New Hampshire DOT

Research Record

Alternate Approach Slab Reinforcement

Final Report

Prepared by the New Hampshire Department of Transportation, in cooperation with the
U.S. Department of Transportation, Federal Highway Administration

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In cooperation with the U. S. Department of Transportation, Federal Highway Administration

16. Abstract

The upper mat of reinforcing steel, in exposed concrete bridge approach slabs, is prone to corrosion damage. Chlorides applied to the highways for winter maintenance can penetrate this concrete layer. Eventually chlorides reach the steel and begin the corrosion process.

The objective of this research project was to investigate the performance of approach slabs constructed with structural fibers to replace the top mat of reinforcing steel. The research studied whether the performance of approach slabs reinforced with structural fibers would be equivalent to traditionally reinforced approach slabs.

NHDOT Materials & Research Bureau technicians performed standard quality acceptance tests on the fresh concrete at the time of placement. Technicians also fabricated three freeze/thaw prisms for each mix. The specimens survived freeze/thaw testing with only minor physical deterioration, consisting of slight scaling and pitting. The Civil Engineering Department of the University of New Hampshire (UNH) was contracted to perform laboratory testing. The beam samples were tested for First Crack Strength and Average Residual Strength in accordance with ASTM C 1018 and C 1399, respectively. An independent testing laboratory extracted two cores from each approach slab to evaluate the air matrix within the concrete. Comparisons of the laboratory test results show that compressive and flexural strengths are similar for both mixes. The plots resulting from the residual strength testing show that the fiber-mix had greater strength after cracking than the normal mix. Periodic visual observations of the approach slabs were made to evaluate field performance by comparing crack size, frequency and scaling. After more than three and half years in service, the two approach slabs have performed similarly and well. The expected advantages of a thicker concrete cover over steel reinforcement will not be seen for many years. The epoxy-coated steel in the conventional slab construction should also delay damage from corrosion.

Based on the performance observations to date, fiber-reinforced concrete is recommended for use in this and other applications where delaying the effects of steel corrosion is of interest. The NHDOT has implemented the use of fiber-reinforced concrete for all approach slabs as a result of this study.

17. Key Words Bridge decks, Concrete, Fiber reinforced concrete, Reinforcing steel, MAT, Bridge approaches, Slabs	**18. Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161

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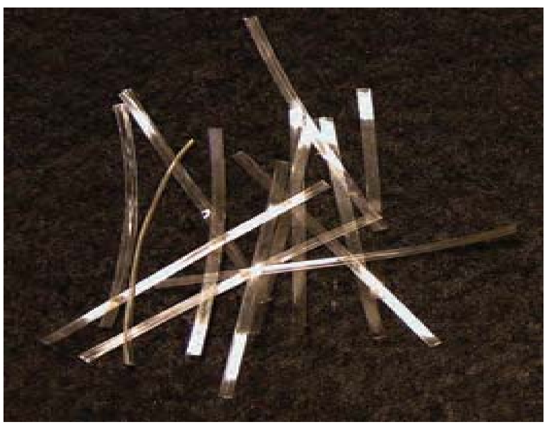
ACKNOWLEDGEMENTS

The author would like to thank the NHDOT Construction Bureau, and specifically Contract Administrator Chuck Flanders, for accommodating the disruptions necessary to complete this project, as well as the laboratory staff of the University of New Hampshire Engineering Department and the Vermont Agency of Transportation for their testing contributions.

ALTERNATIVE APPROACH SLAB REINFORCEMENT

STATEWIDE SPR 13733H



Prepared By:

Denis M. Boisvert, P.E.
Chief of Materials Technology

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June 21, 2010

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BACKGROUND

The upper mat of reinforcing steel in exposed concrete bridge approach slabs is prone to corrosion damage. The design concrete cover over the mat is typically 2.5 inches. Chlorides applied to the highways for winter maintenance can penetrate this concrete layer. Eventually chlorides reach the steel and begin the corrosion process which will crack the concrete. The cracks accelerate the deterioration process by providing direct access for contaminants to attack the reinforcing steel.

RESEARCH OBJECTIVE

The objective of this research project was to investigate the performance of approach slabs constructed with structural fibers to replace the top mat of reinforcing steel, which performs essentially as temperature steel for crack resistance. The proposed design concept effectively increases the concrete cover over the remaining bottom reinforcing mat and should delay chloride contact with the reinforcing steel and the effects of corrosion. The research studied whether the performance of approach slabs reinforced with structural fibers would be equivalent to traditionally reinforced approach slabs.

PROJECT SITE

The Pembroke-Allenstown bridge replacement Project 12978 over the Suncook River was selected as the test site for the study. It was designed to include construction of unpaved approach slabs at grade using a Class AA, Q/C-Q/A concrete mix containing 50% slag.

The 16.75-inch thick approach slab at Abutment A (south end of the bridge) was constructed with fiber reinforced concrete mix and a conventional bottom mat of #16 (mm) epoxy-coated reinforcing steel. Grace STRUX 90/40 synthetic fibers were specified in Special Provision Item 544 of the contract documents. They were added to the mix as a substitute for installing the upper reinforcing mat of NHDOT's typical approach slab design. The fiber reinforcement was added at the rate of seven LBS/CY, per the manufacturer's recommendation, to achieve the design requirements. Persons Concrete of Bow, NH supplied the mix. The approach slab at Abutment B (north end of the bridge) was traditionally reinforced with an upper and lower epoxy-coated reinforcing steel mat of #16 (mm) bars.

The contractor completed each approach slab by applying a broom finish. The slabs were covered with wet burlap and poly sheeting immediately after finishing and wet cured for seven days, per NHDOT specification. The bridge was opened to traffic on December 8, 2005.

TESTING

NHDOT Materials & Research Bureau technicians performed standard quality acceptance tests on the fresh concrete at the time of placement, October 20, 2005. Slump, air content, temperature, permeability and compressive strength tests documented the quality of the delivered fiber-reinforced and standard mixes. Each mix met the requirements of the NHDOT Standard Specifications. Laboratory test reports are included in Appendix A.

NHDOT technicians also fabricated three freeze/thaw prisms for each mix. The prisms were transported to the Vermont Agency of Transportation (VTrans) concrete laboratory where they were tested and evaluated for freeze/thaw durability in accordance with ASTM C 666 and C 215, respectively in October 2005. The specimens survived freeze/thaw testing with only minor physical deterioration, consisting of slight scaling and pitting. The computed Durability Factors were not consistent with the physical conditions of the specimens. While the fiber-mix prisms had a range of durability factors from 106, 120 and 139, the normal concrete prisms had factors of 40, 44 and 104. Freeze/Thaw test reports are included in Appendix B.

The Civil Engineering Department of the University of New Hampshire (UNH) was contracted to perform laboratory testing. See Appendix C for the test data for this test series. A test panel was cast for each of the fiber reinforced and control concrete mixes at the time of the approach slab placements. After 28 days, the UNH staff saw-cut four 4” x 4” x 14” beam samples from each test slab.

Figure 1: Reinforcing steel was located to avoid damage when coring samples 10/17/ 2005

Figure 2: Preparation of test beam slabs on 10/17/2005

The beam samples were tested in August 2006 for First Crack Strength and Average Residual Strength in accordance with ASTM C 1018 and C 1399, respectively. Testing compared mix performance and verified whether the fiber reinforced mix design strength had been achieved based on the manufacturer-recommended fiber addition rate. The maximum flexural load placed on the beam samples showed the fiber mix to be equivalent to the conventional mix. Maximum loads for three of the fiber-mix beams ranged from 3.0 to 4.5 kips; one failed at 1.6 kips. The four normal concrete beams sustained loads ranging from 3.0 to 3.7 kips. The initial beam cracking did not appear until loading had exceeded the parameters for average residual strength computations, voiding those test procedures.

An independent testing laboratory extracted two cores from each approach slab for UNH to evaluate the air matrix within the concrete. Measurements had been made to locate the reinforcing steel prior to the placement so that the cores could be retrieved without damaging the steel. Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete -- ASTM C 457 was followed. The data showed that the air content of the non-fiber samples and fiber samples had average air contents of 7.9 and 7.0 percent, respectively, with an average spacing factor of 0.001 for both the non-fiber and fiber concretes. The paste, fine aggregate and coarse aggregate percentages were also similar for both concretes. Based on these data, the concretes would be expected to resist cycles of freezing and thawing. Polished sections of the near surface of the fiber-reinforced and traditionally reinforced concretes were prepared for petrographic analysis. Both sections showed good distribution of aggregates and a surface that was well compacted, but not over finished. The sections also showed a uniform distribution of the fibers. Even though an attempt was made to avoid hitting reinforcement during coring, an epoxy coated reinforcement bar did appear in one of the samples.

MONITORING

Periodic visual observations of the approach slabs were made to evaluate field performance by comparing crack size, frequency and scaling. No cracks were observed in either approach slab after two years in service. A longitudinal crack was observed in the fiber-reinforced slab during a July 9, 2009 inspection. The narrow crack was located approximately two feet off centerline and extended the entire length of the approach slab. The arrows in the Figure 3 photo locate the ends of the crack.

Figure 3: Longitudinal crack in fiber mix

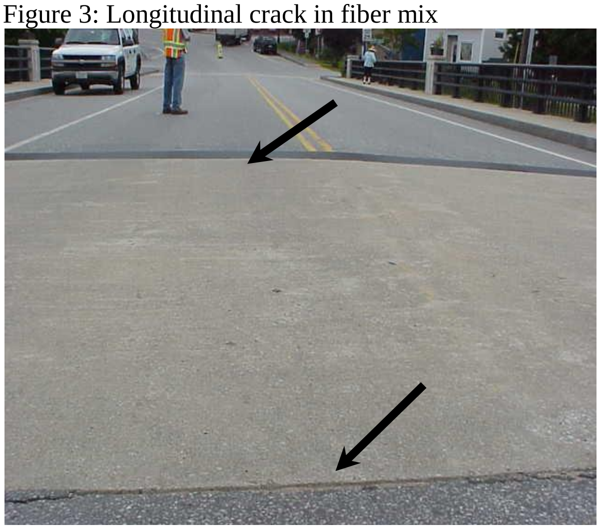

Figure 4: Exposed aggregate in fiber mix

After four winters of snow plow abrasion, the fiber-reinforced slab shows greater signs of surface wear. Shallow scaling has exposed the aggregate in high contact areas such as the centerline crown, as shown in the Figure 4 photo. The broom finish has been lost in traffic areas. Although worn, the streaks of the broom finish are still visible in the normal slab.

Several areas in the fiber-reinforced slab have been monitored with interest. What appeared to be shallow pop-outs or potential scaling were observed along the easterly shoulder and at the centerline. These areas are now considered to be finishing defects, since they have not deteriorated or expanded since first observed during the April 2006 initial inspection after placement.

Figure 5: Centerline defect in fiber reinforced mix

Figure 6: Shoulder defect in fiber reinforced mix

EVALUATION

Comparisons of the laboratory test results show that compressive and flexural strengths are similar for both mixes. The plots resulting from the residual strength testing show that the fiber-mix had greater strength after cracking than the normal mix. This is a known trait of fiber mixes, since their reinforcing is distributed throughout the slab.

After more than three and half years in service, the two approach slabs have performed similarly and well. Visually, they can only be identified by a slight difference in surface texture and noticeable fibers in the shoulder area where snow plowing and traffic has not worn them to the surface. Except for the longitudinal crack observed in the fiber mix following the initial monitoring period, neither slab has significantly cracked or shown excessive wear. The expected advantages of a thicker concrete cover over steel reinforcement will not be seen for many years. The epoxy-coated steel in the conventional slab construction should also delay damage from corrosion.

CONCLUSIONS AND RECOMMENDATIONS

Based on the performance observations to date, fiber-reinforced concrete is recommended for use in this and other applications where delaying the effects of steel corrosion is of interest. The NHDOT has implemented the use of fiber-reinforced concrete for all approach slabs as a result of this study.

APPENDIX A - FRESH CONCRETE TESTS

STATE of NEW HAMPSHIRE DEPARTMENT of TRANSPORTATION
BUREAU of MATERIALS and RESEARCH

Project: PEMBROKE-ALLENSTOWN **State#:** 12978
Federal#: BRO-X-361(001) **Report to:** Charles Flanders

Concrete Independent Assurance *AA22033*

Cylinder#: 203/088 **Submitted by:** 10/21/2005
Source: Persons Concrete
Material: AA 50% SLAG **Quantity** 40 cy.
Purpose: Abut b approach slabs
Date Cast: 10/17/2005
% Air *Slump(in):* *Mix Temp (F):* *Air Temp (F):* clou

Analysis	Result	Min	Max	Violation	Method
QA Testing by:	C. Flanders, T				
QC Testing by:	Bruce Turmell				
IA Testing by:	S. Drouin				
Sub Lot #	3				
Load #	2				
% Air (IA)	5.5				
% Air (QA)	5.9				
Within Tolerance?	Yes				
% Air (QC)	7.5				
Unit Wgt (IA)	N/A				
Unit Wgt (QA)	N/A				
Within Tolerance?	N/A				
Concrete Temp (IA)	61.0				
Concrete Temp (QA)	61.0				
Air Temp	58.0				
Slump (IA)	N/A				T119
Slump (QA))	N/A				T119
Within Tolerance?	N/A				
W/C Ratio (IA)	0.441				
W/C Ratio (QA)	0.446				

Remarks:

Comments: Three beam specimens fabricated for Denis Boisvert, Assistant Research Engineer- Freeze/Thaw Test Method.

Analysis Validated by: JA **Date:** 10/24/2005
Sample Vaildated by: ADP **Date:** 10/28/2005

STATE of NEW HAMPSHIRE DEPARTMENT of TRANSPORTATION
BUREAU of MATERIALS and RESEARCH

Project: PEMBROKE-ALLENSTOWN
Federal#: BRO-X-361(001)
State#: 12978
Report to: Charles Flanders

Compressive Strength-4000 PSI *AA22064*

Cylinder#: IA PA-QCQ ***Submitted by:*** S. DROUIN 10/24/2005
Source: Person's Bow
Material: Class AA Q/C-Q/A ***Quantity*** 40 cy.
Purpose: 520.0102 QC/QA Approach Slab B
Date Cast: 10/17/2005
% Air ***Slump(in):*** ***Mix Temp (F):*** ***Air Temp (F):***

Analysis	*Result*	*Min*	*Max*	*Violation*	*Method*
Tested By:	DF				
Date Broken	11/14/05				T22
Age (days)	28				T22
Diameter (in)	4				T22
Area (sq in)	12.57				T22
Load Reading	76800				T22
Density (lbs/ft3)	145.4				T22
Density (kg/m3)	2329.3				T22
Strength (psi)	6112	4000			T22
Strength (Mpa)	42.14	30.0			T22

Remarks:

Comments:

Analysis Validated by: JA ***Date:*** 11/15/2005
Sample Vaildated by: ADP ***Date:*** 11/21/2005

Compressive Strength-4000 PSI *AA22065*

Cylinder#: IA PA-QCQ ***Submitted by:*** S. DROUIN 10/24/2005
Source: Person's Bow
Material: Class AA Q/C-Q/A ***Quantity*** 40 cy.
Purpose: 520.0102 QC/QA Approach Slab B
Date Cast: 10/17/2005
% Air ***Slump(in):*** ***Mix Temp (F):*** ***Air Temp (F):***

Analysis	*Result*	*Min*	*Max*	*Violation*	*Method*
Tested By:	DF				
Date Broken	11/14/05				T22
Age (days)	28				T22
Diameter (in)	4				T22
Area (sq in)	12.57				T22
Load Reading	74000				T22
Density (lbs/ft3)	145.1				T22
Density (kg/m3)	2323.8				T22
Strength (psi)	5889	4000			T22
Strength (Mpa)	40.60	30.0			T22

Remarks:

Comments:

Analysis Validated by: JA ***Date:*** 11/15/2005
Sample Vaildated by: ADP ***Date:*** 11/21/2005

Compressive Strength-4000 PSI *AA22066*

Cylinder#: PA-QCQA- ***Submitted by:*** C. FLANDERS 10/24/2005
Source: Person's Bow
Material: Class AA Q/C-Q/A ***Quantity*** 40 cy.
Purpose: 520.0102 QC/QA Approach Slab B
Date Cast: 10/17/2005
% Air ***Slump(in):*** ***Mix Temp (F):*** ***Air Temp (F):***

Analysis	*Result*	*Min*	*Max*	*Violation*	*Method*
Tested By:	DF				
Date Broken	11/14/05				T22
Age (days)	28				T22
Diameter (in)	4				T22
Area (sq in)	12.57				T22
Load Reading	68400				T22
Density (lbs/ft3)	142.0				T22
Density (kg/m3)	2274.3				T22
Strength (psi)	5443	4000			T22
Strength (Mpa)	37.53	30.0			T22

Remarks:

Comments:

Analysis Validated by: JA ***Date:*** 11/15/2005
Sample Vaildated by: ADP ***Date:*** 11/21/2005

Compressive Strength-4000 PSI *AA22067*

Cylinder#: PA-QCQA- ***Submitted by:*** C. FLANDERS 10/24/2005
Source: Person's Bow
Material: Class AA Q/C-Q/A ***Quantity*** 40 cy.
Purpose: 520.0102 QC/QA Approach Slab B
Date Cast: 10/17/2005
% Air ***Slump(in):*** ***Mix Temp (F):*** ***Air Temp (F):***

Analysis	*Result*	*Min*	*Max*	*Violation*	*Method*
Tested By:	DF				
Date Broken	11/14/05				T22
Age (days)	28				T22
Diameter (in)	4				T22
Area (sq in)	12.57				T22
Load Reading	67000				T22
Density (lbs/ft3)	142.7				T22
Density (kg/m3)	2285.3				T22
Strength (psi)	5332	4000			T22
Strength (Mpa)	36.76	30.0			T22

Remarks:

Comments:

Analysis Validated by: JA ***Date:*** 11/15/2005
Sample Vaildated by: ADP ***Date:*** 11/21/2005

STATE of NEW HAMPSHIRE DEPARTMENT of TRANSPORTATION
BUREAU of MATERIALS and RESEARCH

Project: PEMBROKE-ALLENSTOWN **State#:** 12978
Federal#: BRO-X-361(001) **Report to:** Charles Flanders

Concrete Independent Assurance *AA22101*

Cylinder#: **Submitted by:** 10/25/2005
Source: Person's Bow
Material: QC/QA AA WITH F **Quantity** +-40cy
Purpose: Abut a approach slabs
Date Cast: 10/20/2005
% Air **Slump(in):** **Mix Temp (F):** **Air Temp (F):** clou

Analysis	Result	Min	Max	Violation	Method
QA Testing by:	C.Flanders				
QC Testing by:	B.Flanders				
IA Testing by:	D.John				
Sub Lot #	4				
Load #	3				
% Air (IA)	6.0				
% Air (QA)	5.7				
Within Tolerance?	Yes				
% Air (QC)	n/a				
Unit Wgt (IA)	n/a				
Unit Wgt (QA)	n/a				
Within Tolerance?	n/a				
Concrete Temp (IA)	61				
Concrete Temp (QA)	61				
Air Temp	50				
Slump (IA)	4.5				T119
Slump (QA))	4.5				T119
Within Tolerance?	Yes				
W/C Ratio (IA)	.487				
W/C Ratio (QA)	.456				

Remarks:

Comments:

Analysis Validated by: JA **Date:** 10/26/2005
Sample Vaildated by: ADP **Date:** 10/28/2005

STATE of NEW HAMPSHIRE DEPARTMENT of TRANSPORTATION
BUREAU of MATERIALS and RESEARCH

Project: PEMBROKE-ALLENSTOWN **State#:** 12978
Federal#: BRO-X-361(001) **Report to:** Charles Flanders

Compressive Strength-4000 PSI *AA22071*

Cylinder#: IA PA-QCQ **Submitted by:** D. JOHN 10/24/2005
Source: Person's Bow
Material: Class AA Q/C-Q/A **Quantity** 40 cy.
Purpose: 520.0102 QC/QA Approach Slab A
Date Cast: 10/20/2005
% Air *Slump(in):* *Mix Temp (F):* *Air Temp (F):*

Analysis	Result	Min	Max	Violation	Method
Tested By:	DF				
Date Broken	11/17/05				T22
Age (days)	28				T22
Diameter (in)	4				T22
Area (sq in)	12.57				T22
Load Reading	66000				T22
Density (lbs/ft3)	140.6				T22
Density (kg/m3)	2252.3				T22
Strength (psi)	5252	4000			T22
Strength (Mpa)	36.21	30.0			T22

Remarks:

Comments:

Analysis Validated by: JA **Date:** 11/17/2005
Sample Vaildated by: ADP **Date:** 11/21/2005

Compressive Strength-4000 PSI *AA22073*

Cylinder#: PA-QCQA- **Submitted by:** C. FLANDERS 10/24/2005
Source: Person's Bow
Material: Class AA Q/C-Q/A **Quantity** 40 cy.
Purpose: 520.0102 QC/QA Approach Slab A
Date Cast: 10/20/2005
% Air *Slump(in):* *Mix Temp (F):* *Air Temp (F):*

Analysis	Result	Min	Max	Violation	Method
Tested By:	DF				
Date Broken	11/17/05				T22
Age (days)	28				T22
Diameter (in)	4				T22
Area (sq in)	12.57				T22
Load Reading	63600				T22
Density (lbs/ft3)	140.9				T22
Density (kg/m3)	2257.8				T22
Strength (psi)	5061	4000			T22
Strength (Mpa)	34.90	30.0			T22

Remarks:

Comments:

Analysis Validated by: JA **Date:** 11/17/2005
Sample Vaildated by: ADP **Date:** 11/21/2005

Compressive Strength-4000 PSI *AA22072*

Cylinder#: IA PA-QCQ **Submitted by:** D. JOHN 10/24/2005
Source: Person's Bow
Material: Class AA Q/C-Q/A **Quantity** 40 cy.
Purpose: 520.0102 QC/QA Approach Slab A
Date Cast: 10/20/2005
% Air *Slump(in):* *Mix Temp (F):* *Air Temp (F):*

Analysis	Result	Min	Max	Violation	Method
Tested By:	DF				
Date Broken	11/17/05				T22
Age (days)	28				T22
Diameter (in)	4				T22
Area (sq in)	12.57				T22
Load Reading	70000				T22
Density (lbs/ft3)	142.0				T22
Density (kg/m3)	2274.3				T22
Strength (psi)	5570	4000			T22
Strength (Mpa)	38.41	30.0			T22

Remarks:

Comments:

Analysis Validated by: JA **Date:** 11/17/2005
Sample Vaildated by: ADP **Date:** 11/21/2005

Compressive Strength-4000 PSI *AA22074*

Cylinder#: PA-QCQA- **Submitted by:** C. FLANDERS 10/24/2005
Source: Person's Bow
Material: Class AA Q/C-Q/A **Quantity** 40 cy.
Purpose: 520.0102 QC/QA Approach Slab A
Date Cast: 10/20/2005
% Air *Slump(in):* *Mix Temp (F):* *Air Temp (F):*

Analysis	Result	Min	Max	Violation	Method
Tested By:	DF				
Date Broken	11/17/05				T22
Age (days)	28				T22
Diameter (in)	4				T22
Area (sq in)	12.57				T22
Load Reading	65200				T22
Density (lbs/ft3)	141.3				T22
Density (kg/m3)	2263.3				T22
Strength (psi)	5188	4000			T22
Strength (Mpa)	35.77	30.0			T22

Remarks:

Comments:

Analysis Validated by: JA **Date:** 11/17/2005
Sample Vaildated by: ADP **Date:** 11/21/2005

Wednesday, February 01, 2006

STATE of NEW HAMPSHIRE DEPARTMENT of TRANSPORTATION
BUREAU of MATERIALS and RESEARCH

Project: **PEMBROKE-ALLENSTOWN** *State#:* 12978
Federal#: BRO-X-361(001) *Report to:* Charles Flanders

Permeability of Concrete *AA22068*

Cylinder#: PA-QCQA- *Submitted by:* C. FLANDERS 10/24/2005
Source: Person's Bow
Material: Class AA Q/C-Q/A *Quantity* 40 cy.
Purpose: 520.0102 QC/QA Approach Slab B
Date Cast: 10/17/2005
% Air *Slump(in):* *Mix Temp (F):* *Air Temp (F):*

Analysis	*Result*	*Min*	*Max*	*Violation*	*Method*
Date of Placement	10/17/05				
Date Tested	12/13/05				
Age (days)	57				
Perm. Coulombs	1600	100	4000		
Tested By:	RD				

Remarks:

Comments:

Analysis Validated by: JA *Date:* 12/13/2005
Sample Vaildated by: ADP *Date:* 12/15/2005

Permeability of Concrete *AA22075*

Cylinder#: PA-QCQA- *Submitted by:* C. FLANDERS 10/24/2005
Source: Person's Bow
Material: Class AA Q/C-Q/A *Quantity* 40 cy.
Purpose: 520.0102 QC/QA Approach Slab A
Date Cast: 10/20/2005
% Air *Slump(in):* *Mix Temp (F):* *Air Temp (F):*

Analysis	*Result*	*Min*	*Max*	*Violation*	*Method*
Date of Placement	10/20/05				
Date Tested	12/15/05				
Age (days)	56				
Permeability Coulombs	1546	100	4000		
Tested By:	RD				

Remarks:

Comments:

Analysis Validated by: JA *Date:* 12/15/2005
Sample Vaildated by: ADP *Date:* 12/21/2005

APPENDIX B - FREEZE-THAW TESTS

PREPARED BY: Jim Wild
DATE: 11/4/2005

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS AND RESEARCH DIVISION
STRUCTURAL CONCRETE SUBDIVISION

FREEZE-THAW DATA WORKSHEET

WORKPLAN NUMBER: NH no fiber Ref. DATE CAST: 10/17/2005
SPECIMEN I.D.: NH REF. 1 SPECIMEN SIZE: 3 x 3 x 16
TRAY NUMBER: #1

MATERIAL SOURCE AND GENERAL COMMENTS

3/4
Sand
Cement
pozz admix
pozz admix
pozz admix

air admix:
water reducer admix:
H.R.W.R:

H.R.W.R - high range water reducer

FRESH CONCRETE DATA

unit weight (lb/cf)
% air
slump (in.)
water/cement ratio

concrete temp (F)
air temp (F)

DATE	CYCLE	WEIGHT	% WGT. LOSS	FREQUENCY *	COMMENTS
11/04/05		3860.00		2002	
11/10/05	51	3860.20	0.0	1758	good
11/17/05	105	3859.40	0.0	2052	good
11/23/05	154	3857.3	0.1	2046	good
12/01/05	220	3857.3	0.1	2004	good
12/09/05	287	3859.9	0.0	1477	Very slight scaling around bottom
12/13/05	322	3861.2	0.0	1275	Very slight scaling around bottom

Note: Not sure why frequency dropped, bars showed no signs of deteriation.

Durability factor (DF) = (end frequency ^2/start frequency ^2) *100% = 40.56

* FUNDAMENTAL TRANSVERSE FREQUENCY; REFER TO AASHTO DESIGNATION T 161-86

PREPARED BY: Jim Wild
DATE: 11/4/2005

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS AND RESEARCH DIVISION
STRUCTURAL CONCRETE SUBDIVISION

FREEZE-THAW DATA WORKSHEET

WORKPLAN NUMBER: NH no fiber Ref. DATE CAST: 10/17/2005
SPECIMEN I.D.: NH REF. 1 SPECIMEN SIZE: 3 x 3 x 16
TRAY NUMBER: #2

MATERIAL SOURCE AND GENERAL COMMENTS

3/4
Sand
Cement
pozz admix
pozz admix
pozz admix

air admix:
water reducer admix:
H.R.W.R:

H.R.W.R - high range water reducer

FRESH CONCRETE DATA

unit weight (lb/cf)
% air
slump (in.)
water/cement ratio

concrete temp (F)
air temp (F)

DATE	CYCLE	WEIGHT	% WGT. LOSS	FREQUENCY *	COMMENTS
11/04/05		3856.10		1975	
11/10/05	51	3855.30	0.0	1751	Good
11/17/05	105	3852.50	0.1	2147	Good
11/23/05	154	3850.7	0.1	2150	Good
12/01/05	220	3851.6	0.1	1824	Good
12/09/05	287	3853.5	0.1	1401	Good
12/13/05	322	3854.7	0.0	1320	Good

Note: Not sure why frequency dropped, bars showed no signs of deteriation.

Durability factor (DF) = (end frequency ^2/start frequency ^2) *100% = 44.67

* FUNDAMENTAL TRANSVERSE FREQUENCY; REFER TO AASHTO DESIGNATION T 161-86

PREPARED BY: Jim Wild
DATE: 11/4/2005

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS AND RESEARCH DIVISION
STRUCTURAL CONCRETE SUBDIVISION

FREEZE-THAW DATA WORKSHEET

WORKPLAN NUMBER: NH no fiber Ref. DATE CAST: 10/17/2005
SPECIMEN I.D.: NH REF. 1 SPECIMEN SIZE: 3 x 3 x 16
TRAY NUMBER: #3

MATERIAL SOURCE AND GENERAL COMMENTS

3/4
Sand
Cement
pozz admix
pozz admix
pozz admix

air admix:
water reducer admix:
H.R.W.R:

H.R.W.R - high range water reducer

FRESH CONCRETE DATA

unit weight (lb/cf)
% air
slump (in.)
water/cement ratio

concrete temp (F)
air temp (F)

DATE	CYCLE	WEIGHT	% WGT. LOSS	FREQUENCY *	COMMENTS
11/04/05		3896.60		1845	
11/10/05	51	3894.00	0.1	1796	Very slight weight loss & scaling
11/17/05	105	3892.20	0.1	1741	Very slight weight loss & scaling
11/23/05	154	3891.5	0.1	1727	Very slight weight loss & scaling
12/01/05	220	3892	0.1	1775	Very slight weight loss & scaling
12/09/05	287	3895.2	0.0	1382	Slight scaling
12/13/05	322	3893.5	0.1	1882	Slight scaling
Durability factor (DF) = (end frequency ^2/start frequency ^2) *100% =					104.05

* FUNDAMENTAL TRANSVERSE FREQUENCY; REFER TO AASHTO DESIGNATION T 161-86

PREPARED BY: Jim Wild
DATE: 11/4/2005

STATE OF VERMONT
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FREEZE-THAW DATA WORKSHEET

WORKPLAN NUMBER: NH Fiber
DATE CAST: 10/17/2005
SPECIMEN I.D.: NH Fiber #1
SPECIMEN SIZE: 3 x 3 x 16
TRAY NUMBER: #4

MATERIAL SOURCE AND GENERAL COMMENTS

3/4
Sand
Cement
pozz admix
pozz admix
pozz admix

air admix:
water reducer admix:
H.R.W.R:

H.R.W.R - high range water reducer

FRESH CONCRETE DATA

unit weight (lb/cf)
% air
slump (in.)
water/cement ratio

concrete temp (F)
air temp (F)

DATE	CYCLE	WEIGHT	% WGT. LOSS	FREQUENCY *	COMMENTS
11/04/05		3912.60		1650	
11/10/05	51	3910.80	0.0	1638	Very slight weight loss & scaling
11/17/05	105	3911.10	0.0	1429	Very slight weight loss & scaling
11/23/05	154	3909.1	0.1	1394	Very slight weight loss & scaling 10 to 15 fibers balled up in bottom
12/01/05	220	3910	0.1	1447	Very slight scaling
12/09/05	287	3910.6	0.1	1631	Very slight scaling
~~12/13/05~~	~~322~~	~~3911.1~~	~~0.0~~	~~1706~~	~~Very slight scaling~~
Durability factor (DF) = (end frequency ^2/start frequency ^2) *100% =					106.90

* FUNDAMENTAL TRANSVERSE FREQUENCY; REFER TO AASHTO DESIGNATION T 161-86

PREPARED BY: Jim Wild
DATE: 11/4/2005

STATE OF VERMONT
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FREEZE-THAW DATA WORKSHEET

WORKPLAN NUMBER: NH Fiber
DATE CAST: 10/17/2005
SPECIMEN I.D.: NH Fiber #1
SPECIMEN SIZE: 3 x 3 x 16
TRAY NUMBER: #5

MATERIAL SOURCE AND GENERAL COMMENTS

3/4
Sand
Cement
pozz admix
pozz admix
pozz admix

air admix:
water reducer admix:
H.R.W.R:

H.R.W.R - high range water reducer

FRESH CONCRETE DATA

unit weight (lb/cf)
% air
slump (in.)
water/cement ratio

concrete temp (F)
air temp (F)

DATE	CYCLE	WEIGHT	% WGT. LOSS	FREQUENCY *	COMMENTS
11/04/05		3867.20		1241	
11/10/05	51	3868.50	0.0	1351	Good
11/17/05	105	3866.60	0.0	1628	Good
11/23/05	154	3866	0.0	1601	Good
12/01/05	220	3867.7	0.1	1870	Good
12/09/05	287	3870.3	-0.1	1728	Very slight scaling
12/13/05	322	3869.1	0.0	1362	Very slight scaling
Durability factor (DF) = (end frequency ^2/start frequency ^2) *100% =					120.45

* FUNDAMENTAL TRANSVERSE FREQUENCY; REFER TO AASHTO DESIGNATION T 161-86

PREPARED BY: Jim Wild
DATE: 11/4/2005

STATE OF VERMONT
AGENCY OF TRANSPORTATION
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STRUCTURAL CONCRETE SUBDIVISION

FREEZE-THAW DATA WORKSHEET

WORKPLAN NUMBER: NH Fiber   DATE CAST: 10/17/2005
SPECIMEN I.D.: NH Fiber #1   SPECIMEN SIZE: 3 x 3 x 16
TRAY NUMBER: #6

MATERIAL SOURCE AND GENERAL COMMENTS

3/4
Sand   air admix:
Cement   water reducer admix:
pozz admix   H.R.W.R:
pozz admix
pozz admix

H.R.W.R - high range water reducer

FRESH CONCRETE DATA

unit weight (lb/cf)   concrete temp (F)
% air   air temp (F)
slump (in.)
water/cement ratio

DATE	CYCLE	WEIGHT	% WGT. LOSS	FREQUENCY *	COMMENTS
11/04/05		3921.80		1205	
11/10/05	51	3921.00	0.0	1696	Slight pitting
11/17/05	105	3920.00	0.0	1280	Slight pitting
11/23/05	154	3920.6	0.0	1350	Slight pitting
12/01/05	220	3919.2	0.1	1327	Slight pitting
12/09/05	287	3923	0.0	1387	Slight pitting
12/13/05	322	3920.6	0.0	1422	Slight pitting
Durability factor (DF) = (end frequency ^2/start frequency ^2) *100% =					139.26

* FUNDAMENTAL TRANSVERSE FREQUENCY; REFER TO AASHTO DESIGNATION T 161-86

APPENDIX C - BEAM TESTING AND PETROGRAPHICS

Alternate Approach Slab Reinforcement

SPR Project 13733-H

Final Report

July 24, 2008

Submitted to

New Hampshire Department of Transportation

By

David Gress

Department of Civil Engineering

University of New Hampshire

Background

The Pembroke Bridge construction project was selected by the NHDOT to evaluate an alternate approach slab reinforcement technique. One approach slab was conventionally placed as per traditional practice (reinforcement top and bottom both directions. The alternate slab consisted of fiber reinforced concrete with only bottom reinforcement (both directions). This work consisted of the laboratory evaluation of the two concretes.

Procedure

The procedure to obtain viable laboratory samples was to cast 4" slabs large enough to prevent segregation and alignment of fibers during casting but small enough to transport back to UNH and cut 4" x 4" x 14" beams for flexural testing. Two field cores were obtained from each approach slab for determining air void parameters using petrographic analysis.

Beam testing was based on procedures outlined in ASTM C 1018 and C 1399. The intent of these two ASTM testing procedures was to compare the benefits of fiber reinforced concrete to conventional concrete. Emphasis was placed on First crack Toughness, toughness after the first crack, total toughness, Average Residual Strength and conventional flexural strength. Third point loading was used with a span of 12". An Instron closed loop testing machine was used with digital dial gauges monitoring the deformations.

Cores obtained by Turner Testing and Engineering were cut and polished for air void analysis as per ASTM C457 modified point count procedure.

Data

Data from the beam laboratory testing is presented in Table 1. Four beams from each approach slab were tested. The traditional concrete was identified as samples NF1 through NF4 and the fiber reinforced concrete as F1 through F4.

The average flexural strengths of the traditional and fiber reinforced concretes were 730 psi and 660 psi respectively. The quality of the two concretes is apparent with the high flexural strengths. As would be expected with a plastic fiber the flexural strength of the fiber reinforced concrete was reduced by 70 psi, approximately 10 percent.

First Crack Toughness as defined by the maximum load as is used in determining the standard flexural strength was an average of 178.4 psi for the traditional concrete and 53.8 psi for the fiber reinforced concrete. This is basically the energy required per unit volume of concrete to cause the first crack to occur. The benefit of the fiber is not obvious due the difference between the two by approximately a factor of three. The presence of the fibers lowers the strength, as previously shown by the flexural strength, as well as the First Crack Toughness.

Table 1: Beam laboratory testing data

Beam	Flexural Strength, psi	First crack toughness, in-lb	After first crack toughness, in-lb	Total toughness, in-lb	ARS[1], psi
NF1	750	78.2	0	0	0
NF2	660	38.8	0	0	0
NF3	825	558.7	0	0	0
NF4	675	37.7	0	0	0
Avg	730	178.4	0	0	0
F1	565	31.1	223.7	254.8	160
F2	660	35.4	275.0	310.4	330
F3	845	78.3	526.9	605.2	290
F4	565	70.2	233.0	303.2	170
Avg	660	53.8	314.7	368.4	240

Note: [1] ARS is Average Residual Strength after the first crack

The amount of unit energy required to fail the concrete after the first crack is exceptionally large for the fiber reinforced concrete and equal to 0 for the traditional concrete. Likewise the total toughness shows the real benefit of using fibers in concrete. Comparing the average of the two values shows a difference of approximately a factor of two (368.4/178.4) again showing the real benefit of the fiber is after it cracks.

The Average Residual Strength (ARS) was estimated to be an average of 240 psi. This is just another way to identify the remaining strength after the first crack, again showing the benefit of using fibers.

Petrographic

Figures 1 and 3 show the polished sections of the near surface of the fiber reinforced and traditionally reinforced concretes. Both show good distribution of aggregates and a surface well compacted but not over finished. Even though an attempt to avoid hitting reinforcement during coring was made, Figure 3 shows an epoxy coated reinforcement bar. The two areas of the figure showing little epoxy cover may be the result of pulling the coating during polishing. Figure 2 shows a close up of the section noted by an arrow in Figure 1. This shows the uniform distribution of the fibers.

Air Void Analysis

Three cores were cut and polished to analyze the air void properties of the two approach slabs as per ASTM C 457 – 98 Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete. Table 2 presents the results of the air void testing. These data show that the air content of the non fiber samples and fiber samples had average air contents of 7.9 and 7.0 percent with a average spacing factors of 0.001 for the non fiber and fiber concretes. The paste, fine aggregate and coarse aggregate percentages were also similar for both concretes. Based on these data the concretes would be expected to be resistant to cycles of freezing and thawing.

Table 2: ASTM C 457 Air void analysis data

Sample	Paste	Air	Aggregate		Spacing Factor		Specific Surface
			Fine	Coarse	Inches	mm	α, in-1
NF1 top	37.9%	7.0%	18.1%	37.0%	0.0013	0.033	3657
NF1 bot	37.7%	8.8%	17.0%	36.6%	0.0012	0.030	3657
Average	37.8%	7.9%	17.5%	36.8%	0.0012	0.032	3657
F1 top	38.3%	8.7%	17.4%	35.6%	0.0012	0.030	3657
F1 bot	39.1%	6.0%	18.2%	36.7%	0.0014	0.036	3657
F2 top	39.7%	6.5%	17.6%	36.3%	0.0014	0.035	3657
F2 bot	37.4%	6.8%	17.2%	38.6%	0.0013	0.034	3657
Average	38.6%	7.0%	17.6%	36.8%	0.0013	0.034	3657

Conclusions

The laboratory testing of the approach slab concretes showed the benefit of fiber reinforcing. Petrographic analysis showed the fibers to be very uniformly dispersed suggesting they would be expected to control cracking if and when cracking occurs in the field. Both concretes were shown to have air void systems capable of resisting freeze thaw cycles supporting the hypothesis that fibers have little if any impact on entraining air.

Recommendations

Based on the laboratory data it is recommend that future approach slabs be designed and placed without any conventional reinforcing. This is consistent with state of the art airport pavement design procedures, which typically require no reinforcing what so ever for much thicker slabs. On the other hand since the use of fibers is so inexpensive and their presence has such a significant impact on crack arrest it is highly recommended future approach slabs always specify them.