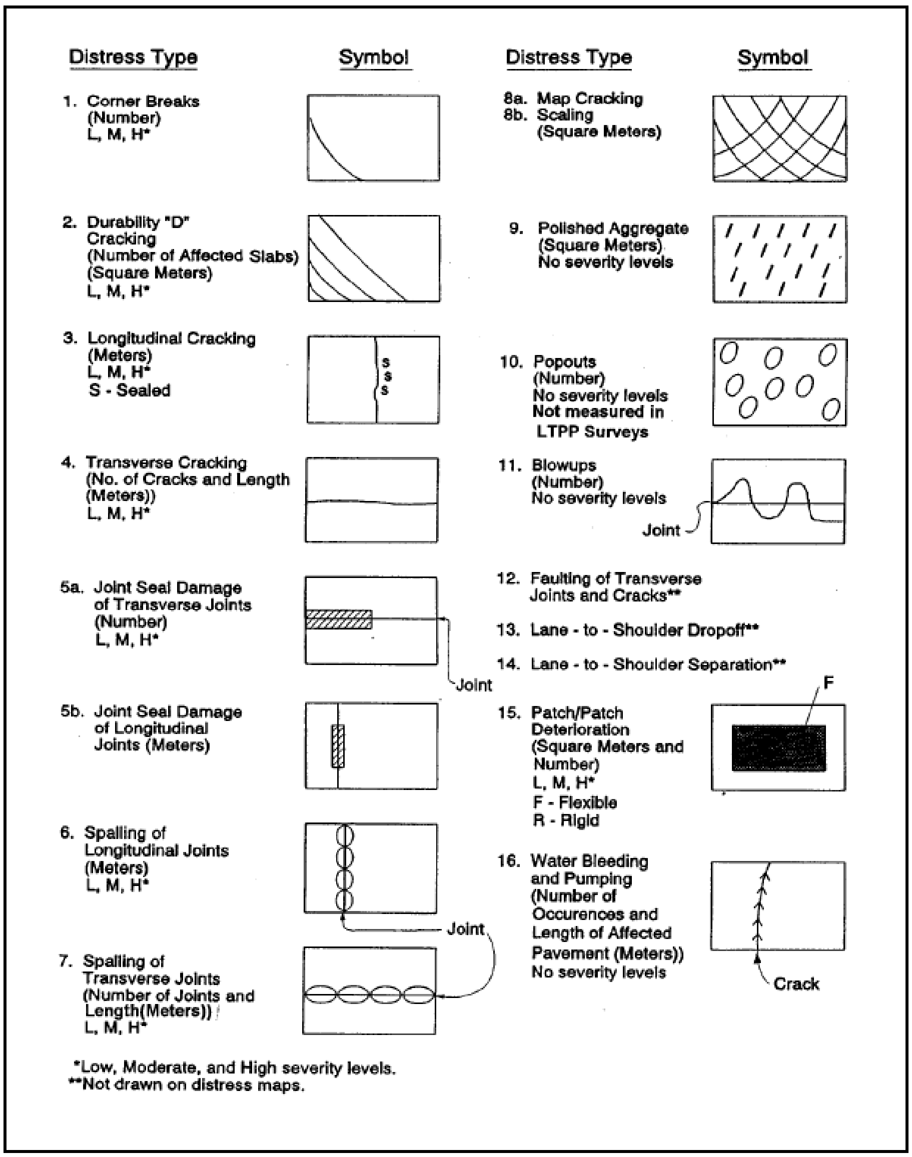


Figure 19. Map symbols for jointed concrete pavements (Miller and Bellinger 2003)

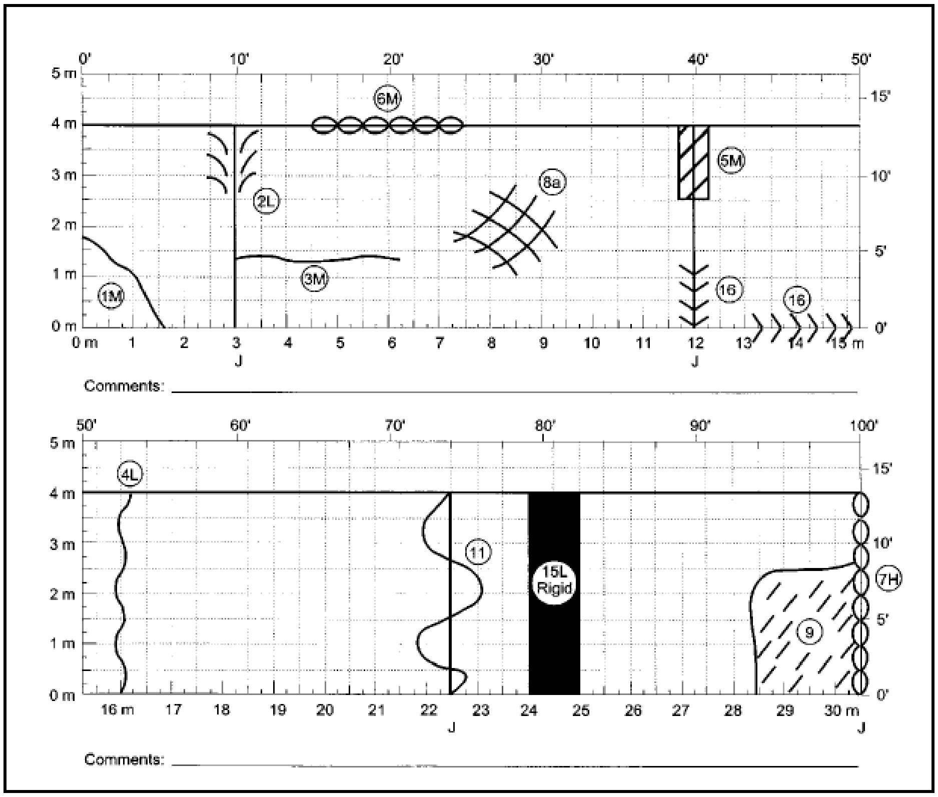


Figure 20. Example distress map (Miller and Bellinger 2003)

7.2 Historical Pavement Surface Condition Information from PMIS

Through visual distress surveys, the current pavement surface condition information could be collected, but not the past history. The current and past pavement surface condition information for the field test sections, from 1992 to 2006, was extracted from the Iowa DOT's Pavement Management Information System (PMIS) to study the changes in pavement surface condition with time. Since Iowa DOT's PMIS has been developed from 1994 for all Federal Aid Eligible (FAE) roads in the State, the pavement condition information before 1992 and for local roads such as Knapp Street in Ames was not available.

7.3 Visual Distress Survey Results

All visual survey distress maps prepared as part of the field evaluation program are provided in Appendix I. The current pavement surface condition information for the surveyed test sections is summarized in Table 26. The total number of distress listed in Table 26 is the sum of the number of distresses identified through the visual distress survey. The types and severities of the distress for each test section are presented in Table 27.

The pavement condition index (PCI) listed in Table 26 is a numerical index, ranging from 0 for a failed pavement to 100 for a pavement in perfect condition, to provide an index of the pavement's structural integrity and pavement surface condition. The International Roughness

Index (IRI) in Table 26 represents the severity of roughness on pavement surface computed from the measured longitudinal pavement profile. The PCI and IRI in this study were obtained from the 2006 Iowa DOT's PMIS.

Table 26. Summary of current pavement surface condition information

I.D. No.	Road	Dir.	Type of subbase	PCC thick	Subbase thick	ADTT (2005)	Constr-uction year	Total No. of distress (2007)	PCI, Percent (2006)	IRI, m/km (2006)
1	Knapp Street, Ames, Iowa (first visit)	W	RPCC	9.3	6.2	N/A*	N/A*	14.0	N/A	N/A
2	US-20 in Webster County: Mile Post No. 122.50–122.55	E	Virgin	11.0	11.4	1,066	1990	7.0	86.0	1.54
3	US-20 in Webster County: Mile Post No. 116.80–121.06	W	Virgin	10.2	10.2	N/A*	2005	N/A*	90.0	N/A*
4	US-30 in Tama County: Mile Post No. 194.35–194.40	E	Virgin	10.0	N/A	N/A	2005	9.0	90.0	N/A
5	I-235 in Polk County (Guthrie Ave): Mile Post No. 10.9–11.0	S	Virgin	13.0	N/A	2,562	2004	24.0	39.0	1.00
6	IA-330 in Marshall County: Mile Post No. 20.05–20.10	S	RPCC	12.0	5.0	N/A	2006	5.0	N/A	N/A
7	I-35 in Story County: Mile Post No. 119.95–120.05	S	RPCC	12.0	6.0	5,074	1999	20.0	93.0	1.50
8	I-35 in Hamilton County: Mile Post No. 140.75–140.80	N	RPCC	10.5	8.0	4,657	2003	16.0	98.0	1.42
9	I-80 in Jasper County: Mile Post No. 165.0–165.05	E	RPCC	13.0	5.0	8,883	1996	46.0	83.0	1.16
10	I-80 in Jasper County: Mile Post No. 165.20–165.25	E	RPCC	13.0	7.0	8,870	1994	18.0	78.0	2.29
11	I-35 in Hamilton County: Mile Post No. 131.40–131.45	N	RPCC	10.5	8.0	4,709	1983	16.0	55.0	1.72
12	IA-92 in Warren County: Mile Post No. 132.16–133.80	E	Virgin	10.0	12.0	254	1993	37.0	90.0	1.44
13	I-80 in Pottawattamie County: Mile Post No. 10.55–10.60	W	RPCC	13.0	11.0	5,421	1999	30.0	92.0	1.87
14	I-80 in Pottawattamie County: Mile Post No. 10.55–10.65	E	RPCC	12.0	N/A	5,421	2003	26.0	99.0	1.42
15	I-80 in Cass County: Mile Post No. 65.10–65.20	E	RPCC	12.0	N/A	7,506	1988	60.0	70.0	1.66
16	I-80 in Cass County: Mile Post No. 65.80–65.90	W	RPCC	12.0	N/A	7,506	1987	25.0	68.0	1.67
17	Knapp Street, Ames, Iowa (second visit)	W	RPCC	9.4	6.7	N/A	N/A	48.0	N/A	N/A
18	I-80 in Cedar County: Mile Post No. 269.00–269.10	E	RPCC	13.0	6.0	10,777	1991	37.0	72.0	1.60
19	I-80 in Cedar County: Mile Post No. 272.30–272.40	E	RPCC	13.0	9.0	10,919	1992	32.0	74.0	1.32
20	I-80 in Cedar County: Mile Post No. 272.55–272.65	E	RPCC	13.0	9.0	10,919	1992	39.0	74.0	1.32
21	I-80 in Cedar County: Mile Post No. 269.30–269.40	W	RPCC	12.5	8.5	10,847	1992	45.0	74.0	1.39
22	I-80 in Cedar County: Mile Post No. 269.10–269.20	W	RPCC	13.0	8.0	10,847	1992	34.0	74.0	1.39
23	I-80 in Polk County: Mile Post No. 128.50–128.55—Travel	E	RPCC	14.0	9.0	13,322	1994	39.0	81.0	1.78
24	I-80 in Cedar County: Mile Post No. 275.70–275.75	W	RPCC	13.0	8.0	10,847	1992	57.0	74.0	1.39
25	I-80 in Cedar County: Mile Post No. 275.90–275.95	W	RPCC	13.0	8.0	10,847	1992	44.0	74.0	1.39
26	I-80 in Polk County: Mile Post No. 128.50–128.60—Passing	E	Virgin	13.5	9.0	13,322	1994	44.0	81.0	1.78
27	I-80 in Cedar County: Mile Post No. 276.60–276.70	E	RPCC	13.5	9.0	10,920	1991	52.0	72.0	1.39

* N/A = Not Available.

Table 27. Summary of visual distress survey results

I.D.	Distress symbol no. / severity / # of distress																																		
	1			2			3			4			5a			5b			6			7			8a	8b	9	10	11	12	13	14	15		16
No	L*	M*	H*	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H									L	M	H
1													6	1		6	1																		
2													4															3							
3**																																			
4													1			2	2															4			
5	1									1	1		1	2			2	1	1	5	3	2	1	3											
6																			3			2													
7																			5	1		8	2					2				2			
8																			2			11						3							
9													2	2					3			6	2					26			1	4			
10													1															9				8			
11													1			2				2		1	2					4			2		2		
12			2										8			11	6	1	5	1		1	1					1							
13			1							4			3						1			3									1	13	3		1
14																						10	3									13			
15											1		5			1			2			10	8	2				2				18			4	7
16													1						2			6						1				15			
17													5	8		6	16	13																	
18													11						1			4						1				20			
19													6			1						1	2					2				20			
20													17			1						1										20			
21													12			6			1			4						1		1		20			
22													3			1						9						1				20			
23															20							1	1					4				13			
24													1	8	8	2	4	5	1			4						4				20			
25														9	2	3	4	2	1	1		2										20			
26													9	3	2				21			6						3							
27													7	8	3	3	5		3			3									1	19			

* L= low severity, M= middle severity, H= high severity.
** = Was not available for conducting visual distress survey

As seen in Table 27, and in Figures 19 and 20, few longitudinal and transverse cracks were observed in the surveyed field test sections. Although a large number of pictures were taken as part of the visual distress survey for individual test sections, some representative pictures are included here which are indicative of the overall conclusion. The predominant distresses exhibited along all the surveyed test sections are joint sealing damage, spalling, and popouts. Especially, the lane-to-shoulder separation and the lane-to-shoulder drop off as shown in Figures 21 and 22, respectively, are more often observed in RPCC test sections than virgin aggregate subbase test sections. These observations are consistent with those reported by Rollings et al. (2006), who concluded that the cause of the distresses between lane and shoulder is probably due to sulfate attack on the RPCC used as fill and base course.

Figure 21. Picture of US-20 (W) pavement section in Webster County (Mile Post No. 122.50–122.55)—virgin aggregate subbase section

Figure 22. Picture of I-80 (E) pavement section in Cedar County (Mile Post No. 276.60–276.70)—RPCC subbase section

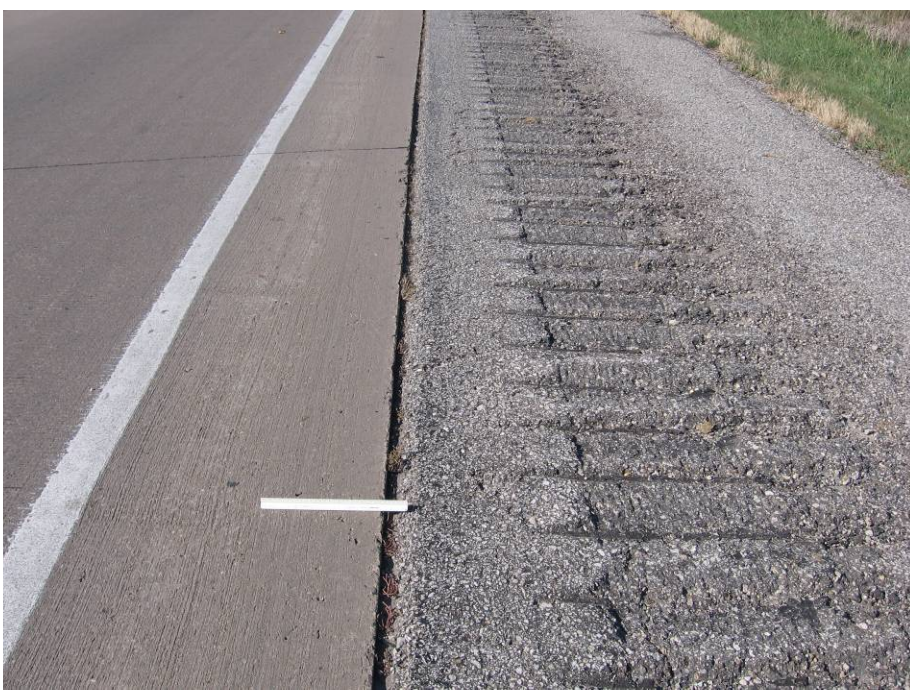


Figure 23. Lane to shoulder separation on I-80 (W) in Cedar County (Mile Post No. 269.30–269.40)—RPCC subbase section

Figure 24. Lane to shoulder drop off on I-35(N) in Hamilton County (Mile Post No. 131.40–131.45)—RPCC subbase section

The traffic volumes and the pavement age affect pavement performance. As a result, it is difficult to evaluate the differences in pavement performance between the RPCC and the virgin aggregate subbase sections using the pavement condition results presented in Table 26. Note that the traffic volume and the construction year of test sections listed in Table 26 are different for different test sections. Also, it is obvious that the surveyed RPCC subbase sections outnumber the virgin subbase sections. To overcome this difficulty, and to enable comparison between the virgin and RPCC subbase sections, two different comparison approaches were employed in this study:

1. Normalize the pavement condition results by traffic volume and by pavement age.
2. Locate a virgin subbase section identical (in terms of pavement condition, traffic volume, construction year, etc.) to the surveyed RPCC subbase section and extract necessary information from Iowa DOT's PMIS for comparison.

7.3.1 Comparison Approach 1: Normalize by Traffic Volume and Pavement Age

The available pavement surface condition results including Total Number of Distress (TOD), PCI and IRI in Table 26 were normalized by traffic volume and by pavement age using the following equations (7), (8), and (9):

$$TOD_{normal} = \frac{TOD}{ADTT \times PA} \times ADTT_{ave} \times PA_{ave} \quad (7)$$

where:
TOD_{normal} = Total number of distress (normalized)
TOD = Total number of distress on the given test section
$ADTT$ = Average daily truck traffic for the given test section
PA = Pavement age for the given test section = the current year - the actual construction year
$ADTT_{ave}$ = Average of ADTT for all test sections = 7997
PA_{ave} = Average pavement age for all test sections = 15 years

$$PCI_{normal} = \frac{PCI}{ADTT \times PA} \times ADTT_{ave} \times PA_{ave} \quad (8)$$

where:
PCI_{normal} = Pavement Condition Index (normalized)
PCI = Pavement Condition Index for a given test section

$$IRI_{normal} = \frac{IRI}{ADTT \times PA} \times ADTT_{ave} \times PA_{ave} \quad (9)$$

where:
IRI_{normal} = International Roughness Index (normalized)
IRI = International Roughness Index for a given test section

Table 28. Summary of current pavement surface condition results (normalized) for virgin aggregate subbase sections

I.D. No.	Project location	Type of subbase	TOD_{normal} (2007)	PCI_{normal}, %(2006)	IRI_{normal}, m/km (2006)
2	US-20 in Webster County: Mile Post No. 122.50–122.55	Virgin	46	566	1.01
5	I-235 in Polk County (Guthrie Ave): Mile Post No. 109–110	Virgin	29	47	0.12
12	IA-92 in Warren County: Mile Post No. 132.16–133.80	Virgin	1,241	3,019	4.83
26	I-80 in Polk County: Mile Post No. 128.50–128.60—Passing	Virgin	30	56	0.12
Average			337	922	1.52

The normalized values associated with existing pavement condition information for both virgin aggregate subbase sections and the RPCC subbase sections are presented in Tables 28 and 29, respectively. The number of pavement sections for both groups are different (4 test sections for virgin aggregate subbase and 18 test sections for RPCC subbase). Thus, it is difficult to compare the pavement condition results of both groups in terms of average. However, the results show that the pavement condition values for individual RPCC subbase sections are similar or even better than those of individual virgin aggregate subbase sections. This indicates that the recycled PCC subbase provides at least similar, if not better performance compared to the virgin aggregate subbase in Iowa pavements and are performing adequately.

Table 29. Summary of current pavement surface condition results (normalized) for RPCC subbase sections

I.D. No.	Project location	Type of subbase	TOD_{normal} (2007)	PCI_{normal}, %(2006)	IRI_{normal}, m/km (2006)
7	I-35 in Story County: Mile Post No. 119.95–120.05	RPCC	59	273	0.44
8	I-35 in Hamilton County: Mile Post No. 140.75–140.80	RPCC	102	628	0.91
9	I-80 in Jasper County: Mile Post No. 165.0–165.05	RPCC	56	101	0.14
10	I-80 in Jasper County: Mile Post No. 165.20–165.25	RPCC	19	81	0.24
11	I-35 in Hamilton County: Mile Post No. 131.40–131.45	RPCC	17	58	0.18
13	I-80 in Pottawattamie County: Mile Post No. 10.55–10.60	RPCC	83	253	0.51
14	I-80 in Pottawattamie County: Mile Post No. 10.55–10.65	RPCC	143	545	0.78
15	I-80 in Cass County: Mile Post No. 65.10–65.20	RPCC	50	59	0.14
16	I-80 in Cass County: Mile Post No. 65.80–65.90	RPCC	20	54	0.13
18	I-80 in Cedar County: Mile Post No. 269.00–269.10	RPCC	26	50	0.11
19	I-80 in Cedar County: Mile Post No. 272.30–272.40	RPCC	23	54	0.10
20	I-80 in Cedar County: Mile Post No. 272.55–272.65	RPCC	28	54	0.10
21	I-80 in Cedar County: Mile Post No. 269.30–269.40	RPCC	33	54	0.10
22	I-80 in Cedar County: Mile Post No. 269.10–269.20	RPCC	25	54	0.10
23	I-80 in Polk County: Mile Post No. 128.50–128.55 – Travel	RPCC	27	56	0.12
24	I-80 in Cedar County: Mile Post No. 275.70–275.75	RPCC	42	54	0.10
25	I-80 in Cedar County: Mile Post No. 275.90–275.95	RPCC	32	54	0.10
27	I-80 in Cedar County: Mile Post No. 276.60–276.70	RPCC	36	49	0.09
Average			46	141	0.24

One of the sub-objectives of this research was to characterize the ride quality and geometric characteristics of the pavement layer for correlation to the subbase properties. In pursuance of this objective, the relation between pavement thicknesses and the normalized pavement surface condition indices for the surveyed field test sections was investigated. Figures 25–27 show TODnormal, PCI normal, and IRI normal values plotted against PCC slab thicknesses, RPCC subbbase thickness and the total thicknesses (sum of PCC slab thickness and RPCC slab thickness). As seen from these figures, there is no definite trend/correlation between pavement ride quality and RPCC subbase/pavement thicknesses.

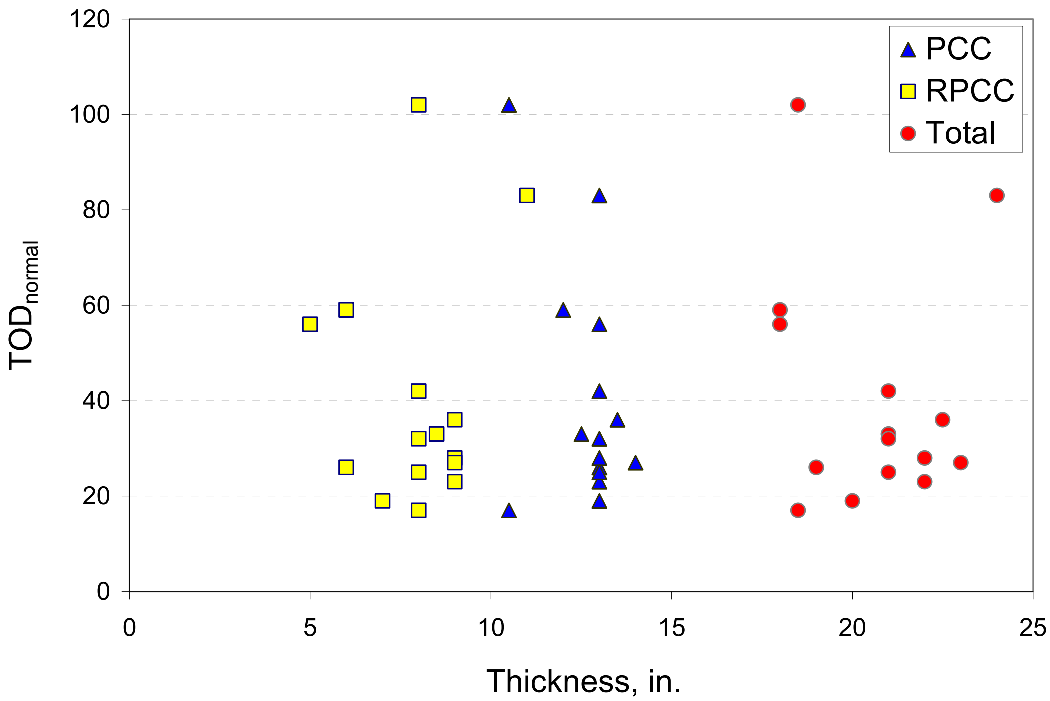


Figure 25. TOD_{normal} versus pavement thickness

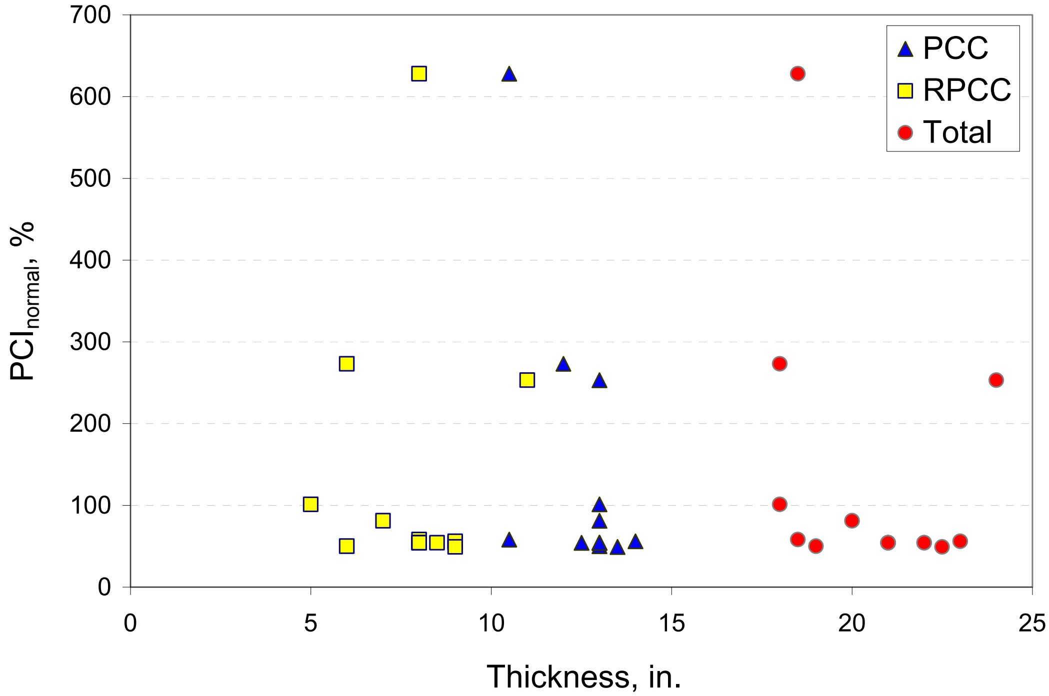


Figure 26. PCI_{normal} versus pavement thickness

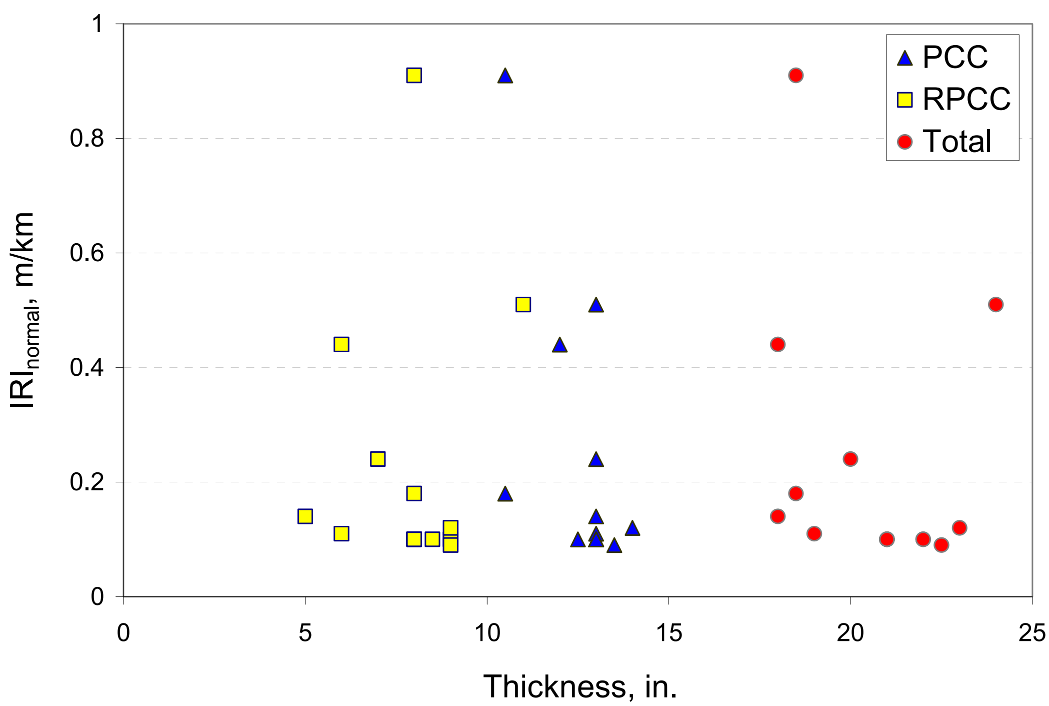


Figure 27. IRI_{normal} versus pavement thickness

7.3.2 Comparison Approach 2: Locating and Extracting Virgin Subbase Sections from Iowa DOT's PMIS Identical to RPCC Subbase Sections

The pavement information data for available virgin aggregate subbase sections in similar conditions to the surveyed RPCC aggregate subbase sections were extracted from Iowa DOT's PMIS. Unfortunately, the Iowa DOT PMIS database does not include subbase type as one of the columns. However, it is expected that virgin subbase sections and RPCC subbase sections along a stretch of highway would have been carried out as different construction projects although the traffic volume, construction year, and location would be similar. This could be confirmed by information provided by county/city engineers.

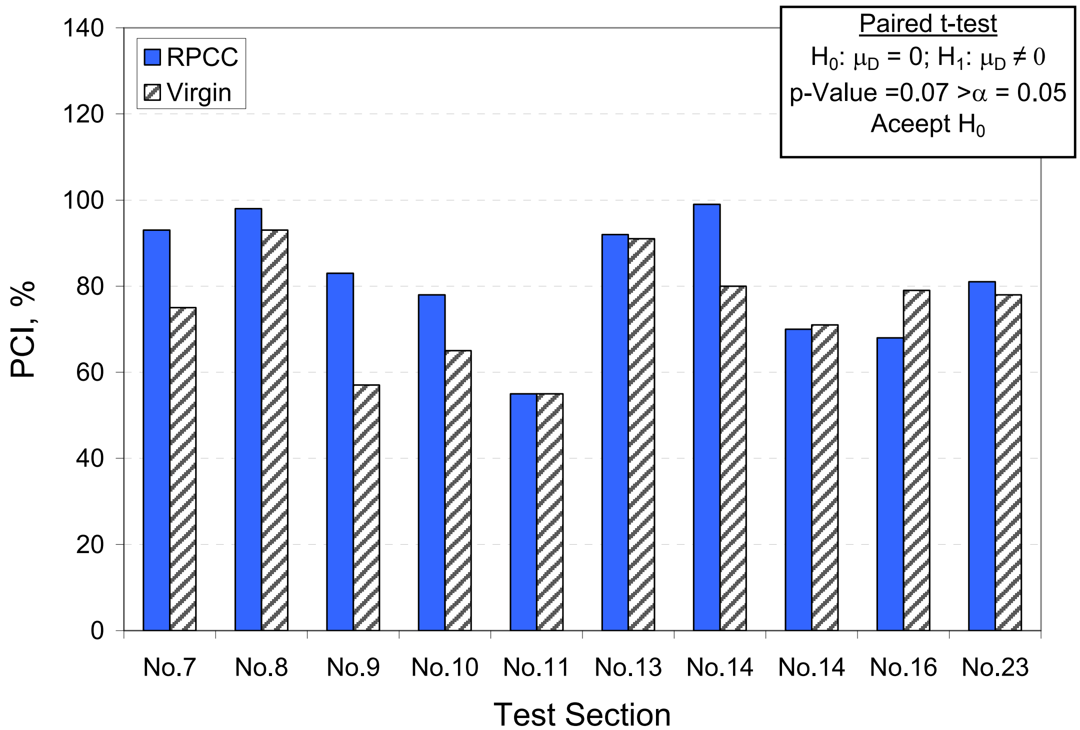
The extracted virgin subbase sections corresponding to the surveyed RPCC subbases are listed in Table 30. As seen in Table 30, the average PCI and IRI value of RPCC aggregate sections (82 % and 1.65 m/km) are a little higher than the average PCI value of virgin aggregate subbase sections (74 % and 1.48 m/km).

Table 30. RPCC subbase sections matched against the extracted virgin subbase sections

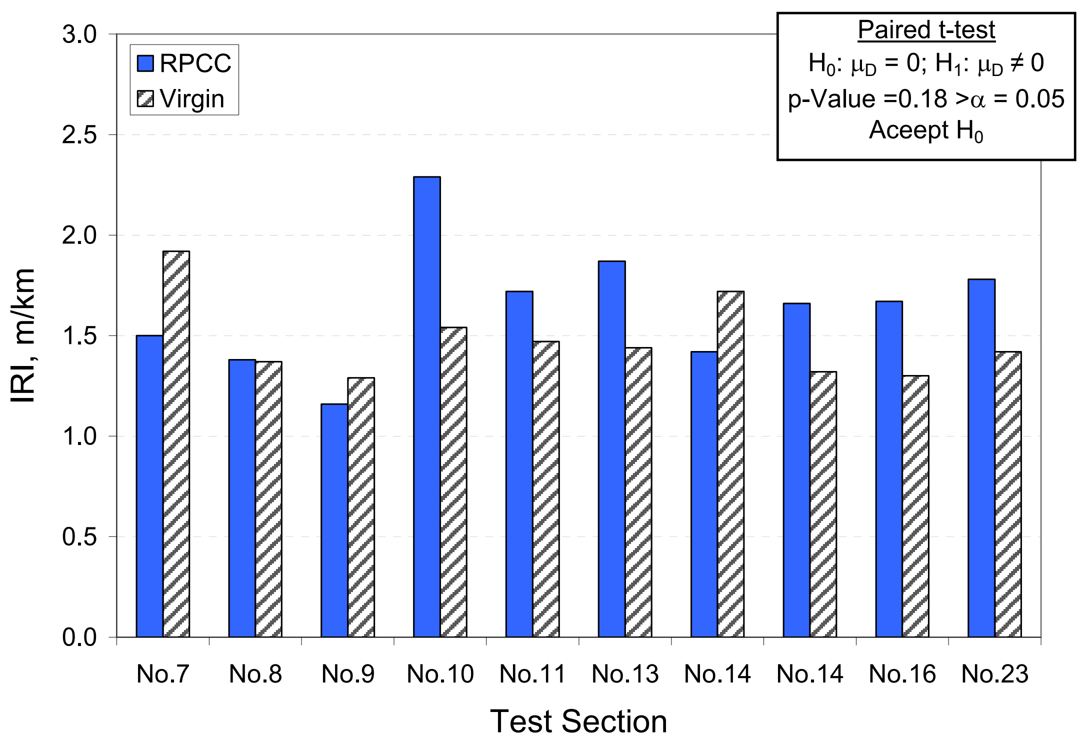
I.D. no.	Road	Dir.	Mile post no.	Type of subbase	Project no.	Constr-uction year	ADTT (2005)	PCI percent (2006)	IRI, m/km (2006)
7	I-35 in Story	S	111.75–126.04	RPCC	IM-35-5(71)111-13-85	1999	5,074	93	1.5
7*	I-35 in Story	N	117.09–121.48	Virgin	IR-35-5(45)111	1988	5,069	75	1.92
8	I-35 in Hamilton	N	140.19–142.07	RPCC	IM-35-6(94)140--13-40	2003	4,657	98	1.38
8*	I-35 in Hamilton	S	126.04–131.03	Virgin	IM-35-5(71)111--13-85	1999	4,762	93	1.37
9	I-80 in Jasper (1)	E	160.35–165.12	RPCC	IM-80-5(184)160--13-50	1996	8,883	83	1.16
9*	I-80 in Jasper (1)	E	151.48–156.28	Virgin	IM-80-5(164)154--13-50	1993	8,837	57	1.29
10	I-80 in Jasper (2)	E	165.12–169.57	RPCC	IM-80-5(169)165--13-50	1994	8,870	78	2.29
10*	I-80 in Jasper (2)	W	149.89–151.48	Virgin	IR-80-5(130)143	1990	8,848	65	1.54
11	I-35 in Hamilton	N	130.60–134.01	RPCC	IR-35-5(36)133	1983	4,709	55	1.72
11*	I-35 in Hamilton	N	126.04–130.60	Virgin	IR-35-5(40)121	1985	4,763	55	1.47
13	I-80 in Pottawattamie	W	5.21–10.80	RPCC	IM-80-1(249)6--13-78	1999	5,421	92	1.87
13*	I-80 in Pottawattamie	W	21.70–28.04	Virgin	IM-80-1(235)23--13-78	1998	5,306	91	1.44
14	I-80 in Pottawattamie	E	5.10–10.80	RPCC	IM-80-1(251)6--13-78	2003	5,421	99	1.42
14*	I-80 in Pottawattamie	E	20.70–28.04	Virgin	IM-80-1(236)23--13-78	1999	5,331	80	1.72
15	I-80 in Cass	E	59.90 – 73.32	RPCC	IR-80-2(117)61	1988	7,506	70	1.66
15*	I-80 in Cass	E	49.71–55.33	Virgin	IR-80-1(171)50	1989	7,285	71	1.32
16	I-80 in Cass	W	59.90–73.32	RPCC	IR-80-2(108)61	1987	7,506	68	1.67
16*	I-80 in Cass	W	55.33–59.90	Virgin	IR-80-1(186)43	1992	7,478	79	1.3
23	I-80 in Polk	E	128.21–130.80	RPCC	IM-35-3(70)77--13-77	1994	13,322	81	1.78
23*	I-80 in Polk	E	137.81–141.58	Virgin	IM-80-5(145)37--13-77	1994	11,445	78	1.42
Average for RPCC section						**1995**	**7,137**	**82**	**1.65**
Average for Virgin section						**1993**	**6,912**	**74**	**1.48**

*Virgin aggregate section s corresponding to RPCC aggregate test section.

To establish if the PCI and IRI obtained for the virgin aggregate sections are significantly different (higher or lower) from those calculated for the RPCC aggregate sections, paired *t*-tests were performed. Two kinds of *t*-tests, an independent *t*-test and a paired *t*-test can be used to examine the difference between two groups. In statistical testing schemes, an independent *t*-test uses the difference of means between two groups while a paired *t*-test uses the mean of difference between the observations in one group and the matched observations in the other group. Thus, a paired *t*-test can consider the correlation between observations, which can be ignored in an independent *t*-test (SAS 2005). Figure 28 presents the paired *t*-test results of PCI and IRI values between the virgin and the RPCC sections. In Figure 28, the symbol 'μ_D' indicates the mean of differences between the PCI or IRI in the RPCC sections and those for the corresponding virgin aggregate sections. The results indicate that the null hypothesis should be accepted, i.e., the PCI or IRI values in both test sections are not significantly different. This confirms the conclusion derived from comparison approach 1 that the RPCC aggregate subbase provides performance comparable to the virgin aggregate subbase in Iowa pavements and is performing adequately.



(a)



(b)

Figure 28. Paired *t*-test results for the RPCC and the virgin aggregate sections; (a) PCI, (b) IRI

7.4 Historical Pavement Surface Condition Evaluation Results

Even though a total of 27 pavement test sites were evaluated through visual distress surveys, the pavement condition information for local roads such as Knapp Street in Ames and the recent constructed sections including the IA-330 in Marshall County and the US-30 in Tama County was not available in the Iowa PMIS. For the sake of consistency and uniformity, the test sections are reorganized and listed in Table 31. The I.D. No. listed in Table 31 is the identification number originally used in Table 26. The Iowa PMIS information was available from 1992 while some test sections in Table 31 were constructed prior to 1992. In these cases, the original construction year was assumed to be 1992 and the pavement age is different than that used in equations (7), (8), and (9). Note that the pavement age used in equations (7), (8), and (9) is the actual pavement age (current year - the actual original construction year) for those sections.

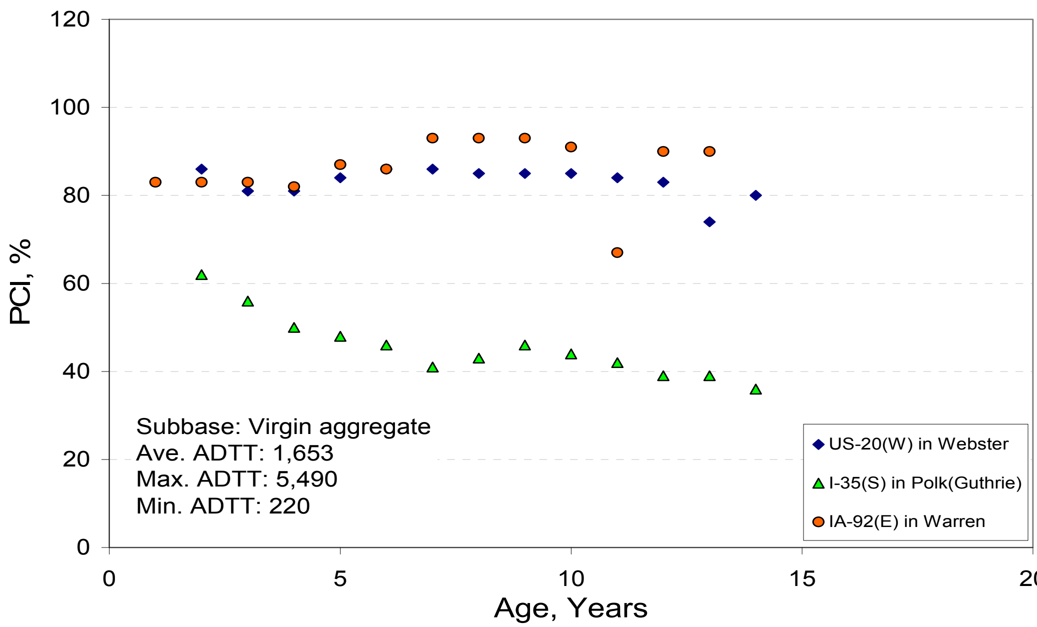
Table 31. List of pavement sections for historical pavement surface condition evaluation

No.	I.D. No.*	Location	Dir.	Mile post no.	Type of subbase	Ages (year)
1	2	US-20 in Webster	E	120.73–124.10	Virgin	14**
2	5	I-35 in Polk	S	10.43–14.26	Virgin	14**
3	7	I-35 in Story	S	111.75–126.04	RPCC	7
4	8	I-35 in Hamilton	N	140.19–142.07	RPCC	3
5	9	I-80 in Jasper (1)	E	160.35–165.12	RPCC	10
6	10	I-80 in Jasper (2)	E	165.12–169.57	RPCC	12
7	11	I-35 in Hamilton	N	130.60–134.01	RPCC	14**
8	12	IA-92 in Warren	E	132.16–133.80	Virgin	13
9	13	I-80 in Pottawattamie	W	5.21–10.80	RPCC	7
10	14	I-80 in Pottawattamie	E	5.10–10.80	RPCC	3
11	15	I-80 in Cass	E	59.90–73.32	RPCC	14**
12	16	I-80 in Cass	W	59.90–73.32	RPCC	14**
13	18	I-80 in Cedar (1)	E	265.76–272.08	RPCC	14**
14	19,20	I-80 in Cedar (2,3)	E	272.08–275.34	RPCC	14
15	27	I-80 in Cedar (4)	E	275.34–278.10	RPCC	14**
16	21,22, 24,25	I-80 in Cedar (1,2,3,4)	W	265.76–278.10	RPCC	14
17	23,26	I-80 in Polk (1,2)	E	128.21–130.80	RPCC	14

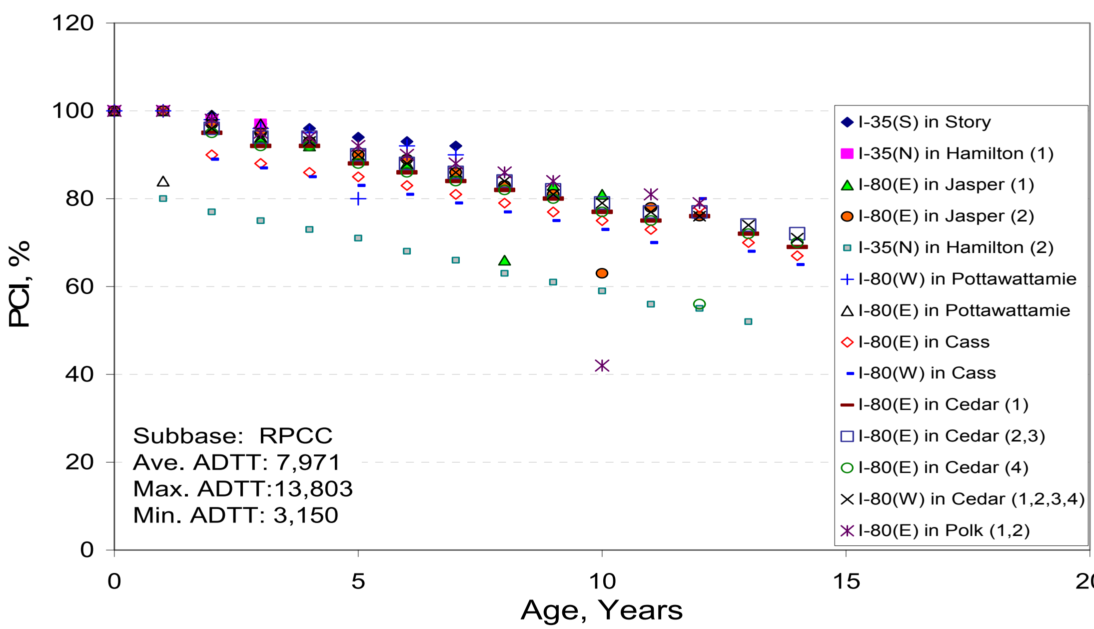
* I.D. Number in Table 1.

** Constructed before 1992.

The detailed pavement condition information from PMIS for each test section is provided in Appendix II. The variations in pavement surface condition indices in terms of PCI and IRI with age are illustrated in Figures 29 and 30, respectively. As seen in Figure 29(a), the PCI for the virgin aggregate subbbase sections, except I-35 in Polk County, did not vary much with age, but PCI for the RPCC sections decreased with age (see Figure 29(b)). The difference in PCI trends between I-35 in Polk County (ADTT = 2,562) and the other two sections, US-20 in Webster County (ADTT= 1,066) and IA-90 in Warren County (ADTT = 254), could probably be attributed to the different traffic volumes experienced by the test sections. As seen in Figure 29, the IRI values for both the virgin aggregate subbase and RPCC subbase sections did not vary much with time. These results indicate that the variations in pavement surface condition over time for the RPCC subbase test sections are not significantly different from those for the virgin aggregate subbase sections.

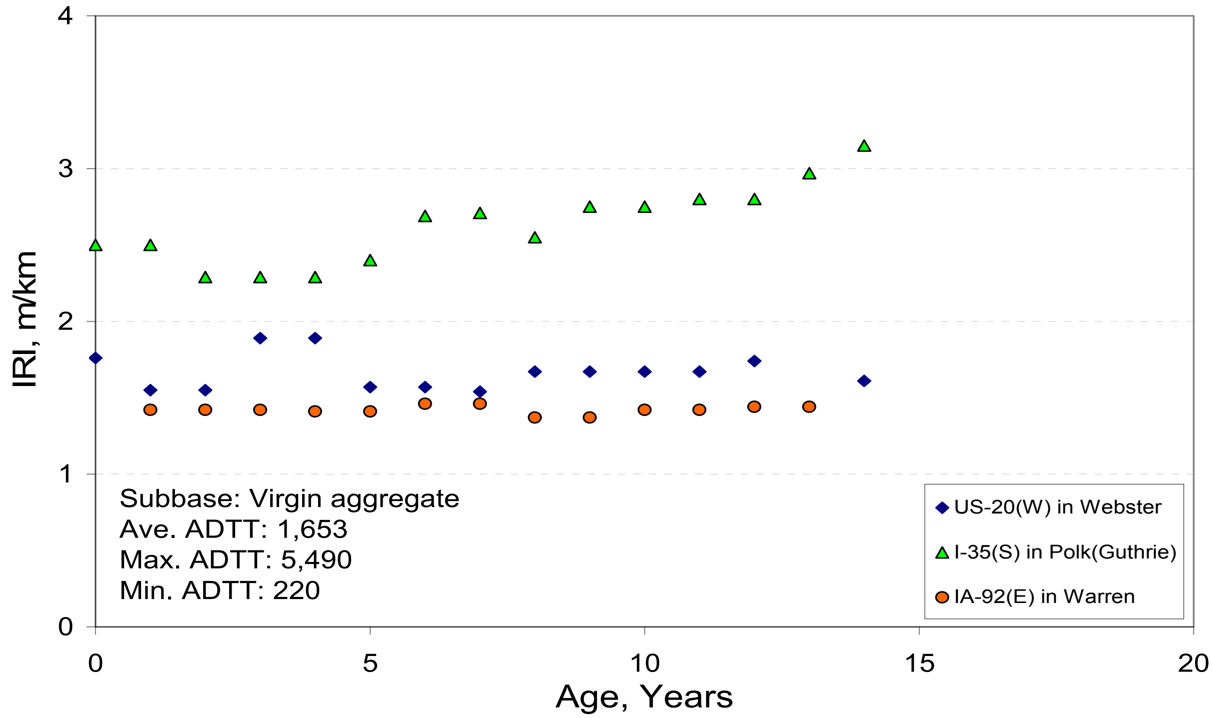


(a)

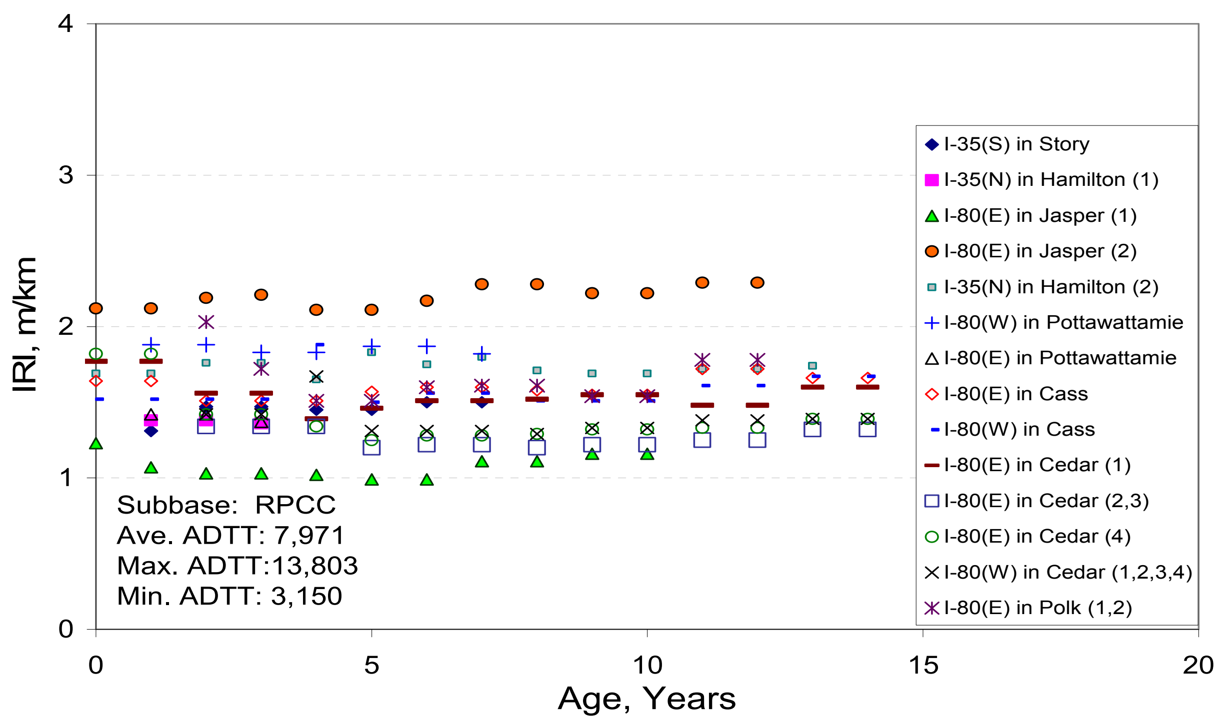


(b)

Figure 29. Variations in PCI with age; (a) virgin aggregate subbase, (b) RPCC subbase



(a)



(b)

Figure 30. Variations in IRI with age; (a) virgin aggregate subbase, (b) RPCC subbase

8. SUMMARY OF FINDINGS

The main findings developed from this research are summarized as follows:

8.1 Laboratory and Field Investigation

- Specific gravities of RPCC are significantly lower than those of crushed limestone.
- Virgin aggregate materials from different projects classified as GP-GM. RPCC aggregate material vary from either poorly- or well- graded sand to gravel.
- Micro-Deval abrasion losses of virgin aggregate materials were within the maximum Micro-Deval abrasion loss of 30% recommended by ASTM D6028-06.
- Micro-Deval abrasion loss of RPCC aggregate materials was normally higher than the maximum Micro-Deval abrasion loss of 30% suggested by the ASTM D 6928-06.
- Modulus of elasticity of RPCC subbase materials is high and variable from one project to another.
- CIV obtained from many Clegg hammer tests are high.
- The CBR value obtained from a DCP test was lower than CBR converted from CIV.
- RPCC subbase layers normally have low permeability.

8.2 Distress Survey

Based on the results of this study, the followings findings and conclusions were drawn:

- The current pavement surface condition of RPCC subbase sections is comparable to that of virgin aggregate subbase sections in terms of the Pavement Condition Index (PCI) and the International Roughness Index (IRI).
- Based on the evaluation of representative RPCC subbase pavement sections with comparisons to virgin aggregate subbase sections, it can be concluded that the RPCC pavement subbase is performing adequately.
- The pavement surface condition history of RPCC subbase sections is not much different from that of virgin aggregate subbase sections.
- Few longitudinal and transverse cracks were observed on all test sections evaluated in this study. The featured distresses on RPCC are the lane-to-shoulder separation and lane-to-shoulder drop off, which are consistent with the findings reported by previous researchers.
- No correlation was observed between the pavement surface condition indices and the RPCC subbase thickness.

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APPENDIX A: DATA COLLECTION SUMMARY

An effort was made by investigators to fully identify the use of RPCC subbase in Iowa. This effort was challenging because Iowa DOT's data base does not differentiate between RPCC and other base materials that met the specification. Therefore investigators had to search old files of contract documents and interview participants of past RPCC project. In some cases investigators could rely on their personal experience making field visits to RPCC projects.

The Iowa DOT has an electronic repository of documents from past construction projects. The use of this repository greatly facilitated the investigation and has the potential to benefit future investigators. The electronic repository includes documents in the following categories:

- Construction Documents which resulted from the construction administration process
- Materials Documents which resulted from the materials testing process
- Plans and Specifications.

Within time limitations, investigators obtained electronic copies of documents for as many of these projects as possible and summaries each in a separate spreadsheet for each project. Electronic copies will be retained by the investigators and provided to the Iowa DOT.

Table 32 summaries the entire data collection effort for this investigation. The project number is critical for retrieving construction documents and is thus provided for the benefit of future investigators. The subbase type is noted with important comments regarding the location of the material and the certainty that it extists. The columns under the spanner entitled "Data Collected" indicate the results of the investigators efforts to retrieve electronic data.

Table 32. Summary of RPCC projects in Iowa from field investigation and database search

Year	Project number	Route and milepost	Direction	Subbase type	Data collected				
					Field visit	Constructio n documents	Material documents	Plans	Spreadshee t summary
1983	IR – 35-5(36)133	I-35 in Hamilton County: Mile Post No. 130.60–134.01	N	RPCC	Yes	No	No	Yes	Yes
1983	F330-2(19)--20-64	IA-330 in Marshall County: Mile Post No. 005.55–013.42	NE	Virgin (*)	Yes (*)	No	No	No	No
1983	F330-1(11)--20-50	IA-330 in Jasper County: Mile Post No. 000.05–005.50	NE	Virgin (*)	Yes (*)	No	No	No	No
1985	IR-35-5(40)121	I-35 in Story County: Mile Post No. 121.42-126.04	N	Unknown	No	No	No	Yes	No
1987	IR-80-2 (108)61	I-80 in Cass County: Mile Post No. 059.90–073.32	W	RPCC	Yes	No	No	Yes	No
1988	IR-80-2(117)61	I-80 in Cass County: Mile Post No. 059.90–073.32	E	RPCC	Yes	No	No	Yes	Yes
1988	IR-80-3(57)106--12-25	I-80 in Dallas/Polk County: Mile Post No. 106.71–122.92	E	RPCC	No	Yes	Yes	Yes	Yes
1989	F-14-4(31)--20-50	IA-14 in Jasper County: Mile Post No. 072.46-079.10	N/S	Virgin (**)	No	No	No	No	No
1990	F-520-3(11)--20-94	US-20 in Webster County: Mile Post No. 120.73–124.10	E	Virgin	Yes	Yes	Yes	Yes	Yes
1991	IR-80-7(57)265--12-16	I-80 in Cedar County: Mile Post No. 265.76–272.08	E	RPCC	Yes	Yes	Yes	Yes	Yes
1991	IR-80-7(57)265--12-16	I-80 in Cedar County: Mile Post No. 272.08–275.34	E	RPCC	Yes	Yes	Yes	Yes	Yes
1991	IR-80-7(57)265--12-16	I-80 in Cedar County: Mile Post No. 275.80–278.50	E	RPCC	Yes	Yes	Yes	Yes	Yes
1992	IR-80-7(57)265--12-16	I-80 in Cedar County: Mile Post No. 275.34–278.10	E	RPCC	Yes	Yes	Yes	Yes	Yes
1992	IR-80-7(57)265--12-16	I-80 in Cedar County: Mile Post No. 269.25–272.25	W	RPCC	Yes	Yes	Yes	Yes	Yes
1992	IR-80-7(57)265--12-16	I-80 in Cedar County: Mile Post No. 265.76–269.25	W	RPCC	Yes	Yes	Yes	Yes	Yes
1992	IR-80-7(57)265--12-16	I-80 in Cedar County: Mile Post No. 272.50–275.80	W	RPCC	Yes	Yes	Yes	Yes	Yes
1992	IR-80-7(57)265--12-16	I-80 in Cedar County: Mile Post No. 275.80–278.50	W	RPCC	Yes	Yes	Yes	Yes	Yes

1993	HES-92-5(27)--2H-91	IA-92 in Warren County: Mile Post No. 132.16–133.80	E	Virgin	Yes	Yes	Yes	Yes	Yes
1993	IM-80-7(59)247--13-52	I-80 in Cedar County: Mile Post No. 240.22-257.86	E	Virgin	No	Yes	Yes	Yes	Yes
1993	NHS–28–2(9)--19-77	IA-28 in Polk County: Mile Post No. 015.6-017.46	N	Virgin	No	Yes	Yes	Yes	Yes
1994	IM–80–5(169)165–13-50	I-80 in Jasper County: Mile Post No. 160.35–165.12	E	RPCC	Yes	No	No	Yes	Yes
1994	IM-35-3(70)77- -13-77	I-80 in Polk County: Mile Post No. 128.21–130.80—Travel	E	RPCC	Yes	Yes	Yes	No	Yes
1994	IM-35-3(70)77- -13-77	I-80 in Polk County: Mile Post No. 128.50–128.60—Passing	E	Virgin	Yes	Yes	Yes	No	Yes
1994	IM-29-3(38) 58--13-78	I-29 in Pottawattamie County: Mile Post No. 056.64-076.87	N	RPCC	No	Yes	Yes	Yes	Yes
1994	IM-80-5(145)137--13-77	I-80 in Polk County: Mile Post No. 137.81-141.58	E/W	RPCC (***)	No	No	No	Yes	No
1995	IM-29-3(47)56--13-78 (#)	I-29 in Pottawattamie County: Mile Post No. 056.64-057.69	N	RPCC	No	No	No	Yes	No
1996	IM–80–5(184)160–13-50	I-80 in Jasper County: Mile Post No. 165.12–169.57	E	RPCC	Yes	No	No	Yes	Yes
1996	NHS-30-2(65)--19-14	US-30 in Carroll County: Mile Post No. 082.59–083.42	E	RPCC (##)	No	No	No	Yes	No
1997	IM-35-3(69)82- -13-77	I-80 in Polk County: Mile Post No. 132.84-134.90	E/W	RPCC	No	No	No	Yes	No
1998	IM-35-3(71)81- -13-77	I-80 in Polk County: Mile Post No. 130.80-132.84	E	Virgin	No	No	No	Yes	No
1998	STP-5-4(27)--2C-91	IA-5 in Warren County: Mile Post No. 088.09-090.33	E/W	RPCC (##)	No	No	No	Yes	No
1998	STP-5-4(40)--2J-91	IA-5 in Warren County: Mile Post No. 085.05-088.02	W	RPCC (##)	No	No	No	Yes	No
1999	IM–35–5(71)111--13-85	I-35 in Story County: Mile Post No. 111.75–126.04	S	RPCC	Yes	Yes	No	Yes	Yes
1999	IM-80-1(249)6--13-78	I-80 in Pottawattamie County: Mile Post No. 005.21–010.80	W	RPCC	Yes	Yes	Yes	Yes	Yes
2000	IM-35-3(115)85--13-77	I-80 in Polk County: Mile Post No. 134.90-137.40	E	RPCC (***)	No	No	No	Yes	No
2000	NHSX-71-3(34)--3H-15	US-71 in Cass County: Mile Post No. 052.47-054.85	N	RPCC	No	No	No	No	No
2000	NHSX-71-3(34)--3H-15	US-71 in Cass County: Mile Post No.	N	RPCC	No	No	No	No	No

		055.25-058.56							
2003	City of Ames Project	Knapp Street, Ames, Iowa (first visit)	W	RPCC	Yes	Yes	Yes	No	No
2003	IM-35-6(94)140- -13-40	I-35 in Hamilton County: Mile Post No. 140.19–142.07	N	RPCC	Yes	No	No	Yes	Yes
2003	IM-80-1(251)6--13-78	I-80 in Pottawattamie County: Mile Post No. 005.10–010.80	E	RPCC	Yes	Yes	Yes	Yes	Yes
2003	City of Ames Project	Knapp Street, Ames, Iowa (second visit)	W	RPCC	Yes	Yes	Yes	No	No
2004	IM-235-2(341)11--13-77	I-235 in Polk County (Guthrie Ave): Mile Post No. 010.43–014.26	W	Virgin	Yes	Yes	Yes	No	No
2005	NHSX–20–3–(130)–3H-94	US-20 in Webster County: Mile Post No. 116.80–121.06	W	Virgin	Yes	No	No	Yes	Yes
2005	NHSX–30–6(104)–3H-86	US-30 in Tama County: Mile Post No. 193.10–197.53	E	Virgin	Yes	No	No	Yes	Yes
2005	NHSN–330–2(50)–2R-64	IA-330 in Marshall County: Mile Post No. 020.05–21.05	S	RPCC	Yes	No	No	Yes	Yes

Notes:

*: Originally this was reported to be an RPCC subbase. None was found during a field visit. Later, Reilly Construction Company personnel remembered that all RPCC was used as "winter rock" (temporary crushed rock access roads used by neighboring land owners in the winter between the grading and the paving projects).

**: Originally this was reported to be a RPCC subbase. Reilly Construction Company personnel remembered that all RPCC was used as "winter rock" (temporary crushed rock access roads used by neighboring land owners in the winter between the grading and the paving projects).

***: According to Reilly Construction Company personnel, RPCC used under the right and middle lanes while virgin aggregate was used under the left lane.

#: According to Reilly Construction Company personnel, the contractor ran out of recycled material and used virgin material for one mile on both sides of the 16th street exit.

##: According to Reilly Construction Company personnel, RPCC was used for the subbase.

Personnel from the Reilly Construction Company, Ossian, IA, developed a list of possible RPCC sites during a winter superintendents meeting. This list provided considerable assistance to the investigators and most of the locations in the list were investigated as documented in Table 32. However, due to time limitations, it was not possible to fully investigate some areas. To assist future investigators, a list of locations is provided below which according to Reilly personnel may have RPCC subbase. All locations represent approximate locations bounded by exit numbers. Some detailed investigations were conducted within some of the areas listed; however, this information is given to emphasize that RPCC base may be found beyond the areas investigated.

- I-80 Exit 40 to Exit 70
- I-80 Exit 100 to I.235/35 system interchange
- I-80 Exit 168 to Exit 230
- I-80 Exit 249 to Exit 301

APPENDIX B: SUMMARY SITE DESCRIPTION, IN-SITU TESTING AND CRACK SURVEY RESULTS

Site number: 1

Location: Knapp Street (second visit), Ames, Iowa
GPS coordination: N.42º01.1504'/W.93º39.2187', E.L:265.8m
Test date: March 14, 2007
Weather: 40º F
Site description: Test area is on the Knapp Street. Recycled material for base layer.
The PCC pavement was constructed in 2003. The street is lower than the shoulders, so water flows over the surface if it is rainy. Test site is by the corner with Sheldon avenue.
Soil and subbase are frozen.

Core	Location	Activity
2" core	P1	DCP, subbase samples
10" core	P2	LWD, Clegg Hammer, DCP, subbase & subgrade sample

Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	17	17	—	17
	CBR	22	22	—	22
Subgrade	CIV	13	15	—	14
	CBR	17	19	—	18

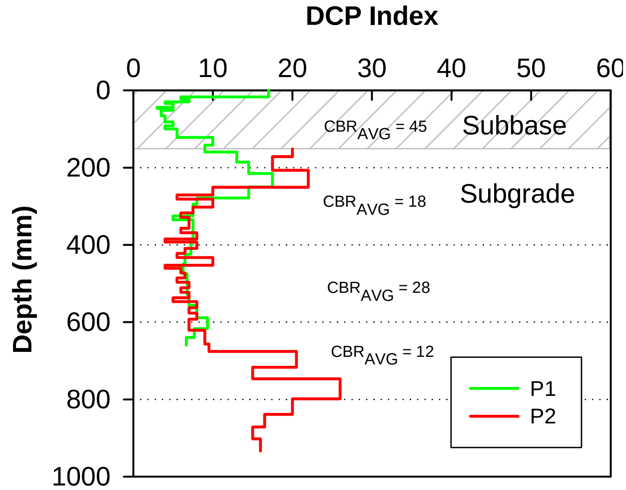
Light Weight Deflectometer Modulus:

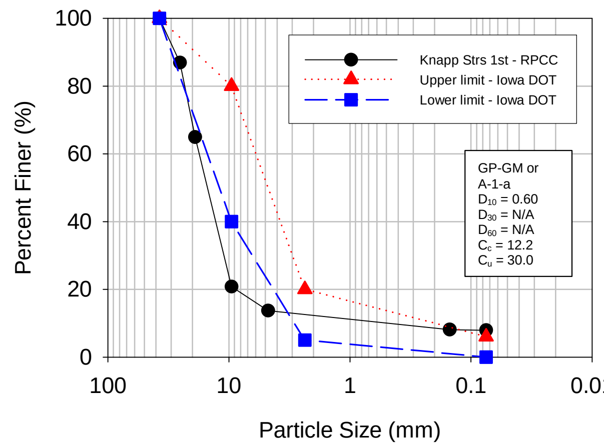
On subbase layer: E = 206 MPa

On subgrade layer: E = 33 MPa

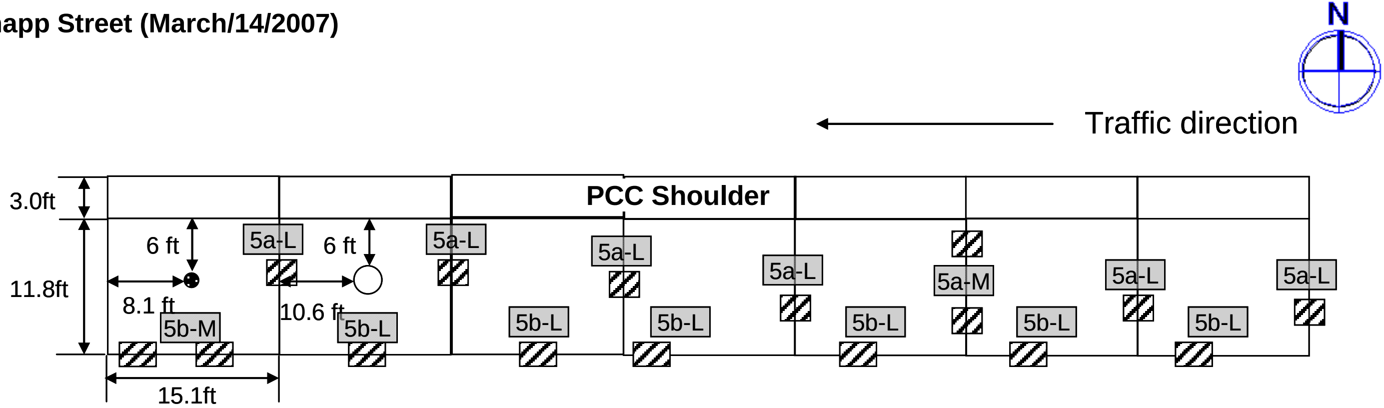
Moisture Content of Subgrade Material:

w = 14.1%





Knapp Street (March/14/2007)



Note:

Core	Activity
● (2" Core)	DCP, Clegg hammer
○ (10" Core)	LWD, Clegg hammer, DCP

Survey Type	Comment
Slab thickness	9.3 in
Base thickness	6.2 in (RPCC)
Joint orientation	Rectangular
Joint width	0.3 in
Joint depth	0.2 in
Sealing condition	Bad
Shoulder condition	Good
Cut or fill	Cut

(a) Joint sealing damage of longitudinal joint at slab #1

(b) Joint sealing damage of transverse joint at slab #1

(c) Joint sealing damage of longitudinal joint at slab #2

(d) Joint sealing damage of transverse joint at slab #2

Site number: 2

Location: US-20 in Webster County: Mile Post No. 122.50 to 122.55
GPS coordination: N.42º26.6984'/W.94º09.8481' E.L:318.0M
Test date: April 16, 2007
Weather: Sunny, 70º F.
Site description: Test location is near Fort Dodge. Crushed limestone material for subbase layer. PCC thickness = 11"

Core	Location	Activity
2" core	P4, P5	DCP
4" core	P1, P2	Shelby Tube
10" core	P3	LWD, Clegg Hammer, DCP, Shelby Tube

Clegg Impact and CBR Values

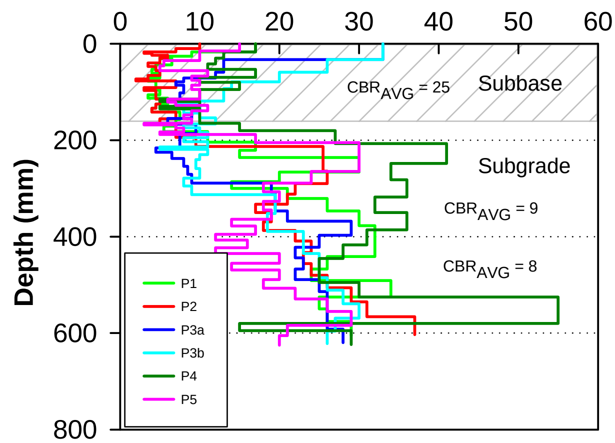
Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	33	33	23	30
	CBR	45	45	30	41

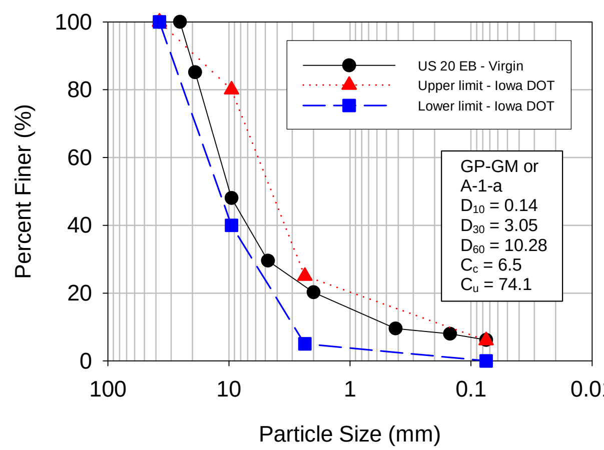
Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (µm)	E (MPa)
Subbase	7.83	249.4	386	18.3	108

Photos of Testing Site

DCP Index

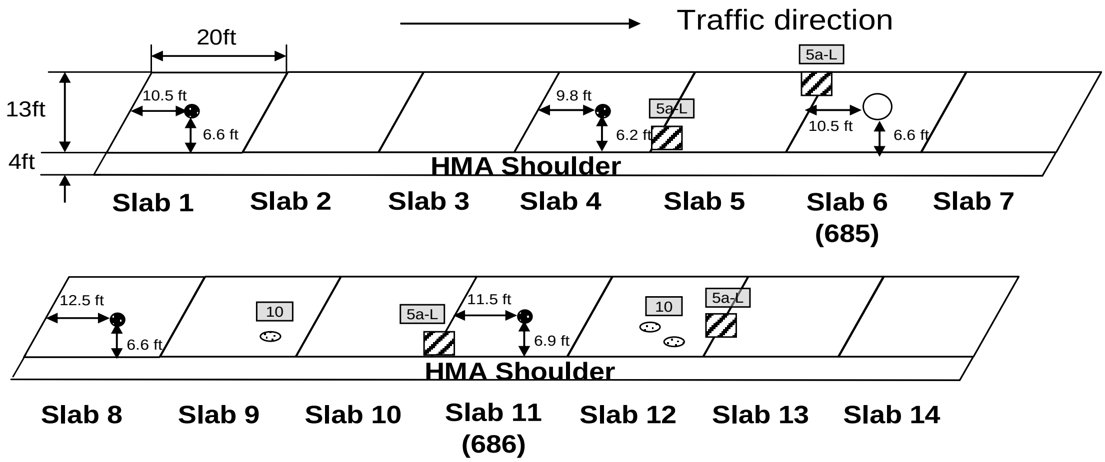




Drainage Pipe

10 inch core

US-20 in Webster County: Mile Post No. 122.50 to 122.55 (April/16/2007)

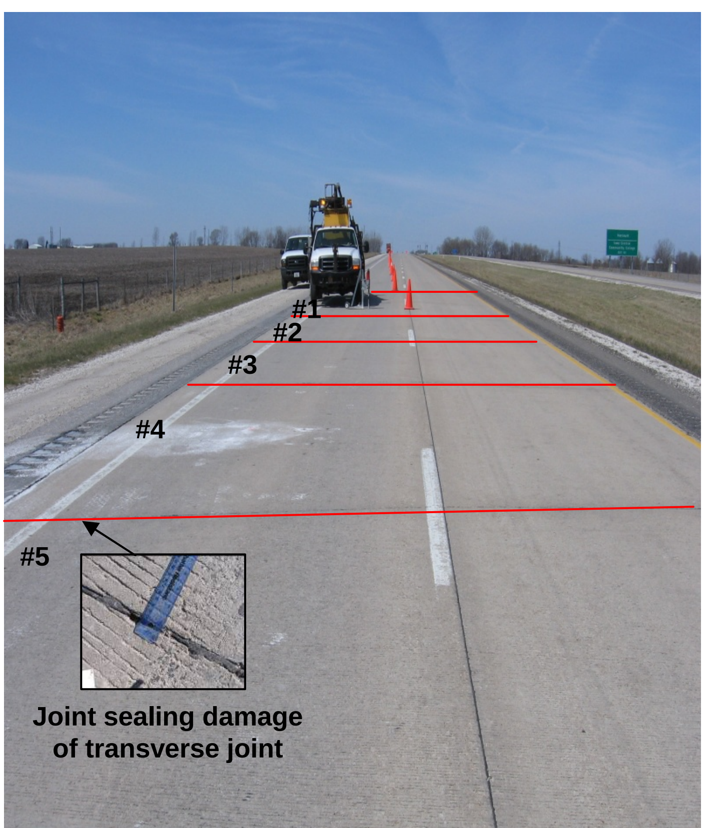


Note:

Core	Activity
● (2" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	F-520-3(11) --20-94
Construction year	1990
PCI (2006)	86 %
IRI (2006)	1.54 m/km

Survey Type	Comment
Slab thickness	11 in
Base thickness	11.4 in (Virgin)
Joint orientation	Diagonal
Joint width	0.4 in
Joint depth	0.3 in
Sealing condition	Good
Shoulder condition	Good
Cut or fill	Fill



(a) Overall surface distress condition from slab #1 to #5

(b) Joint sealing damage of transverse joint at slab #6

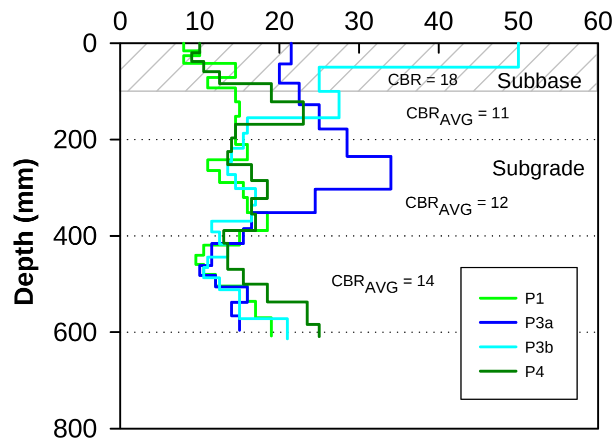
(c) Popout at slab #9

Site number: 3

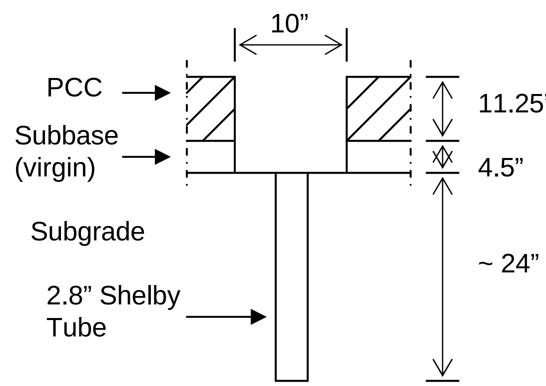
Location: US 20 in Webster, Mile Post No. 116.80 to 121.06
GPS coordination: N.42º26.7030’/W.94º09.8660’ E.L:299.2m
Test date: April 23, 2007
Site description: Test area is at the station 930+00 (Mile post 119.90), Westbound, near Fort Dodge. Virgin material for subbase layer. New PCC pavement.

Core	Location	Activity
2” core	P1, P4	DCP
4” core	P2, P5	Shelby Tube
10” core	P3	LWD, Clegg Hammer, DCP, Shelby Tube

DCP Index



Core # P3:

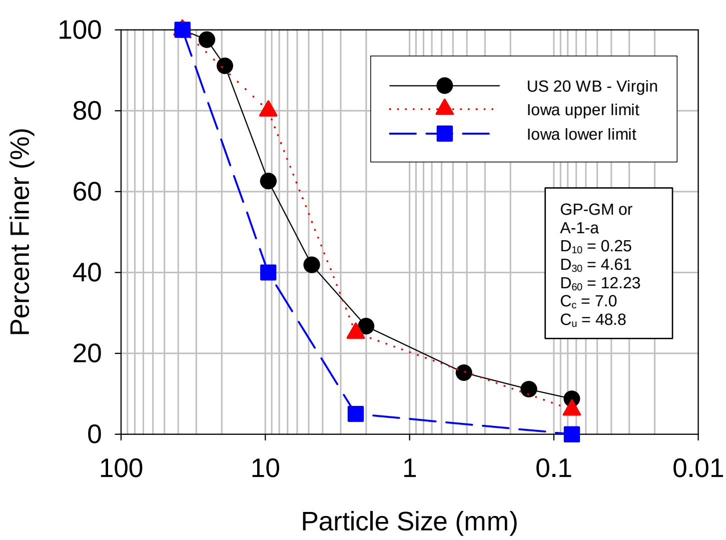


Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	6.8	100	216.5	659	43

Clegg Impact and CBR Values

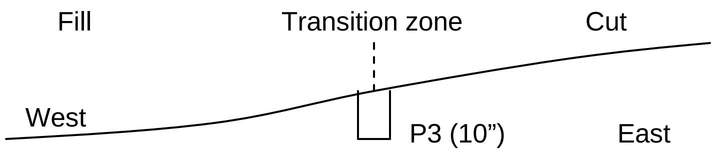
Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	24	19	—	22
	CBR	32	24	—	29



Photos of Testing Site

Site number: 4

Location: US-30 in Tama County: Mile Post No. 194.35 to 194.40
GPS coordination:
Test date: May 01, 2007
Weather: Sunny.
Site description: Test area is on East bound side, US hwy 30, near La Grant bypass. Virgin material for base layer. PCC thickness is 10”. Base material thickness is more than 18”.



Core	Location	Activity
2” core	P1, P5	DCP
4” core	P2, P4	Shelby Tube
10” core	P3	LWD, Clegg Hammer, DCP, Shelby Tube

Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	35	48	33	38
	CBR	49	70	46	54

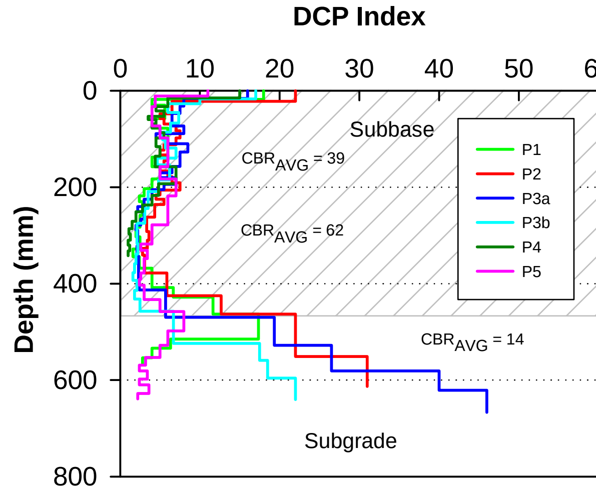
Light Weight Deflectometer Modulus

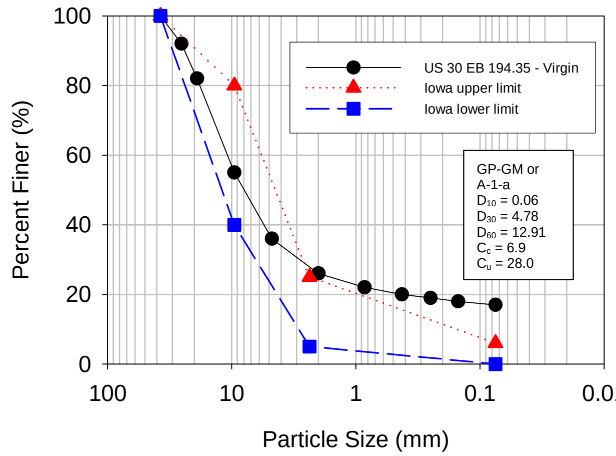
Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	7.5	100	238.7	168	131

Hydraulic conductivity of subbase layer

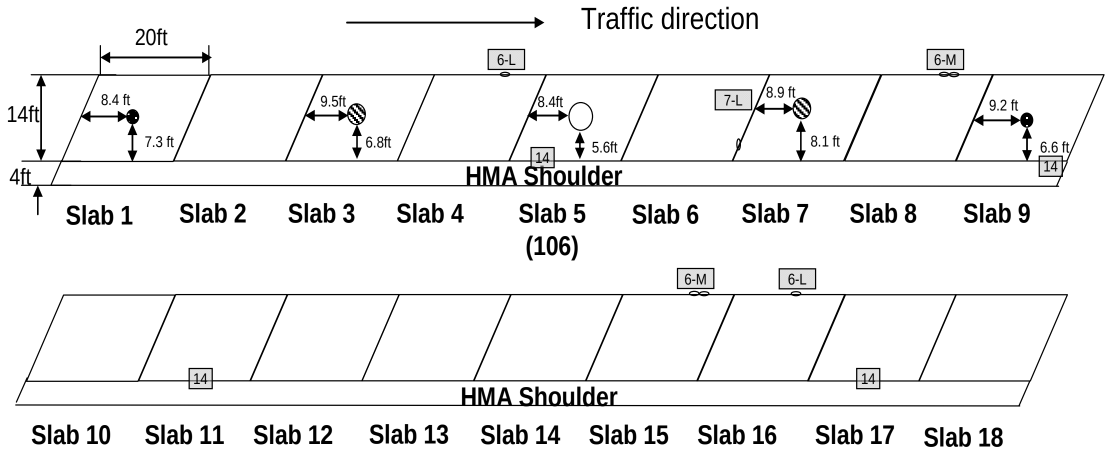
$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
2.61	3.69

10 inch Core Samples





US-30 in Tama County: Mile Post No. 194.35 to 194.40 (May/1/2007)



Note:

Core	Activity
(2" Core)	DCP
(4" Core)	DCP, Permeability test
(10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	NHSX-030-6(104)- -3H-86
Construction year	2005
PCI (2006)	90 %
IRI (2006)	N/A

Survey Type	Comment
Slab thickness	10 in
Base thickness	More than 18 in (Virgin)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	0.4 in
Sealing condition	Good
Shoulder condition	Bad
Cut or fill	Cut

(a) Spalling of longitudinal joint at slab #4

(b) Lane to shoulder separation at slab #5

(c) Spalling of Transverse joint at slab #6

(d) Spalling of longitudinal joint at slab #8

Site number: 5

Location: I-235 in Polk County (Guthrie Ave): Mile Post No. 10.9 to 11.0
GPS coordination: N.41º36.5805'/W.93º34.7406' E.L:217.5M
Test date: May 17, 2007
Weather: Night time.
Site description: Test area is on the left lane of the three-lane-Interstate 235 South bound in Des Moines. Virgin material for base layer. New PCC pavement.
A geogrid layer at the bottom of base layer was found at P2 and P4.

Core	Location	Activity
4" core	P1, P2, P4, P5	Permeability Test at P5, DCP
10" core	P3	LWD, Clegg Hammer, DCP

Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	30	23	—	27
	CBR	41	30	—	36

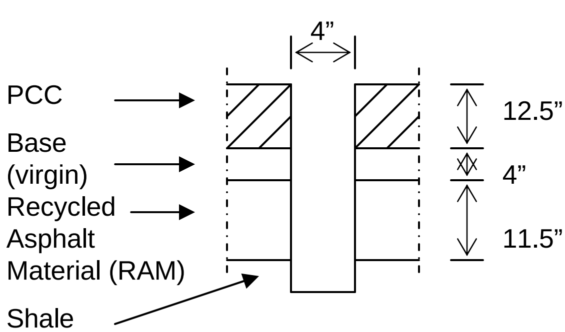
Light Weight Deflectometer Modulus

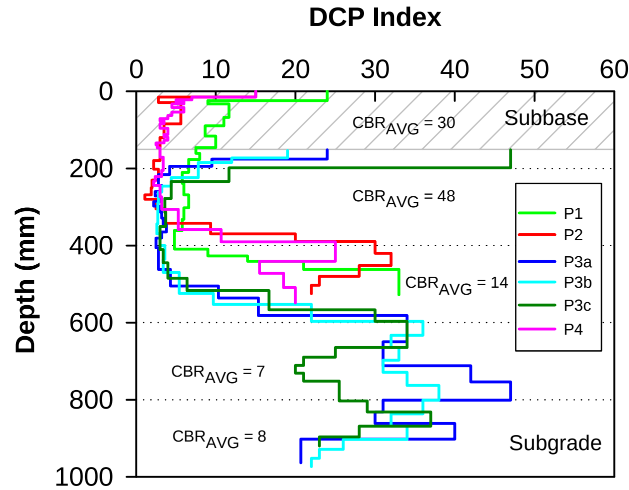
LWD (Zorn ZFG-2000): Elastic Modulus E = 91.5 MPa

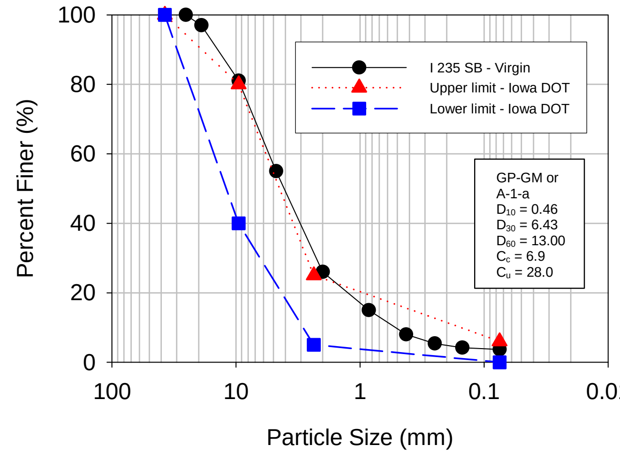
Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
2.61	3.69

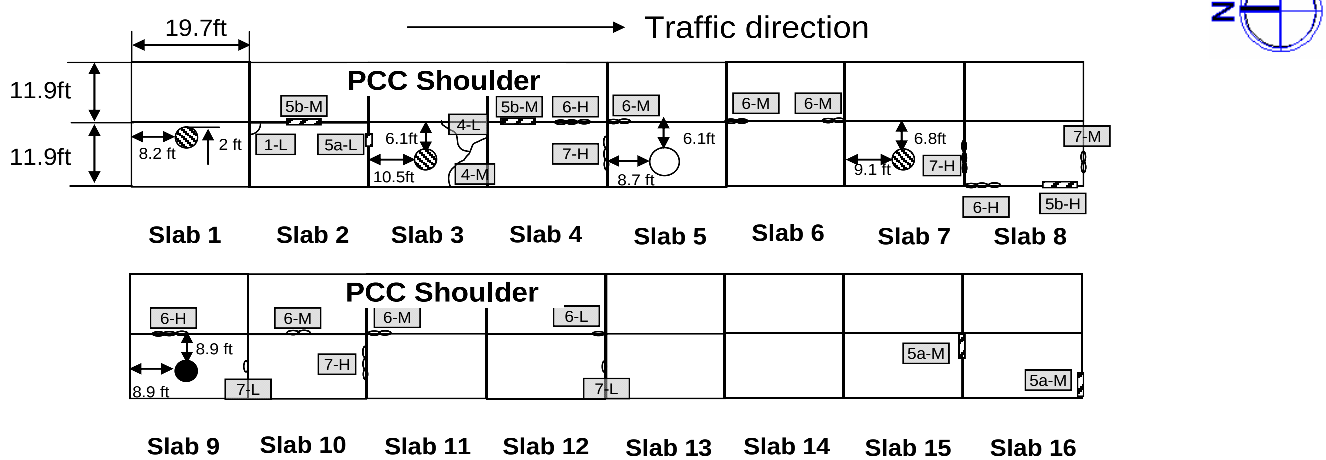
4 inches core at location P4







I-235 in Polk County (Guthrie Ave): Mile Post No. 10.9 to 11.0 (May/17/2007 to May/18/2007)



Note:

Core	Activity
● (4" Core)	Permeability test
(hatched) (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	Various projects
Construction year	1968 (Initial construction)
PCI (2006)	39 %
IRI (2006)	1m/km

Survey Type	Comment
Slab thickness	13 in
Base thickness	3 in limestone + RAP
Joint orientation	Rectangular
Joint width	0.4 in
Joint depth	0.6 in
Sealing condition	Good
Shoulder condition	Good
Cut or fill	Fill


(a) Joint sealing damage of transverse joint at slab #2


(b) Transverse cracking at slab #3


(c) Spalling of longitudinal joint at slab #4


(d) Spalling of transverse joint at slab #4

Site number: 6

Location: IA-330 in Marshall County: Mile Post No. 20.05 to 20.
GPS coordination: N.42º00.3451'/W. 93º01.4245'
Test date: June 14, 2007
Weather: Sunny, 85º F, windy 20 mph
Site description: Test area is on hwy 330 South bound near Marshall Town, at MP 20.
Recycled material for base layer. PCC thickness = 30 cm
Constructed in 2006.

Core	Location	Activity
4" core	P1, P2, P4, P5	Permeability Test at P5, DCP at P1, 2, 4
10" core	P3	LWD, Clegg Hammer, DCP

Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	32	39	40	37
	CBR	44	55	57	52

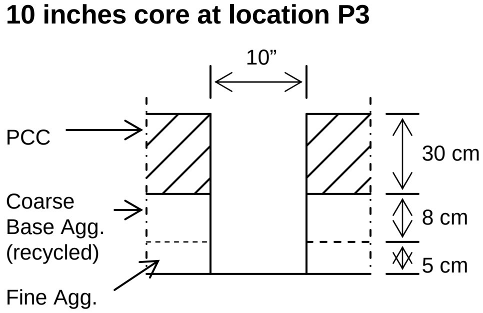
Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.2	100	261	383	89.9
Subgrade	7.6	100	241.9	610	46.9

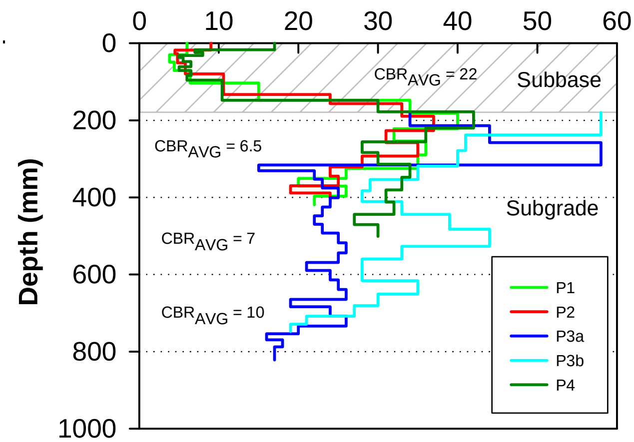
Hydraulic conductivity of subbase layer

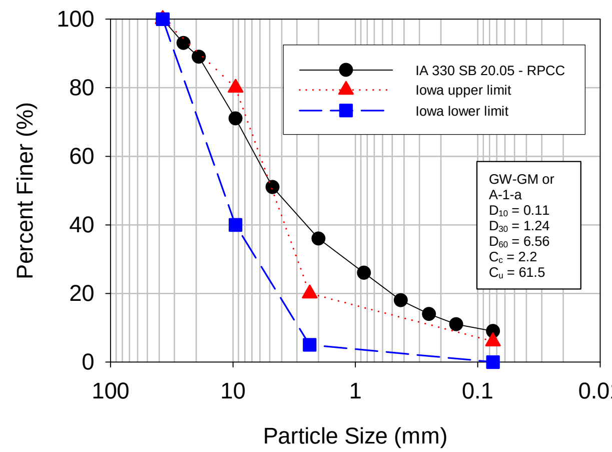
$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.016	0.010

10 inches core at location P3



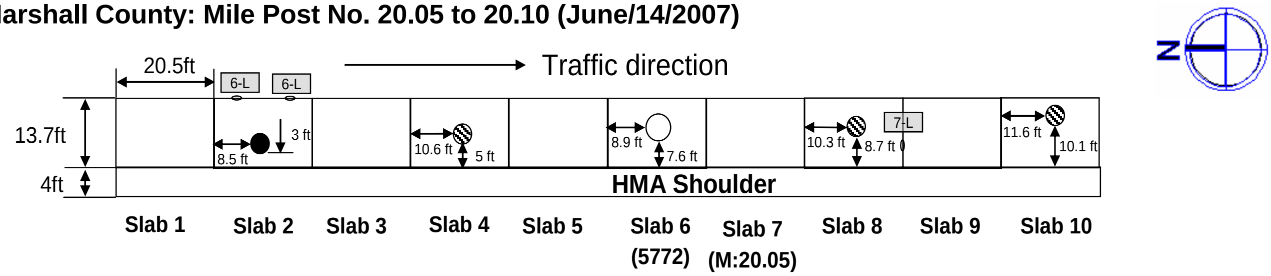
DCP Index

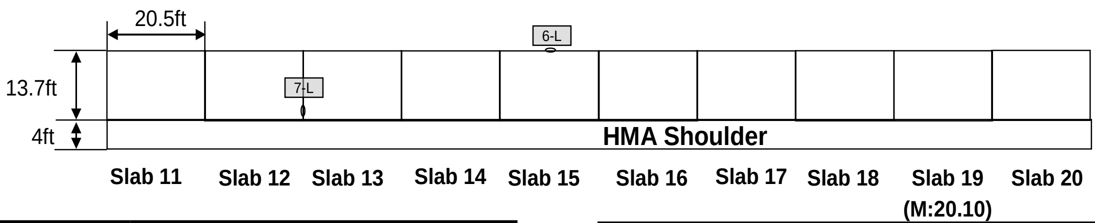




Photos of Field Tests

IA-330 in Marshall County: Mile Post No. 20.05 to 20.10 (June/14/2007)



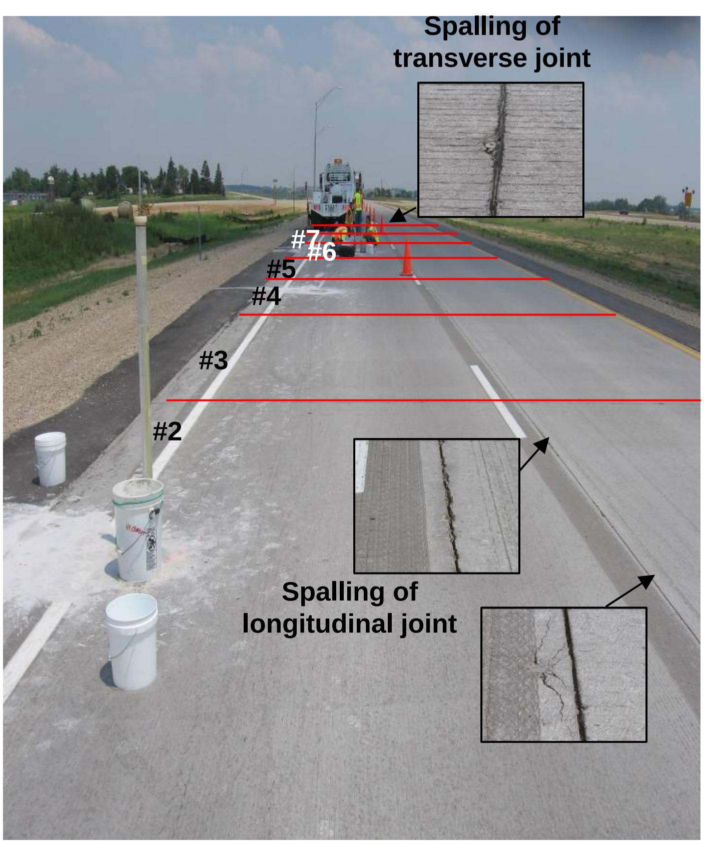


Note:

Core	Activity
● (4" Core)	Permeability test
◍ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	N/A
Construction year	2006
PCI (2006)	N/A
IRI (2006)	N/A

Survey Type	Comment
Slab thickness	12 in
Base thickness	5 in(RPCC)
Joint orientation	Rectangular
Joint width	0.4 in
Joint depth	0.4 in
Sealing condition	Good
Shoulder condition	Good
Cut or fill	Fill



(a) Overall surface distress condition from slab #2 to #8

(b) Spalling of transverse joint at slab #12

(c) Spalling of longitudinal joint at slab #15

Site number: 7

Location: I-35 in Story County: Mile Post No. 119.95 to 120.05
GPS coordination:
Test date: June 19, 2007
Weather: Sunny, 82º F to 88ºF
Site description: Test area is at MP 120, South bound, I 35, near Ames. Recycled material for base layer. PCC thickness = 30.5 cm. A Geogrid layer below base layer. Pavement was built in 1999.

Core	Location	Activity
4” core	P1, P2, P4, P5	Permeability Test at P1, DCP
10” core	P3	LWD, Clegg Hammer, DCP

Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	35	36	37	36
	CBR	48	50	52	50
Subgrade	CIV	14	15	17	15
	CBR	13	14	15	14

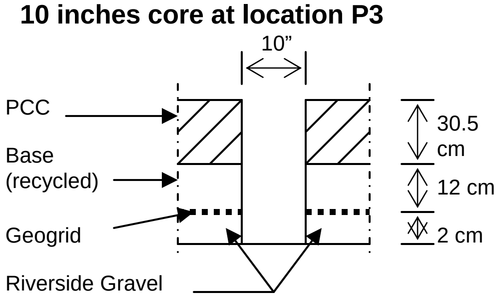
Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.4	100	267.4	247	129
Subgrade	No LWD (battery problem)				

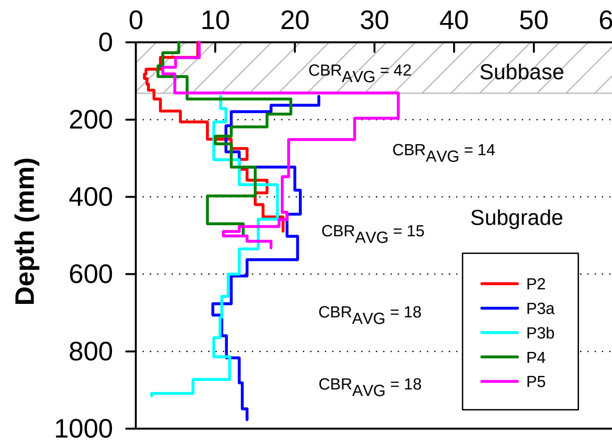
Hydraulic conductivity of subbase layer

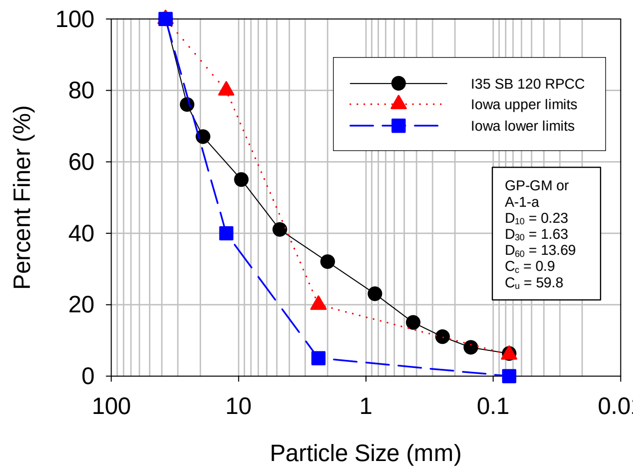
$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.427	0.234

10 inches core at location P3

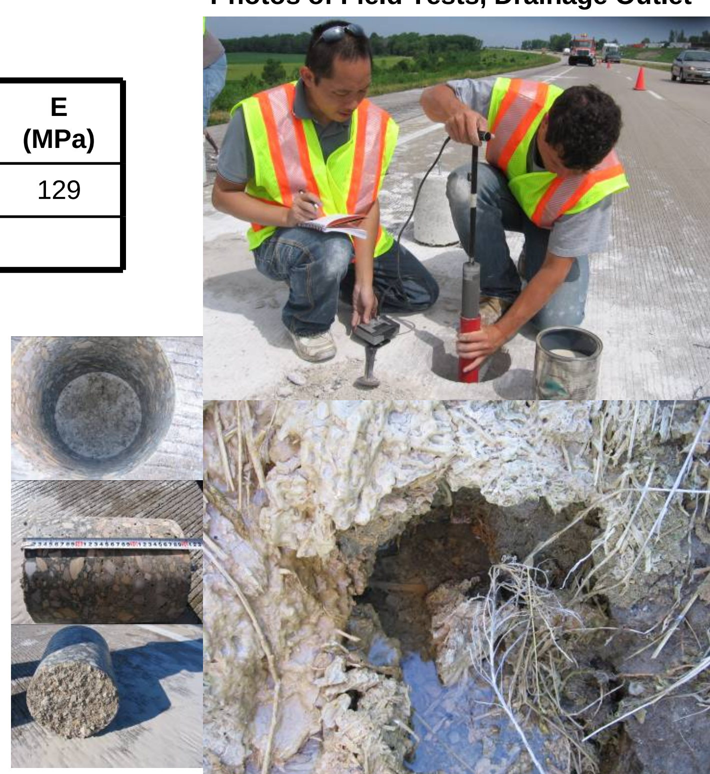


DCP Index

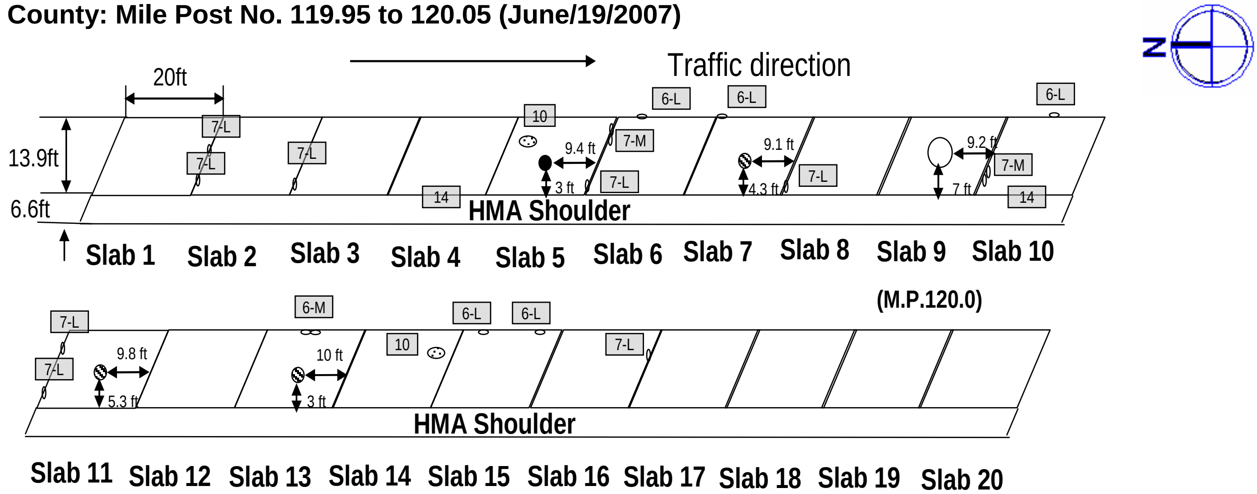




Photos of Field Tests, Drainage Outlet



I-35 in Story County: Mile Post No. 119.95 to 120.05 (June/19/2007)



Note:

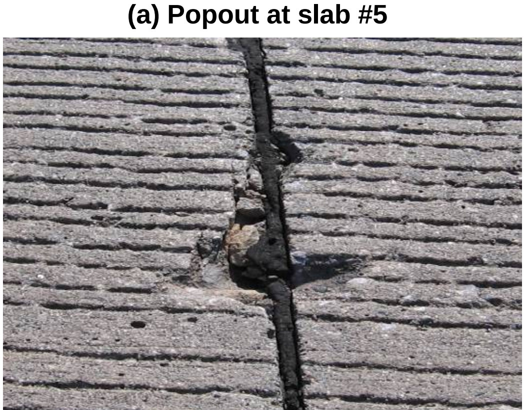
Core	Activity
● (4" Core)	Permeability test
▨ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IM-35-5(71)111-13-85
Construction year	1999
PCI (2006)	93 %
IRI (2006)	1.5 m/km

Survey Type	Comment
Slab thickness	12 in
Base thickness	5 in (RPCC) + 1 in (Virgin)
Joint orientation	Diagonal
Joint width	0.4 in
Joint depth	0.4 in
Sealing condition	Good
Shoulder condition	Bad
Cut or fill	Fill

(a) Popout at slab #5

(b) Spalling of transverse joint at slab #5



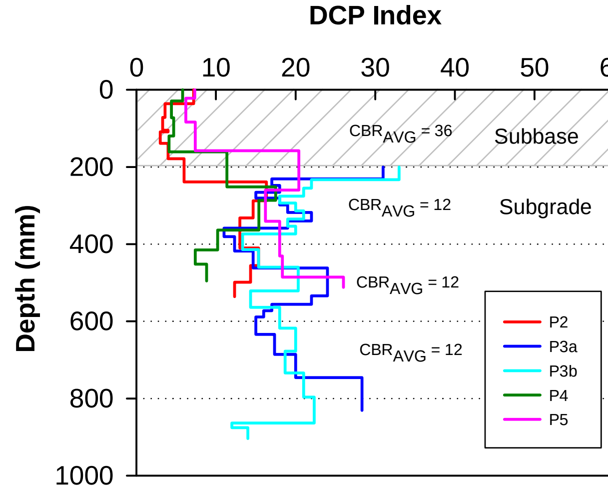
(c) Spalling of transverse joint at slab #9

(d) Spalling of longitudinal joint at slab #13

Site number: 8

Location: I-35 in Hamilton County: Mile Post No. 140.75 to 140.80
GPS coordination: N.42º07.4882'/W. 93º33.2378', Elev. 273.9m
Test date: June 19, 2007
Weather: Sunny, 82º F to 88ºF
Site description: Test area is on I 35 Northbound at station MP 140.75. Recycled material for base layer. PCC thickness = 30.5 cm.
A drainage pipe at PM 141 has water with high base (pH=11). Surrounding soil is hardened and vegetation die.

Core	Location	Activity
4" core	P1, P2, P4, P5	Permeability Test at P1, DCP
10" core	P3	LWD, Clegg Hammer, DCP



Hydraulic conductivity of subbase layer

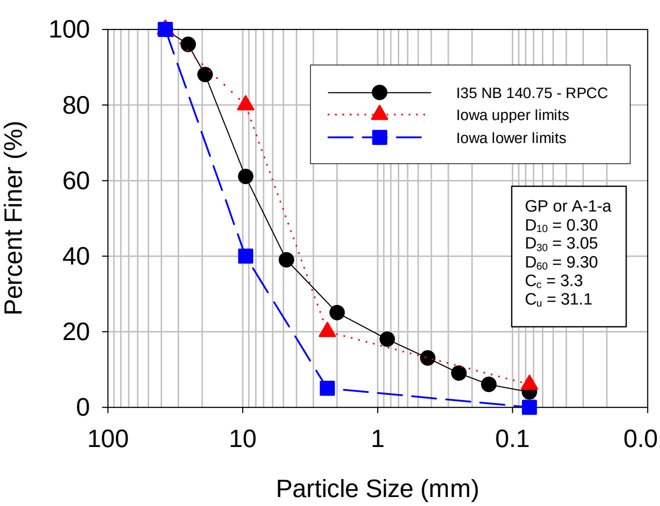
$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.712	0.369

Clegg Impact and CBR Values

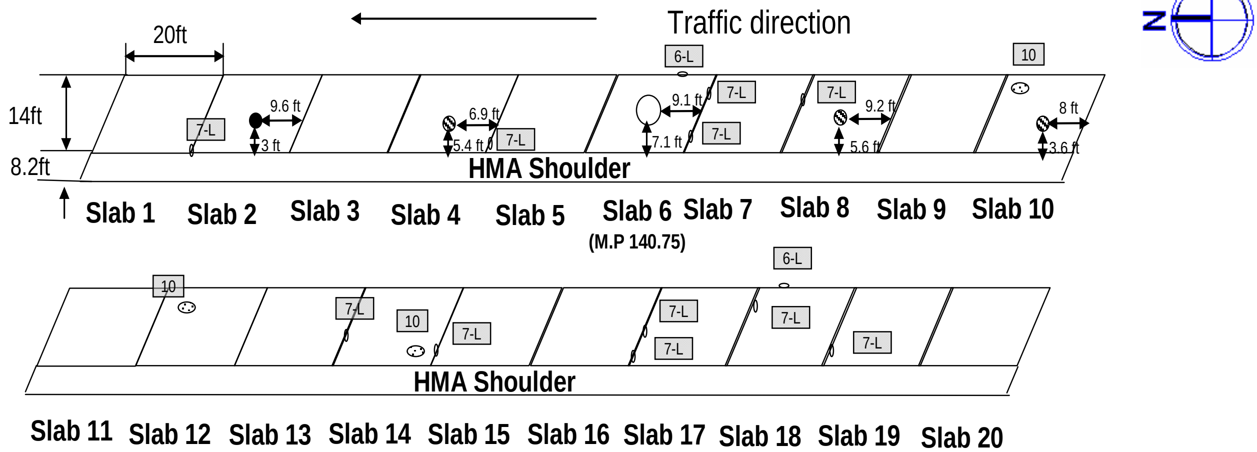
Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	40	50	54	48
	CBR	57	74	80	70
Subgrade	CIV	17	20	-	19
	CBR	27	33	-	30

Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Sunbase	8.2	100	261	252	123
Subgrade	7.5	100	238.7	673	42



I-35 in Hamilton County: Mile Post No. 140.75 to 140.80 (June/19/2007)

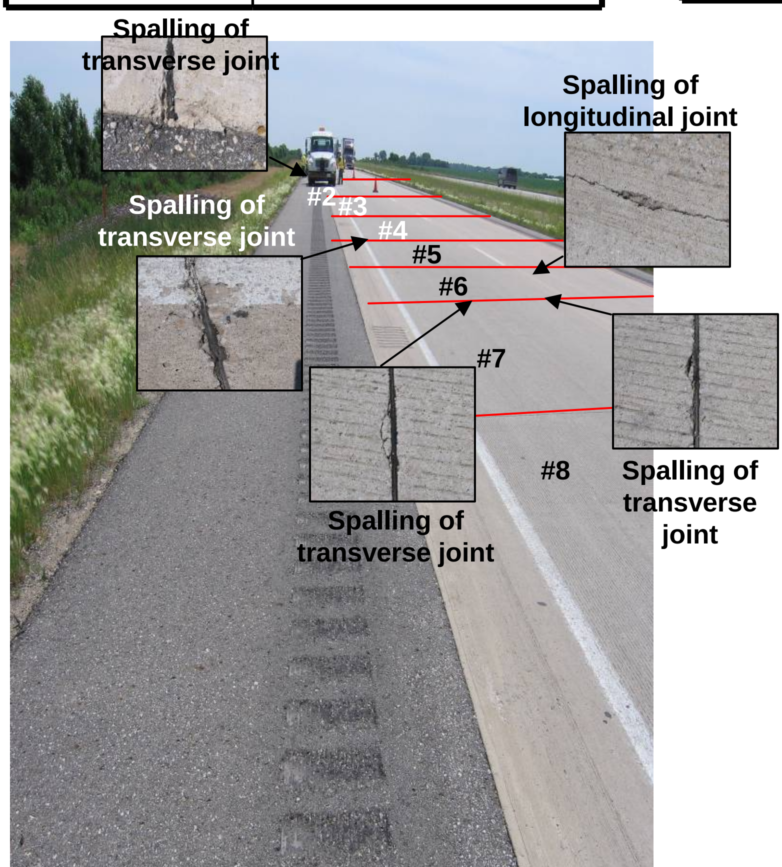


Note:

Core	Activity
● (4" Core)	Permeability test
▨ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IM-35-6(94)140-13-40
Construction year	2003
PCI (2006)	98 %
IRI (2006)	1.38 m/km

Survey Type	Comment
Slab thickness	10.5 in
Base thickness	8 in (RPCC)
Joint orientation	Diagonal
Joint width	0.4 in
Joint depth	More than 0.4 in
Sealing condition	No sealing
Shoulder condition	Good
Cut or fill	Fill



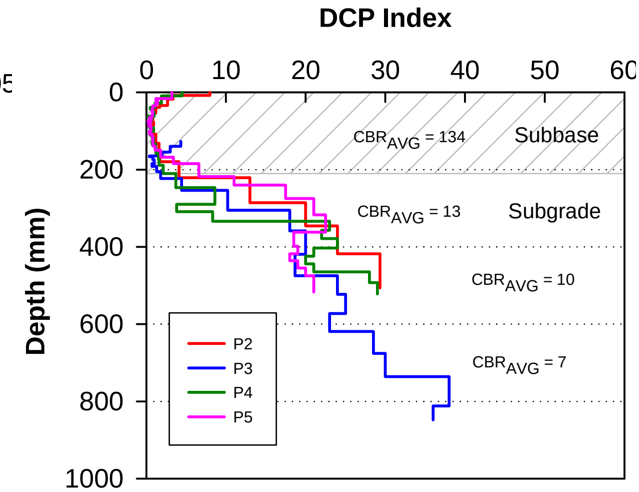
(a) Overall surface distress condition from slab #2 to #8

(b) Popout at slab #10

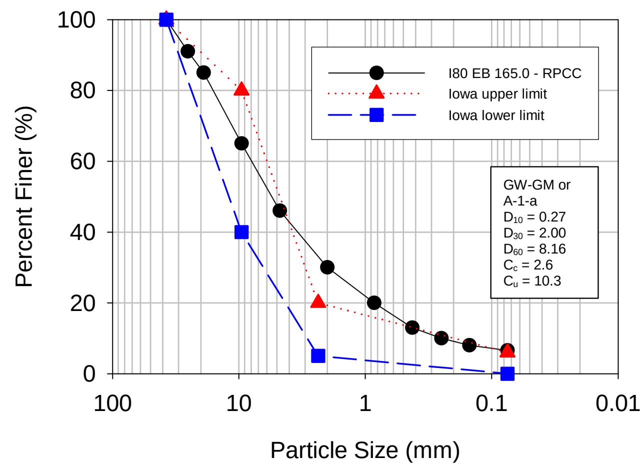
(c) Spalling of transverse joint at slab #14

Site number: 9

Location: I-80 in Jasper County: Mile Post No. 165.00 to 165.05
GPS coordination: N.41º41.0210’/W. 93º03.8771’, Elev. 259.1m
Test date: June 21, 2007
Weather: Sunny, 85ºF to 90ºF
Site description: Test area is on I 80 Eastbound at station MP 165. Recycled material for subbase layer. PCC thickness = 13 inches.
The PCC pavement was constructed in 1996.
The subbase layer is recycled material. It is a very hard layer and the particles seem to bond to each other.
Stop digging at 5 in. below PCC. No LWD, Clegg on subgrade layer.



Core	Location	Activity
4” core	P1, P2, P4, P5	Permeability Test at P1, DCP
10” core	P3	LWD, Clegg Hammer, DCP



Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	93	106	133	110
	CBR	100+	100+	100+	100+
Subgrade	CIV	No	——	——	——
	CBR	test	——	——	——

Photos of Field Test, Core Samples

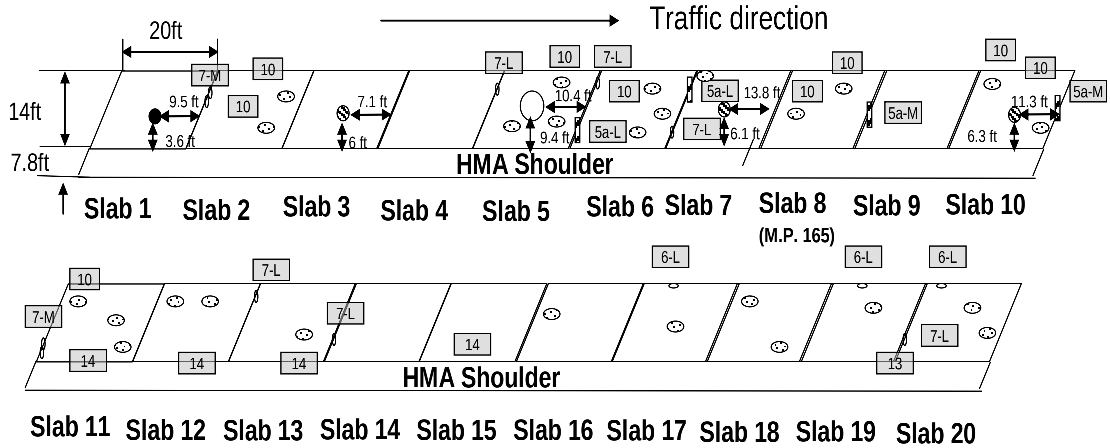
Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.4	100	267.4	56	629
Subgrade	No	test	——	——	——

Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.083	0.045

I-80 in Jasper County: Mile Post No. 165.00 to 165.05 (June/21/2007)



Note:

Core	Activity
● (4" Core)	Permeability test
(hatched) (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IM-80-5(184)160-13-50
Construction year	1996
PCI (2006)	83 %
IRI (2006)	1.16 m/km

Survey Type	Comment
Slab thickness	13 in
Base thickness	5 In (RPCC)
Joint orientation	Diagonal
Joint width	0.4 in
Joint depth	0.6 in
Sealing condition	Bad
Shoulder condition	Bad
Cut or fill	Cut

(a) Spalling of transverse joint at slab #4

(b) Popout at slab #6

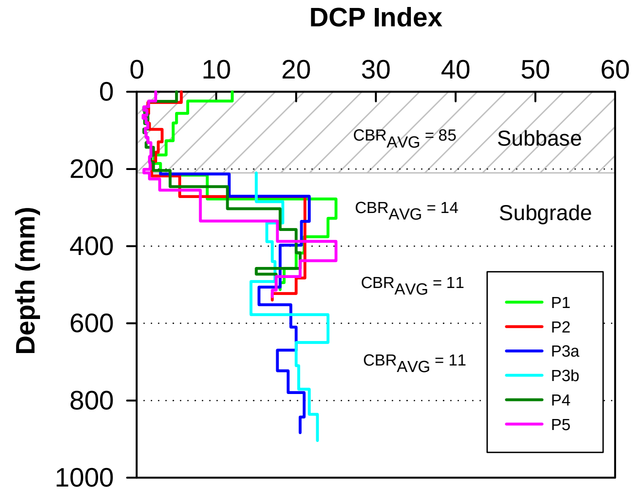
(c) Lane to shoulder separation at slab #11

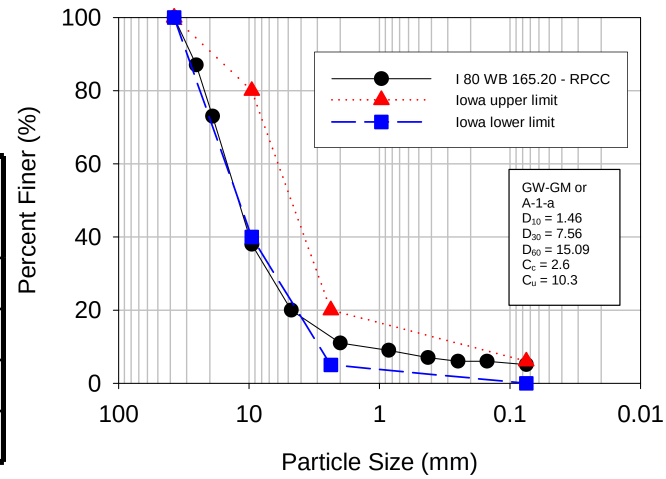
(d) Lane to shoulder drop-off at slab #20

Site number: 10

Location: I-80 in Jasper County: Mile Post No. 165.20 to 165.25
GPS coordination:
Test date: June 21, 2007
Weather: Sunny, 85ºF to 90ºF, light wind
Site description: Test area is on I 80 Eastbound at station Mile Post 165.20. Recycled material for base layer. PCC thickness = 13 inches. Base layer thickness = 7 inches. The PCC pavement was constructed in 1994.
LWD, Clegg are on subbase and subgrade layers.

Core	Location	Activity
4" core	P1, P2, P4, P5	Permeability Test at P1, DCP
10" core	P3	LWD, Clegg Hammer, DCP





Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	58	72	92	74
	CBR	87	100+	100+	100+
Subgrade	CIV	33	—	—	—
	CBR	80	—	—	—

Light Weight Deflectometer Modulus

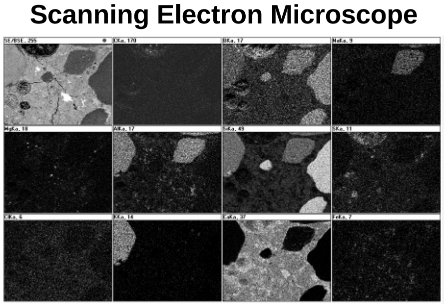
Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.6	100	273.7	101	322
Subgrade	7.7	100	245.1	454	64

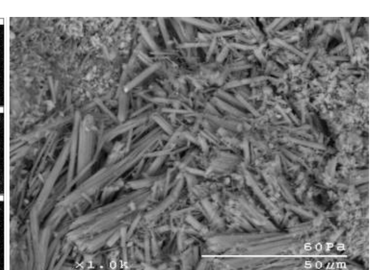
Hydraulic conductivity of subbase layer

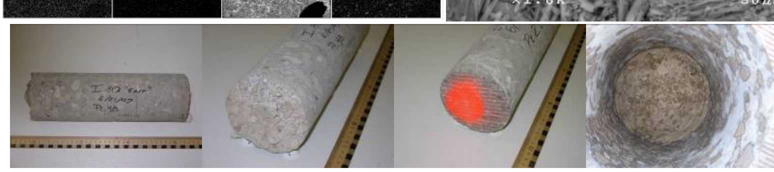
$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.103	—

Photos of Field Test, Core Samples

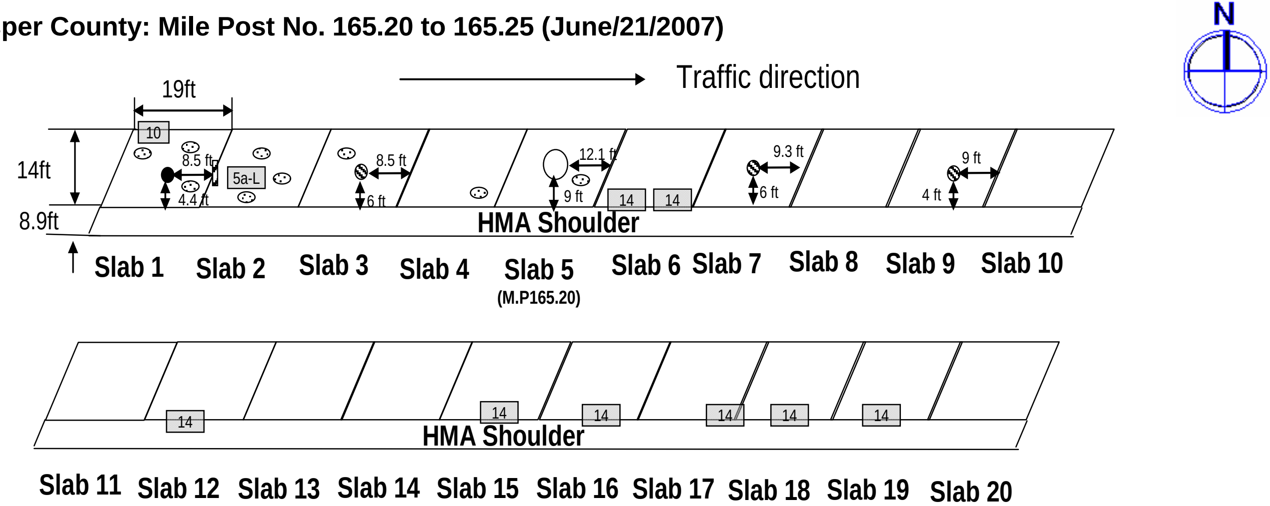
Scanning Electron Microscope







I-80 in Jasper County: Mile Post No. 165.20 to 165.25 (June/21/2007)



Note:

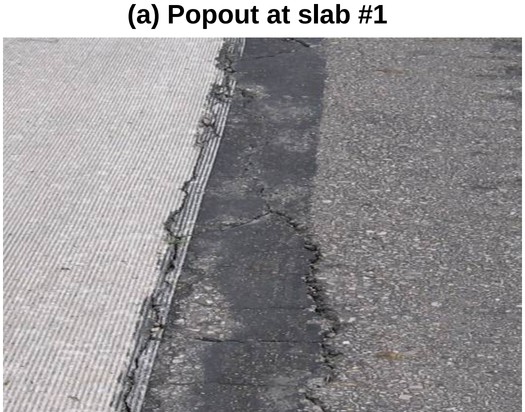
Core	Activity
● (4" Core)	Permeability test
▨ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IM-80-5(169)165-13-50
Construction year	1994
PCI (2006)	78 %
IRI (2006)	2.29 m/km

Survey Type	Comment
Slab thickness	13 in
Base thickness	7 in (RPCC)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	1.0 in
Sealing condition	Good
Shoulder condition	Bad
Cut or fill	Cut

(a) Popout at slab #1

(b) Joint sealing damage of transverse joint at slab #1



(c) Lane to shoulder separation at slab #15

(d) Lane to shoulder separation at slab #18

Site number: 11

Location: I-35 in Hamilton County: Mile Post No. 131.40 to 131.45
GPS coordination: N.42º17.2470'/W. 93º34.2158', Elev. 303.7m
Test date: June 27, 2007
Weather: Sunny, 75ºF, wind 25 mph
Site description: Test area is on I 35 Northbound at station MP 131.40. Recycled material for base layer. PCC thickness = 10.5 inches. **Constructed in 1983**.
Water from a drainage pipe nearby is very fresh. There is no sign of carbonate calcite like what was at mile post 141.00. Vegetation grows on the shoulder.
Reason: may be the base was constructed so long ago, all the leaking carbonate calcite were washed out.

Core	Location	Activity
4" core	P1, P2, P4, P5	Permeability Test at P1, DCP
10" core	P3	LWD, Clegg Hammer, DCP

Clegg Impact and CBR Values

Level	CIV / CBR	Test points					Avg.
		1	2	3	4	5	
Subbase	CIV	34	52	31	72	74	53
	CBR	45	76	43	100+	100+	75
Subgd.	CIV	14	14	—	—	—	14
	CBR	19	19	—	—	—	19

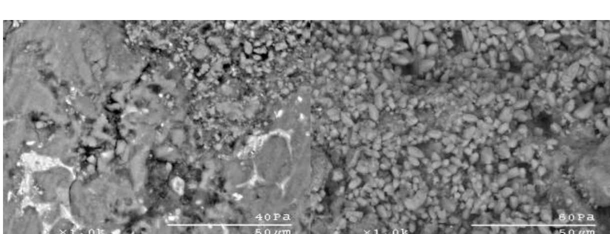
Light Weight Deflectometer Modulus

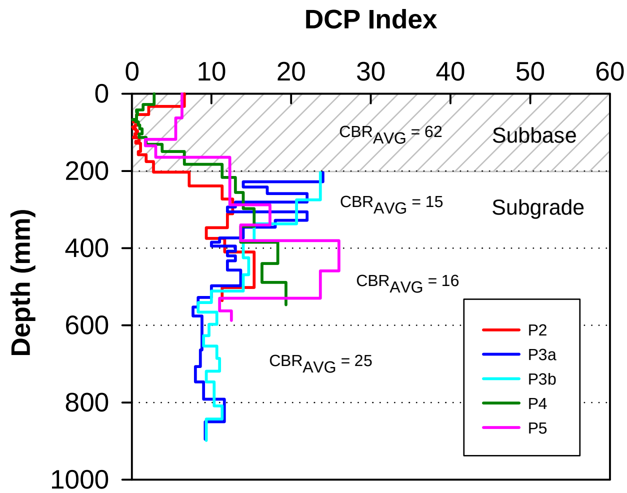
Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.2	100	261	185	186
Subgrade	7.6	100	241.9	947	34

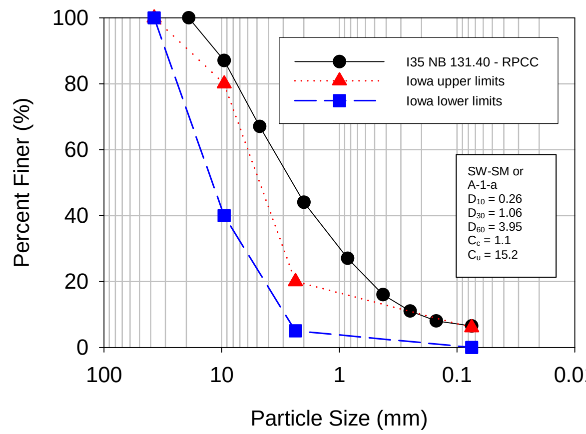
Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.142	0.066

Scanning Electron Microscope

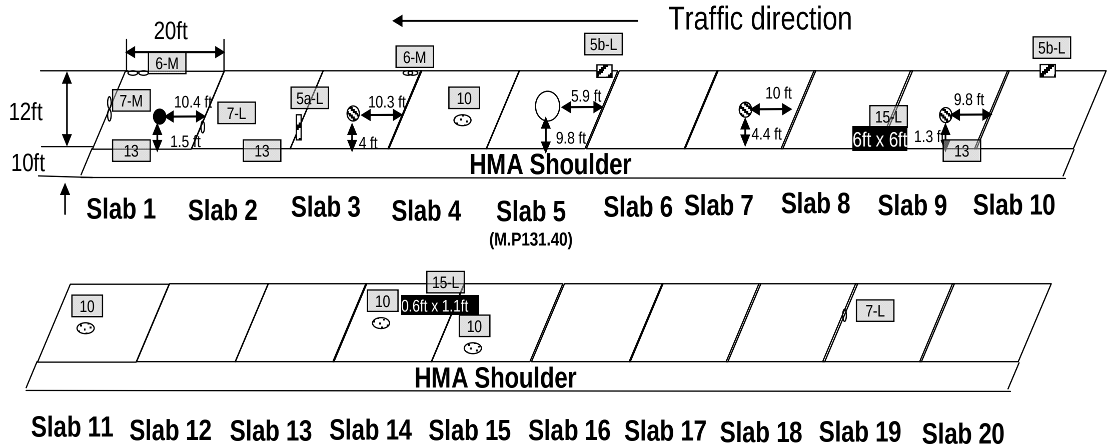






Photos of Field Test, Core Samples

I-35 in Hamilton County: Mile Post No. 131.40 to 131.45 (June/28/2007)



Note:

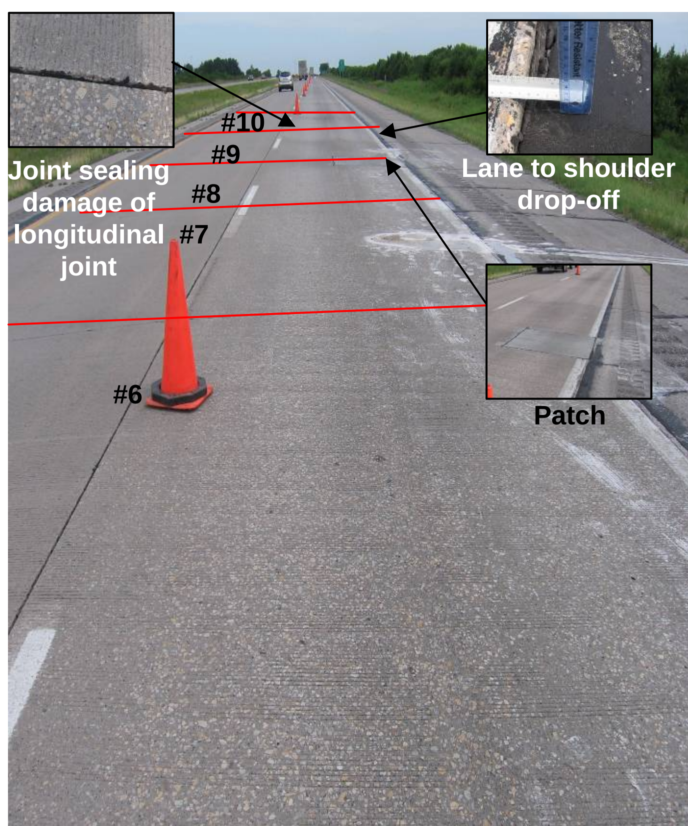
Core	Activity
● (4" Core)	Permeability test
◍ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IR-35-5(36)133
Construction year	1983
PCI (2006)	55 %
IRI (2006)	1.72 m/km

Survey Type	Comment
Slab thickness	10.5 in
Base thickness	8 in (RPCC)
Joint orientation	Diagonal
Joint width	0.5 in
Joint depth	0.8 in
Sealing condition	Good
Shoulder condition	Bad
Cut or fill	Fill

(a) Lane to shoulder drop-off at slab #1

(b) Joint sealing damage of longitudinal joint at slab #5

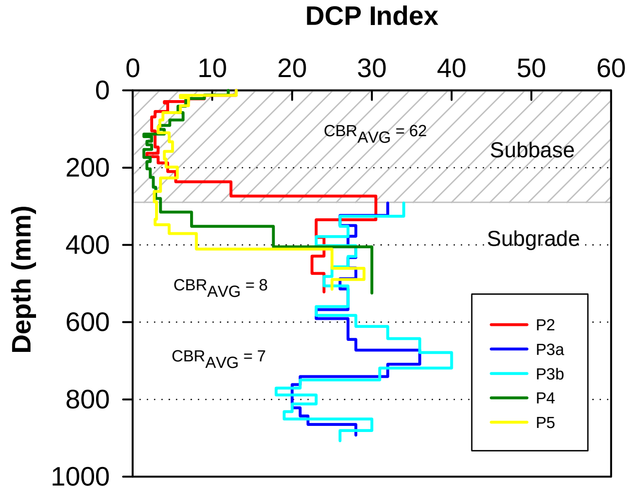


(c) Overall surface distress condition from slab #6 to #10

Site number: 12

Location: IA 92in Warren County: Mile Post No. 132.16 to 133.80
GPS coordination: N.41º21.4662'/W. 93º32.0633', Elev. 265.8m
Test date: August 07, 2007
Weather: Cloudy, light rain in the morning, 70-75º F
Site description: Test area is on Hwy 92 Eastbound between 132.16 and 133.80. It was believed that base material was Recycled, but in fact it was **Virgin**. > Control section. One-Lane-Hwy for each direction.

Core	Location	Activity
4" core	P1, P2, P4, P5	DCP
10" core	P3	LWD, Clegg Hammer, DCP



Clegg Impact and CBR Values

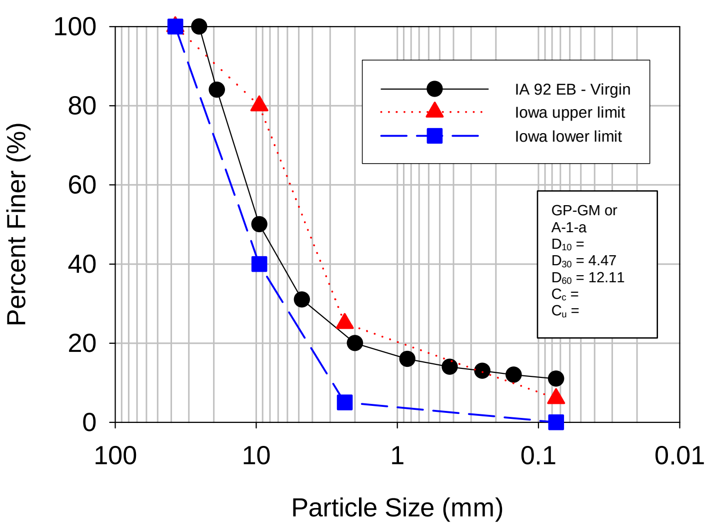
Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	38	39	39	39
	CBR	54	55	55	55
Subgrade	CIV	10	9	—	10
	CBR	11	9	—	11

Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (µm)	E (MPa)
Subbase	8.2	100	261.1	63	547
Subgrade	8	100	254.8	241	140

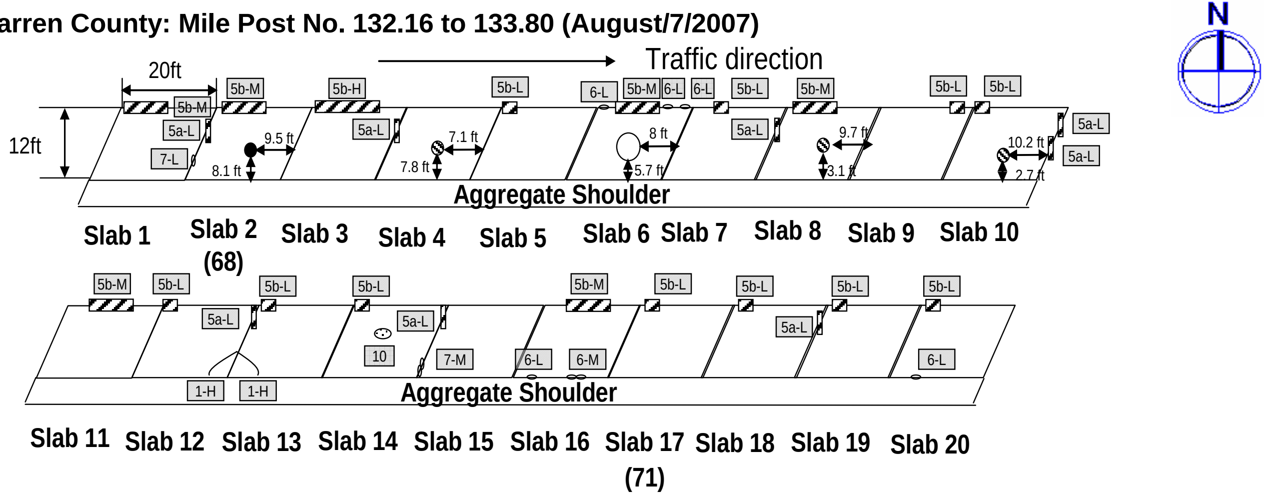
Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.103	—



Photos of Field Test, Core Samples

IA-92 in Warren County: Mile Post No. 132.16 to 133.80 (August/7/2007)

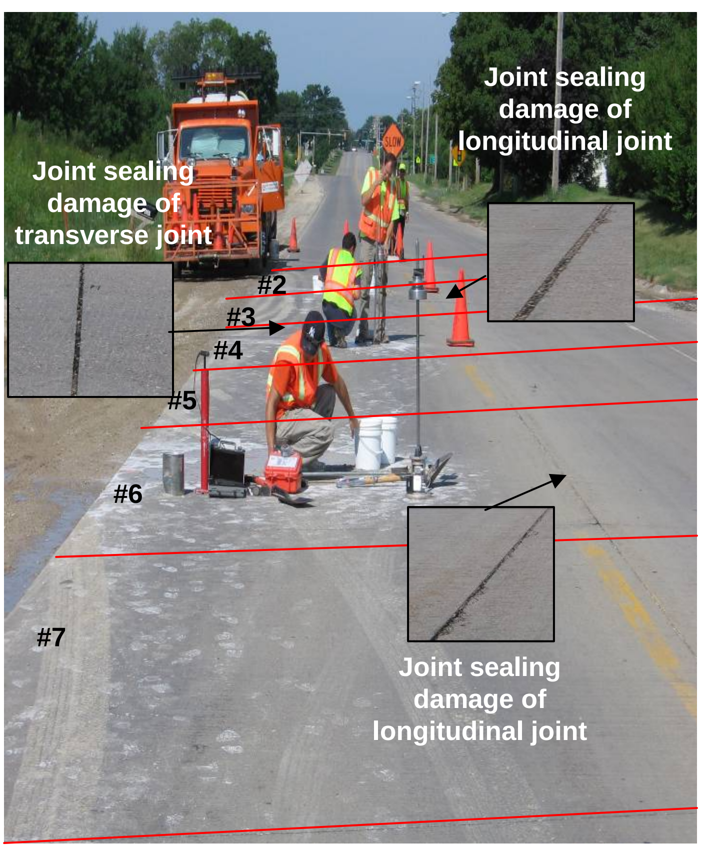


Note:

Core	Activity
● (4" Core)	Permeability test
▨ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	HES-92-5(27)—2H-91
Construction year	1993
PCI (2006)	90 %
IRI (2006)	1.44 m/km

Survey Type	Comment
Slab thickness	10 in
Base thickness	12 in (Virgin)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	0.8 in
Sealing condition	Bad
Shoulder condition	N/A (Aggregate Shoulder)
Cut or fill	Cut



(a) Overall surface distress condition from slab #2 to #7

(b) Corner break at slab #12 and #13

(c) Spalling of transverse joint at slab #14

Site number: 13

Location: I 80 in Pottawattamie County: Mile Post No. 10.55 to 10.60
GPS coordination: N.41º18.402'/W.095º45.990', E.L:3.15m
Test date: August 09, 2007
Weather: Sunny – partly cloudy, 80-85º F
Site description: Test area is on **I 80** Westbound at station MP **10.60**. Recycled material for base layer. PCC thickness = 13 inches. Base layer thickness = 10.5 inches.
The PCC pavement was constructed in 1999.

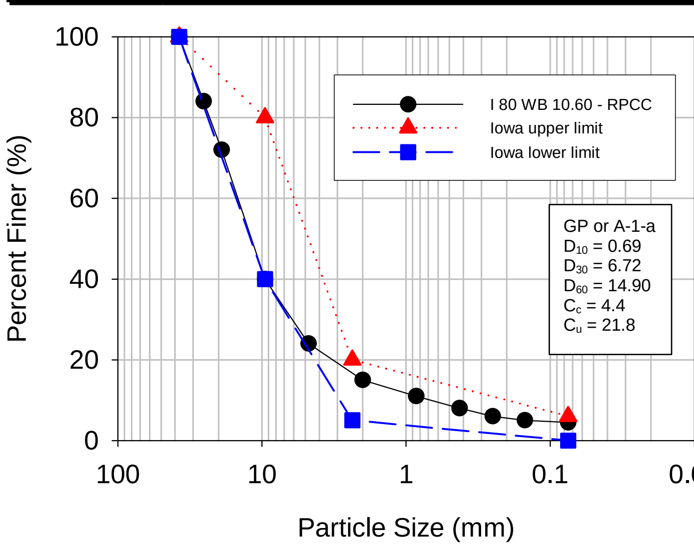
Core	Location	Activity
4" core	P1, P2, P4, P5	DCP, base samples
10" core	P3	LWD, Clegg Hammer, DCP, base & subgrade sample

Clegg Impact and CBR Values

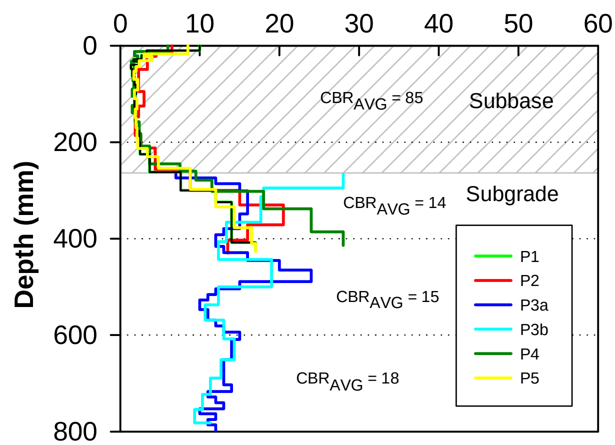
Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	41	36	36	38
	CBR	58	50	50	54
Subgrade	CIV	10	10	—	10
	CBR	12	12	—	12

Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (µm)	E (MPa)
Subbase	8.4	100	267.5	66	535
Subgrade	7.8	100	248.4	550	60

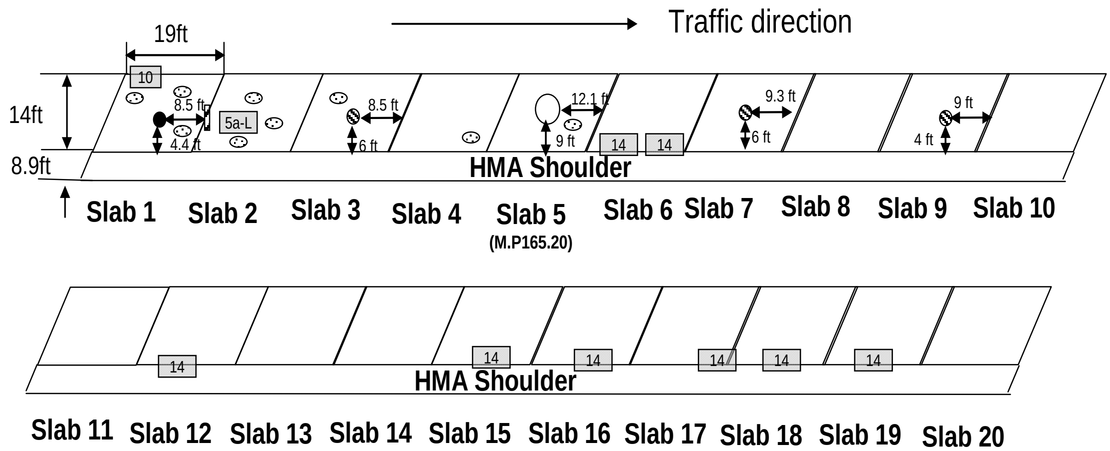


DCP Index



Core Samples

I-80 in Pottawattamie County: Mile Post No. 10.55 to 10.60 (August/9/2007)



Note:

Core	Activity
(4" Core)	DCP
(10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IM-80-1(249)6—13-78
Construction year	1999
PCI (2006)	92 %
IRI (2006)	1.87 m/km

Survey Type	Comment
Slab thickness	13 in
Base thickness	11 in (RPCC)
Joint orientation	Diagonal
Joint width	0.4 in
Joint depth	1.2 in
Sealing condition	Good
Shoulder condition	Good
Cut or fill	Fill

(a) Lane to shoulder separation at slab #2

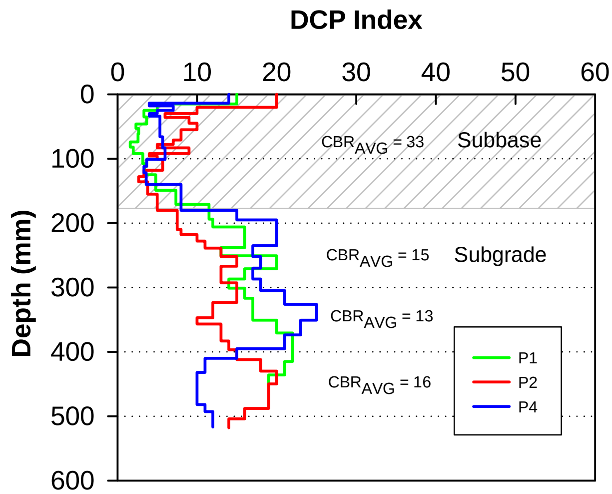
(b) Transverse cracking at slab #5

(c) Lane to shoulder drop-off at slab #6

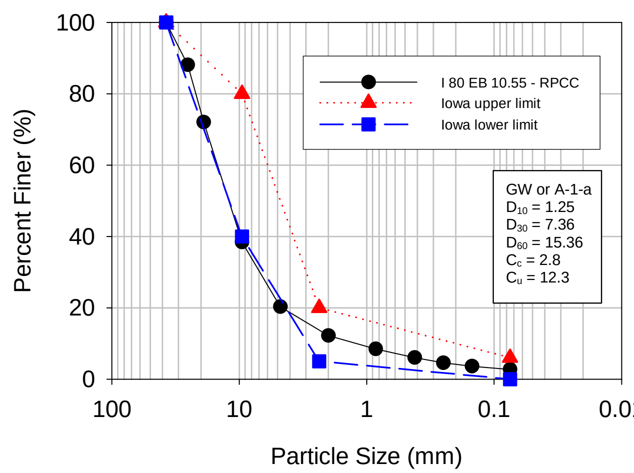
(d) Patch at slab #13

Site number: 14

Location: I 80 in Pottawattamie County: Mile Post No. 10.55 to 10.60
GPS coordination: N.41º18.373'/W.95º45.991',E.L:3.13m
Test date: September 11, 2007
Weather: Sunny, 65º F, windy 10 mph.
Site description: Test area is on **I 80** Eastbound at station MP **10.60**. Recycled material for base layer.
The PCC pavement was constructed in 2003.
Problems: The pavement is too thick and made of very hard aggregate materials. Cannot drill 10" core (P3) and don't have time to core P5. Thus, no LWD, Clegg hammer tests are conducted.



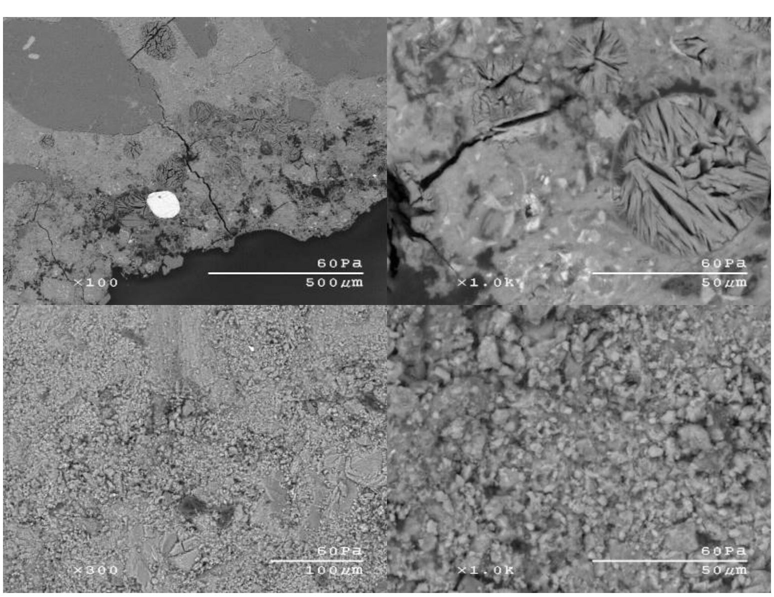
Core	Location	Activity
4" core	P1, P2, P4, P5	DCP, subbase samples, permeability test
10" core	P3	No test



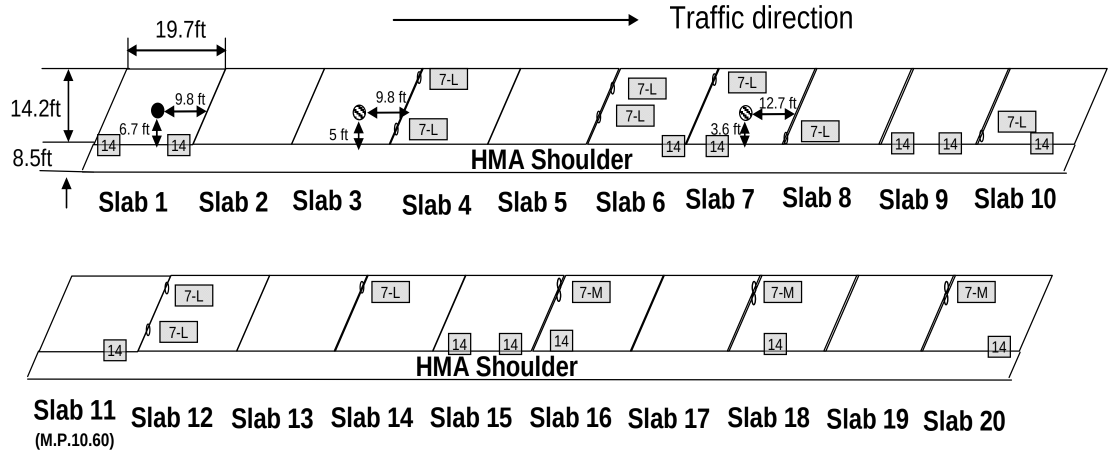
Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.997	0.922

Scanning Electron Microscope



I-80 in Pottawattamie County: Mile Post No. 10.55 to 10.65 (September/11/2007)



Note:

Core	Activity
● (4" Core)	Permeability test
▨ (4" Core)	DCP

PMIS Data	Number
Project No.	IM-80-1(251)6--13-78
Construction year	2003
PCI (2006)	99 %
IRI (2006)	1.42 m/km

Survey Type	Comment
Slab thickness	12 in
Base thickness	N/A (RPCC)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	0.6 in
Sealing condition	Good
Shoulder condition	Good
Cut or fill	Fill

(a) Lane to shoulder separation at slab #1

(b) Spalling of transverse joint at slab #5

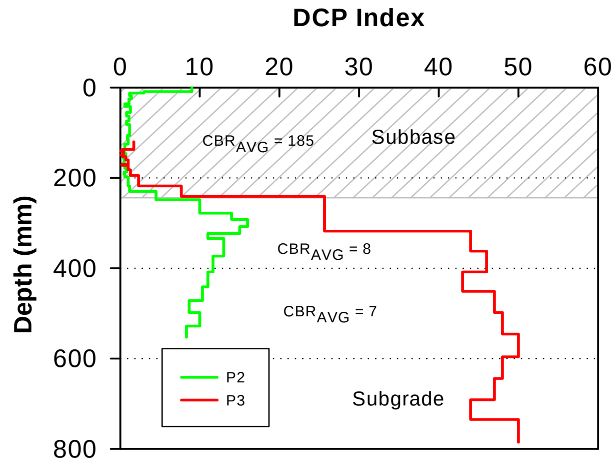
(c) Spalling of transverse joint at slab #7

(d) Lane to shoulder separation at slab #10

Site number: 15

Location: I 80 in Cass County: Mile Post No. 65.10 to 65.20
GPS coordination: N.41º29.824'/W.94º51.459', E.L:3.79 m
Test date: September 25, 2007
Weather: Light rain in the morning, 65º F, wind 5-10 mph.
Site description: Test area is on **I 80** Eastbound at station MP **65.15**. Recycled material for base layer. The PCC pavement was constructed in 1988. Pavement have some big cracks. In the slab that has P3, a crack cut across the pavement, divided it into 2 parts. Permeability is very low. "Fresh" water drains out of the drainage pipe. The grass is green.
The subbase was too hard to get down to subgrade layer – no tests on subgrade. Permeability was significantly low. DCP tests can get through the subbase layer since it was extremely stiff. DCP in P2 did provide results, but it was not correct because the tip was lost without recognition. Later on we found that the DCP equipment just bounce up after each drop that made the tip lose out of the DCP rod. In the following DCP tests, we eliminated this problem, but the tip couldn't go down since the subbase was too stiff.

Core	Location	Activity
4"	P1, P2, P4, P5	DCP (was not successful), subbase samples, permeability test
10"	P3	LWD, Clegg Hammer, DCP, subbase

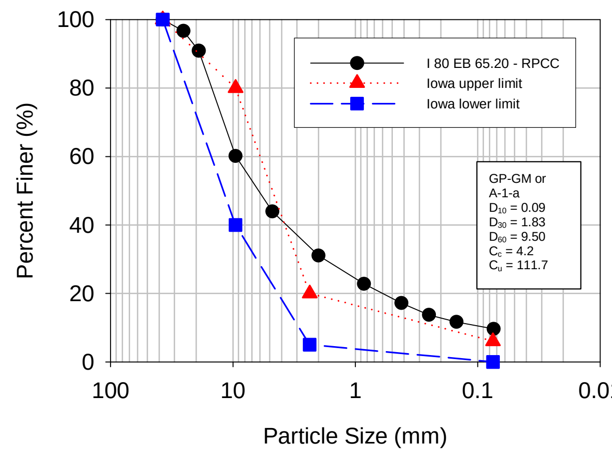


Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	107	143	—	125
	CBR	100+	100+	—	100+

Light Weight Deflectometer Modulus

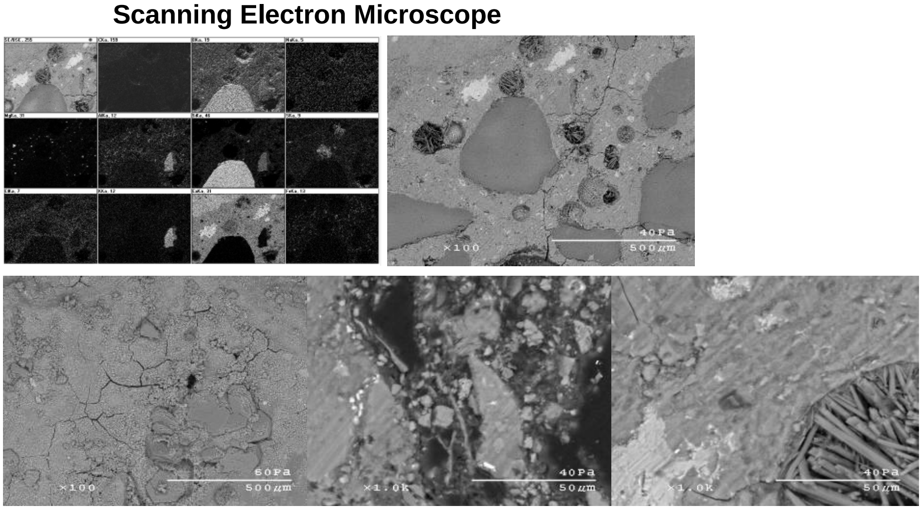
Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (µm)	E (MPa)
Subbase	8.1	100	257.8	16	2126

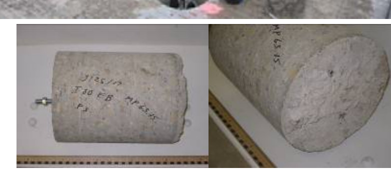


Hydraulic conductivity of subbase layer

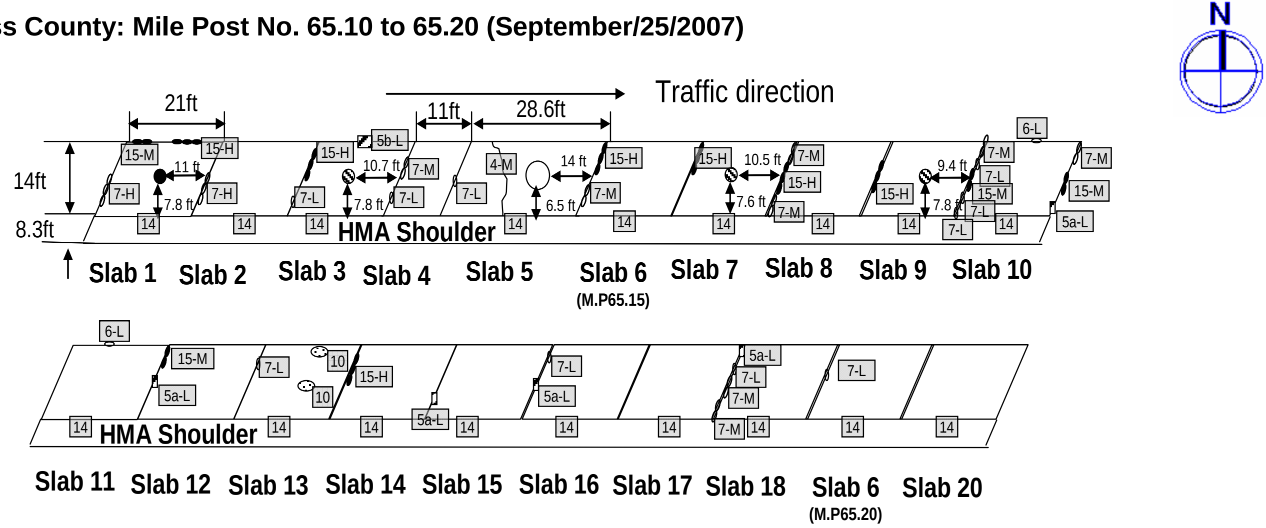
$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.006	0.003

Scanning Electron Microscope





I-80 in Cass County: Mile Post No. 65.10 to 65.20 (September/25/2007)



Note:

Core	Activity
● (4" Core)	Permeability test
▨ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IR-80-2(117)61
Construction year	1988
PCI (2006)	70 %
IRI (2006)	1.66 m/km

Survey Type	Comment
Slab thickness	12.3 in
Base thickness	N/A (RPCC)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	1.0 in
Sealing condition	Bad
Shoulder condition	Bad
Cut or fill	Fill

(a) Patch at slab at slab #1

(b) Transverse cracking at slab #5

(c) Lane to shoulder separation at slab #13

(d) Popout at slab #13

Site number: 16

Location: I 80 in Cass County: Mile Post No. 65.80 to 65.90
GPS coordination: N.41º29.833'/W.94º50.630', E.L:3.9 m
Test date: October 3, 2007
Weather: Sunny, 60-70ºF, wind 5-10 mph
Site description: Test area is on I 80 Westbound at station MP 65.85. Recycled material for base layer. **Constructed in 1987**.
Water from a drainage pipe flows out normally and is fresh. No sign of high pH. Grass, vegetation surrounding the outlet are green and similar with those in other areas. Water trench along the highway at the test point was approximate 3 m lower than the PCC surface. Very stiff subbase layer, no DCP in P3; cannot get down to subgrade layer for LWD, Clegg hammer.

Core	Location	Activity
4" core	P1, P2, P4, P5	Permeability Test at P1, DCP
10" core	P3	LWD, Clegg Hammer

Clegg Impact and CBR Values

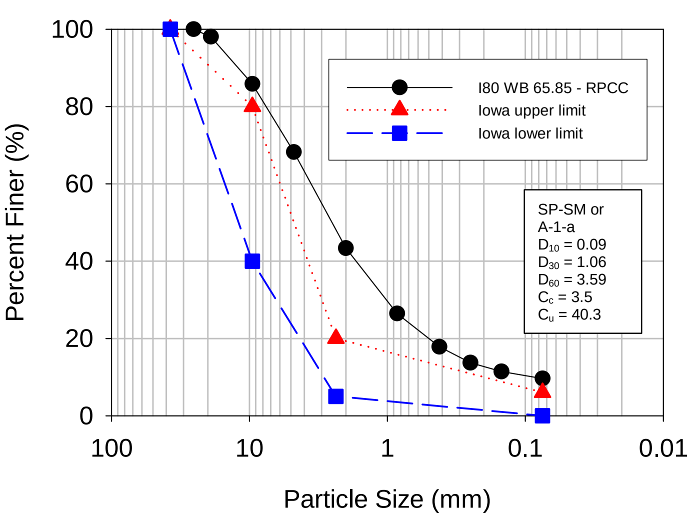
Level	CIV / CBR	Test points			Avg.
		1	2	3	
Subbase	CIV	77	88	65	77
	CBR	100+	100+	99	100+

Light Weight Deflectometer Modulus

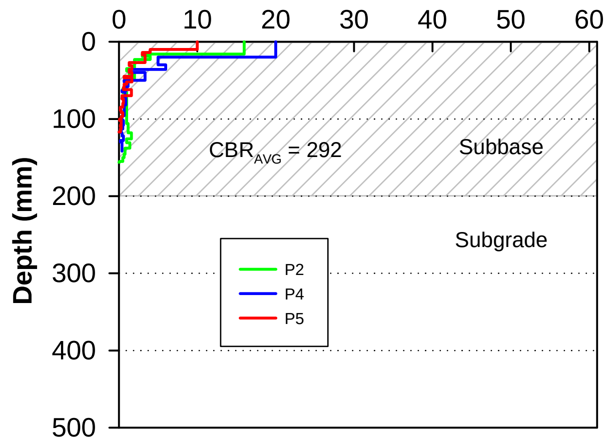
Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.2	100	261	29	1188

Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.014	0.008



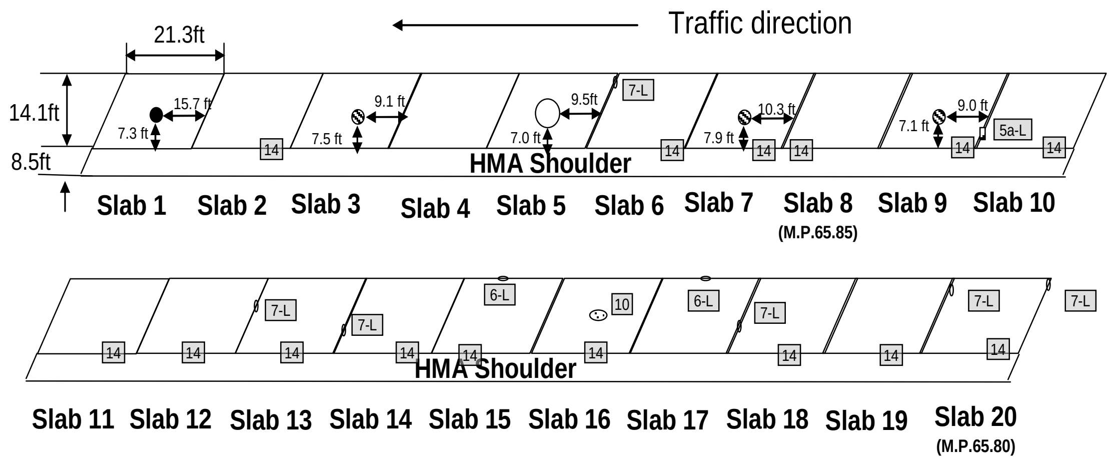
DCP Index



Photos of Field Test

Core Samples

I-80 in Cass County: Mile Post No. 65.80 to 65.90 (October/3/2007)



Note:

Core	Activity
● (4" Core)	Permeability test
◍ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IR-80-2(108)61
Construction year	1987
PCI (2006)	68%
IRI (2006)	1.67m/km

Survey Type	Comment
Slab thickness	12 in
Base thickness	N/A (RPCC)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	1.0 in
Sealing condition	Good
Shoulder condition	Bad
Cut or fill	Cut

(a) Lane to shoulder separation at slab #2

(b) Spalling of transverse joint at slab #5

(c) Lane to shoulder separation at slab #15

(d) Popout at slab #16

Site number: 17

Location: Knapp Street, Westbound, Ames, Iowa
GPS coordination: N.42º01.151'/W.93º39.218', E.L:265.8m
Test date: October 9, 2007
Weather: Sunny, 50-60º F.
Site description: Test area is on the Knapp Street. Recycled material for base layer.
The PCC pavement was constructed in 2003. The street is lower than the shoulders, so water flows over the surface if it is rainy. Test site is by the corner with Sheldon avenue.

Core	Location	Activity
4"	P1, P2, P4, P5	DCP, subbase samples, permeability tests
10"	P3	LWD, Clegg Hammer, DCP, subbase & subgrade sample

Clegg Impact and CBR Values

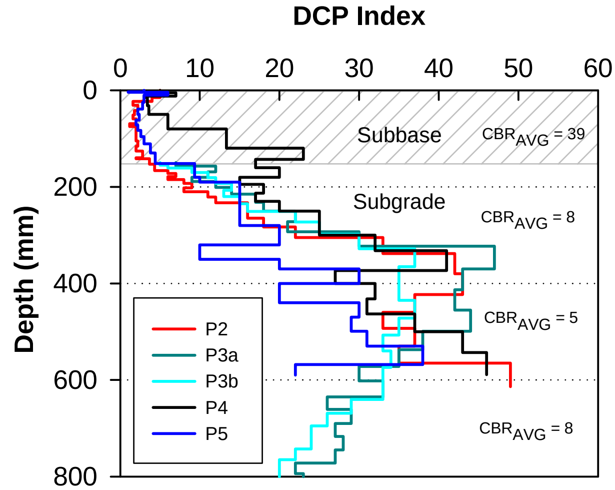
Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	46	52	50	50
	CBR	67	77	72	72
Subgrade	CIV	14	15	—	15
	CBR	20	22	—	21

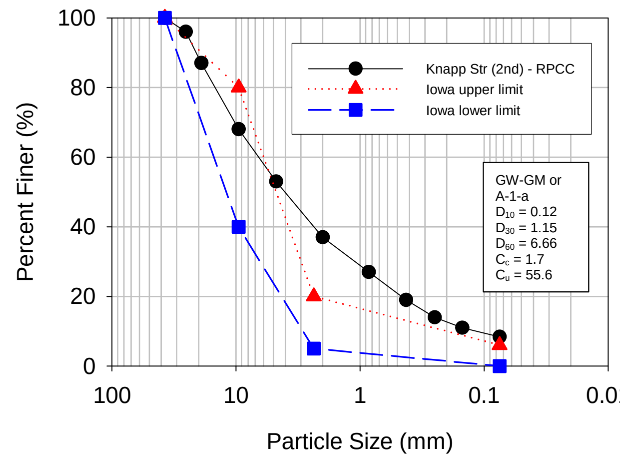
Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.3	100	264.2	53	658
Subgrade	7.6	100	241.9	537	59.4

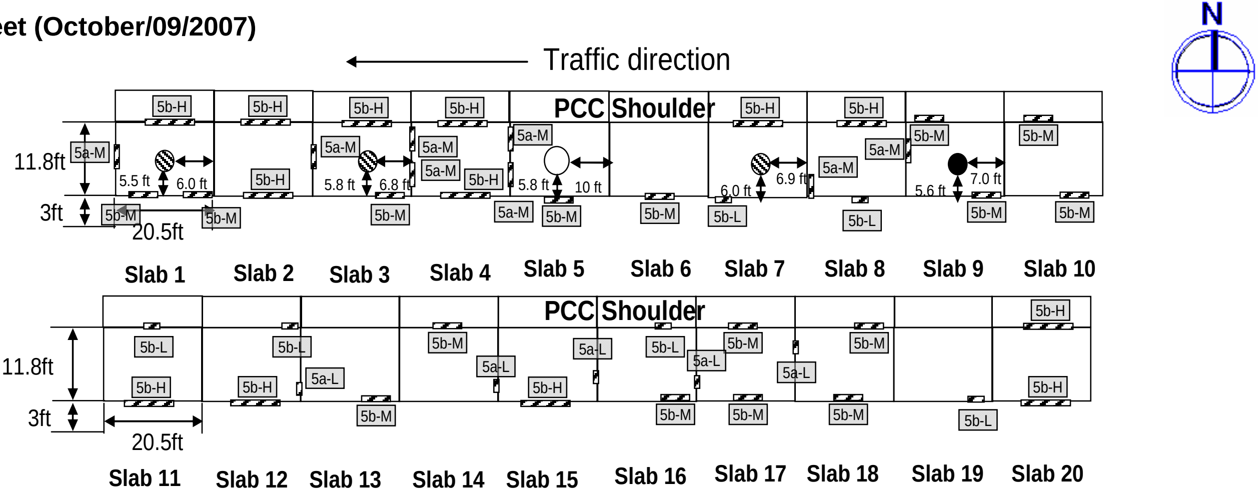
Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.036	0.076





Knapp Street (October/09/2007)



Note:

Core	Activity
● (4" Core)	Permeability test
▨ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	N/A
Construction year	2003
PCI (2006)	N/A
IRI (2006)	N/A

Survey Type	Comment
Slab thickness	9.4 in
Base thickness	6.7 in (RPCC)
Joint orientation	Rectangular
Joint width	0.4 in
Joint depth	0.2 in
Sealing condition	Bad
Shoulder condition	Good
Cut or fill	Cut

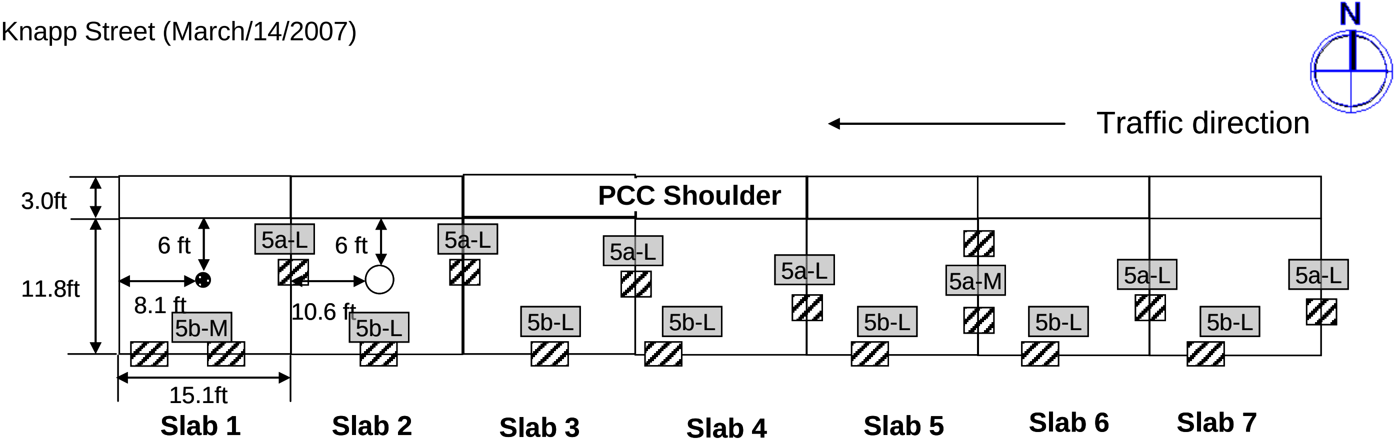
(a) Joint sealing damage of transverse joint at slab #3

(b) Joint sealing damage of longitudinal joint at slab #6

(c) Joint sealing damage of longitudinal joint at slab #8

(d) Joint sealing damage of transverse joint at slab #12

Knapp Street (March/14/2007)



Note:

Core	Activity
(2" Core)	DCP, Clegg hammer
(10" Core)	LWD, Clegg hammer, DCP

Survey Type	Comment
Slab thickness	9.3 in
Base thickness	6.2 in (RPCC)
Joint orientation	Rectangular
Joint width	0.3 in
Joint depth	0.2 in
Sealing condition	Bad
Shoulder condition	Good
Cut or fill	Cut

(a) Joint sealing damage of longitudinal joint at slab #1

(b) Joint sealing damage of transverse joint at slab #1

(c) Joint sealing damage of longitudinal joint at slab #2

(d) Joint sealing damage of transverse joint at slab #2

Site number: 18

Location: I 80 in Cedar County: Mile Post No. 269.00 to 269.10
GPS coordination: N.41º18.402'/W.095º45.990', E.L:3.15m
Test date: October 16, 2007
Weather: Cloudy – some small rain, 50-60º F
Site description: Test area is on **I 80** Eastbound at MP **269.05**. Recycled material for base layer. PCC thickness = 13 inches. Base layer thickness = 6 inches.
The PCC pavement was constructed in 8/ 1991.

Core	Location	Activity
4" core	P1, P2, P4, P5	DCP; subbase samples; DOT, ISU, old type permeability tests
10" core	P3	LWD, Clegg Hammer, DCP, base & subgrade sample

Clegg Impact and CBR Values

Level	CIV / CBR	Test points 1	Test points 2	Test points 3	Average
Subbase	CIV	42	32	42	39
	CBR	60	44	60	55
Subgrade	CIV	18	14	—	16
	CBR	28	20	—	24

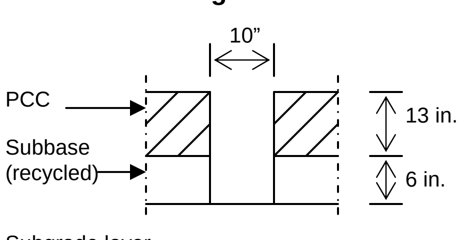
Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (µm)	E (MPa)
Subbase	7.7	100	245.1	109	297
Subgrade	7.8	100	248.4	745	44

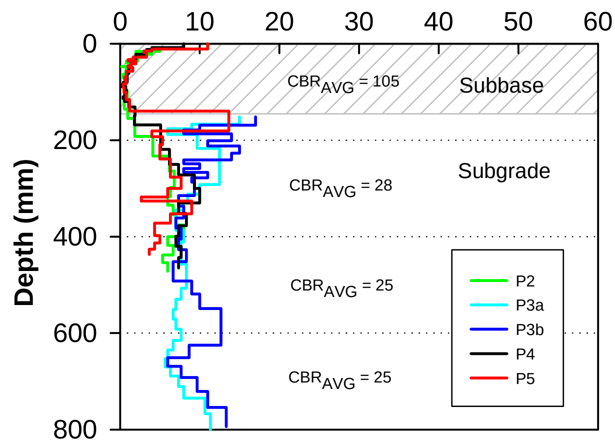
Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.059	0.038

10 inches core at P3 for subgrade tests



DCP Index



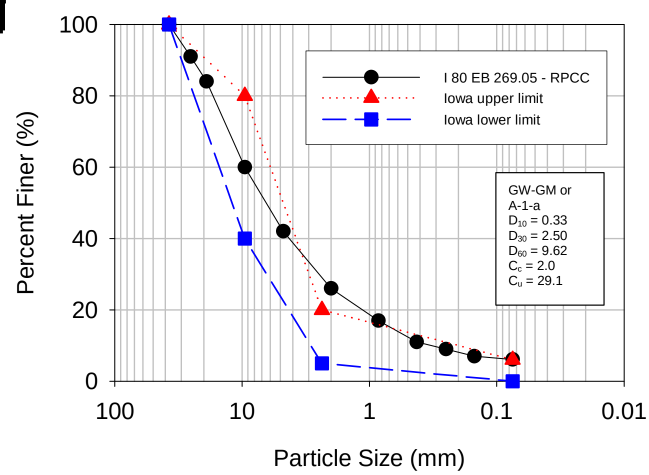
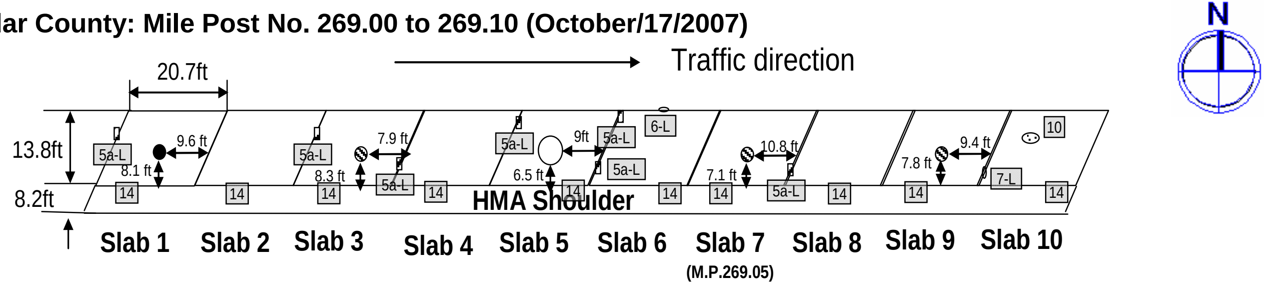
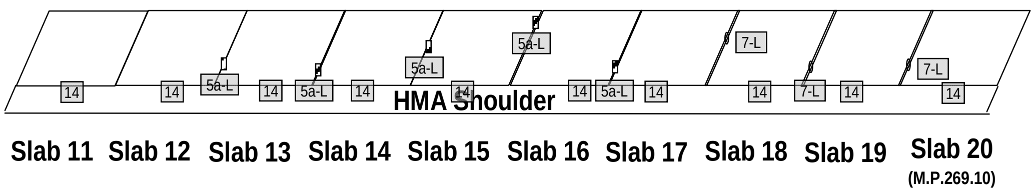


Photo of Field Test

Core Samples

I-80 in Cedar County: Mile Post No. 269.00 to 269.10 (October/17/2007)



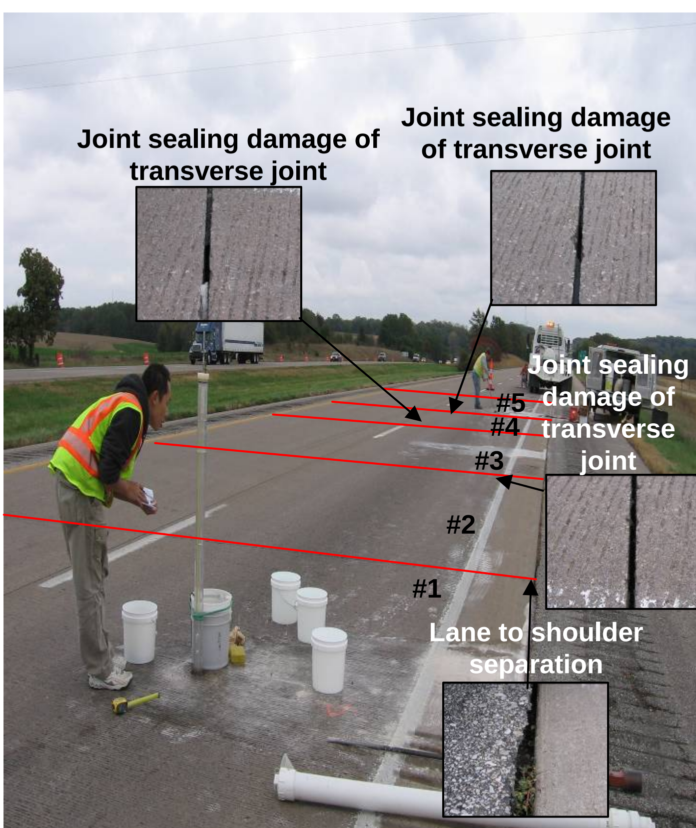


Note:

Core	Activity
● (4" Core)	Permeability test
▨ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IR-80-7(57)265
Construction year	1991
PCI (2006)	72%
IRI (2006)	1.6m/km

Survey Type	Comment
Slab thickness	13 in
Base thickness	6 in (RPCC)
Joint orientation	Diagonal
Joint width	0.4 in
Joint depth	2.2 in
Sealing condition	Bad
Shoulder condition	Bad
Cut or fill	Fill



(a) Overall surface distress condition from slab #1 to #5

(b) Lane to shoulder separation at slab #10

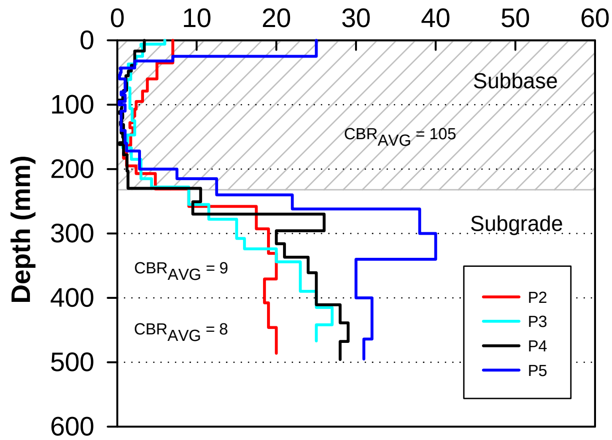
(c) Spalling of transverse joint at slab #17

Site number: 19

Location: I 80 in Cedar County: Mile Post No. 272.30 to 272.40
GPS coordination: N.41º37.997'/W.91º00.628', E.L:218.5 m
Test date: October 23, 2007
Weather: Sunny, 40-60º F
Site description: Test area is on **I 80** Eastbound at MP **272.35**, on the flat surface at the foot of the slope. The PCC surface is about 3 ft higher than the ditch. Recycled material for base layer. PCC thickness = 13 inches. Subbase layer thickness = 6 inches. The PCC pavement was constructed in 9/ 1991.
Note: The Clegg Hammer seems to run out of is range, since the subbase is too stiff. Sometimes it appeared 622.

Core	Location	Activity
4" core	P1, P2, P4, P5	DCP; subbase samples; DOT, ISU, old type permeability tests
10" core	P3	LWD, Clegg Hammer, DCP, base & subgrade sample

DCP Index



Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	160	166	—	163
	CBR	100+	100+	—	100+

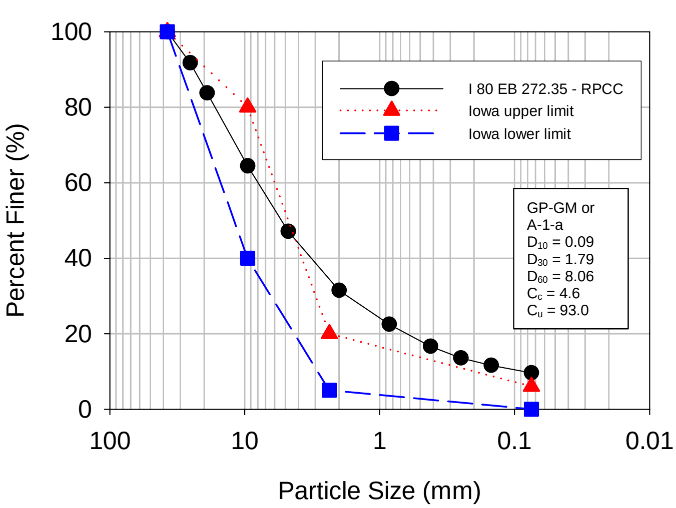
Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.2	100	261	29	1188
Subgrade	—	100	—	—	—

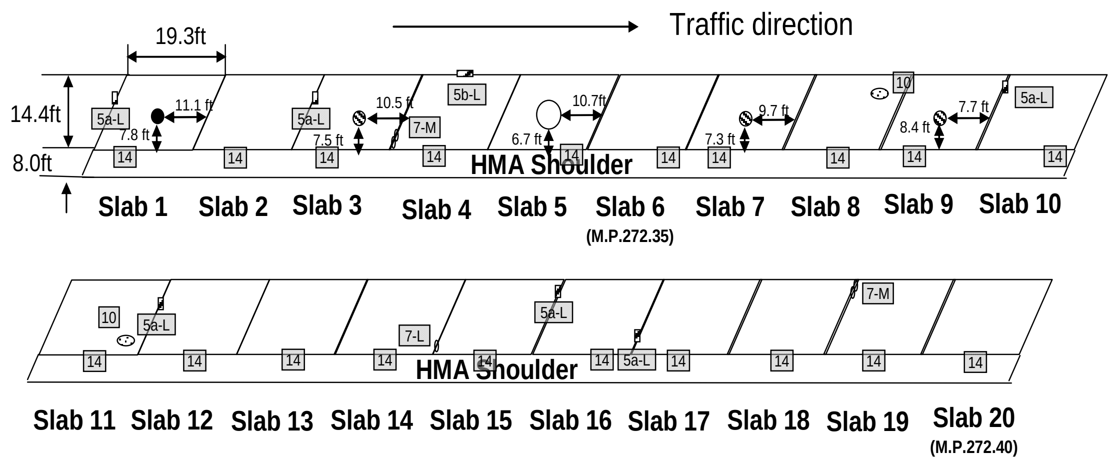
Photo of Field Test

Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.010	0.026



I-80 in Cedar County: Mile Post No. 272.30 to 272.40 (October/24/2007)



Note:

Core	Activity
● (4" Core)	Permeability test
(4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IR-80-7(57)265
Construction year	1992
PCI (2006)	74%
IRI (2006)	1.32m/km

Survey Type	Comment
Slab thickness	13 in
Base thickness	9 in (RPCC)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	1.2 in
Sealing condition	Bad
Shoulder condition	Bad
Cut or fill	Cut

(a) Lane to shoulder separation at slab #3

(b) Joint sealing damage of longitudinal joint at slab #4

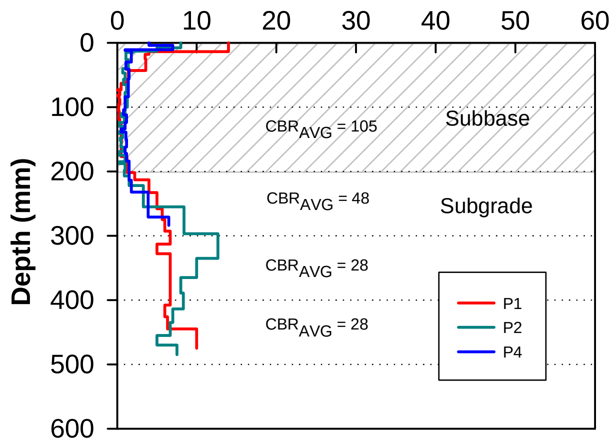
(c) Popout at slab #8

(d) Spalling of transverse joint at slab #18

Site number: 20

Location: I 80 in Cedar County: Mile Post No. 272.55 to 272.65
GPS coordination: N.41º37.996'/W.91º00.340', E.L:226.5 m
Test date: October 23, 2007
Weather: Sunny, 40-60º F
Site description: Test area is on **I 80** Eastbound at MP **272.60**, which is on the top of the slope – about 7 ft above the ditch. Recycled material for base layer. PCC thickness = 13 inches. Subbase layer thickness = 6 inches.
The PCC pavement was constructed in 5/ 1992.
Note: The Clegg Hammer seems to run out of is range, since the subbase is too stiff. Sometimes it appeared 659.1. This may raise a question about the suitability of CL to this type of materials.

DCP Index



Core	Location	Activity
4" core	P1, P2, P4, P5	DCP; subbase samples; DOT, old type permeability tests
10" core	P3	LWD, Clegg Hammer, DCP, base & subgrade sample

Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	622	632	659	638
	CBR	100+	100+	100+	100+

Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.3	100	264.2	18	1937

Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.534	0.359

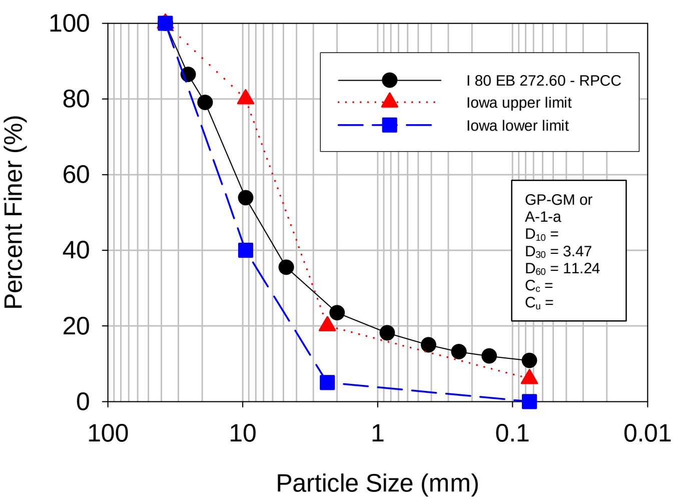
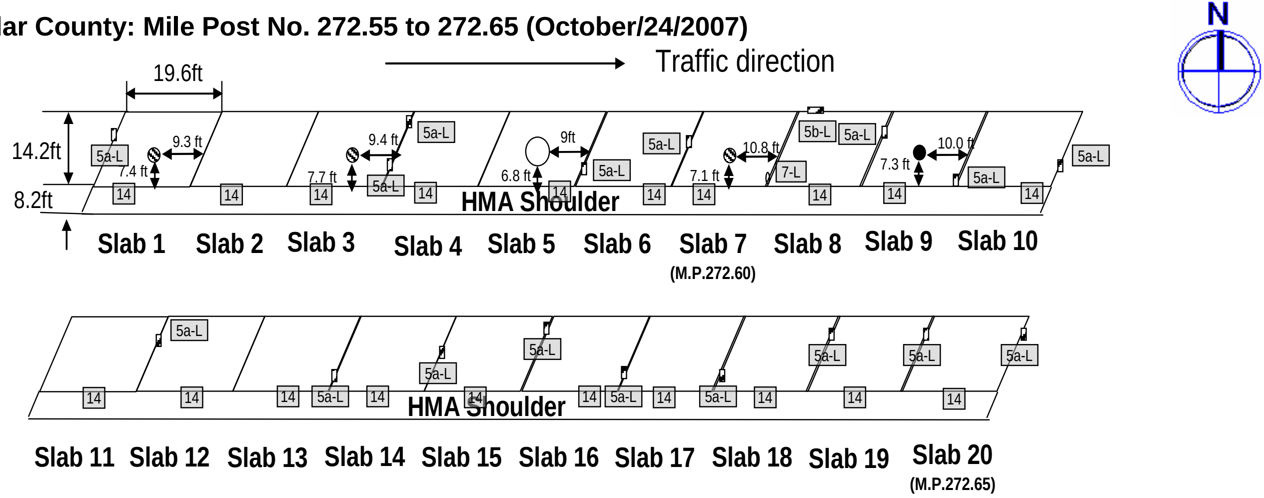


Photo of Field Test

I-80 in Cedar County: Mile Post No. 272.55 to 272.65 (October/24/2007)



Note:

Core	Activity
● (4" Core)	Permeability test
▨ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IR-80-7(57)265
Construction year	1992
PCI (2006)	74%
IRI (2006)	1.32m/km

Survey Type	Comment
Slab thickness	13 in
Base thickness	9 in (RPCC)
Joint orientation	Diagonal
Joint width	0.4 in
Joint depth	1.2 in
Sealing condition	Bad
Shoulder condition	Bad
Cut or fill	Fill

(a) Lane to shoulder separation at slab #2

(b) Joint sealing damage of transverse joint at slab #5

(c) Joint sealing damage of longitudinal joint at slab #8

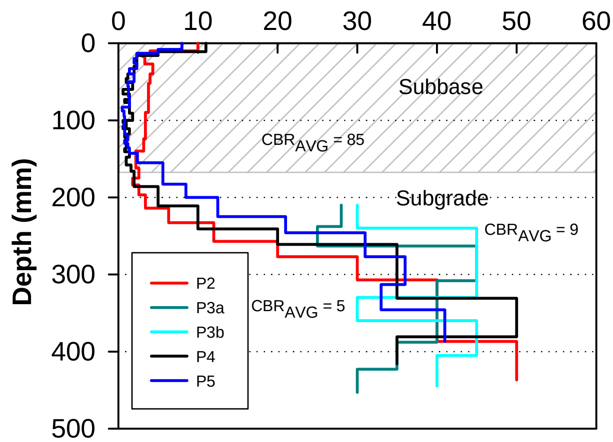
(d) Lane to shoulder separation at slab #15

Site number: 21

Location: I 80 in Cedar County: Mile Post No. 269.30 to 269.40
GPS coordination: N.41º38.581'/W.91º03.989', E.L: 215.8 m
Test date: October 30, 2007
Weather: Sunny, 51-71º F
Site description: Test area is on **I 80** Westbound at MP **269.35**, which is on the slope – about 10 ft above the ditch. Recycled material for base layer. PCC thickness = 13 inches. Subbase layer thickness = 6 inches.
The PCC pavement was constructed in 9/ 1992.
Note: It seems like the Clegg Hammer does not work properly. The digits might either be frozen after the second drop, or disappeared, or run out of its range.

Core	Location	Activity
4" core	P1, P2, P4, P5	DCP; subbase samples; DOT permeability test
10" core	P3	LWD, Clegg Hammer, DCP, base & subgrade sample

DCP Index



Photos of Field Test

Clegg Impact and CBR Values

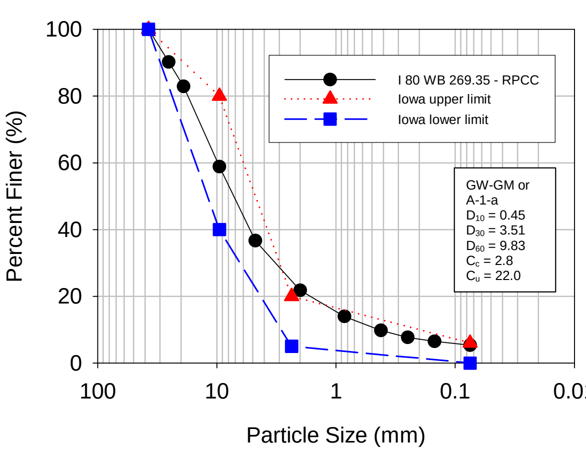
Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	44	63	71	59
	CBR	63	95	100+	88
Subgrade	CIV	18	23	—	21
	CBR	27	42	—	35

Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.1	100	257.8	114	298
Subgrade	7.8	100	248.3	826	39.7

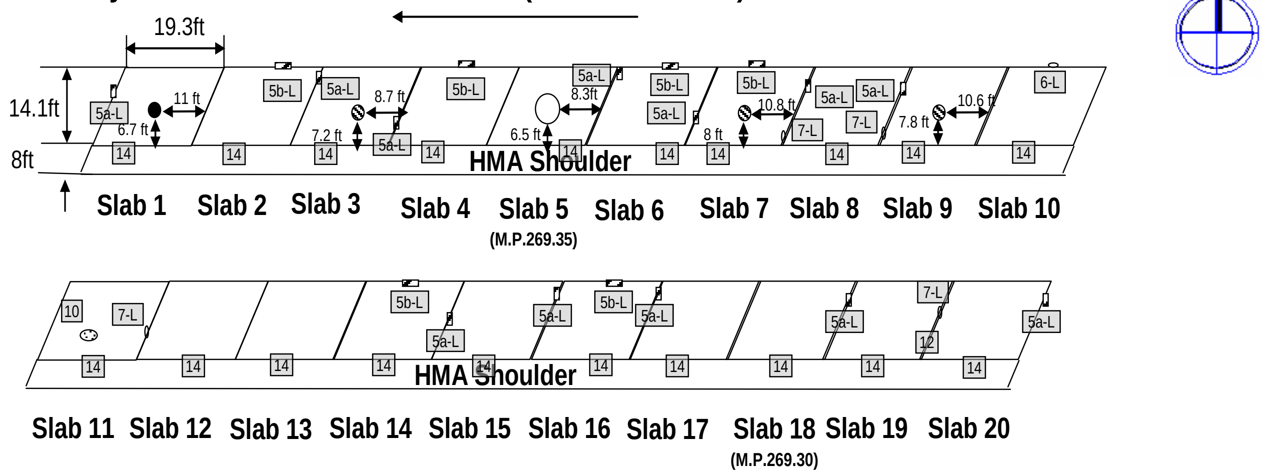
Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.119	0.059



Core Samples

I-80 in Cedar County: Mile Post No. 269.30 to 269.40 (October/30/2007)



Note:

Core	Activity
● (4" Core)	Permeability test
▨ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IR-80-7(57)265
Construction year	1992
PCI (2006)	74%
IRI (2006)	1.39m/km

Survey Type	Comment
Slab thickness	12.5 in
Base thickness	8.5 in (RPCC)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	1.0 in
Sealing condition	Bad
Shoulder condition	Bad
Cut or fill	Cut

(a) Joint sealing damage of transverse joint at slab #1

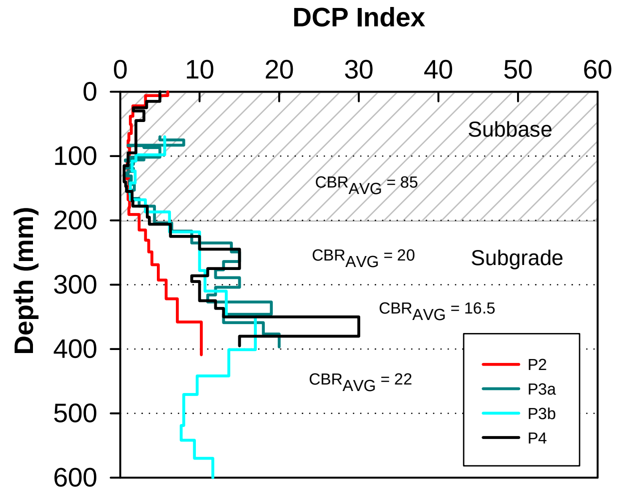
(b) Lane to shoulder separation at slab #5

(c) Spalling of longitudinal joint at slab #10

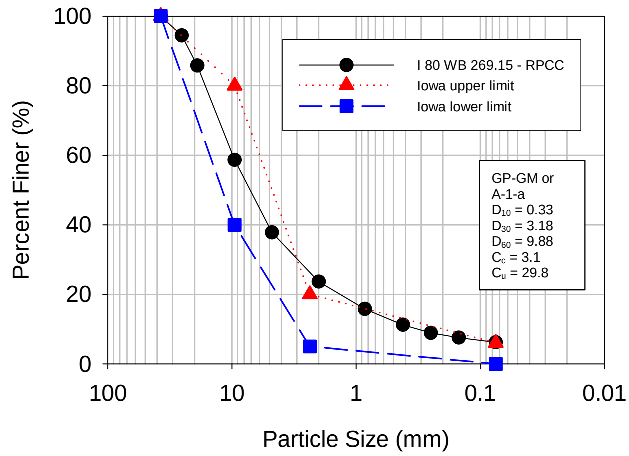
(d) Faulting joint at slab #19

Site number: 22

Location: I 80 in Cedar County: Mile Post No. 269.10 to 269.20
GPS coordination: N.41º38.607'/W.91º04.222', E.L: 229.5 m
Test date: October 30, 2007
Weather: Sunny, 51-71º F
Site description: Test area is on **I 80** Westbound at MP **269.15**, which is on top of the slope – about 7 ft above the ditch. Recycled material for base layer. PCC thickness = 13 inches. Subbase layer thickness = 6 inches.
The PCC pavement was constructed in 5/ 1992.



Core	Location	Activity
4" core	P1, P2, P4, P5	DCP; subbase samples; DOT permeability test
10" core	P3	LWD, Clegg Hammer, DCP, base & subgrade sample



Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	43	23	32	33
	CBR	62	30	45	46

Light Weight Deflectometer Modulus

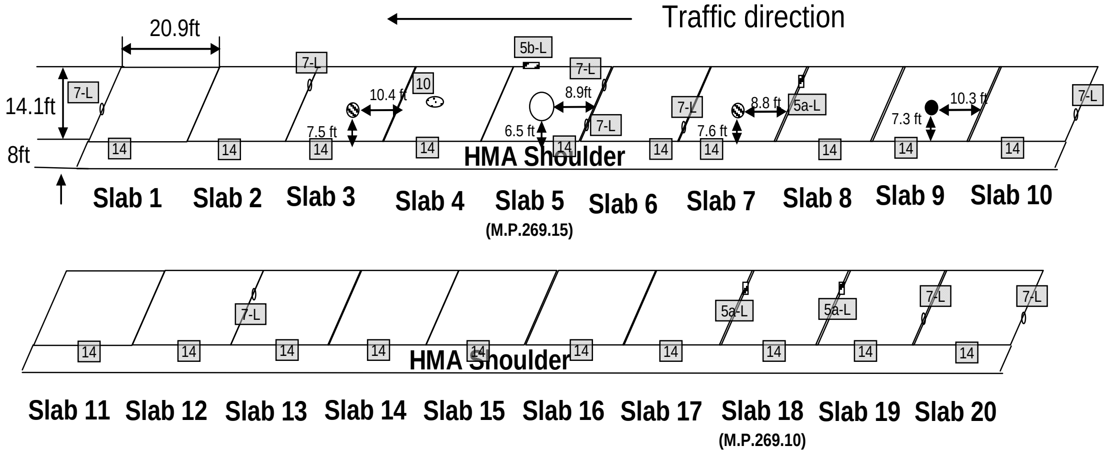
Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.3	100	264.2	135	258

Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.178	0.104

Core Samples

I-80 in Cedar County: Mile Post No. 269.10 to 269.20 (October/30/2007)

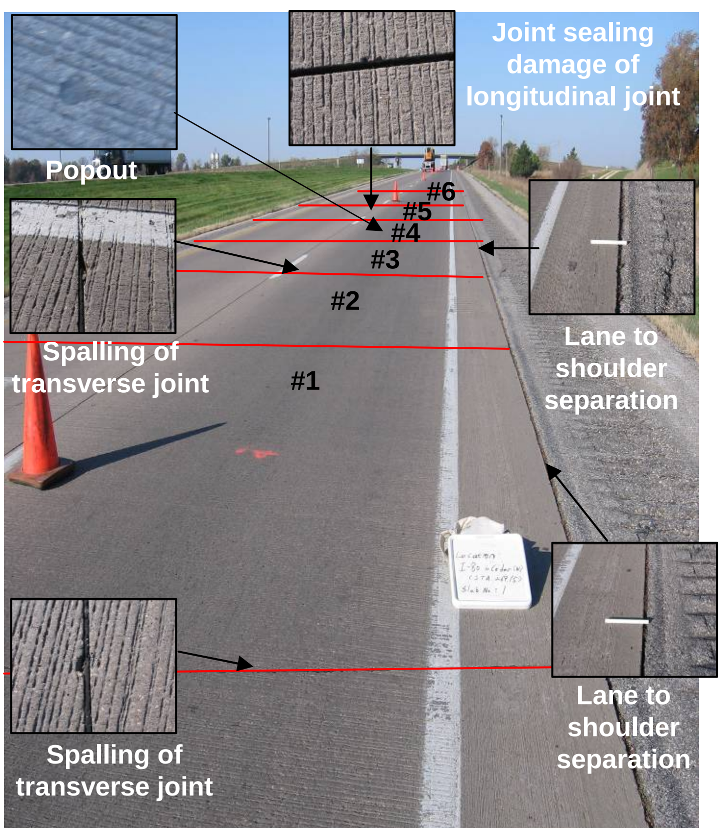


Note:

Core	Activity
● (4" Core)	Permeability test
(hatched) (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IR-80-7(57)265
Construction year	1992
PCI (2006)	74%
IRI (2006)	1.39m/km

Survey Type	Comment
Slab thickness	13 in
Base thickness	8 in (RPCC)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	1.2 in
Sealing condition	Bad
Shoulder condition	Bad
Cut or fill	Cut



(a) Overall surface distress condition from slab #1 to #5

(b) Spalling of transverse joint at slab #12

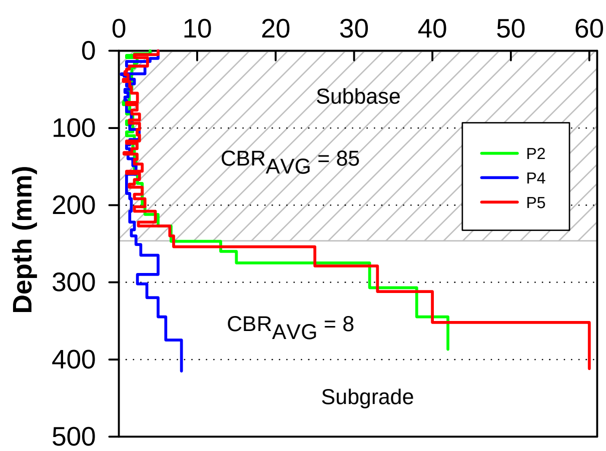
(c) Lane to shoulder separation at slab #17

Site number: 23

Location: I 80 in Polk County: Mile Post No. 128.50 to 128.55
GPS coordination: N.41º39.093'/W.93º45.316', E.L: 274.9 m
Test date: November 1, 2007
Weather: Night time [11:45 PM – 3 AM], 36-45º F
Site description: Test area is on the travel lane of **I 80** Eastbound at MP **128.50**, which is on the flat surface. The ditch is about 0.7m below PCC surface. Recycled material for subbase layer. PCC thickness = 34 cm. The PCC pavement was constructed in 1994.

Core	Location	Activity
4" core	P2, P3, P4, P5	DCP; subbase samples; DOT and ISU permeability tests
10" core	P1	LWD, Clegg Hammer, DCP, base & subgrade sample

DCP Index



Clegg Impact and CBR Values

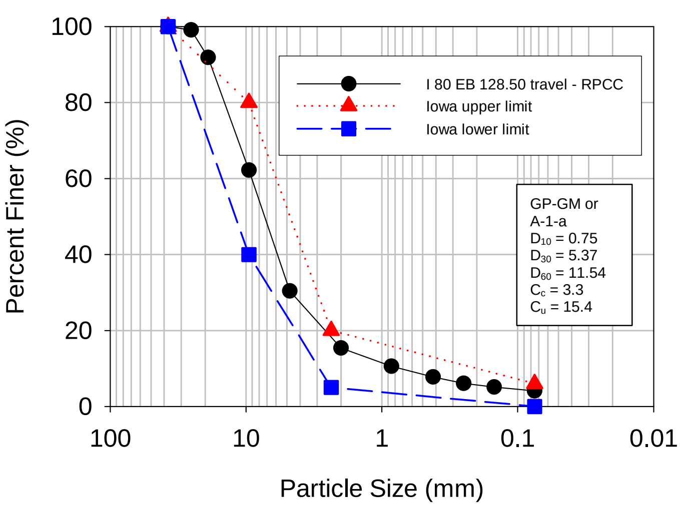
Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	62	110	106	93
	CBR	94	100+	100+	100+

Light Weight Deflectometer Modulus

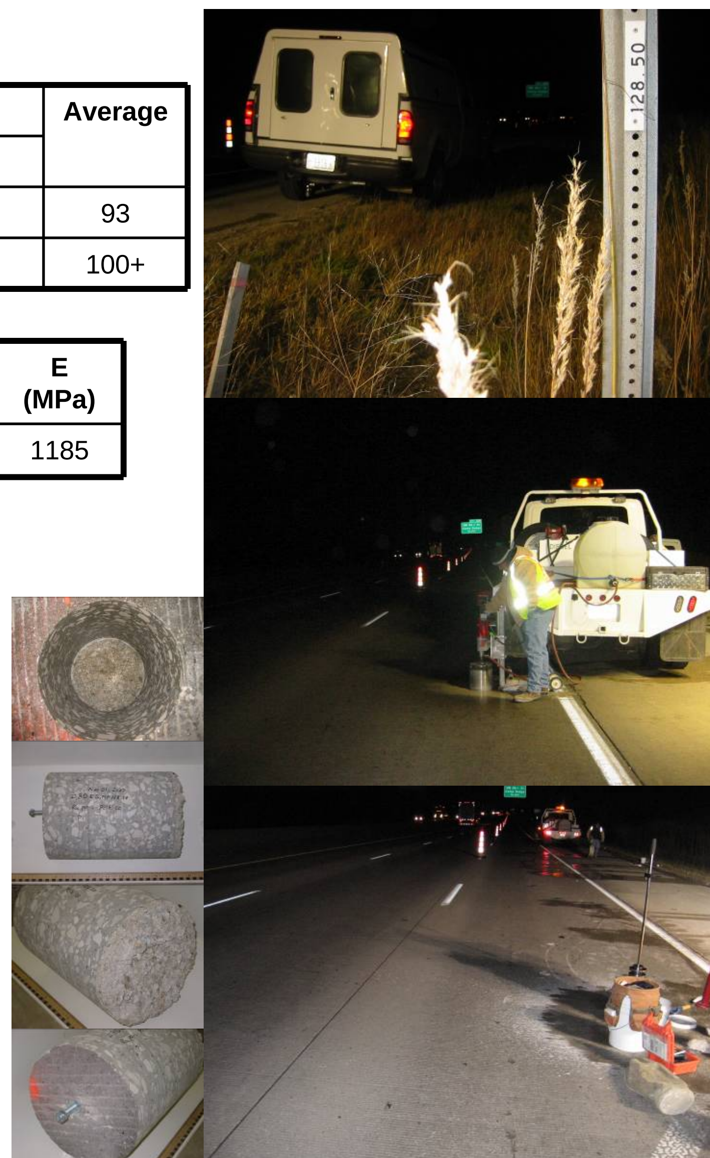
Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (µm)	E (MPa)
Subbase	7.9	100	251.5	28	1185

Hydraulic conductivity of subbase layer

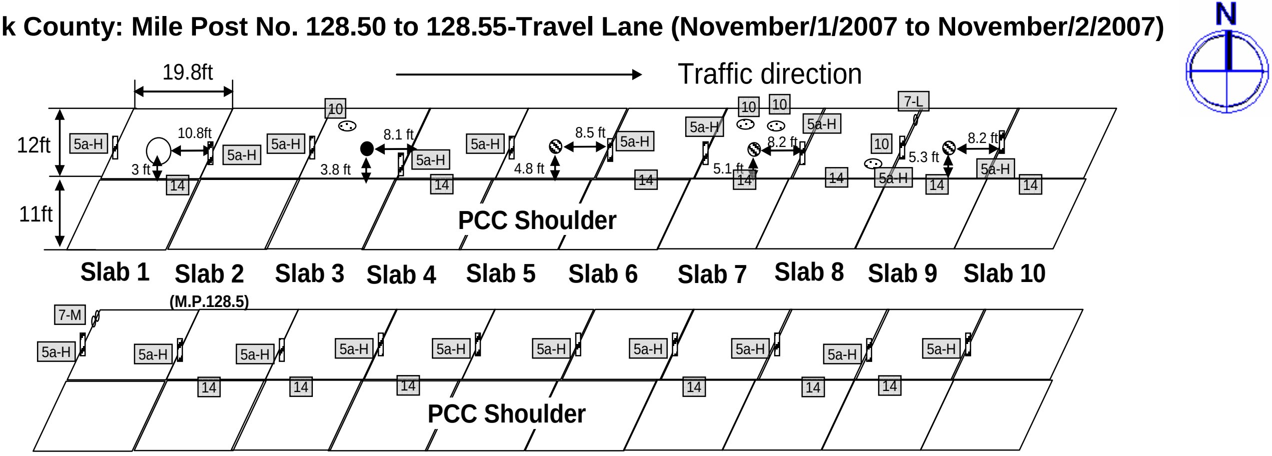
$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.053	0.038



Photos of Field Test



I-80 in Polk County: Mile Post No. 128.50 to 128.55-Travel Lane (November/1/2007 to November/2/2007)



Note:

Core	Activity
● (4” Core)	Permeability test
(hatched) (4” Core)	DCP
○ (10“ Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IM-35-3(70)77--13-77
Construction year	1994
PCI (2006)	81%
IRI (2006)	1.78m/km

Survey Type	Comment
Slab thickness	14 in
Base thickness	9 in (RPCC)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	1.2 in
Sealing condition	Bad
Shoulder condition	Good
Cut or fill	Cut


(a) Lane to shoulder separation at slab #1


(b) Joint sealing damage of transverse joint at slab #3


(c) Popout at slab #3

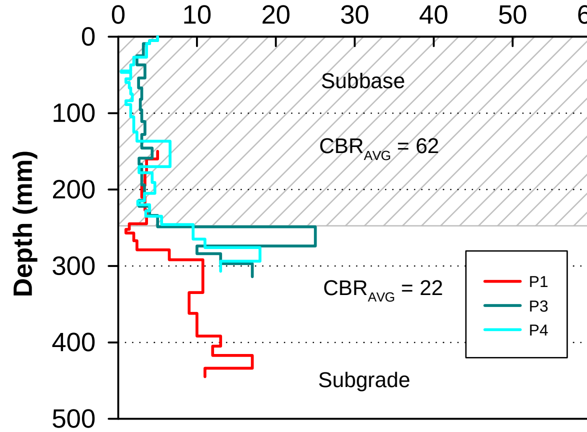

(d) Lane to shoulder separation at slab #9

Site number: 24

Location: I 80 in Cedar County: Mile Post No. 275.70 to 275.75
GPS coordination: N.41º38.056'/W.90º50.715', E.L:225.2 m
Test date: November 6, 2007
Weather: Sunny 36º F, wind 20-25 mph
Site description: Test area is on **I 80** Westbound at MP **275.70**. Recycled material for base layer. PCC thickness = 13.5 inches.
The PCC pavement was constructed in 7/1992.
Note: It seems like the Clegg Hammer does not work properly. The digits might either be frozen after the second drop, or disappeared, or run out of its range.

Core	Location	Activity
4" core	P1, P2, P4, P5	DCP; subbase samples; DOT permeability test
10" core	P3	LWD, Clegg Hammer, DCP, base & subgrade sample

DCP Index



Clegg Impact and CBR Values

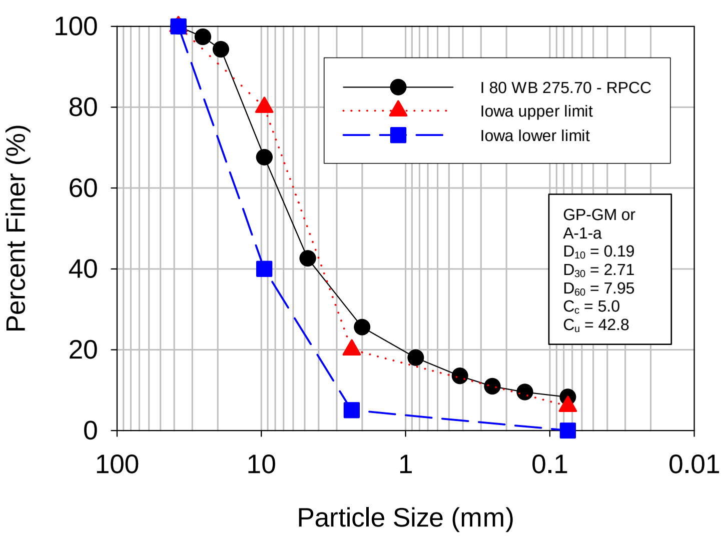
Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	156	101	157	138
	CBR	100+	100+	100+	100+

Light Weight Deflectometer Modulus

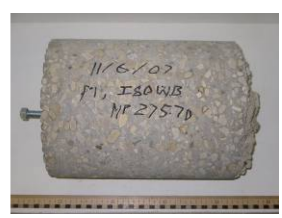
Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.0	100	254.6	65	517

Hydraulic conductivity of subbase layer

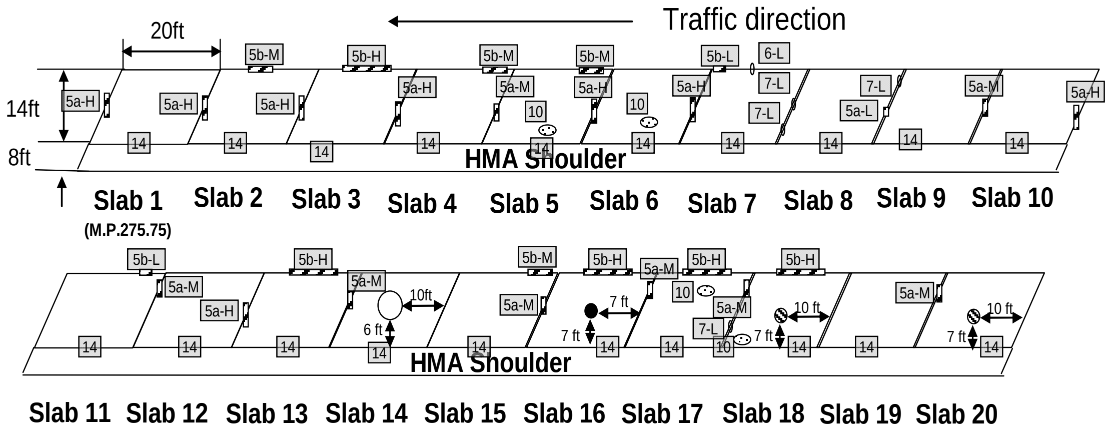
$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.380	0.307



Photos of Field Test



I-80 in Cedar County: Mile Post No. 275.70 to 275.75 (November/6/2007)



Note:

Core	Activity
● (4" Core)	Permeability test
◍ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IR-80-7(57)265
Construction year	1992
PCI (2006)	74%
IRI (2006)	1.39m/km

Survey Type	Comment
Slab thickness	13 in
Base thickness	8 in (RPCC)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	1.2 in
Sealing condition	Bad
Shoulder condition	Bad
Cut or fill	Cut

(a) Joint sealing damage of transverse joint at slab #2

(b) Spalling of transverse joint at slab #7

(c) Lane to shoulder separation at slab #12

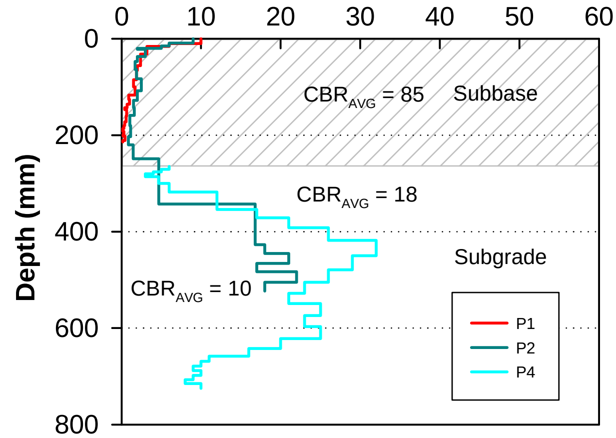
(d) Joint sealing damage of longitudinal joint at slab #15

Site number: 25

Location: I 80 in Cedar County: Mile Post No. 275.90 to 275.95
GPS coordination: N.41º38.044'/W.90º50.574', E.L: 221.6 m
Test date: November 6, 2007
Weather: 36º F, wind 20-25 mph
Site description: Test area is on **I 80** Westbound at MP **275.90**. Recycled material for base layer. PCC thickness = 31.5 cm. Subbase layer thickness = 26.5 cm.
The PCC pavement was constructed in 8/ 1992.

Core	Location	Activity
4" core	P1, P2, P4, P5	DCP; subbase samples; DOT permeability test
10" core	P3	LWD, Clegg Hammer, DCP, base & subgrade sample

DCP Index



Clegg Impact and CBR Values

Level	CIV / CBR	Test points 1	Test points 2	Test points 3	Average
Subbase	CIV	111	103	130	115
	CBR	100+	100+	100+	100+
Subgrade	CIV	89	110	—	99
	CBR	100+	100+	-	100+

Photo of Field Test

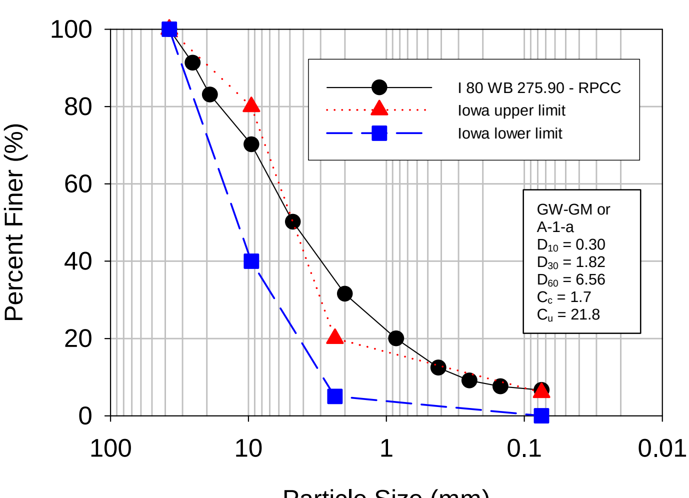
Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (µm)	E (MPa)
Subbase	8.2	100	261	88	391
Subgrade	7.9	100	251.5	222	150

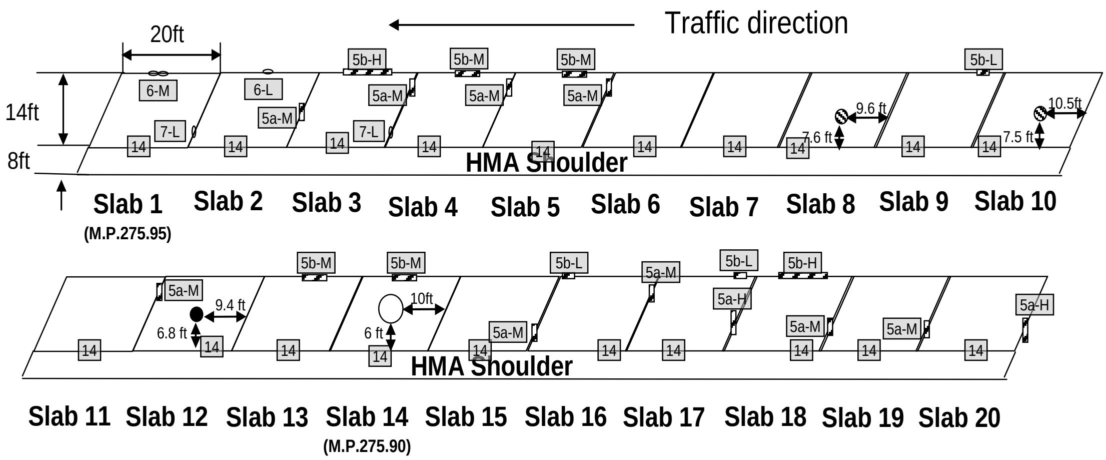
Photo of Core Samples

Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
1.069	0.992



I-80 in Cedar County: Mile Post No. 275.90 to 275.95 (November/6/2007)



Note:

Core	Activity
● (4" Core)	Permeability test
▨ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IR-80-7(57)265
Construction year	1992
PCI (2006)	74%
IRI (2006)	1.39m/km

Survey Type	Comment
Slab thickness	13 in
Base thickness	8 in (RPCC)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	1.2 in
Sealing condition	Bad
Shoulder condition	Bad
Cut or fill	Cut

(a) Spalling of transverse joint at slab #1

(b) Joint sealing damage of transverse joint at slab #5

(c) Joint sealing damage of longitudinal joint at slab #9

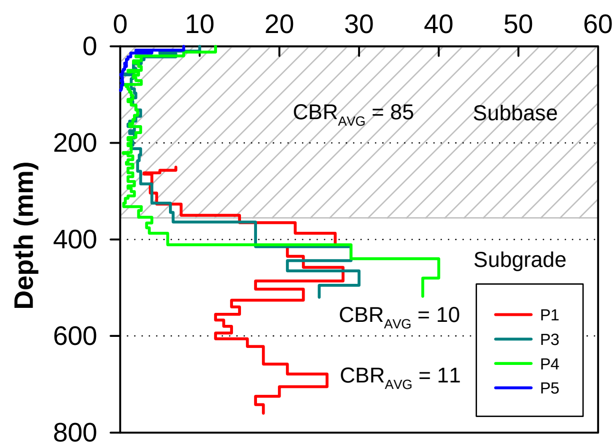
(d) Lane to shoulder separation at slab #18

Site number: 26

Location: I 80 in Polk County: Mile Post No. 128.50 to 128.55
GPS coordination: N.41º39.097'/W.93º45.311', E.L: 270.4 m
Test date: November 08, 2007
Weather: Night time [11:45 PM – 3 AM], 33-36º F, wind 5 mph
Site description: Test area is on the passing lane of **I 80** Eastbound at MP **128.50**, which is on the flat surface. The ditch is about 0.7m below PCC surface. River gravel, mixed with sand, fine aggregate, and small amount of recycled PCC to form subbase layer. PCC thickness is 35 cm.

Core	Location	Activity
4" core	P2, P3, P4, P5	DCP; subbase samples; DOT permeability test
10" core	P1	LWD, Clegg Hammer, DCP on subbase

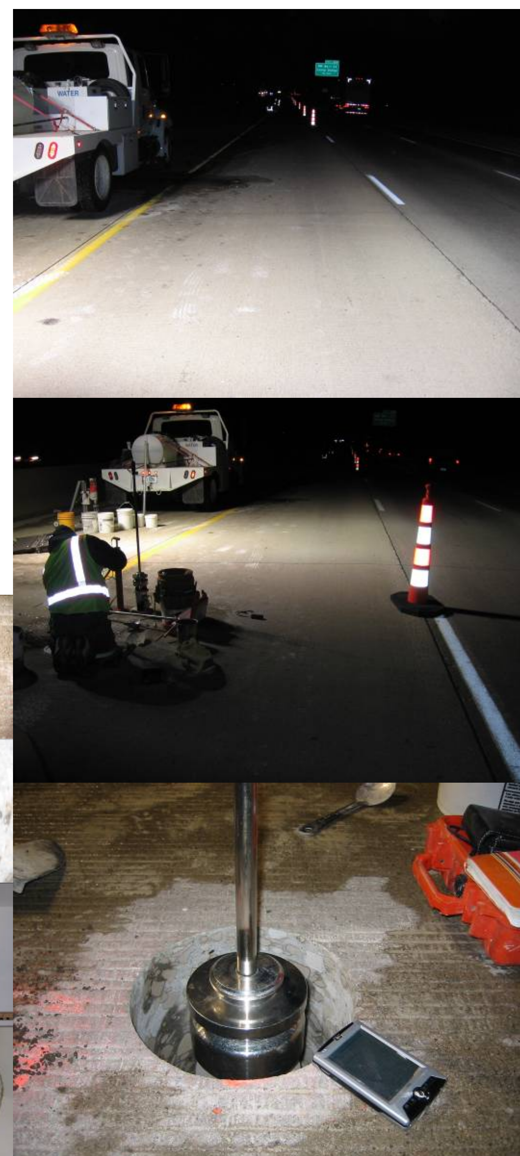
DCP Index



Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	148	113	166	143
	CBR	100+	100+	100+	100+

Photos of Field Test

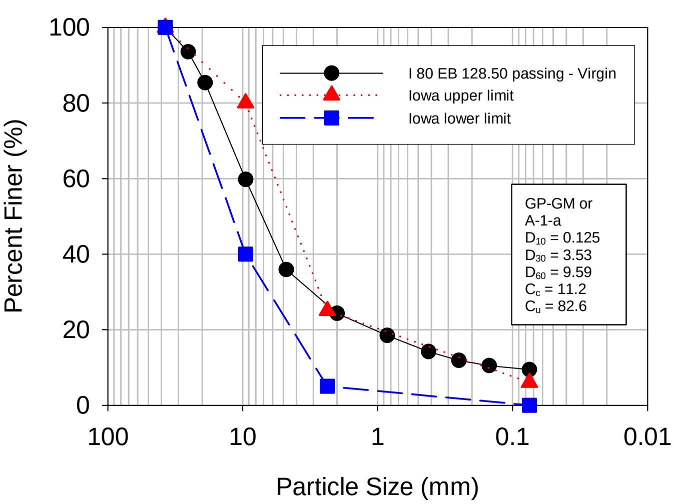


Light Weight Deflectometer Modulus

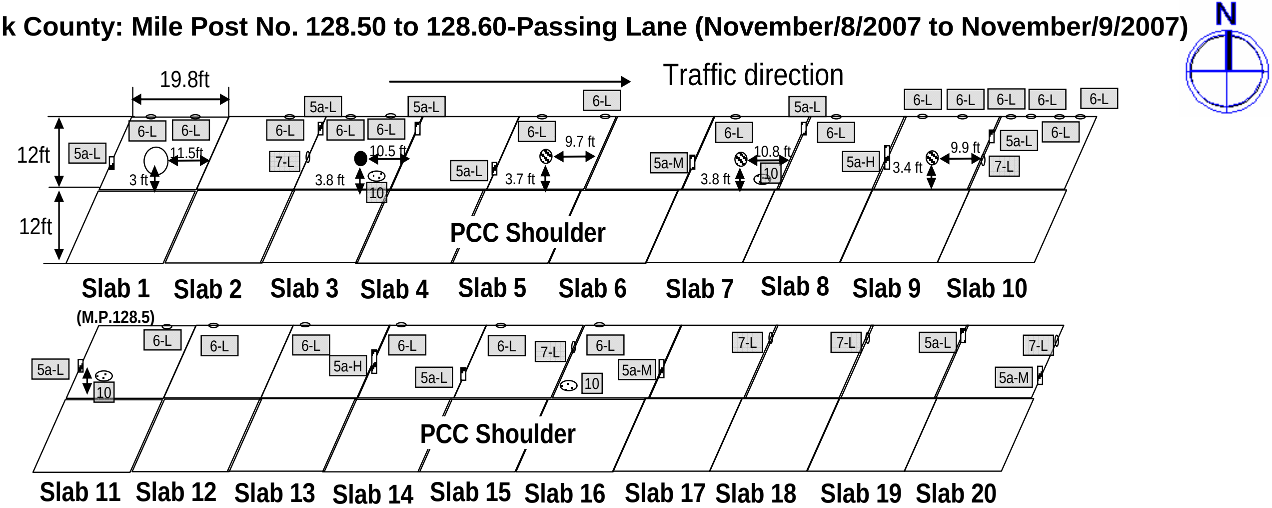
Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8	100	254.6	76	442

Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
1.069	0.992



I-80 in Polk County: Mile Post No. 128.50 to 128.60-Passing Lane (November/8/2007 to November/9/2007)



Note:

Core	Activity
● (4" Core)	Permeability test
(4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IM-35-3(70)77--13-77
Construction year	1994
PCI (2006)	81%
IRI (2006)	1.78m/km

Survey Type	Comment
Slab thickness	13.5 in
Base thickness	9 in (Virgin)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	1.4 in
Sealing condition	Bad
Shoulder condition	Good
Cut or fill	Cut

(a) Spalling of longitudinal joint at slab #1

(b) Joint sealing damage of transverse joint at slab #4

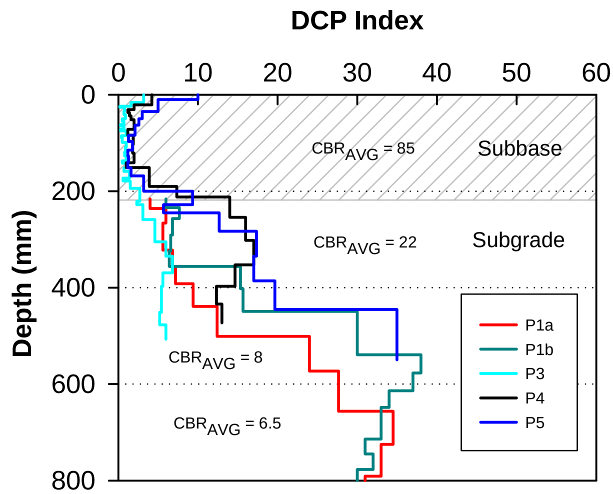
(c) Popout at slab #11

(d) Spalling of transverse joint at slab #15

Site number: 27

Location: I 80 in Cedar County: Mile Post No. 276.60 to 276.70
GPS coordination: N.41º38.054'/W.90º55.698', E.L: 221 m
Test date: November 13, 2007
Weather: Sunny, 40-60º F
Site description: Test area is on **I 80** Eastbound at MP **276.60**, which is on the flat area. Recycled material for base layer. PCC thickness = 13.5 inches. Subbase layer thickness = 8.5 inches.
The PCC pavement was constructed in 10/ 1991.

Core	Location	Activity
4" core	P2, P3, P4, P5	DCP; subbase samples; DOT, ISU, old type permeability tests
10" core	P1	LWD, Clegg Hammer, DCP, subbase & subgrade sample



Clegg Impact and CBR Values

Level	CIV / CBR	Test points			Average
		1	2	3	
Subbase	CIV	80	79	88	83
	CBR	100+	100+	100+	100+
Subgrade	CIV	84	94	—	98
	CBR	100+	100+	—	100+

Light Weight Deflectometer Modulus

Level	Force (kN)	Radius a (mm)	Pres. (kPa)	Defl. (μm)	E (MPa)
Subbase	8.1	100	257.8	123	277
Subgrade	8.1	100	257.8	425	80

Hydraulic conductivity of subbase layer

$K_{5\ cm}$ (m/day)	$K_{10\ cm}$ (m/day)
0.148	0.142

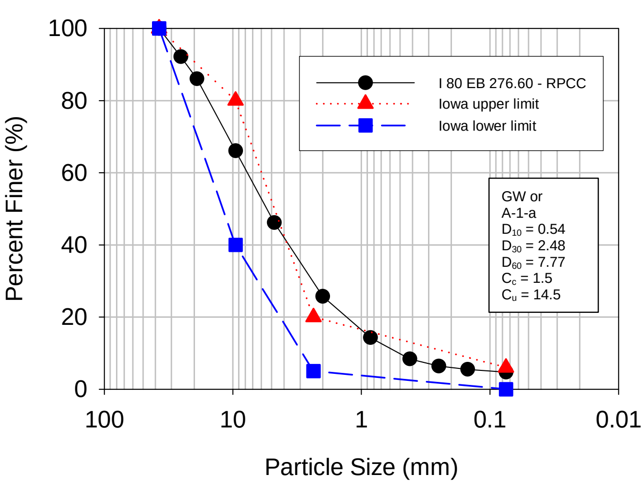
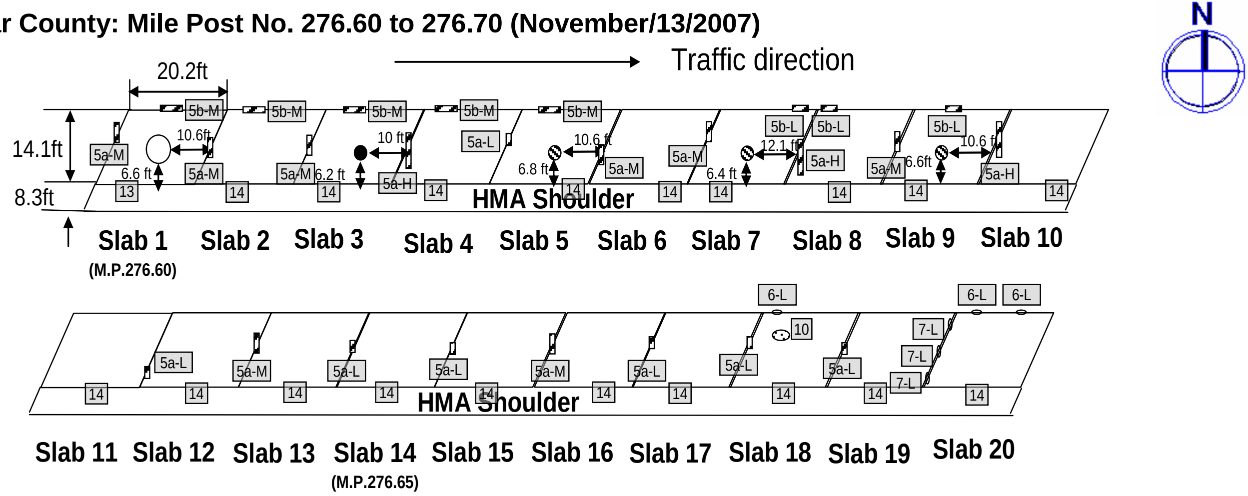


Photo of Field Test

I-80 in Cedar County: Mile Post No. 276.60 to 276.70 (November/13/2007)

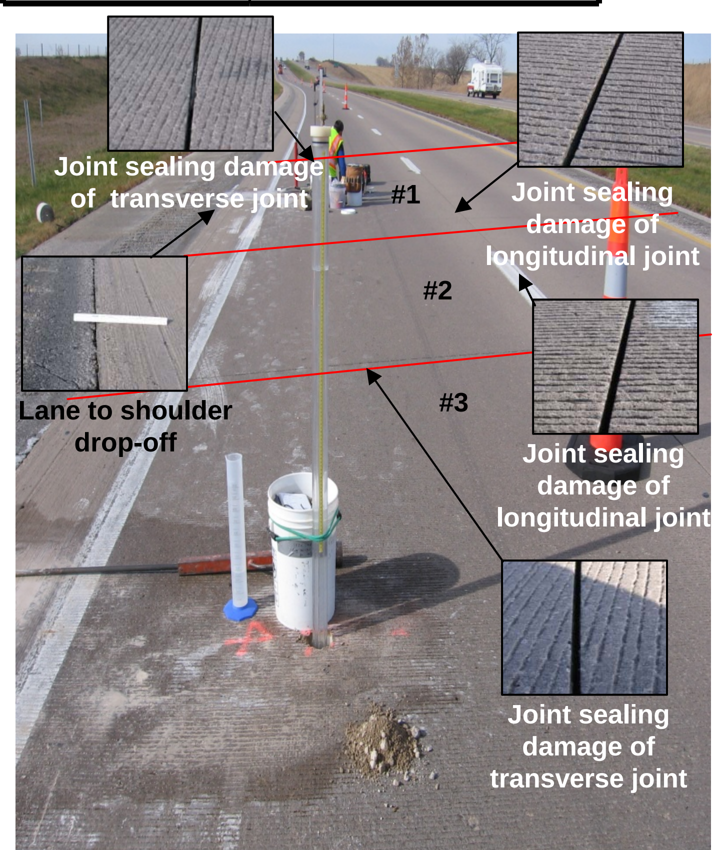


Note:

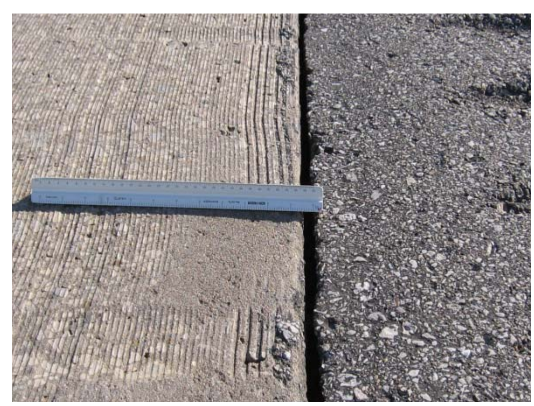
Core	Activity
● (4" Core)	Permeability test
◍ (4" Core)	DCP
○ (10" Core)	LWD, Clegg hammer, DCP

PMIS Data	Number
Project No.	IR-80-7(57)265
Construction year	1991
PCI (2006)	72%
IRI (2006)	1.39m/km

Survey Type	Comment
Slab thickness	13.5 in
Base thickness	9 in (RPCC)
Joint orientation	Diagonal
Joint width	0.6 in
Joint depth	1.4 in
Sealing condition	Bad
Shoulder condition	Bad
Cut or fill	Fill



(a) Overall surface distress condition from slab #1 to #3



(b) Lane to shoulder separation at slab #9

(c) Popout at slab #18