

FINAL REPORT

**ACCELERATED SLAB REPLACEMENT USING TEMPORARY PRECAST PANELS
AND SELF-CONSOLIDATING CONCRETE**

**Florida Department of Transportation
BDV30TWO 977-02**

Submitted by

Dr. Kamal Tawfiq, P.E.
Principal Investigator
FAMU-FSU College of Engineering
Department of Civil and Environmental Engineering
2525 Pottsdamer Street, Room 129
Tallahassee, Florida 32310
Phone: (850) 410-6143
Email: tawfiq@eng.fsu.edu

Dr. Jamshid Armaghani, P.E.
Project Consultant
Global Sustainable Solutions
Gainesville, Florida 32653
Phone: (352) 336-1161
Email: jamshid@bellsouth.net

Submitted to

Michael Bergin, P.E.
Florida Department of Transportation
State Structural Materials Engineer
State Materials Office
Gainesville, Florida 32609
Phone: 352-955-6666
Email: michael.bergin@dot.state.fl.us

June 6, 2016

DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation or the U.S. Department of Transportation.

Prepared in cooperation with the State of Florida Department of Transportation and the U.S. Department of Transportation.

ACKNOWLEDGMENTS

This work has been sponsored by the Florida Department of Transportation (FDOT). Mike Bergin served as the Project Manager. His valuable contributions and advice are greatly appreciated. Also, the contributions of Dr. Harvey DeFord are much appreciated. Acknowledgements for their valuable help go to Mr. Jeff O'Leary and the ARGOS USA team, Jim Maples and the A-Materials team, Jeremy Mertens of BASF, Tommy Langdo of Concrete Specialists, and Dayton Superior for their assistance and material supply. The following former FAMU-FSU students are acknowledged for their significant contributions to this research: Steven Squillacote, Matt Sotirin, and Milad Fatehnia.

SI (MODERN METRIC) CONVERSION FACTORS (FROM FHWA)

Symbol	When You Know	Multiply By	To Find	Symbol
Length				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
Area				
in²	square inches	645.2	square millimeters	mm ²
ft²	square feet	0.093	square meters	m ²
yd²	square yard	0.836	square meters	m ²
mi²	square miles	2.59	square kilometers	km ²
Volume				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m ³
yd³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m³				
Mass				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
Temperature (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
Illumination				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
Force and Pressure or Stress				
lbf	pound-force	4.45	newton	N
lbf/in²	pound-force per square inch	6.89	kilopascal	kPa

TECHNICAL REPORT DOCUMENTATION

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Accelerated Slab Replacement Using Temporary Precast Panels and Self-consolidating Concrete		5. Report Date : June 30, 2016	
		6. Performing Organization Code	
7. Author(s) Kamal S. Tawfiq and Jamshid Armaghani		8. Performing Organization Report No.	
9. Performing Organization Name and Address FAMU-FSU College of Engineering Department of Civil and Environmental Engineering Florida State University 2525 Pottsdamer Street Tallahassee, FL 32310		10. Work Unit No.	
		11. Contract or Grant No. BDV30TWO 977-02	
12. Sponsoring Agency Name and Address Florida Department of Transportation State Structural Materials Engineer State Materials Office Gainesville, FL 32609		13. Type of Report and Period Covered March 2013 – June 2016	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract <p>Slab replacement is the main activity in any concrete pavement rehabilitation project. According to a survey of industry and FDOT, contractor productivity in slab replacements has been very low, ranging between 25 to 50 cu. yds. The low number of slab replacements constructed during a lane closure period is due to the short closure window to complete the time consuming construction activities.</p> <p>In an effort to increase productivity, the concrete mix is often designed to achieve the lane opening strength requirement of 2,200 psi in the shortest possible time to enable placing more slabs per lane closure period. This requires the use of excessive quantities of cement and accelerators in the concrete mix to achieve the required strength. A likely consequence of such action has been the development of premature cracking in many newly replaced slabs in Florida rehabilitation projects.</p> <p>This project was initiated with the objective to develop a method using temporary reusable precast panels and self-consolidating concrete (SCC) to accelerate the slab replacement process. The method involves installing one or two precast panels in the replacement slab pit after removing the deteriorated segment of the original slab. The panels are kept as placeholders for a few days and then removed. The open pit is then cast using SCC mix to form a permanent replacement slab.</p> <p>The ultimate goal of the Precast Panel-SCC Mix method is to increase contractor productivity, reduce maintenance of traffic (MOT) and construction completion time, reduce project cost, and minimize premature cracking. The two components of this method, namely, reinforced precast panels and SCC mix were designed, prepared, and tested in the laboratory, and then demonstrated successfully in the field. Construction criteria, detailed guidelines and specifications were also developed to facilitate implementation of this method in concrete pavement rehabilitation projects.</p>			
17. Keywords. Precast Slabs, Pavement Rehabilitation, Concrete Pavement, Self-Consolidating Concrete		18. Distribution Statement No restrictions.	
19. Security Classify. (of this report) Unclassified.	20. Security Classify. (of this page) Unclassified.	21. Pages 202	22. Price --

EXECUTIVE SUMMARY

INTRODUCTION

Slab replacement is the main activity in concrete pavement rehabilitation projects. The construction process involves removing the deteriorated section of or the entire slab and replacing it with new concrete after installing new dowel bars as required in the design plans. The process is slow and time consuming. Also, the window for lane closures to perform the work is generally short. This results in low contractor productivity, which increases maintenance of traffic (MOT) effort, construction time and cost of the project.

In an attempt to increase productivity, contractors often try to extend the construction period to place more replacement slabs during the limited lane closure hours. This requires using concrete mixes with excessive cement content and/or high dosage of accelerating admixtures to shorten the curing time to achieve the required strength for lane opening. However, such action has often contributed to premature cracking in replacement slabs due to high thermal and shrinkage stresses.

RESEARCH OBJECTIVES

Florida DOT sponsored the research project to develop a method using temporary and reusable precast concrete panels and self-consolidating concrete (SCC) mix to accelerate slab replacements in concrete rehabilitation projects.

The ultimate goal of the method is to increase contractors' productivity, reduce maintenance of traffic (MOT) and construction completion time, reduce project cost and minimize premature cracking.

SCOPE OF WORK

The project included several tasks to achieve the research objective of developing the method to accelerate slab replacements. The following tasks were performed:

1. Design and construct reinforced precast panels for quick installation and removal.
2. Develop a SCC mix in the laboratory with the required high workability and early strength.
3. Demonstrate panel and installation of panels in a specially prepared replacement slab pit.
4. Test the robustness and stability of installed precast panels under repeated heavy truckloads.
5. Produce and sustain highly workable SCC mix in the field and cast a full-scale replacement slab.
6. Test the new SCC slab under repeated truck loading after 6 hr. from placement.
7. Evaluate the new slab for cracks and mix segregation.
8. Evaluate time of execution for various activities in the new method for slab replacement.
9. Develop construction guidelines and implementation recommendations.

Method Details

The two components of this method, namely, reinforced precast panels and SCC mix were designed, prepared, and tested in the lab, and then demonstrated their viability in the field.

The method involves installing one or two temporary and reusable precast panels in the replacement slab pit after removing the deteriorated section of the original slab. The panels are kept as placeholders from one to seven days and then removed. The open pit is cast using SCC mix to form a permanent replacement slab.

The method was developed and tested and is summarized in the following steps:

1. Remove the deteriorated sections of the pavement slabs.

2. Drill holes for the new dowel bars in the appropriate sides of the replacement pit, then clean and patch the holes with tape. Alternatively leave the holes uncleaned and uncovered until prior to casting the new slab.
3. If the depth of the resulting pit does not match the thickness of the precast panels, add a leveling course to the bottom of the pit or grub the bottom of the pit, whichever applies to achieve the desired depth.
4. Install one or two precast panels in each slab replacement pit. The precast panels would remain in the pit for a short period of time ranging from one to seven days.
5. Remove the precast panel(s) and transport to the next segment of the project for re-installation.
6. Remove the tape that covered the dowel holes and fill the holes with epoxy, or clean the open hole and then inject epoxy.
7. Insert and anchor the new dowel bars in the epoxied holes.
8. Cast the replacement slab using the SCC mix.
9. Finish and cure the slab surface.
10. Repeat the construction sequence (steps 1-9) until completing the required slab replacements for the project.

Construction criteria, detailed guidelines and specifications were developed to facilitate implementation of this method in concrete pavement rehabilitation projects.

CONCLUSIONS

Temporary Reusable Precast Panels

1. Two 6'x 12'x 8" panels were designed using double mats of no. 4 and no. 5 reinforcing bars. Both designs showed similar robust performance in laboratory and field demonstration.
2. The imbedded backer rod gasket along the sides of the panels facilitated installation in and removal of panels from the replacement slab pits. The gasket also softened any impact of the panels against the surrounding concrete.
3. Maintaining a 1.5" gap between the panels and the surrounding concrete facilitated installation of panels inside the replacement slab pits.
4. The recessed stripes along the bottom surface of the panels provided stability and strong interlock with the base to resist panel shifting under traffic.
5. The panels displaced 3/16" vertically and had very low horizontal displacement when subjected to 50-load repetition from a passing 60,000 lb truck. This faulting is considered acceptable since the panels are temporary placeholders and would remain in the pits for only a few days.
6. The installation time for each panel was approximately 10 min. and its removal was 5 min. With more dedicated lifting and maneuvering equipment, these times may be shortened further.

Self-Consolidating Concrete (SCC) Mix

1. An innovative SCC mix was developed for slab replacements.
2. This SCC mix is a departure from conventional SCC mixes used in structural applications; Grade 57 aggregate and accelerator were used in the mix.

3. The SCC mix design was highly effective for casting slab replacements in the field without the need for compaction. This will potentially save time and labor.
4. The concrete workability was retained for at least 60 minutes after adding and mixing the accelerator. This will allow the concrete in truck mixers to maintain a high workability rate during truck idle times between successive concrete placements at isolated replacement pits.
5. Vibrated and nonvibrated samples cast from the same SCC mix showed very small differences in compressive strength and weight. As a result, no concrete vibration was needed during slab placements.
6. There was no segregation in placement of the SCC mix in a 12' x 12' x 8" replacement slab pit.
7. It took less than three min. to completely cast a 12' x 12' x 8" replacement slab.
8. Adjustments to the admixture dosage rates may be necessary when the SCC mix is specified for longer concrete transportation periods, or when the admixture sources are changed.
9. At high or low temperature paving, adjustments in the cement content and accelerator dosage rate of the SCC mix may be needed to maintain high workability and agency-required strength for lane-opening.
10. Strength of the SCC mix at 6 hr. greatly exceeded the required 2,200 psi strength requirement for lane opening.
11. The ability of the SCC mix for rapid discharge without segregation and for reaching the required strength at lane-opening time will increase productivity of contractors.

12. It is necessary to maintain the truck mixer in agitation mode, non-stop, and at a slightly higher speed than the conventional agitation rate. This will prevent premature setting of the SCC mix after the addition of the accelerator at the jobsite.
13. When casting replacement slabs, simultaneous leveling and finishing of the cast slab will be required due to rapid loss of SCC workability upon discharge in the replacement slab pit.

RECOMMENDATIONS

General

This method is most cost effective and efficient when:

1. The volume of concrete specified in the contract bid is more than 1000 cu. yds.
2. Limited window for lane closure is specified, especially during nighttime.
3. Significant premature cracking is observed using conventional concrete mixes with an excessive amount of cement and accelerator to achieve required strength in less than 4 hr. from the lane opening time.
4. Many deteriorated slabs that require removal and replacement are located in close proximity of each other.
5. The cost benefit analysis favors the use of this method.

Other favorable factors include close proximity of a concrete batch plant and contractor's storage yard to the project site, and onsite safety concerns of having too many workers.

IMPLEMENTATION

The implementation of the method is an option for the contractor and when it is within his “means and methods”. It is also acknowledged, that current methods and patterns that contractors use in replacning slabs may be difficult to change. However, the FDOT can facilitate and encourage rapid implementation of the method by making changes to design and material specifications, provide training and develop demonstration projects as outlined in the following recommendations:

1. Revise FDOT Standard Index 308 for 20’ long slabs that requires the designer to use only four standard dimensions for the deteriorated area to be removed. These dimensions shall be, 6’ x 12’, 8’ x 12’, 10’ x 12’ and 12’ x 12’. Cracks that exceed 12’ shall require replacement of the entire slab. For 15’ long slabs, use only two standard dimensions, 6’ x 12’ and 8’ x 12’. Cracks exceeding 8’ would require replacing the entire slab.
2. Modify FDOT specification 353 as follows
 - a. Allow the use of SCC mix in slab replacements. Allow the use of 67 or 57 grade aggregates and accelerator admixture in the SCC mix.
 - b. Require removal of concrete from a replacement pit when segregation is observed.
 - c. Allow the retention of the thin leveling course when casting the SCC mix in the replacement pit. The material would have been compacted sufficiently under the load of the precast panel and moving traffic and thus would have transformed into a stable and stiff base beneath the pavement. Also, remove the requirement for density test for the base material.

3. Prepare and deliver training workshops on the method for FDOT engineers, consultants and contractors to encourage its application.
4. Select one or two rehabilitation projects in the design phase to plan and implement the method in a segment of the project. Monitor its efficiency and effectiveness. This will also provide contractors the opportunity to evaluate the cost and benefits of the method compared to using conventional slab replacement.

TABLE OF CONTENTS

DISCLAIMER.....	2
ACKNOWLEDGMENTS.....	3
SI (MODERN METRIC) CONVERSION FACTORS (FROM FHWA).....	4
TECHNICAL REPORT DOCUMENTATION.....	5
EXECUTIVE SUMMARY	6
INTRODUCTION	6
RESEARCH OBJECTIVES	6
SCOPE OF WORK.....	7
Method Details	7
CONCLUSIONS.....	9
Temporary Reusable Precast Panels	9
Self-Consolidating Concrete (SCC) Mix	9
RECOMMENDATIONS	11
General	11
IMPLEMENTATION	12
LIST OF FIGURES.....	18
LIST OF TABLES	24
CHAPTER 1.....	25
1.1 Background	25
1.2 Challenges of Traditional Slab Replacement Method	25
1.3 Accelerated Slab Replacement Method	27
1.4 Contents of the Report	27
CHAPTER 2.....	29
LITERATURE REVIEW.....	29
2.1 Introduction.....	29
2.2 Precast Concrete Pavements (PCP).....	29
2.3 Demonstration of PCP Project in Florida	42
2.4 Temporary Precast Concrete Applications	44
2.5 Self-Consolidating Concrete (SCC) For Pavements	45
2.6 Research Scope	48

CHAPTER 3.....	50
INDUSTRY SURVEY.....	50
3.1 Introduction	50
3.2 Electronic Survey Questionnaire and Response.....	50
3.3 Survey Results.....	54
3.4 Direct Communications.....	54
3.5 Summary of Survey Findings.....	56
CHAPTER 4.....	58
PRECAST PANEL MODELING	58
4.1 Introduction	58
4.2 Numerical Modeling and Field Testing of Precast Slab	58
4.3 Field Test Results vs. Finite Element Modeling	60
4.4 Conclusion.....	63
CHAPTER 5.....	65
DEVELOPMENT OF SCC MIX FOR SLAB REPLACEMENT.....	65
5.1 Introduction.....	65
5.2 SCC Mix Ingredients	66
5.3 Trial Mixes	70
5.4 SCC Testing – Plastic Phase	71
5.5 Compressive Strength	75
5.6 Summary of SCC Mix Design	79
CHAPTER 6.....	80
FIELD DEMONSTRATION AND EVALUATION.....	80
6.1 Introduction and Scope.....	80
6.2 Test Track.....	82
6.2.1 Preparation of Replacement-Slab Test-Pit	83
6.2.2 Construction of Temporary Precast Panels	87
6.2.3 Installation of Precast Panels	91
6.2.4 Instrumentation and test loading the panels.....	95
6.2.5 Removal of Precast Panels from the test Pit.....	97
6.3 SCC Mix - Field Evaluation.....	98
6.3.1 Verification of Workability Retention at FAMU-FSU Laboratory	100
6.3.2 Casting of Replacement Slab in Test Pit at Test track.....	107

6.3.3	Truck Loading of Replacement Slab.....	111
6.4	Conclusions.....	112
CHAPTER 7	114
FILED TESTING AND MODELING	114
7.1	Introduction.....	114
7.2	Performance of the Precast Panels Under Truck Loads.....	115
7.2.1	Instrumentation of Panels at Green Cove Springs Test Track.....	115
7.2.2	Truck loading.....	117
7.2.3	Finite Element Analysis (FEA).....	123
7.2.4	Field Test Measurements vs. Numerical analysis Results.....	127
7.3	Maturity Measurements for SCC Mix.....	131
7.3.1	Concrete Maturity.....	131
7.5.2	Maturity Functions.....	134
7.3.2	Strength–Maturity Relationships.....	138
7.3.3	Developing Laboratory SCC Maturity Relationship.....	140
7.3.4	Thermal Devices Used in Maturity Testing.....	142
7.3.5	Novel Method for Concrete Maturity.....	146
7.3.6	Thermal Measurements at Test Track.....	147
CHAPTER 8	153
CONSTRUCTION GUIDELINES AND SPECIFICATIONS	153
8.1	Introduction.....	153
8.2	Summary of New Method.....	155
8.3	Project Design Requirements.....	156
8.4	Design of Precast Panels.....	156
8.4.1	Reinforcement and Lift anchors.....	160
8.4.2	Alternate detail options.....	162
8.5	Self-Consolidating Concrete Mix.....	163
8.6	Specification Requirements.....	166
8.7	Construction Guidelines.....	168
8.7.1	Installation of Precast Panels.....	168
8.7.2	Casting the Replacement Slabs.....	176
8.8	Criteria for Applying the Precast Panel-SCC Method.....	180
8.9	Project Time and Cost savings.....	181

8.9.1 Illustration of Time and Cost Savings	183
8.10 Challenges and Opportunities	186
8.10.1 Robustness of precast panels under traffic	186
8.10.2 Production of the SCC Mix and management of its properties.....	188
8.10.3 Agency and industry acceptance	189
CHAPTER 9.....	190
CONCLUSIONS, RECOMMENDATIONS AND IMPLEMENTATION PLAN	190
9.1 PROJECT SUMMERY	190
9.2 CONCLUSIONS.....	192
9.2.1 Temporary Reusable Precast Panels	192
9.2.2 Self-Consolidating Concrete (SCC) Mix	192
9.3 RECOMMENDATIONS	194
9.3.1 General	194
9.3.2 Temporary Reusable Precast Panels	195
9.3.3 Self-Consolidating Concrete (SCC) Mix	197
9.4 IMPLEMENTATION PLAN.....	198
REFERENCES.....	200

LIST OF FIGURES

Figure 2.1: Precast lab design for test pavement (Larson and Hang, 1972).....	31
Figure 2.2: Installing precast slab with Polyethylene filler (Simonsen, 1975).	33
Figure 2.3: Lift hook-up arrangement.	33
Figure 2.4: Details of joints used with experimental repairs (Simonsen, 1975).	34
Figure 2.5: Intermittent repair technique using precast jointed pavement with slots for dowel bars cut in existing concrete pavement.	36
Figure 2.6: Intermittent repair technique in precast jointed pavement with dowel bars positioned in existing concrete pavement.	37
Figure 2.7: Precast panel details.....	38
Figure 2.8: Assembled panels at project site.....	38
Figure 2.9: Posttensioning panels.....	38
Figure 2.10: Precast pavement construction.....	39
Figure 2.11: Applications of PCP for (top) localized, (center) short-length, and (bottom) continuous repair (Tayabji, et al. 2011)	41
Figure 2.12: Installation of precast slabs on US 92.....	42
Figure 2.13: Joint and posttensioning ducts between adjacent panels	43
Figure 2.14: Project under traffic. Note joint grout and ground pavement surface	43
Figure 2.15: Precast panels on SR 228, near Jacksonville	44
Figure 2.16: SCC placement and finishing of precast slabs.....	47
Figure 2.17: Removal of deteriorated concrete and formation of a replacement slab pit	48
Figure 2.18: Placement of temporary precast panels	48

Figure 2.19: Casting of replacement slab using SCC mix after removal of temporary precast panels 49

Figure 4.1: Model precast panels (6’ x 6’ x 8”) used in field testing..... 59

Figure 4.2: Finite element model of a precast panel 59

Figure 4.3: Field Test on the Precast Panels 60

Figure 4.4: Vertical Displacement of Precast Panels 61

Figure 4.5: Horizontal Displacement of Precast Panels 61

Figure 4.6: Maximum Vertical Displacement from FEA..... 62

Figure 4.7: Maximum Horizontal Displacement from FEA 63

Figure 4.8: One-inch diameter backer rod inserted in the recess along the edge of model panel. 64

Figure 5.1: Batching of a trial mix at Civil Engineering Concrete Lab 71

Figure 5.2: Compressive strength of trial mixes 76

Figure 5.3: Compressive strength of vibrated and non-vibrated cylinder samples 78

Figure 6.1: Pavement test track 83

Figure 6.2: Preparing forms for the replacement-slab test-pit 83

Figure 6.3: Paving concrete around the replacement slabs test pit 84

Figure 6.4: Test pit with fine recycled concrete aggregate as leveling course..... 85

Figure 6.6: Precast slab design 88

Figure 6.7: Construction of the precast panels 88

Figure 6.8: Locations of covered lift anchors..... 89

Figure 6.9: Casting of precast panel..... 89

Figure 6.10: Striped panel bottom and backer glued baker rod along the panel sides..... 90

Figure 6.11: Lubricated backer rod 91

Figure 6.12: Rigging and maneuvering the precast panel 92

Figure 6.13: Alternative Rigging Methods..... 93

Figure 6.14: Use of a four-sling-lift method and a boom crane at FSU test site..... 93

Figure 6.15: Placement of the two precast panels 94

Figure 6.16: Instrumentation of the precast panels 95

Figure 6.17: Front and rear view of the truck used in load testing of precast panels..... 97

Figure 6.18: Damage to one of the precast panels during removal..... 98

Figure 6.19: Temperature measurement of SCC mix 101

Table 6.2: Slump Flow and T20 Test results..... 102

Figure 6.20: Slump flow test 103

Figure 6.21: Trial batches at Argos concrete plant in Jacksonville 104

Table 6.3: Test results at Argos plant trial batches 106

Figure 6.22: Addition of the accelerator at the track 108

Figure 6.23: Discharging SCC mix in the pit to cast the replacement slab..... 108

Figure 6.24: Surface finish of replacement slab 109

Figure 6.25: Slab curing with plastic sheet 110

Figure 6.26: Load testing of the replacement slab using a 25,000 lb truck..... 111

Figure 6.27: Core samples from the replacement slab – no sign of any segregation..... 112

Figure 7.1: Schematic plan of instrumentation of the precast panels..... 116

Figure 7.2: Vertical and horizontal LVDTs on the precast panels 116

Figure 7.3: Concrete pump truck loading precast panels 117

Figure 7.4: Configuration of LVDTs and wheel loads..... 117

Figure 7.5: Vertical displacements of the two precast panels 119

Figure 7.6: Horizontal displacement of precast panel 2..... 119

Figure 7.7: Profile of vertical displacement of precast panel 1 120

Figure 7.8: Vertical displacements in panels due to sudden braking 121

Figure 7.9: Horizontal displacements in panels due to sudden braking 122

Figure 7.10: Imprints of ridged stripes on the surface of recycled aggregate leveling layer 122

Figure 7.11: FEM of precast panels at Green Cove Springs test track 124

Figure 7.12: Load configuration of the FE models 124

Figure 7.13: Vertical displacement of panel 2 126

Figure 7.14: Horizontal displacement of panel 2 126

Figure 7.15: Vertical displacements from field and FEA results at CH2 B1 128

Figure 7.16: Vertical displacements from field and FEA results at CH4 B1 129

Figure 7.17: Vertical displacements from field and FEA results at CH3 B1 129

Figure 7.18: Vertical displacements from field and FEA results at CH2 B2 130

Figure 7.19: Vertical displacements from field and FEA results at CH1 B2 130

Figure 7.20: Horizontal displacements due to sudden braking in the moving load 131

Figure 7.21: Strength-Maturity relationship concept 133

Figure 7.22: Strength vs. Maturity function/s 134

Figure 7.23: Age conversion factor and equivalent age concept 136

Figure 7.24: Curing bag with temperature monitoring devices 141

Figure 7.26: Temperature measuring devices 143

Figure 7.27: FLIR-ONE and Smartpone 144

Figure 7.28: Strength-Maturity relationship from all thermal devices 144

Figure 7.29: Strength-Maturity relationships from various measuring devices 145

Figure 7.30: Initial temperature at the bottom of test pit before pouring the SCC mix 149

Figure 7.31: Temperature gradient of the SCC slab 4 hr. after casting, 149

(a) Surface temperature at interior of slab, 149

(b) Surface temperature at edge of slab..... 149

Figure 7.32: Using plastic sheeting to cover SCC slab 150

Figure 7.33: Exposing the slab to existing weather conditions..... 150

Figure 7. 34: Detecting temperature increase after adding the accelerator 151

Figure 7.35: Temperature of the SCC mix in the test pit (FAMU –FSU Site) 152

Figure 7.36: Strength-Maturity relationship of SCC mix using Anderson materials..... 152

Figure 8.1: Design of (5’-9” x 11’-9” x 9”) Panel A..... 157

Figure 8.2: Design of (3’-9” x 11’-9” x 9”) Panel B 158

Figure 8.3: Placement of Panel A in 6’ x 12’ replacement pit 158

Figure 8.4: Placement of Panels A&B in 10’ x 12’ pit 159

Figure 8.5: Backer rod details 159

Figure 8.6: Components of lift anchor assembly 160

Figure 8.7: Reinforcement and form design..... 161

Figure 8.8: Details of Lift Anchor installation and clutch connection 161

Figure 8.9: Demonstration panels showing backer rod and bottom recessed stripes..... 162

Figure 8.10: Fine recycled material for base leveling course..... 171

Figure 8.11: Drilling new holes for dowel bars with a Gang drill 172

Figure 8.12: Possible methods for moving, installing and lifting precast panels..... 172

Figure 8.13: Installation of the first precast panel using a backhoe 173

Figure 8.14: Installation of second panel 173

Figure 8.15: Two precast panels temporarily filling a 12’ x 12’ x 8” slab replacement pit..... 174

Figure 8.16: Allowing vehicles on the temporary precast panels 174

Figure 8.17: Removing temporary precast panels from the replacement pit 175

Figure 8.18: Application of epoxy starting from the back of the hole 175

Figure 8.19: Insert new dowel bars fitted with a retention disk to prevent epoxy leak 176

Figure 8.20: Replacement slab pit ready for concrete placement 177

Figure 8.21: Slump Flow test 178

Figure 8.22: Add accelerator to the SCC mix at the jobsite..... 178

Figure 8.23: Replacement slab casting with SCC mix..... 179

Figure 8.24: Final surface finish with Roller screed 179

Figure 8.25: Allowing traffic on replacement slab after reaching required strength 180

Figure 8.26: Damage to panel corner and stripping of backer rod gasket..... 188

LIST OF TABLES

Table 3.1: Survey Results.....	51
Table 5.1: Basic SCC mix design.....	67
Table 5.2: Coarse aggregate properties	68
Table 5.3: Fine aggregate properties	68
Table 5.4: Admixture type and description	69
Table 5.5: Ambient temperatures and fresh concrete test results.....	71
Table 5.6: SCC fresh properties test methods	73
Table 5.7: General acceptance criteria for SCC workability.....	74
Table 5.8: Compressive strength test results (psi).....	77
Table 5.9: Compressive strengths and weights of vibrated vs. non-vibrated samples of TM1.....	78
Table 6.1: SCC final mix design	98
Table 6.2: Slab Replacement Field Tests	102
Table 6.3: Test results at Argos plant trial batches	114
Table 7.1: Slab Replacement Field Tests	123
Table 7.2: Material properties in FE Model.....	125
Table 7.3: Friction coefficients at various rolling conditions ($\mu = 10\text{km/hr}$)	125
Table 8.1: Proposed SCC Mix Design.....	164
Table 8.2: Slump Flow and T20 Test results.....	165
Table 8.3: Compressive strength during the first 24 hr.....	166
Table 8.4: Cost and time savings in rehabilitation Project A (Example 1).....	185
Table 8.5: Cost and time savings in rehabilitation Project B (Example 2)	185

CHAPTER 1

1.1 Background

Many concrete pavements in Florida have reached or exceeded their design lives and are being rehabilitated to extend their intended life. Pavement rehabilitation involves replacing deteriorated segments of or the full slabs, grinding the pavement surface to restore smoothness, and resealing pavement joints. Slab replacement is the major component of any concrete pavement rehabilitation project. Conventional slab replacement involves several steps that include, removal of the distressed segment or the full slab and repair to any damage to the base, drilling holes in the adjacent slabs and installing new dowels using epoxy, and then casting the replacement segment or full slab in the open pit with fresh high-early strength concrete. After a few hours of curing and when the concrete reaches the required strength, the closed pavement lane is opened to traffic. The current Florida DOT specification 353 requires a concrete strength of 2,200 psi as a condition to open a lane to traffic.

1.2 Challenges of Traditional Slab Replacement Method

The slab replacement process is time consuming and the window for lane closure to perform the work is rather short. The lane closure period on major highways or busy urban roadways may not exceed 8 hr., and it is normally scheduled during nighttime when traffic is light. During this period, barricades are set up to allow the construction to begin, and then they are removed prior to opening the lane to traffic. This consumes at least 1.5 hr. of the allotted 8 hr. of lane closure time leaving 6.5 hr. for construction. During the remaining 6.5 hr., the contractor can proceed as follows:

- Sawcut the distressed areas or entire slabs
- Remove and hauls away the concrete pieces

- Repair any damage to the base
- Drill holes in the adjacent concrete
- Inject epoxy into the holes
- Anchor new dowels in the holes
- Cast the replacement segment or slab in the open pit using high-early strength concrete mix.

Ideally, the last slab is supposed to be cast approximately 4 hr. prior to the scheduled lane opening time. This is to allow sufficient curing time for the concrete to reach the required lane-opening strength.

With such time consuming process, only five to ten slabs or slab segments can be replaced during a lane closure period. When the project requires replacement of hundreds if not more segments or slabs, the need for Maintenance of Traffic (MOT) will be extensive leading to a long project completion time. Obviously this will affect project cost from high bid prices.

In an effort to increase productivity in the traditional slab replacement method, the concrete mix is often designed to achieve the lane opening strength requirement of 2,200 psi in the shortest possible time to extend the construction and enable placing more slabs during the lane closure period. This requires the concrete mix to have excessive quantity of cement that may exceed 1000 lb/cu. yd. as well as a high dosage of the accelerator to reach the required strength. These mixes may reach the desired strength at lane opening time but are highly susceptible to premature cracking during or shortly after construction. The cracking is mainly caused by high shrinkage and thermal stresses induced by the excessive cement and accelerator contents in the mix. Premature cracking is a major problem that the contractors and the FDOT often deal with, and is the main source of dispute between the two sides over the causes and repair responsibilities.

1.3 Accelerated Slab Replacement Method

The FDOT initiated this project with the objective to develop a method using temporary and reusable precast panels and self-consolidating concrete (SCC) to accelerate the slab replacement process. The ultimate goals of the method is to increase contractors' productivity, reduce maintenance of traffic (MOT) and construction completion time, reduce project cost and minimize premature cracking.

The accelerated slab replacement method involves installing one or two precast panels in the replacement portion or full slab pit, after removing the deteriorated section of the original slab and preparing dowel bar holes in the adjacent concrete. The panels are kept in the pit as placeholders for a period of one to seven days, depending on construction and MOT scheduling, and then removed. The open pit is then retrofitted with new dowel bars and cast using SCC mix to form a permanent replacement slab.

The two-component replacement method is well suited for replacement of isolated individual segments or full slabs. Precast panels and SCC mix are both used in replacements of portions of 20' x 12' slabs including 6', 8', 10' or 12' segments, or portions of a 15' x 12' slabs including 6', 8' and 10' segments, while the SCC mix can be used in longer segments or the full slabs.

1.4 Contents of the Report

The report is organized to present in sequence the following contents:

- Background study and literature review on the use of the precast technology and SCC mixes in concrete pavement rehabilitation
- Analyses and design of the precast panels; development of the SCC mix

- Field validation of the robustness of the panels and viability of the SCC mix
- Analysis of the panel performance under traffic; material characteristics and performance of SCC replacement slabs
- Construction guidelines and specification requirements to facilitate implementation of the method
- Conclusions, recommendations and an implementation plan

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The use of precast concrete technology and SCC mixes in pavement construction and rehabilitation is relatively new when compared with their use in structural applications. In recent years, the need to implement alternative methods to accelerate the process of concrete pavement construction and repair has focused attention on the precast concrete technology and SCC mixes to provide a rapid solution to concrete paving construction, and replacement of deteriorated slabs or slab segments. In addition to the accelerated process of repair, the main benefits of utilizing PCC slabs, as permanent replacement, include long life expectancy of the slabs because they are cast and cured under well controlled factory conditions with low water-to-cementitious materials ratio and a high level of uniformity, which minimizes the potential for premature cracking due to traffic loads. The SCC mix has high workability that allows rapid discharge and casting to replacement slabs, when designed to meet the high-early strength requirements for lane opening to traffic. The development of a method that includes both components to accelerate the slab replacement process will benefit the contractors and agency with respect to higher productivity, shorter project completion time and potential cost savings.

2.2 Precast Concrete Pavements (PCP)

Precast concrete pavements (PCP) have been used in rehabilitation projects as permanent replacements or overlays for long continuous sections of concrete pavements, or in isolated individual or group slabs. The PCP technology includes precast post-tensioned slabs for continuous

sections (Merritt et al. 2003), or precast reinforced panels for applications in isolated individual or consecutive slabs (Buch et al. 2003) and (Fort Miller, www.fortmiller.com).

The first PCP slabs were used in airfields in the Soviet Union in 1931-1932. They were precast slabs, unreinforced concrete hexagons 4.1 ft long sides and 3.9 to 5.5 in. thickness (Rollings 1980). Heavier aircraft introduced after World War II required larger hexagons 4.9 ft. long and 5.5 to 8.7 in. thick. These panels developed spalls and were not stable under aviation traffic. Limited use of post-tensioning in highway construction occurred in pavement sections in Missouri, Michigan and Maryland between 1937 and 1941. Examples of prestress in concrete pavements include a 7 in. thick concrete test slab at Patuxent River, Maryland, 1953 (Ray 1953) and a 4 in. overlay slab at San Antonio Airport, Texas, 1955 and Lemoore, California in 1959 (Rey 1959).

In Europe, prestressed concrete highway applications began with two short pavements in France 1946 and 1949. This was followed by British projects totaling 6,000 ft. that were constructed during the period 1950 to 1952 (Stott 1955). These projects included post-tensioned diagonal, longitudinal, and longitudinal and transverse prestressing.

In 1968, the South Dakota Department of Highways and the Federal Highway Administration built a 24 ft-wide, 900 ft-long test section of precast, prestressed concrete slabs on U. S. Highway 14 near Brookings, South Dakota (Larson and Hang 1972). The pavement design was based on South Dakota State University research sponsored by the South Dakota State Department of Highways and the Federal Highway Administration (Gorsuch 1962, Kruse 1966, Jacoby 1967, and Hargett 1970). The final slab design used in construction is shown in Figure 2.1a. These slabs were 6 ft. wide, 24 ft. long and 4-1/2 in. thick. The slabs were prestressed at 400 psi using 3/8 in. diameter longitudinal cables. The concrete slabs were overlaid with asphaltic concrete,

the depth of which varied from 3-1/2 in. at the road center to 1-1/2 in. at the edge to provide the required surface slope and smoothness.

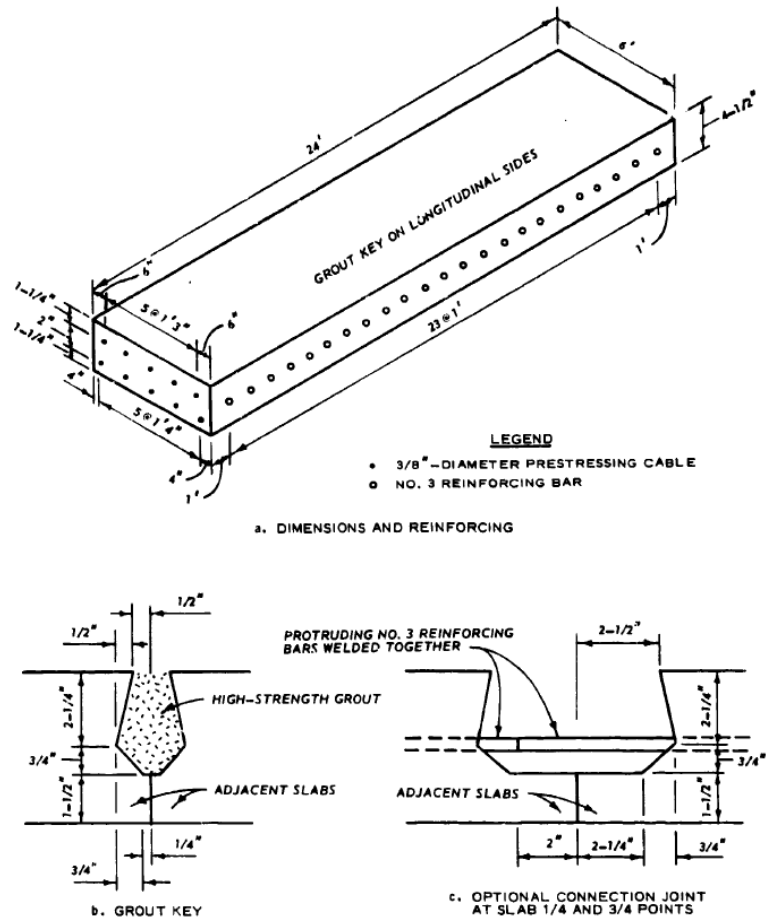


Figure 2.1: Precast lab design for test pavement (Larson and Hang, 1972)

The slabs were lifted by crane, placed on a 1/2-in.-thick sand-bedding layer, and seated by a vibratory roller. Half of the slabs were placed with the long side of the slab parallel to the direction of traffic using the optional connection joints. The remaining slabs were placed with the long side perpendicular to the direction of traffic without connection joints. The South Dakota project was used as a basis or example for recommending precast construction for strengthening airport pavements (Hargett 1969) and urban pavement construction (Zuk 1972).

In 1969, the Michigan Department of State Highways and Transportation (MDSHT) began an experimental program to develop procedures for repairs of concrete pavement joints that could be done rapidly and would be long lasting (Transportation Research Board 1974). The initial development work involved experimental installations of precast slabs for slab repairs. Based on successful results, they expanded the program to include further development of the precast slab repair method and, also, to investigate the use of fast-setting cast-in-place repairs.

In 1975, the MDSHT published a procedure for full depth precast slab replacement (Simonsen 1975). According to the procedure, a sawed concrete area, up to 12 ft long, and one lane wide, would be replaced with a precast slab and opened to traffic in approximately 1-1/2 hr. A similar sized area was also repaired with fast-set concrete and opened to traffic in 6 to 8 hr. Since the precast slabs would be poured away from, and later transported to the repair site this type of repair was approximately 25 percent more expensive than cast-in-place repairs.

It should be noted that MDSHT procedure for precast slab replacement was for both doweled and undoweled repairs. The design selected for constructing a doweled joint between a precast slab and an existing pavement slab consisted of welding the dowels to a 3/8-in. steel plate cast into the transverse sides of the precast slab (Figures 2.2 to 2.4). The addition of the dowel bars increased the construction time by about 1-1/4 hour for precast slab repair as oppose to 35 min. for the cast in place slabs. The method of welding the dowel bars (Figure 2.4) was the main cause of this delay.

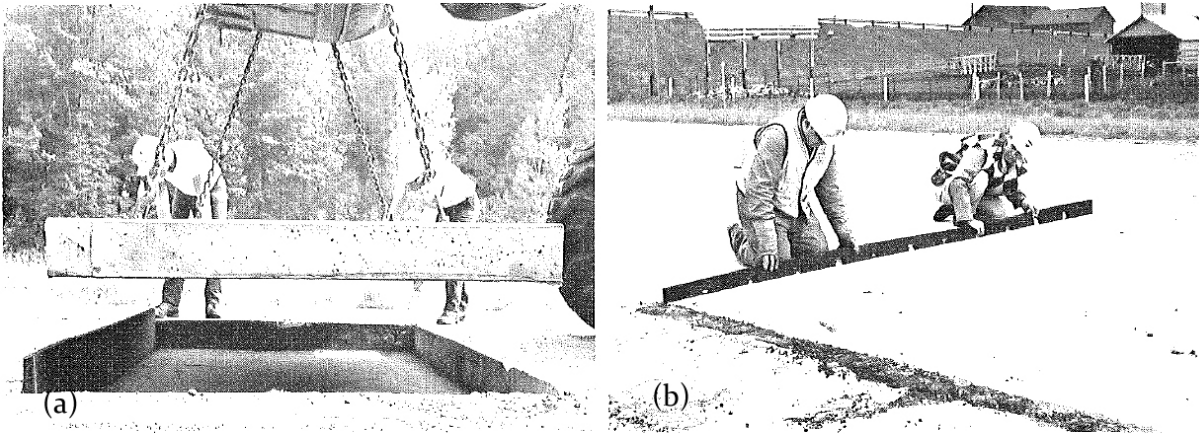


Figure 2.2: Installing precast slab with Polyethylene filler (Simonsen, 1975).

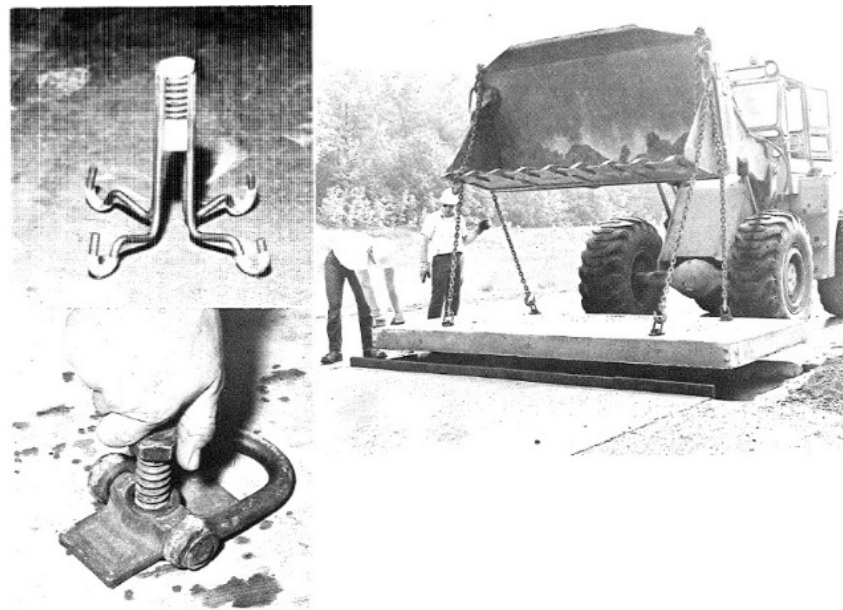


Figure 2.3: Lift hook-up arrangement.

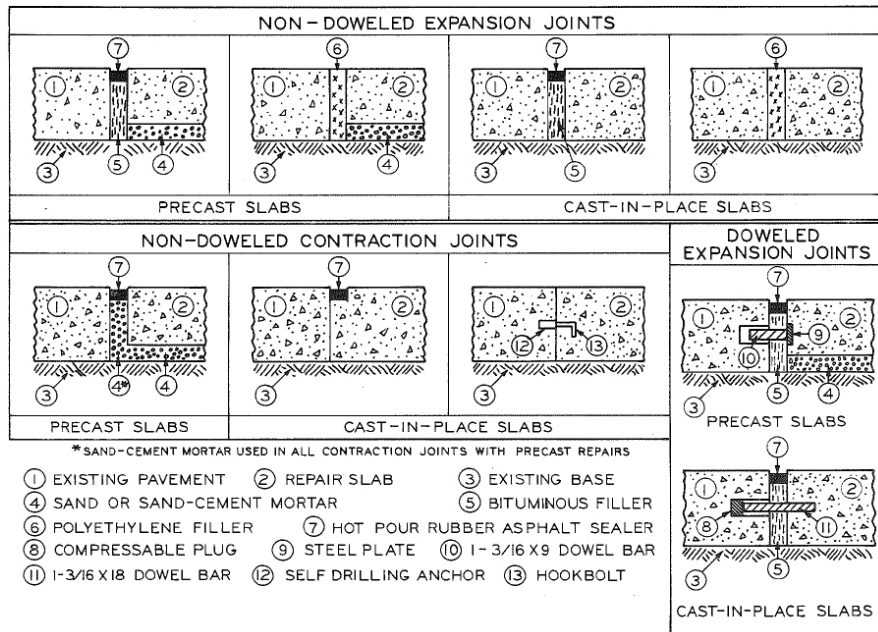


Figure 2.4: Details of joints used with experimental repairs (Simonsen, 1975)

Evaluation of the performance of the repairs indicated that some faulting develops at the joints, but deflection at the joints under load and some slab rocking, did not appear to have any serious effect on the performance of the repairs. With respect to deflection under load, the doweled slabs performed as good as the undoweled ones. The precast slabs were suggested for use as interim repairs on roadways scheduled for overlays, rehabilitation, or reconstruction within five to ten years (Simonsen 1976).

The development of PCP technology continued in the late 1970s and later in 1980s, with more emphasis on the methods of concrete pavement repairs using the technology and on the analysis and design methods. (Elkins et al.1979) presented methods for precast repair of continuously reinforced concrete pavement. Rollings (1981) presented comprehensive guidelines to design and construct PCP slabs for pavement repair.

In 1984, Cable et al. prepared a report that listed significant advantages of using prestressed concrete pavement that require less maintenance and provide longer pavement life. These advantages included efficient use of construction materials, fewer joints, and less probability of cracking.

In their report, (Cable et al. 1984), presented a detailed review of the three primary methods used to prestress pavement, including, pretensioning, posttensioning, and poststressing. The report included the main construction procedures employed with each method and the encountered with the use of each method. In their conclusion, they stated that not all of the problems associated with PCP had been yet solved and it was still much too early to commit to any of the design and construction approaches presented thus far.

In 2006 the American Association of State Highway and Transportation Officials (AASHTO) established a Technology Implementation Group (TIG) to support technology transfer activities related to precast concrete pavements. The mission of this AASHTO TIG was to promote the use of precast concrete panels for paving, pavement rehabilitation, and pavement repairs by transportation agencies and owners nationwide, and to present an unbiased representation to the transportation community on the technical and economic aspects of the current precast paving systems utilized in the marketplace. In June 2008, the AASHTO TIG completed work on the following documents (Tayabji et al. 2008):

1. Generic Specification for Precast Concrete Pavement System.
2. Guidance and Considerations for the Design of Precast Concrete Pavement Systems.
3. Generic Specification for Fabricating and Constructing Precast Concrete Pavement Systems.

In conjunction with highway agencies' efforts, several organizations in the United States also initiated independent development activities to refine precast concrete pavement technologies. These technologies have certain proprietary features and require licensing for product use of the technologies. One of the technologies is the Fort Miller Super-Slab® system (Fort Miller, www.fortmiller.com). The Super-slab system has been used on several short projects, mostly in toll collections areas for repair of isolated slabs or reconstruction of long continues sections. Isolated full slab replacement using precast concrete slab panels are shown in Figures 2.5 and 2.6. Alternative positioning of the retrofitted dowels can be used with the Miller system.

Intermittent repairs, such as full-depth repairs and slab panel replacement, are typically performed at night with a work window from about 8:00 p.m. until about 5:00 a.m. the next morning. Typically, 10 to 15 panel placements are targeted during each work window. The tight work windows and the need to open the facility to traffic by about 6:00 a.m. make it necessary that the contractor have sufficient equipment and labor to complete the planned work each night.

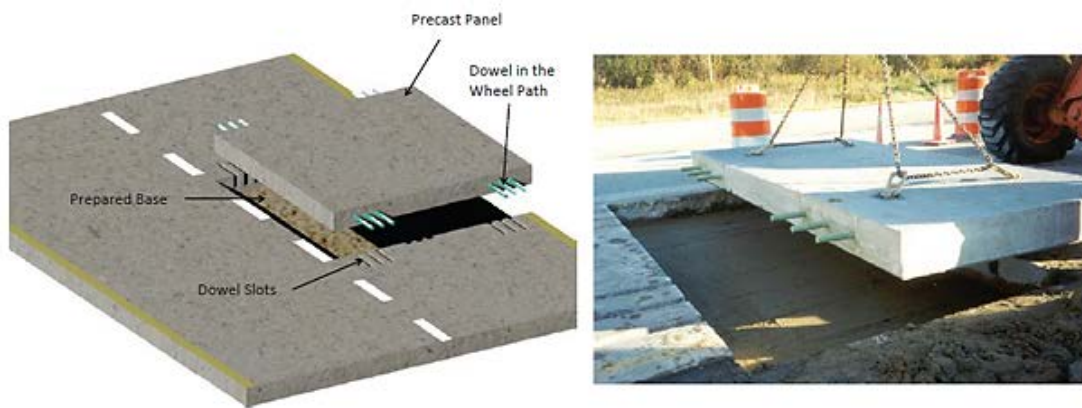


Figure 2.5: Intermittent repair technique using precast jointed pavement with slots for dowel bars cut in existing concrete pavement.

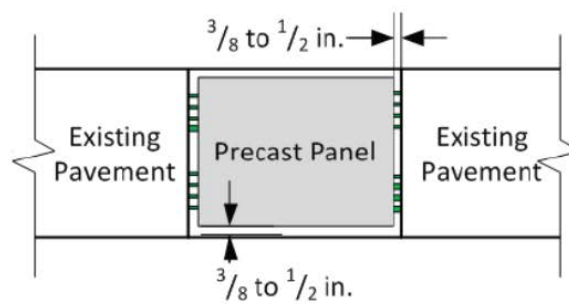
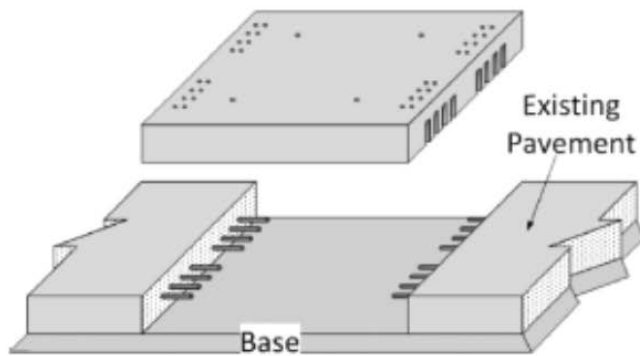


Figure 2.6: Intermittent repair technique in precast jointed pavement with dowel bars positioned in existing concrete pavement.

The continuous precast concrete paving, involves a full-scale project level rehabilitation (overlay) or reconstruction of asphalt and concrete pavements. It is constructed using prestressed precast concrete panels that are posttensions after installation. The first demonstration project was constructed by Texas DOT on a section of frontage road along I-35 near Georgetown, Texas (Merritt, et al. 2003). The construction of continuous precast pavements is shown in Figures 2.7 to 2.10 (Courtesy of D. Merritt, Transtec, and Sam Tyson, FHWA).

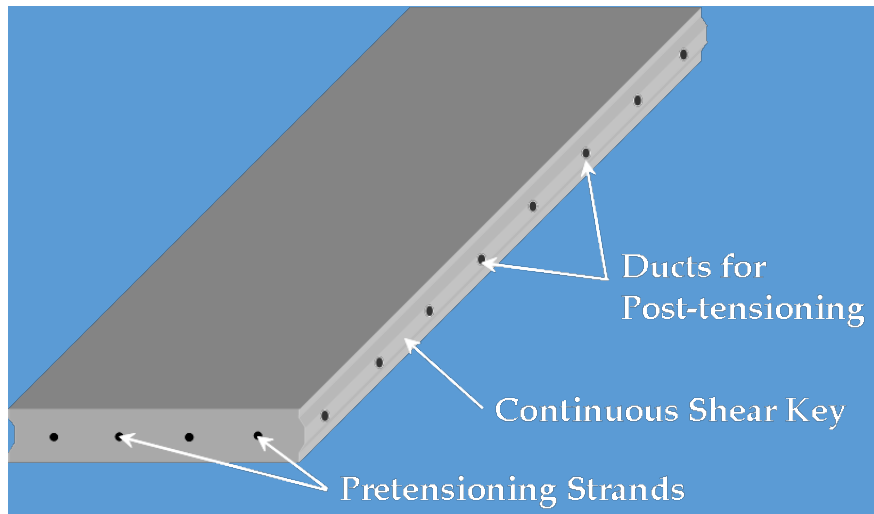


Figure 2.7: Precast panel details

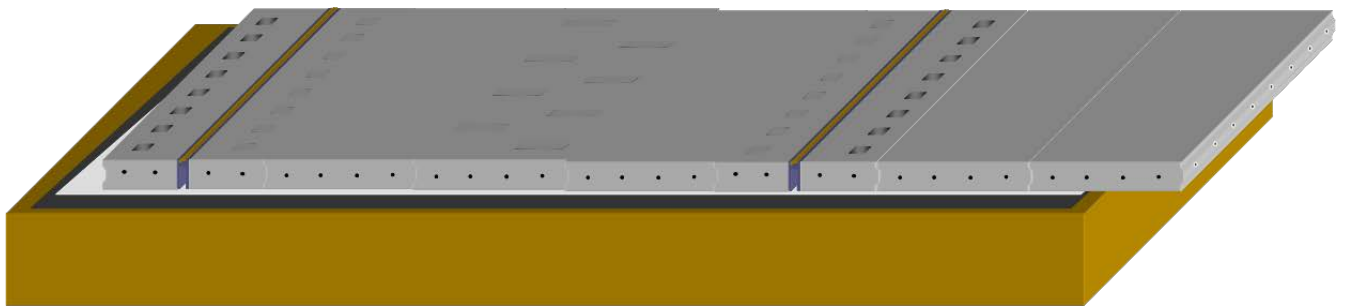


Figure 2.8: Assembled panels at project site

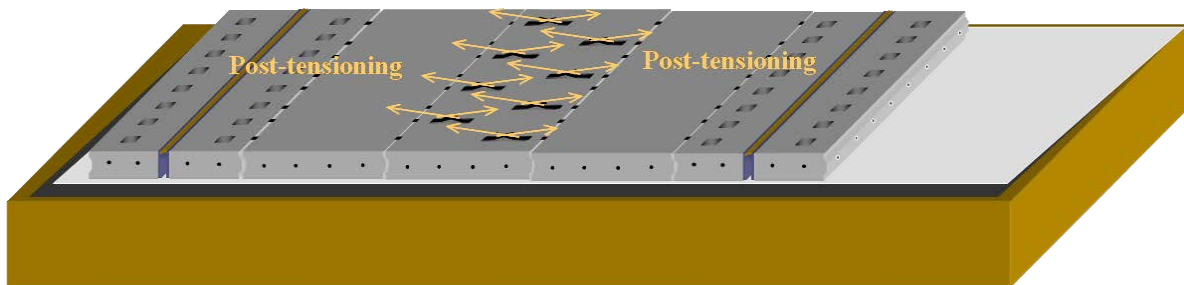


Figure 2.9: Posttensioning panels



Figure 2.10: Precast pavement construction

The Strategic Highway Research Program (SHRP 2), as part of its rapid highway renewal focus area, sponsored a study in early 2008 to develop tools that public agencies can use for the design, construction, installation, maintenance, and evaluation of modular pavement systems. The primary focus of this study was precast concrete pavements. Phase I of the study included a review of modular pavement systems, review of highway agency and industry experience, and identification of successful strategies, promising technologies, and future needs related to modular pavement systems (Tayabji et al. 2008). The team contacted several highway agencies to provide support and the performance data collection effort, as part of Phase II effort under Project R05 (Tayabji et al. 2011).

The report by Tayabji, et al, in 2011 indicated that since 2000 several state highway agencies and authorities have implemented, investigated or demonstrated PCP. Agencies and authorities that have accepted PCP in production included Caltrans, Illinois Tollway Authority, Iowa DOT,

Ministries of Transport, Ontario and Quebec New Jersey DOT, New York State DOT, New York State Thruway Authority. Those agencies that investigated the technology included Colorado, Delaware, Indiana, Michigan, Minnesota, Texas and Virginia DOTs, Port Authority of New York and New Jersey, and Metropolitan Washington Airport Authority.

In addition to the North American initiatives, the Netherlands, France, Russia, and Japan have also investigated the use of the precast concrete pavement technologies. Also, approximately a 20 mile section of a tollway in Indonesia had been constructed using the precast pavement system.

The report showed that PCP study results work was performed during the night, typically from 8 p.m. to 6 a.m., and with short lane closures. The production rate per lane closure was about 15 to 20 repair locations, and about 400 to 600 ft long sections for continuous rehabilitation. The key issues of concern for PCPs were constructability, concrete durability, and pavement performance as primarily affected by joint load transfer and panel support condition. The report also emphasized that PCPs are not “super pavements” and should not be expected to perform at a significantly superior level to cast-in-place (CIP) concrete pavements unless the prestressing technique is used. Once installed, PCP systems can be expected to perform, under traffic and environmental loadings, similarly to comparable CIP concrete pavement systems. The primary difference in the two technologies is how each system is constructed.

PCP technology can be used for projects of different sizes, as the three illustrations in Figure 2.9 show:

1. Localized repair of distressed areas of existing jointed concrete pavements (JCPs) and continuously reinforced concrete pavements (CRCPs). These localized areas may include

deteriorated joints, cracks, shattered slabs in JCP (Figure 2.11, top), and punch-outs and deteriorated cracking in CRCP.

2. Rehabilitation of short lengths of distressed concrete pavements (Figure 2.9, center). Such rehabilitation may include pavement lengths of 200 ft. to more than 1,000 ft., typically within single lanes.
3. Rehabilitation of longer lengths of existing distressed concrete or asphalt pavements. Such rehabilitation may extend several miles in length and may include one or more lanes (Figure 2.9, bottom).

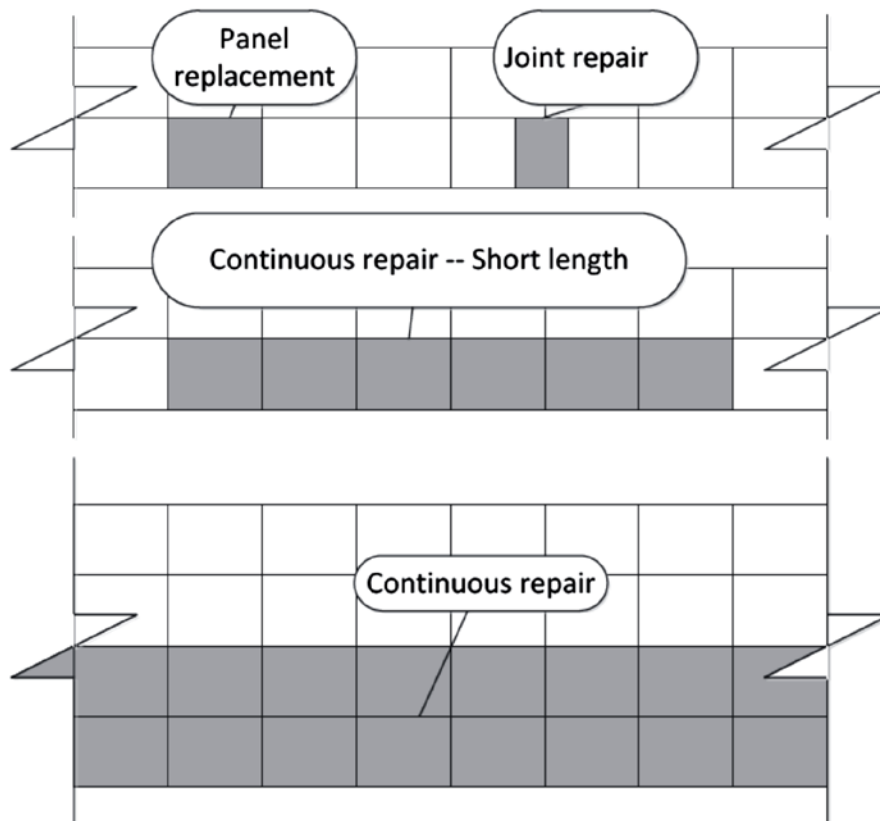


Figure 2.11: Applications of PCP for (top) localized, (center) short-length, and (bottom) continuous repair (Tayabji, et al. 2011).

While many states have either experimented with or implemented the PCP, however, challenges remain in the wider adoption of this viable technology. Among the main challenges,

are high cost, need for better automation and equipment to speed up the installation and increase productivity, and creating more competition among contractors to increase the experience in the technology and reduce cost. Another major challenge is developing an effective repair technique of posttensioned precast panels that are damaged under traffic or because of falling objects or other traffic accidents, since many panels are tied together and stressed through posttensioning.

2.3 Demonstration of PCP Project in Florida

The Florida DOT constructed a demonstration project on US 92 near Deland in 2010. This was part of a larger rehabilitation project which involved a concrete overlay, slab replacements, grinding and joint resealing. The main construction steps of US 92 are shown in Figures 2.12 to 2.14. The panels were fabricated in a precast plant and were reinforced and pretensioned. At the jobsite, they were placed on top of a prepared asphalt-leveling course. After assembly, the panels were posttensioned. The joints and the posttension ducts were later grouted. The pavement was then ground to provide a smooth riding surface. The pavement has performed well and is being monitored regularly by the FDOT.



Figure 2.12: Installation of precast slabs on US 92



Figure 2.13: Joint and posttensioning ducts between adjacent panels



Figure 2.14: Project under traffic. Note joint grout and ground pavement surface

2.4 Temporary Precast Concrete Applications

In addition to their use as permanent installations in precast pavements or in isolation of intermittent slabs, the precast panels may also be re-used temporarily in the installation of the slab replacement process. The panels would be used as placeholders in the pits after removing of the deteriorated segments of the slab. Then the panels are removed prior to casting the concrete mix for the new replaced slab. This option is more suited for replacement of segments of a slab or intermittent individual full slabs, which are the most predominant cases of deteriorated slabs in majority of rehabilitation projects in Florida.

Temporary unreinforced precast panels were demonstrated in a limited application in a rehabilitation project on SR 228 near Jacksonville, Florida as shown in Figure 2.15. Based on communications with the contractor (*Callaway Contracting, Jacksonville, Florida*), the use of precast panels as temporary fillers in replacement pits resulted in 20% cost savings that resulted from casting more slabs compared to the conventional slab replacement method. However, cracks and spalls did develop from multiple use of the precast units. These was mainly attributed to the simple panel design that did not include reinforcement nor special design of the panel sides.



Figure 2.15: Precast panels on SR 228, near Jacksonville. (*Photo courtesy of Callaway Contracting*)

In addition to the Florida project, personal communications with rehabilitation contractors also showed the limited use of temporary panels in projects outside Florida. The main reason given for their use was to the increase productivity rate of slab replacement.

2.5 Self-Consolidating Concrete (SCC) For Pavements

Self-consolidating concrete (SCC) mixes are concrete mixes with very high workability and flow rate (Yang 2004). They are used primarily in cast-in-place or precast structural members with highly congested reinforcement. Conventional SCC mixes are usually designed using small size aggregates (grade 89 or smaller), and incorporate high range water reducers, set retarders and workability retainers to achieve a very high workability for an extended period. This will facilitate concrete flow through narrow spaces in the dense reinforcing bars to fill the formwork without compaction, segregation or honeycombing. The SCC mix has a normal setting time and develops strength gradually. In fact, there might be a delay in the mix setting time due to the high dosage rates of high range water reducing admixtures, retarders and viscosity modifiers.

In recent years, SCC mixes are becoming more widely used in construction due to their favorable attributes, such as productivity improvements, reduced labor costs, improved work environment and safety, and improved final product quality. The cast-in-place applications of SCC are usually limited to applications such bridges, buildings, drilled shafts and tunnel linings. However, there have not been any applications of SCC in highway pavement construction, and there have been limited research studies in this area.

One such research study had been conducted at Iowa State University, National Concrete Pavement Technology Center. The aim was to study the feasibility and application of SCC for slip-form paving (Wang et al. 2005 and 2011). In the feasibility phase (Wang et al. 2005), the

researchers developed an SCC mix that would be adapted to slip-form paving. The mix possessed higher workability while maintaining good shape stability of the extruded concrete. In the application phase (Wang et al. 2011) of a bike path and a pavement, the study demonstrated the importance of using a well-proportioned SCC mix and emphasized need for more attention to construction practices to ensure durable pavements and less tendency for shrinkage cracks.

However, the main characteristics of SCC mixes, such as slow setting time and late strength gain, present a challenge to their use in replacement slabs that require high-early strength. Nevertheless, this challenge can be overcome with thoughtful engineering of the SCC mix to achieve a high slump mix that discharges swiftly and, once in place, starts to develop high-early strength similar to conventional high-early strength mixes, reaching the required strength at lane opening time.

Research by Khayat (Khayat and Mitchel 2009) developed guidelines for the use of SCC in precast, prestressed concrete bridge elements. These guidelines address the selection of constituent materials, proportioning of concrete mixtures, testing methods, fresh and hardened concrete properties, production and quality control issues, and other aspects of SCC. Many of these recommendations can be adopted for cast-in-place applications of SCC.

Traditional, Self-Consolidating Concrete (SCC) has not been used in conventional concrete pavement construction. The main reason for such restriction is the high flowability of SCC that may not be perceived as being compatible with casting of pavements on a 2% or higher slopes or on super elevation turns. In contrast, conventional low slump mixes have always been suitable for conventional concrete paving. However, based on a study by Ouchi (Ouchi et al. 2003) it was determined that with the use of a proper SCC mix, a bridge deck with a 2% slope can be paved with

SCC mix. Also, Wang and Shah (Wang et al. 2005, 2010) did develop a semi-flowable SCC (SFSCC) for slip form pavements. The SFSCC possessed not only the sufficient flowability for self-consolidation but also sufficient stability to hold the shape of the concrete after paving. Through tailoring concrete materials and mix proportions, such SFSCC was designed to have the maximum self-consolidating ability with minimum flowability. The research determined that an SCC mix could be used for slip form paving without additional consolidation. Two field applications (i.e., concrete deck and pavement construction) were conducted using SFSCC in pavements with normal pavement cross slopes. The results indicated that a well-designed and well-constructed SFSCC performed satisfactorily in paving applications.

Other than the above limited applications of SCC in concrete pavement construction, high slump concrete mixes were used in manufacturing PCP panels as long as the allowable water-cementitious materials ratio was not compromised as shown in Figure 2.16. In precast plants, concrete with a slump of 6 to 8 in. (150 to 200 mm) has commonly been used to facilitate manual placement and finishing of the concrete with little, if any, vibration.



Figure 2.16: SCC placement and finishing of precast slabs

2.6 Research Scope

In this study, temporary, reusable precast panels and SCC concrete mixes will be analyzed, designed and tested in lab and field conditions, to evaluate the their use to accelerate slab replacements in concrete pavement rehabilitation projects. The scope is depicted in photos and schematically in Figures 2.17 and 2.19.



Figure 2.17: Removal of deteriorated concrete and formation of a replacement slab pit

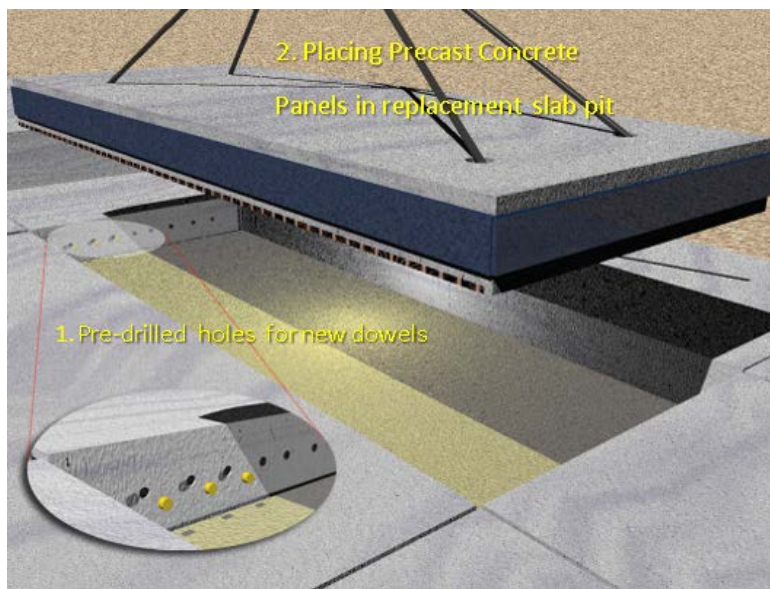


Figure 2.18: Placement of temporary precast panels

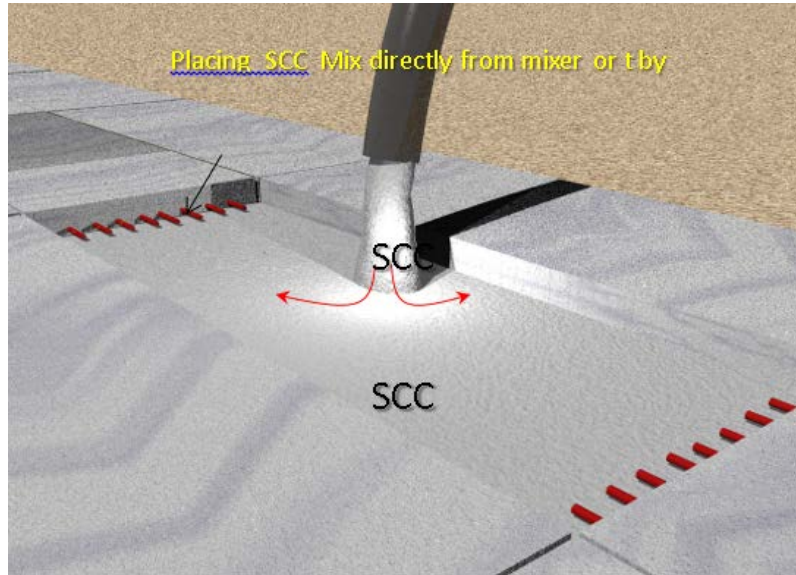


Figure 2.19: Casting of replacement slab using SCC mix after removal of temporary precast panels

Specific criteria will be followed in developing the proper precast panels and SCC mix. The precast panels must be resilient and withstand many applications without major damage. They must also be stable under moving traffic, since they are not connected to the surrounding concrete, and must be handled with ease during transportation and installation in the replacement slab pit. The SCC must be designed with grade size 57 or 67, which are suitable for paving mixes. The mix must be highly workable for quick discharge and placement of the new portion of the slab, and at the same time capable of developing high-early strength required by the FDOT for lane opening to traffic.

CHAPTER 3

INDUSTRY SURVEY

3.1 Introduction

A survey was prepared prior to the start of the experimental work. The purpose of the survey was to obtain input from FDOT and industry on conditions that prevail in rehabilitation projects as related to slab replacements. It was decided to prepare and send the survey electronically to FDOT project managers, project CEIs, contractors, and ready mix producers to get their opinions and feedback on the current state of the practice related to slab replacement. Several responses were received. In addition the team made direct contacts by phone or in personal communication with other contractors, concrete producers and FDOT project engineers to obtain their input on the challenges that they face when replacing slabs, and how best to improve productivity and reduce the premature cracking problems.



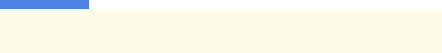
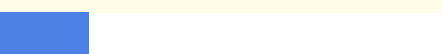


3.2 Electronic Survey Questionnaire and Response

Below are the questions and the responses to the electronic survey developed by the team:

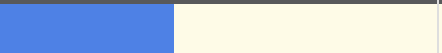
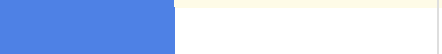
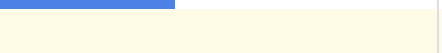
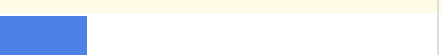
Table 3.1: Survey Results

1. Affiliation and Position				
#	Answer		Response	%
1	Project manager (DOT)		2	40%
2	Project CEI		1	20%
3	Contractor		2	40%
4	Ready mixed concrete producer		0	0%
	Total		5	100%

2. Was (is) the construction session for slab replacement done at ...

#	Answer		Response	%
1	Nighttime		3	60%
2	Daytime		1	20%
3	Weekends		0	0%
4	1 & 3		1	20%
5	2 & 3		0	0%
6	1 & 2		0	0%
	Total		5	100%



3. How many hours per construction session the traffic lanes were closed?

#	Answer		Response	%
1	8 hr.		2	40%
2	10 hr.		2	40%
3	12 hr.		0	0%
4	Other, Please specify _____		1	20%
	Total		5	100%

Other, Please specify _____

Has varied across projects typically window is 8 hr. or less

4. Please indicate the construction sequence that best applies to your project.

#	Answer		Response	%
1	Simultaneous removal of deteriorated slabs followed by placement of concrete for the replacement slab/panel.		1	20%
2	Removal of previously sawed and left in place slabs, followed by placement of concrete for the replacement slabs		4	80%
	Total		5	100%

5. The average volume of concrete used in slab replacements per construction shift was:

#	Answer		Response	%
1	Less than 50 CY		3	60%
2	50 to 70 CY		1	20%
3	70 -100 CY		0	0%
4	Other, Please specify ____		1	20%
Total			5	100%

Other, Please specify ____

50 to 70 is typical, but have seen two crews used at same time one in each direction

6. Were you satisfied with the production level per construction session?

#	Answer		Response	%
1	Yes		3	60%
2	No		2	40%
Total			5	100%

7. If your answer to (6) is no, please rank the possible contributing factors below from highest to lowest impact and include other factors, if you wish.

#	Answer		Response	%
1	Accessibility of proper equipment to construction site		0	0%
2	Setting up MOT		1	33%
3	Base restoration after removal of slab		0	0%
4	Dowel bar retrofit		0	0%
5	Proximity of nearest concrete plant		0	0%
6	Strength at opening and other requirements of specification 353		0	0%
7	Placing, compacting, finishing and curing replacement slabs		1	33%
8	Other, Please specify ____		1	33%
Total			3	100%

Other, Please specify ____

Need to tweak to allow ranking

8. What percent increase in your production rate do you wish to achieve?

#	Answer		Response	%
1	10%		2	40%
2	25%		1	20%
3	30%		1	20%
4	40%		0	0%
5	Other, Please specify____		1	20%
Total			5	100%

Other, Please specify____

Tricky question. We want to make sure we get quality first, production second.

9. On average, how long did it take to set up and dismantle MOT (Cones, warning signs and barricade)?

#	Answer		Response	%
1	1 hr		2	40%
2	2 hr		1	20%
3	3 hr		1	20%
4	4 hr		0	0%
5	Other, Please specify__		1	20%
Total			5	100%

Other, Please specify__

2 to 3 hr. total a night lost time on average

10. On average, how long was the time period between finishing the last replacement slab and lane opening time?

#	Answer		Response	%
1	3 hr		1	20%
2	4 hr		1	20%
3	5 hr		1	20%
4	Other, Please specify_____		2	40%
Total			5	100%

Other, Please specify_____

When rehab has been controlling item for schedule, contractors try to push the envelope as late as possible to pour up to 2 hr. before opening

11. Did you experience any early cracking of replacement slabs?

#	Answer		Response	%
1	Yes		3	60%
2	No		2	40%
	Total		5	100%

3.3 Survey Results

Despite the low number of responses, interesting information was obtained, which confirmed prior knowledge based on personal observations from FDOT rehabilitation projects and informal communications with project personnel. Here is a summary of the responses:

1. Most slab replacements are performed at nighttime.
2. Window for lane closure is 8-10 hr.
3. Majority of respondents stated that the contractors sawcut the concrete and left them in place for subsequent removal during another lane closure period.
4. Slab replacement production per lane closure is less than 50 cu. yds. This production rate can be increased to 70 cu. yd. when two crews are working simultaneously.
5. Setting up and dismantling traffic cones and barricades consumes 1 to 3 hr. of the lane closure period.
6. The time between the last slab cast prior to opening the lane to traffic was 3 to 5 hr. However, to meet production schedule this time was reduced to only 2 hr.
7. Three out of five respondents reported premature cracking on their projects.

3.4 Direct Communications

The team also met or communicated by phone with two of each rehabilitation contractors, concrete producers and FDOT project engineers. A team member also visited the project

engineers of two rehabilitation projects on I-95 in Miami. Questions were directed at these engineers/professionals including: contractors' production rates, concrete volumes produced during the construction window, incidents of premature cracking, and types of cracks observed on the replacement panels or full slabs, and any other opinions the professionals may wanted to express. Here are some of the responses and opinions:

1. The production rate of projects in south Florida is as low as 25 to as high as 50 cubic yards of concrete per production night.
2. The team member noticed widespread cracking shortly after casting of replacement slabs in of two project on I-95 in Miami. In the second project, no early cracking had been observed according to the project engineer.
3. Concrete producers attributed the high cost of concrete for slab replacement to three factors. These factors included low quantity concrete produced when operating the plant during nighttime lane closure; allows a specialty mix which requires a very high cement content, exceeding 800 lb/cu. yd. and admixtures dosage rate, and specifically accelerators; also the potential risk from not meeting the required strength at scheduled lane opening time.
4. The contractors are of the opinion, that the FDOT specification requires removal and replacement of premature cracked replacement slabs at no cost, when they had followed other requirements of the specifications and achieved the strength requirement of 2,200 psi.
5. The FDOT project engineers maintain that the contractors have the flexibility to use their "means and methods" to develop the proper mixes to achieve the required strength but must also be accountable for premature cracking on the replacement slabs.

6. The FDOT engineers and contractors were generally receptive to a new method to accelerate slab replacement.
 - a. From the FDOT position the method would be useful if it reduces project cost and MOT requirement, and shortens project completion time
 - b. From the contractors' point of view, the new method would be useful, if it increases their productivity by more than 20%, reduces premature cracking, and saves them more money to achieve a competitive edge in their bids.

3.5 Summary of Survey Findings

The survey, communications and project visits provided the research team with good information to establish the requirements for the developmental and experimental aspects of the research. Based on the useful information from the survey the following requirements and goals were developed for the accelerated slab replacement method:

1. Achieve a minimum 25% increase in slab replacements per lane closure period.
2. Reduce project MOT by 30%.
3. The precast panels must be simple to design and construct, and robust to resist damage during multiple uses.
4. The SCC mix must be designed with cement content not exceeding 850 lb, low w/c ratio and several admixtures to be highly workable and exceed the lane opening strength
5. The SCC mix must be capable of being produced in a batch plant with high workability sustained for at least 45 min. after addition of the accelerator, to shorten the cast time of replacement slabs without segregation, and to achieve the required lane-opening strength without cracking.

6. The method must be flexible to allow the producer and the contractor to offer more efficient mixes and equipment to execute the new method, and achieve the FDOT specification requirements while maximizing productivity and cost savings.

CHAPTER 4

PRECAST PANEL MODELING

4.1 Introduction

The purpose of the analytical modeling was to determine the possible displacements of the precast slabs under different loading conditions. Additionally, the cracking potential of the reinforced slabs was another objective of the analytical modeling. Under actual loading conditions, precast slabs will be subjected to different loading patterns and magnitude, and, as a result, may develop micro-cracks at certain locations, which may not be detected by visual inspection. These cracks may propagate leading to slab failure. Although the precast slabs are supposed to be used on a temporary basis, the extended service life is one of the important factors that should be considered. The multiple use of the precast panels with minimum damage will certainly contribute to the cost effectiveness of the proposed method to accelerated slab replacement. Development of cracks and further propagation in the panels were evaluated using special concrete elements in the finite element models. The performance of the precast panels during installation was also examined and evaluated during field installation.

4.2 Numerical Modeling and Field Testing of Precast Slab

The precast panels (Figure 4.1) were numerically modeled using ANSYS 14.5 software. Elements used for this model were of SOLID 185 and material properties were selected to simulate the concrete slab and the base layer (Figure 4.2). The clearance between the precast slab and the surrounding pavement was 0.5 in. and it was filled with a soft rubber material to model the foam gasket used in the field-testing. The properties of the materials used in the model are as follows:

- Elements: SOLID 183
- Subgrade material unit weight: 120 lb/ft³
- Subgrade stiffness: 4500 psi
- Concrete unit weight: 150 lb/ft³
- Concrete strength: 4000 psi
- Concrete stiffness: 2000,000 psi
- Concrete Poisson's ratio: 0.2



Figure 4.1: Model precast panels (6' x 6' x 8'') used in field testing

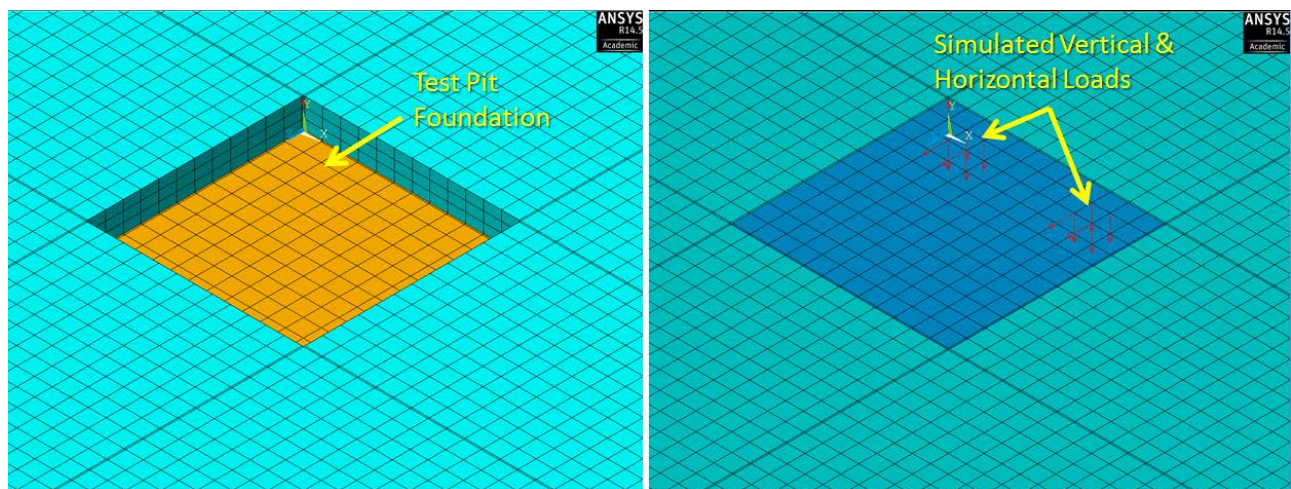


Figure 4.2: Finite element model of a precast panel

The loads on the concrete panels in the field were applied using a 11,000 lb. forklift. The vertical and horizontal displacements of the slabs were measured using two vertical and two horizontal LVDTs (Figure 4.3). The horizontal load was induced on the slab by stooping applying a sudden brake on the forklift. The differences in the horizontal displacement at different speed levels readings were not of significant values. The vertical displacements at the edge of the slab increased as the applied loads approached the LVDTs.

4.3 Field Test Results vs. Finite Element Modeling

When the rear wheels of the 11,000 lb. forklift approached the edge of the slab where the LVDTs were located, the vertical displacements increased to about 0.04 to 0.06 in. Some spikes in the LVDTs reading were noticed, and these peaks were due to the vibration in the slab from the moving forklift. The duration of the peaks were a fraction of a second. Because the loads from the rear wheels were not precisely centered between the vertical LVDTs, readings from the two gauges were averaged to compare with the numerical modeling results (Figure 4.4).

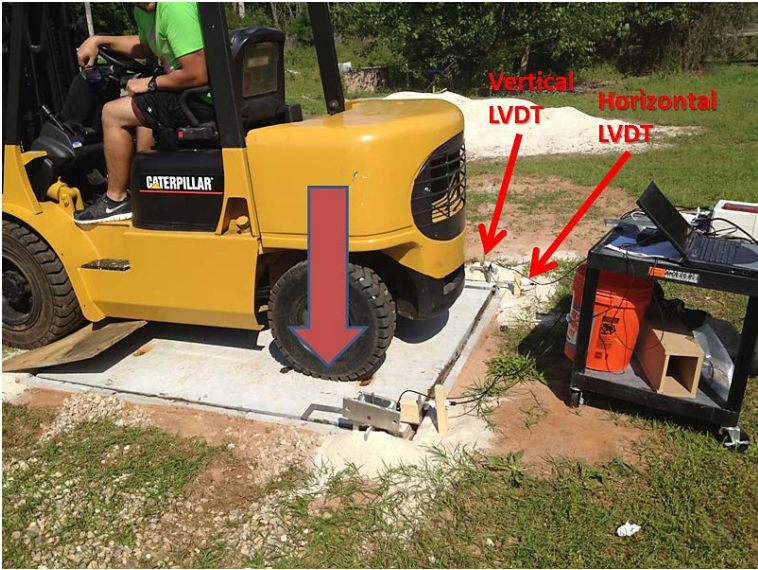


Figure 4.3: Field Test on the Precast Panels

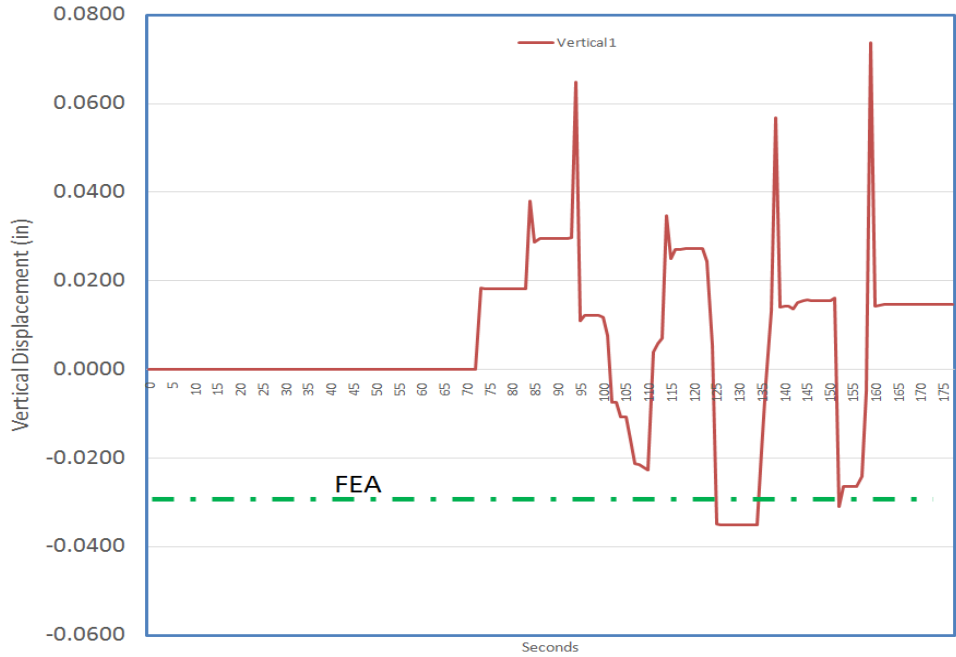


Figure 4.4: Vertical Displacement of Precast Panels

A similar pattern of displacements was noticed from the horizontal LDVTs (Figure 4.5). In addition, the readings of the horizontal gauges were averaged to compare with finite element analysis (FEA) results.

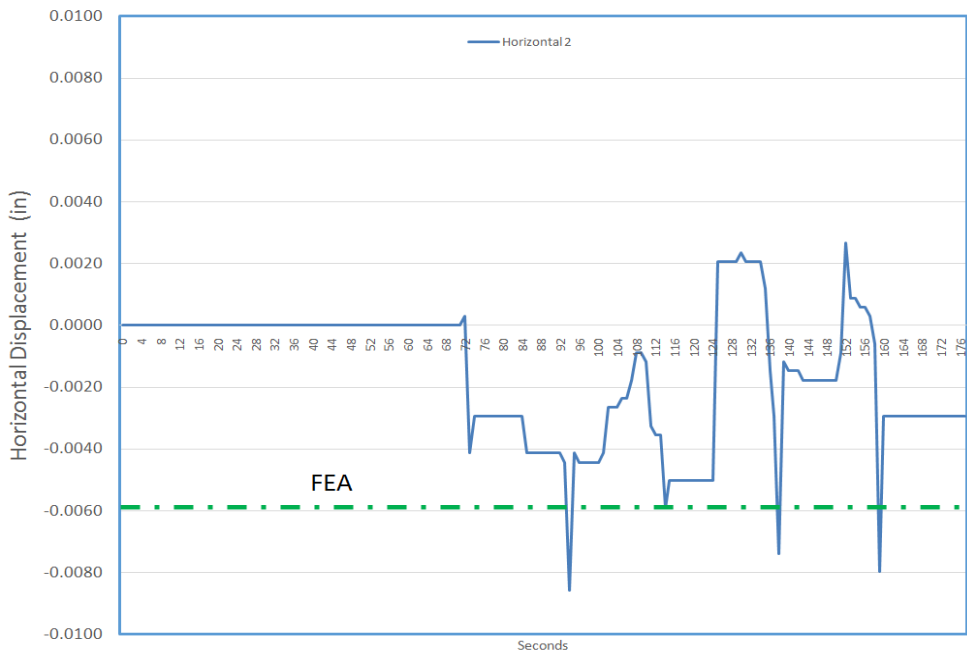


Figure 4.5: Horizontal Displacement of Precast Panels

The maximum vertical displacement from numerical modeling was about 0.0287 in. This value was closely compared to the vertical displacement from the field tests. For the horizontal displacement, the precast panels showed a maximum value of about 0.005 in. (Figure 4.6), and the finite element modeling resulted in a displacement of 0.0061 in. (Figure 4.7).

It was noticed that changing the stiffness values of the foam material used in the finite element models to fill the surrounding space around the precast slab did not influence either the vertical or the horizontal displacements. However, inserting a foam gasket (backer rod) around the precast panels prevented the impact between the precast panels and the surrounding concrete. Additionally, the applied loads on the precast panels in the field and in the finite element analysis did not show any racking in the concrete.

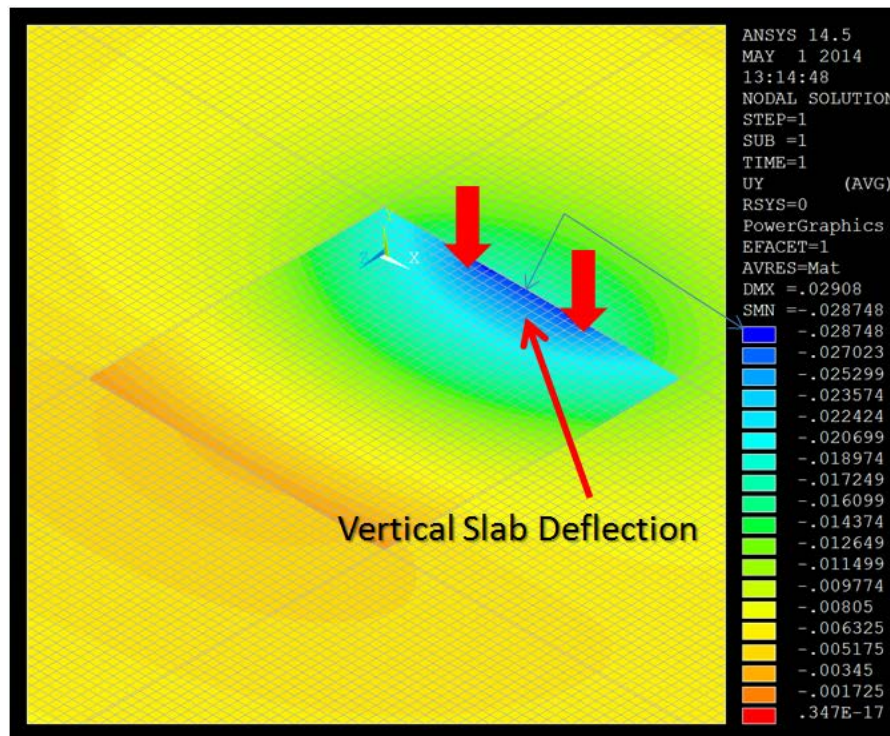


Figure 4.6: Maximum Vertical Displacement from FEA

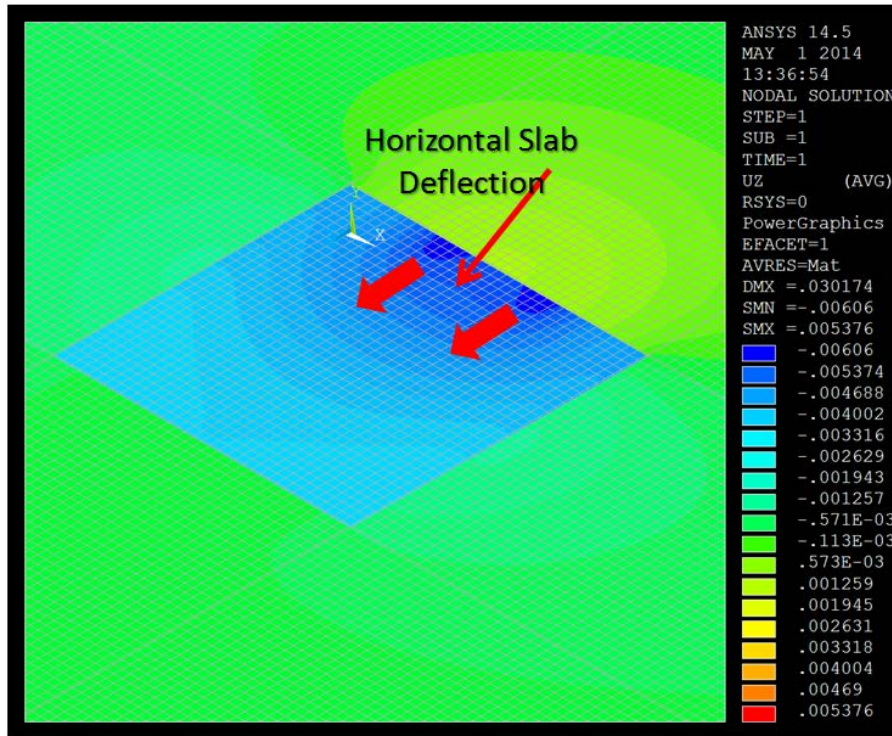


Figure 4.7: Maximum Horizontal Displacement from FEA

4.4 Conclusion

Results from field tests and finite element numerical modeling indicated that the proposed method of using temporary precast panels to fill the slab replacement pit after removing the deteriorated section of concrete pavement is feasible. Installing temporary panels in slab replacement pits will not cause large vertical and horizontal displacements under traffic loads during the short period prior to casting the permanent replacement slab. In addition, it was found from the field tests on 6 ft. x 6 ft. precast slabs, that a one-inch diameter backer rod can effectively be used as a foam gasket around panel edges. Good performance of the backer rod can be achieved by inserting the rod in the slab recess, using a strong epoxy adhesive, and greasing the projected portion of the rod (Figure 4.8). A firm installation and proper lubrication of the backer rod in the

precast panels will prevent the possibility of a rupture or pullout during the lowering and multiple installation cycles of the panels.



Figure 4.8: One-inch diameter backer rod inserted in the recess along the edge of model panel

CHAPTER 5

DEVELOPMENT OF SCC MIX FOR SLAB REPLACEMENT

5.1 Introduction

SCC mixes are used primarily as cast-in-place or precast reinforced structural members. Conventional SCC mixes are designed using small size aggregates (grade 89 or smaller), with very high workability to facilitate its flow through narrow spaces in the dense reinforcing bars. The mixes have normal setting and strength development times. In fact, there might be a delay in setting time due to the high dosage of high range water reducing admixture and viscosity modifier.

In this Task, the SCC mix was designed with specific characteristics to meet the project goal of accelerating the slab replacement process. The mix design included four admixtures to achieve a combination of very high slump flow for rapid discharge and finish, and attain high-early compressive strength of 2,200 psi in 6 hr. to meet the FDOT requirement. Since replacement slabs are not reinforced except for dowel and tie bars at joints, it was not necessary to use smaller size aggregates in the mix. In fact, large aggregates of grades 67 or 57 provide better performance for concrete pavements. Another primary mix design objective was to limit the cement content to reduce the potential for premature cracking.

In addition to identifying the specific parameters of the SCC mix, the team held meetings and communicated with technical representatives of a chemical company to discuss the appropriate admixture types and dosage rates that would achieve a combination of a high workability and high-early strength SCC mix. The company representatives shared their experience in using the 4 x 4 mix system (4000 psi in 4 hr.) for accelerated slab replacement in California, and provided technical information on the most effective admixtures and dosage rates for their SCC mixes. This

information along with other industry consultations, useful information from FDOT Specifications, and experience with Florida concrete mixes helped to develop the SCC mix for the project.

5.2 SCC Mix Ingredients

Based on the specific SCC mix design goals of the project and industry input, a basic SCC mix design was developed for the trial batches through testing and further adjustment. The basic mix had to meet two objectives, high workability at placement and finishing, and early strength at lane opening to traffic. Table 5.1 shows the basic SCC mix design and six trial mixes batched in this task.

The basic mix included 830 lb/y³ of type I/II cement. This is in contrast to the excessive cement content used in some recent mixes for rehabilitation projects. In these cases, thermal and shrinkage stresses from excessive cement content have resulted in premature cracking in the newly replaced slabs. The low w/c ratio of 0.34 was designed to develop high-early strength concrete without the need for higher cement content.

Gradation, specific gravity and absorption of coarse and fine aggregates are presented in Tables 5.2 and 5.3. The coarse aggregate is classified as grade 57 with one-inch maximum aggregate size. This aggregate size has proven to produce mixes suitable for long performing concrete pavements. Absorption of 3.3% is in the medium range for Florida aggregates. The fine aggregate was silica sand with FM of 2.51. It should be noted that the source and properties of aggregates might change depending on the aggregate source and location in the state or from sources outside Florida. As such, the mix design should be adjusted when the type and properties of aggregates are changed.

Table 5.1: Basic SCC mix design

Ingredients (lb)	Basic Mix (yd³)	TM1* 4.5 ft³	TM2 3 ft³	TM3 3 ft³	TM4 4.5 ft³	TM5 3.25 ft³	TM6 3 ft³
Cement	830	138	92	92	138	100	92
C. Aggregate	1625	271	181	181	271	201	181
Fine Aggregate	1224	204	136	136	204	147	136
Design Water	280	47	31	31	47	34	31
Batched Water	----	----	----	----	----	29	29
W/C	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Air Content	2%	2%	2%	2%	2%	2%	2%
Admixtures (Oz)							
Rheotec Z60	42 (5) **	7 (5)	4.6 (5)	4.6 (5)	7 (5)	3 (3)	4.6 (5)
Glenium 7700	33 (4)	6 (4)	3.7 (4)	3.7 (4)	6 (4)	3 (3)	5.5 (6)
Pozzolith 122HE	515 (62)	86 (62)	57 (62)	57 (62)	86 (62)	60 (60)	52 (57)
Pozzolith 700N	42 (5)	7 (5)	4.6 (5)	4.6 (5)	7 (5)	4 (4)	4.6 (5)

* TM – Trial Mix

** () - Values in () are in Oz/CWT

Table 5.2: Coarse aggregate properties

Sieve Size	% Passing
1 1/2"	100
1.0"	96
3/4"	71
1/2"	32
3/8"	14
#4	2
#8	1
FM	7.1
Specific Gravity	2.53
Absorption	3.3%
Type and size: Limestone size 57	Producer: Vulcan

Table 5.3: Fine aggregate properties

Sieve Size	% Passing
#4	99
#8	95
#16	82
#30	54
#50	17
#100	1
FM	2.51
Specific Gravity	2.63
Absorption	0.4%
Type: Silica sand	Producer: Vulcan

Four admixtures were used in the mix, including a workability retainer, a high-range water-reducer, an accelerator and a set retarder/water reducer. Table 5.4 shows the types of admixtures and the description of their functions in the SCC mix. The dosage rates shown in Table 5.1 are in fluid ounces per each 100 lb of cement, and they were calculated for the cubic yard and cubic feet of the mixes.

Some of the admixtures had been successfully used in the production of the 4x4 mixes for accelerated pavement patching in California. The dosage rates of the admixtures were adjusted to produce an SCC mix that meets the project criteria for slab replacement. The combination of the four admixtures was intended to provide the balance between high workability sustained during the discharge and finishing the replacement slab, and the high-early strength to meet the FDOT strength criteria for opening the section to traffic. The dosage rates may need to be adjusted when changing the source/producer of the admixtures, construction environment and weather conditions.

Table 5.4: Admixture type and description

Admixture	Description
Rheotec Z60	Workability (slump) retaining admixture. Meets the interim requirements of ASTM C 494/C 494M Type S
Glenium 7700	High-range water-reducing admixture. Meets The requirements of ASTM C 494 Type A, water-reducing, and Type F, high-range water-reducing, admixtures
Pozzolith 122HE	Accelerating admixture. Meets ASTM C 494 requirements for Type C, accelerating, and Type E, water-reducing and accelerating, admixtures
Pozzolith 700N	Water-reducing and set-retarding admixture. Meets ASTM C 494/C 494M requirements for Type A, water-reducing, Type B, retarding, and Type D, water-reducing and retarding

5.3 Trial Mixes

Six trial mixes were batched at the FSU-FAMU Civil Engineering Concrete Laboratory (Figure 5.1). The mixes were prepared in a 4 ft³ mixer in a single or multiple batches to produce the required mix volume to perform the plastic concrete testing and to prepare required number of samples for strength and other hardened phase testing. The volumes of the trial mixes ranged from 3 ft³ to 4.5 ft³.

The aggregates were stored in covered bins to prevent fluctuations in the moisture content. No adjustment was made in the mix water in trial mixes 1 to 4 as shown in Table 5.1. In trial mixes 5 and 6 (TM5&6) the mix water was adjusted during batching to account for the water in the accelerator and for the moisture content of the coarse aggregate.

The admixture dosage rates were adjusted to achieve a balance between workability and strength properties of the SCC mix. As will be shown in the test results, the TM5 and TM6 met the high workability aspect of the fresh concrete and the 6-hour strength requirement of the FDOT. It should be noted that when admixture source is changed, the dosage rates might need to be adjusted to meet the required SCC properties. Adjustments would be needed in the dosage rates of admixtures to account for transportation time to the jobsite.

The trial mixes were batched at different ambient temperatures as shown in Table 5.5. The significant impact of temperature on strength development during early hours will be shown later in the report. Adjustments need to be made in the admixture dosage rates at high or low temperatures to maintain high workability and achieve the required lane-opening compressive strength. For example the quantity of the accelerator may be reduced when the ambient temperature exceeds 85 °F and may need to be increased when the ambient temperature is lower than 50 °F. Some adjustment to the cement content should also be considered.



Figure 5.1: Batching of a trial mix at Civil Engineering Concrete Lab

Table 5.5: Ambient temperatures and fresh concrete test results

Trial Mix	Ambient Temp	Slump (in)	Flow	T20 (s)	J-Ring (in)	Column Segregation %
TM1	84°F	23.3		3	> 1	---
TM2	79°F	21		4	>1	7.5
TM3	57 °F	16		> 7	>1	---
TM4	82°F	22		5	---	---
TM5	83 °F	24		4	0.9	---
TM6	83 °F	21		6	----	----

5.4 SCC Testing – Plastic Phase

Tests on fresh SCC samples were performed on the trial mixes to evaluate the workability and suitability of the mix for rapid discharge, spread and finish. The test methods, brief



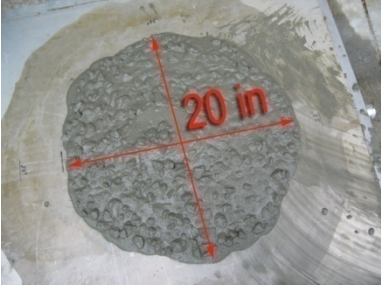
descriptions and photos, are shown in Table 5.6. The Slump Flow and T20 tests were performed on all trial mixes while the J-ring test was performed on some of the mixes. The J-ring test is normally performed to determine the concrete's passing ability through obstructions and reinforcing bars. It may not be relevant to SCC mix placement in large pits such as the replacement slab pits. The column segregation test was performed on TM2. This test may not be relevant to slabs with relatively shallow depths and wide surface dimensions such as the replacement pits. However, the test provides a means to reasonably determine the potential static segregation of self-consolidating concrete.

Test results of plastic properties of the six SCC trial mixes are shown in Table 5.5. The acceptance criteria for the properties of conventional SCC mixes are shown in Table 5.7. (General Criteria for SCC Workability). It should be noted that the acceptance criteria pertain to workability of SCC mixes in the structural applications in heavily reinforced structural members and may not necessarily be relevant to replacement slabs that are relatively thin with wide surface dimensions. However, the research team used Table 5.7 as a guide to assess the suitability of the SCC mix design for slab replacement. Specific plastic concrete requirements will be proposed in subsequent chapters of this report. Except for TM3, which was prepared and tested at low temperature, the slump flow measurements of the trial mixes used in this task ranged from 21 to 24 inch and the T20 ranged from 3 to 7 seconds.

The slump flow and T20 tests measure the extent of spread and velocity of the flow of the SCC at discharge. The results for these tests as shown in Table 5.5 indicated a very good to moderate spread properties of the designed SCC mix for slab replacement, after addition and mixing of the accelerator admixture. These results suggest that the designed SCC mix can be discharged at a high rate to rapidly fill the open pit of the replacement slab. This will result in

higher production rates. Except for TM3, small variations in the ambient temperature seems to have minor, if any, impact on the workability of the SCC mix as evident from the slump flow and T20 test results.

Table 5.6: SCC fresh properties test methods

Test	Description	
<p>Slump Flow (in) ASTM C1611</p>	<p>Slump Flow test determines the slump flow of self-consolidating concrete in the laboratory or the field. It is used to monitor the consistency of fresh, unhardened self-consolidating concrete and its unconfined flow potential. This test method is considered applicable to self-consolidating concrete having coarse aggregate up to 25 mm [1 in.] in size. The rate at which the concrete spreads is related to its viscosity. Appendix X1 provides a non-mandatory procedure that may be used to provide an indication of relative viscosity of self-consolidating concrete mixtures.</p>	 
<p>T20 (T50) (in) ASTM C 1611</p>	<p>T20 (T50) test is a measure of the concrete's viscosity and is measured as the amount of time it takes for concrete in the slump flow test to reach a diameter of 20 in (or 50 cm) centimeters).</p>	



<p>J-Ring ASTM C1621</p>	<p>J-Ring test is a measure of the concrete's passing ability through obstructions and reinforcing bars. ASTM C 1621, "Passing Ability of Self-Consolidating Concrete by J-Ring." The J-Ring is a cage of rebar that is set up around the slump cone. The slump flow test is run both with and without the J-Ring in place and the passing ability is the difference in slump flow.</p>	
<p>Column Segregation % ASTM C1610</p>	<p>Column Segregation test provides a procedure to determine the potential static segregation of self-consolidating concrete. The test is used to develop self-consolidating concrete mixtures with segregation not exceeding specified limits. The static segregation of SCC is determined by measuring the coarse aggregate content in the top and bottom portions of a cylindrical specimen (or column). The degree of segregation can indicate if a mixture is suitable for the application.</p>	

Table 5.7: General acceptance criteria for SCC workability

<p>Slump Flow (in.)</p>	<p>21-24</p>	<p>Appropriate for members with light or no reinforcement, short lateral flow distance, or high placement energy (e.g. panels, barriers, coping)</p>
	<p>24-27</p>	<p>Ideal for most applications</p>
	<p>27-30</p>	<p>Appropriate for members with highly congested reinforcement, long lateral flow distance, or low placement energy (e.g U-beams, I-beams, other beams)</p>
<p>T20 (s)</p>	<p><2</p>	<p>Poor stability</p>
	<p>2-7</p>	<p>Acceptable, should not vary over range of 3 s between batches</p>
	<p>>7</p>	<p>Possible, may reduce palceability</p>

J-Ring Dheight (in.)	<0.5	Appropriate for members with highly congested reinforcement (e.g U-beams, I-beams, other beams)
	0.5-1.0	Appropriate for members with moderately congested reinforcement
	>1.0	Appropriate for unreinforced or highly reinforced members (e.g panels, coping)
Column Segregation (%)	<5	Highly segregation resistant
	5-10	Segregation resistant
	10-15	Borderline segregation resistant
	>15	Not segregation resistant

5.5 Compressive Strength

Compressive strength samples were prepared from each trial mix with the exception of TM2, where only fresh SCC tests were performed. A set of three 6-inch diameter cylinders was prepared for each testing age. Table 5.8 shows the age of tested samples. In preparing the cylinder samples the team decided to fill the molds with the SCC mix without the use of any vibration or rodding. Instead the full scoops of concrete were dropped from a height of 2 in. above the cylinder rim. This is a departure from traditional sample preparation for compressive strength. The test results in Table 5.8 represent the compressive strength of the cylinder samples prepared with no vibration or rodding. The strength test results are also illustrated in Figure 5.2.

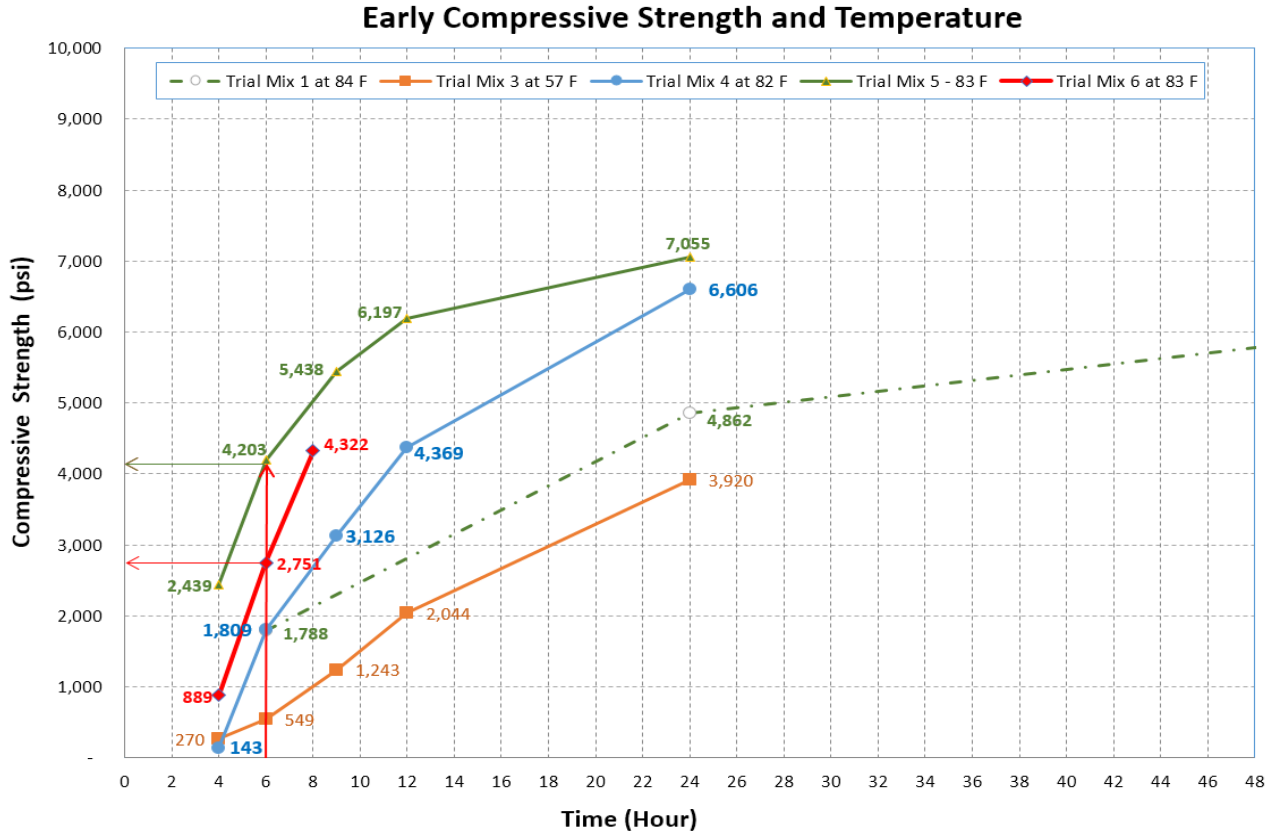


Figure 5.2: Compressive strength of trial mixes

To determine the impact of lack of vibration or rodding on the strength of the concrete cylinders, companion sets of vibrated and non-vibrated samples were prepared from Trial mix 1 (TM1). A vibrating table was used to consolidate one set of the samples. The other set of samples were filled without vibration. The cylinders were weighed and tested for compressive strength at 1, 3, 7, and 28 days.

The test results and percent variation in strength are shown in Table 5.9 and are illustrated in Figure 5.3. The test results show little or no difference in the weight or the strength values between the vibrated and non-vibrated samples. Based on these encouraging test results, samples from the remaining SCC trial mixes were prepared without vibration. It should be noted that no

segregation was observed in any of the vibrated or non-vibrated samples. In fact the result of the column segregation test performed on TM2 (Table 5.5) confirmed that the mix was “segregation resistant” as described in Table 5.7.

The compressive strength at early stages (Figure 5.10) seems to be impacted by the ambient temperature as shown in TM3 compared to the other trial mixes. The FDOT’s 6-hour strength of 2,200 psi was achieved in TM5 after adjusting the dosage rates of the four admixtures, as shown in Figure 5.1. By reducing the amount of the high-range water reducer in TM5, while maintaining the rate of the accelerator constant, and with the help of higher ambient temperature, a strength of 4,203 psi was achieved at 6 hr., which is significantly higher than the required lane-opening strength of 2,200 psi. The team decided to lower the 6-hour strength by preparing and testing TM6. In TM6 the accelerating admixture Pozzolith 122HE was reduced and the HRWR (Glenium 7700) was increased. This change in the mix ingredients reduced the 6-hour strength to 2,752 psi and maintained a good slump flow of 21 and a T20 of 6 seconds.

Table 5.8: Compressive strength test results (psi)

Trial Batch	Ambient Temp	4 hrs	6 hrs	9 hrs	12 hrs	24 hrs	3 days	7 days	14 days	28 days
TM1	84°F	--	1,788	--	--	4,879	6,707	7,682	8,229	8,600
TM2	79 °F	Only fresh concrete testing								
TM3	57 °F	270	549	1,243	2,044	3,290	---	---	---	---
TM4	82 °F	143	1,808	3,215	4,369	6,606	---	---	---	---
TM5	83 °F	2,439	4,203	5,438	6,197	7,055	---	---	---	---
TM6	83 °F	890	2,751	4,322**	---	---	---	---	---	---

** At 8 hr.

Table 5.9: Compressive strengths and weights of vibrated vs. non-vibrated samples of TM1

Sample Compaction Method	1 day		3 days		7 days		28 days	
	Wt. (lb)	Fc' (psi)	Wt. (lb)	Fc' (psi)	Wt. (lb)	Fc' (psi)	Wt. (lb)	Fc' (psi)
Vibrated	28.7	4,862	28.7	6,905	28.6	7,623	28.8	8,458
Non-vibrated	28.6	4,869	28.5	6,312	28.0	7,799	28.3	8,882
% Difference (NV/V) x 100	99.6%	100%	99.3%	91%	98%	102%	98%	105%

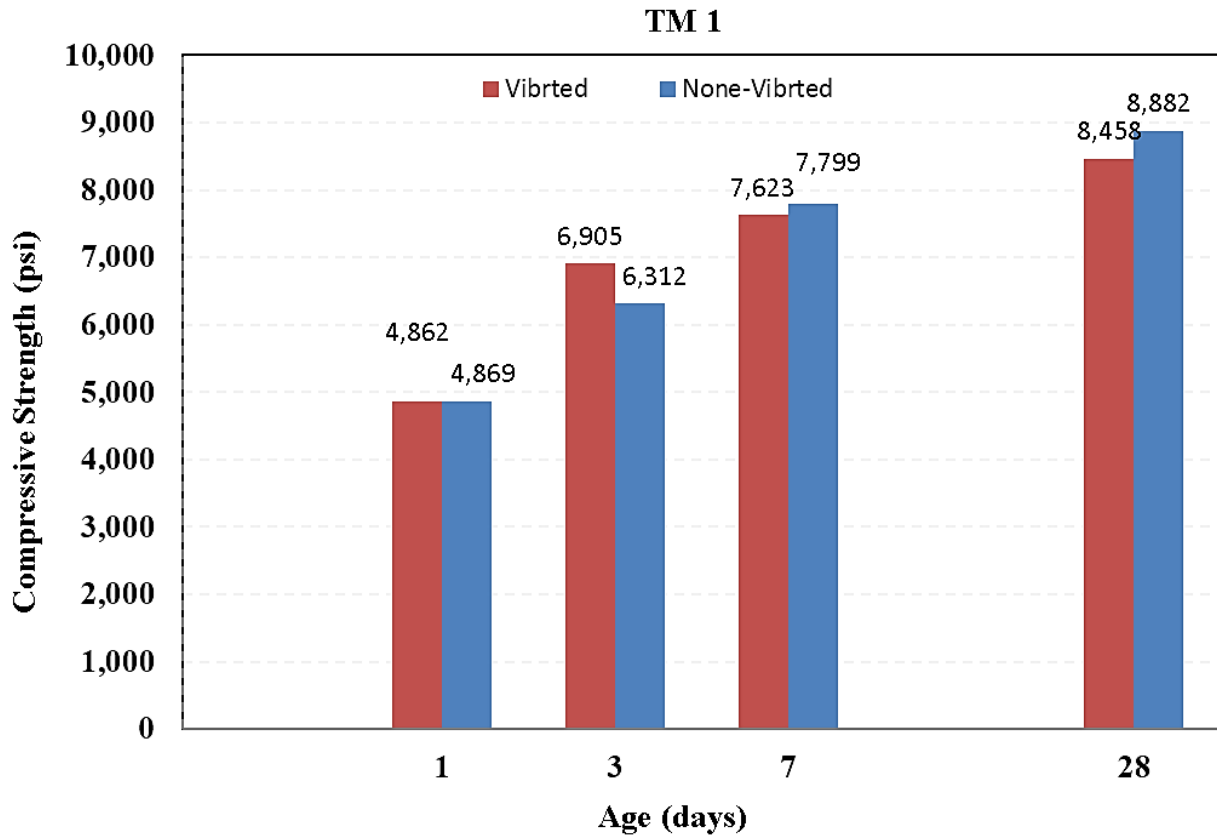


Figure 5.3: Compressive strength of vibrated and non-vibrated cylinder samples

5.6 Summary of SCC Mix Design

The following is a summary of the SCC Properties:

1. A basic mix design was developed for the SCC mix for slab replacements. The mix combines high workability for rapid discharge and finishing, and a 6-hour strength greater than the 2,200 psi that is required by the FDOT for lane-opening.
2. Adjustments to the admixture dosage rates may be necessary when the SCC mix is designed for different ambient temperatures, longer concrete transportation time, or when the admixture source changes.
3. Vibrated and nonvibrated samples cast from the SCC mix showed very small differences in compressive strength and weight. There was no aggregate segregation in any of the samples tested for compressive strength.

CHAPTER 6

FIELD DEMONSTRATION AND EVALUATION

6.1 Introduction and Scope

In this task, a field demonstration and an evaluation of the new slab replacement system of temporary precast panels and SCC mix were performed. Originally, it was planned to select an active FDOT rehabilitation project for field demonstration to implement the proposed method. However, due to the difficulty in finding an ongoing slab replacement project within the duration of the project, the research met with the FDOT project manager to discuss an alternate plan for field testing to simulate truck traffic and achieve goals similar to those of evaluating an ongoing rehabilitation project. At the meeting, it was decided to perform the following:

- 1- Evaluate the workability retention of the SCC mix, developed at FAMU-FSU laboratory, by performing multiple slump flow tests in the lab over a period of one hour. This step was important to allow the SCC mix to be batched in a concrete truck mixer and transported to the field site without significant slump loss.
- 2- Utilize the existing 6' x 6' x 9" test pit at the FAMU-FSU site to evaluate the batching, transporting and discharging the SCC mix in the pit using a commercial concrete truck mixer. This step was to evaluate properties and behavior of the SCC mix in a large batch, and to make necessary adjustments in the process prior to field application of the mix. It should be noted that reference to a large concrete mix in this report indicates a volume of SCC mix larger than one cubic yard that is prepared in a concrete truck mixer.
- 3- Utilize a dedicated 400 ft., oval-shaped test track in Green Cove Springs south of

Jacksonville, Florida, as the site for the field demonstration.

- 4- Construct a 12' x 12' x 8" test pit for the replacement slab at the test track to test and evaluate the temporary precast panels and the casting the replacement slab with the SCC mix.
- 5- Fabricate two 6' x 12' x 8" reinforced precast panels
- 6- Evaluate the robustness of the precast panels during their repeated installation and removal from the test pit, and evaluate their stability under a moving heavy truck.
- 7- Collaborate with a concrete producer in Jacksonville to prepare and evaluate the SCC mix, and then batch a large volume of the mix, transport to the test track and cast the replacement slab.
- 8- Verify properties and behavior of the designated SCC mix at the concrete producer's lab, by preparing small trial batches using the producer's materials, mixer and test equipment. This step was to establish more confidence in the ability of the SCC mix to be produced commercially in large volumes and to be placed in simulated field conditions.
- 9- Batch a 4 cu. yd. SCC mix at the concrete plant, transport it to the test track, and then discharge it in the test pit. This step was needed to test the SCC mix properties and the process efficiency.
- 10- Drive a loaded truck around the test track to apply heavy wheel loads on the SCC slab after 6 hr. from the beginning of concrete placement. Repeat load applications by making 100 laps around the track. This would closely simulates traffic loading expected in early hours after opening the lane to traffic.
- 11- Repeat the evaluation of the SCC mix at the FSU test site using a different concrete producer from the Tallahassee area.

- 12- Monitor all activities with respect to the time required and the efficiency of installing the precast panels; the time required to fill the test pit with the SCC mix; the properties of fresh and hardened the concrete; and concrete temperature during early hours of strength development, and the conditions of precast panel and replacement slab under truck loading.

In executing the above plan, the research team was aware of some issues and concerns related to the SCC mix. The variability of the SCC mix properties was a concern when batched in a large volume in a 10 cu. yd. concrete truck mixer instead of a 4 ft³ laboratory mixer. The workability retention was also a major issue. When transporting the mix to the jobsite, the SCC was expected to lose some of its workability. The travel time to the Green Cove Springs test site was 45 to 60 min. Upon arrival to the jobsite, the accelerator would be added, which would initially increase the slump flow. The challenge was how to delay the setting of the mix inside the truck mixer, and maintain a high workability and flow rate until full discharge of the concrete load. Other concerns were related to possible differences in material properties used by different concrete producers, including coarse and fine aggregates, and cement. The concerns and challenges were taken into account when planning and mobilizing for activities of this task.

6.2 Test Track

Demonstration and evaluation of the temporary precast panels and SCC mix placement were conducted at a dedicated test track in Green Cove Springs, south of Jacksonville. The track is located in a site at an industrial park. The site also includes a concrete recycling plant. The oval shaped test track is 400 ft. long and 14 ft. wide asphalt pavement, as shown in Figure 1. The test track had been used to evaluate pavement products and new technologies. Traffic loads are simulated using a loaded trucks traveling at 10 mph around the track.



Figure 6.1: Pavement test track

6.2.1 Preparation of Replacement-Slab Test-Pit

A 24'x 14' section of the test track pavement was removed to construct the replacement-slab test-pit and the surrounding concrete pavement. After removing the asphalt and base layers, forms were erected to set up the test pit as shown in Figure 6.2. The final pit dimensions were 12'3" x 12'3" x 8", and it was designed to accommodate two 6'x12'x 8" precast panels. To simulate an existing concrete pavement, a 4,000 psi concrete mix was prepared in a commercial batch plant and cast around the test pit as shown in Figure 6.3. The concrete was cured using a plastic sheet.



Figure 6.2: Preparing forms for the replacement-slab test-pit



Figure 6.3: Paving concrete around the replacement slabs test pit

After construction of the test pit, a layer of fine recycled concrete aggregate was placed at the bottom of the pit and compacted as a leveling course to establish the design pit depth of 8” as shown in Figure 6.4. Because of its stiffness, fine recycled concrete aggregate was found to be a suitable leveling course to establish the required depth for the slab replacement pit. Other leveling material options would include builder’s sand or geosynthetic mats. Builder’s sand was used at the FSU site to construct a 6’ x 6’ x 9” test pit as was described in Report 3. In general, the leveling course is necessary if the contractor uses precast slabs with a specific thickness in pits with varying depths.

No holes were drilled in the two faces of the adjacent pavement. The high cost of drilling and the difficulty in finding a contractor for such a small job were the reasons for skipping this step. It should be emphasized that this step is part of the precast/SCC system being proposed. This activity would normally involve drilling the holes for the retrofit dowels, removing debris and

finer from the hole, and covering the hole with tape to prevent contamination during the installation and removal of the temporary precast panels. Prior to casting concrete for the new replacement slab, the tape would be removed, the drilled holes would be filled with epoxy and then the new dowel bars would be inserted.



Figure 6.4: Test pit with fine recycled concrete aggregate as leveling course

The selection of the slab replacement dimensions for the pit was made based on the fact that a 12' x 12' is the maximum design template specified in the proposed precast/SCC system. These dimensions were also specified in FDOT Index 308. Other templates specified in the proposed method for slab replacement, include 6' x 12', 8' x 12', and 10' x 12'. These templates require the contractor to prepare only two groups of precast panels with 6' x 12' and 4' x 12' dimensions. These two sizes can fit individually or in combination to fit all the proposed pit sizes, namely, 6' x 12', 8' x 12', 10' x 12', or 12' x 12', in slab replacement projects as shown in Figure 6.5.

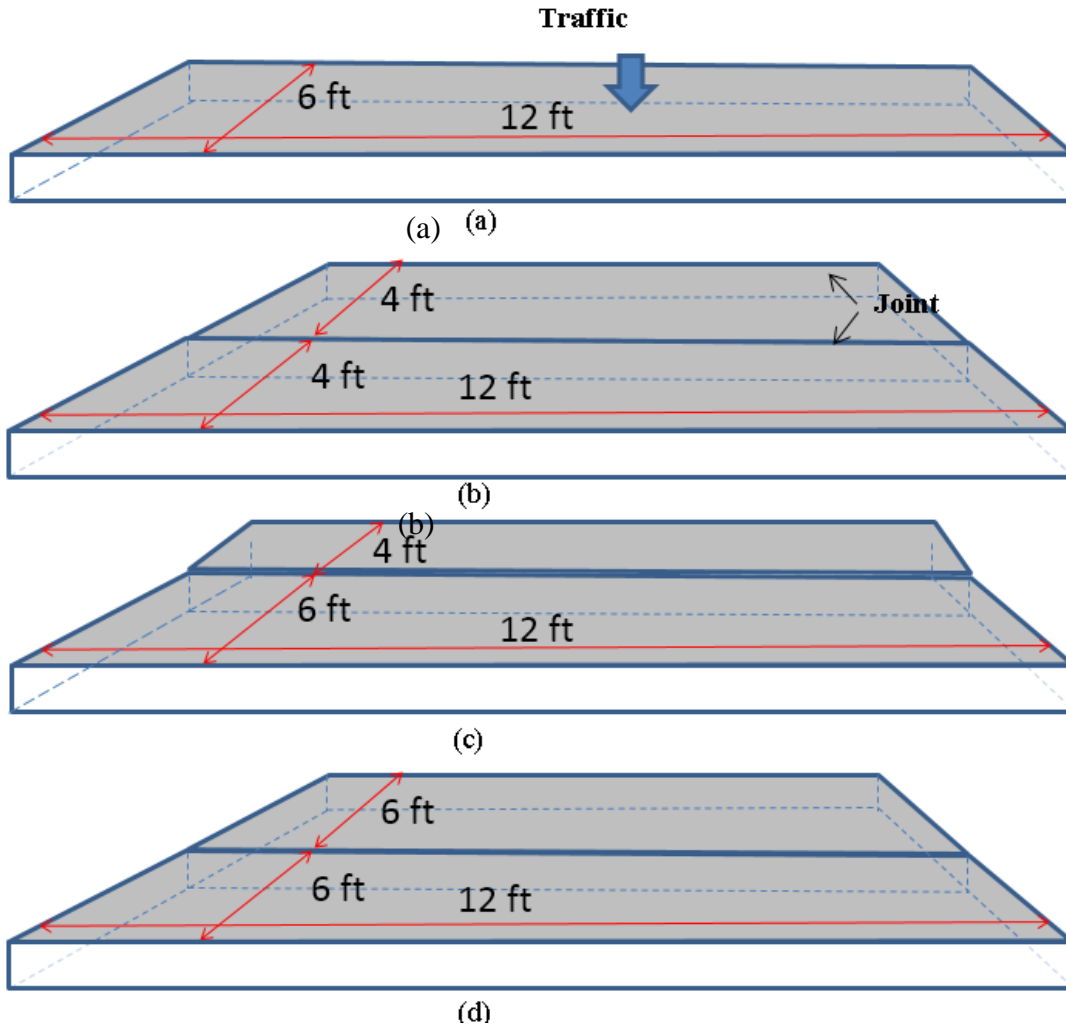


Figure 6.5: Temporary precast panels for 6' x 12', 8' x 12', 10'x 12' and 12'x 12' replacement pits

The dimensions of the test pit in Green Grove Spring site allowed the installation of two standard 6'x 12' panels (Figure 6.5d) with the 12' sides being in the transverse direction. Once installed, three joints were in the direction of traffic. Two of the joints were bordering the surrounding concrete, which represent an existing pavement structure, and the third joint was between the two panels. This arrangement was chosen to test the structural stability of the two precast panels installed side by side under simulated traffic loading conditions. This installation

pattern was considered the most vulnerable case scenario since the middle joint would be between the two movable panels, compared to a single panel (Figure 6.5a) installed with its two transverse joints firmly pressed against sides of the fixed pavement. It should be noted that the edges of the temporary panels would not be doweled or structurally connected to the surrounding concrete.

6.2.2 Construction of Temporary Precast Panels

The two precast panels were fabricate on site at the test track. The panel dimensions were 6'x 12'x 8". These planar dimensions were approximately 3" shorter than the pit dimensions, which would create a 1.5" gap between each panel side and the surrounding concrete. This was to facilitate the installation and removal of the panels from the test pit. It should be noted that a contractor may choose another option, which is to reduce the dimensions of the precast panels by 1" to 3" and maintain round numbers for tests pit dimensions (e.g. 6'x12', 8'x12', 10'x 12' or 12'x12').

The detail design of the two panels is shown in Figure 6.6. The preparation of forms, the assembly of the steel reinforcement and installation of the four lift anchors were completed on site as shown in Figure 6.7. The inside perimeter of the forms was fitted with a plywood strip to create a 1.5" wide and 1.5" deep recess in the middle top half of the slab to contain the foam gasket around the panel. Also, five plywood boards 8"x 3/4" were fastened to the bottom of the form to produce four recessed stripes along the bottom of the panels in Figures 6.6 and 6.7.

The forms were reinforced in two layers using # 4 reinforcing bars in the first panel and # 5 bars in the second panel. Using two bar sizes was intended to determine the structural adequacy of the panels under repeated traffic load and to optimize the final design and panel weights. The reinforcing bars were spaced at 12" on centers in both directions. Also, four lift anchors model

were embedded in each slab and were fastened to the reinforcement. The recess of each anchor was secured with a disposable plastic cover, which could be removed and reused at the time of slab rigging (Figure 6.8). Covering each recess after installing the panels in the pavement pit is necessary to protect and protect the anchors when panels are under traffic and to eliminate pavement noise.

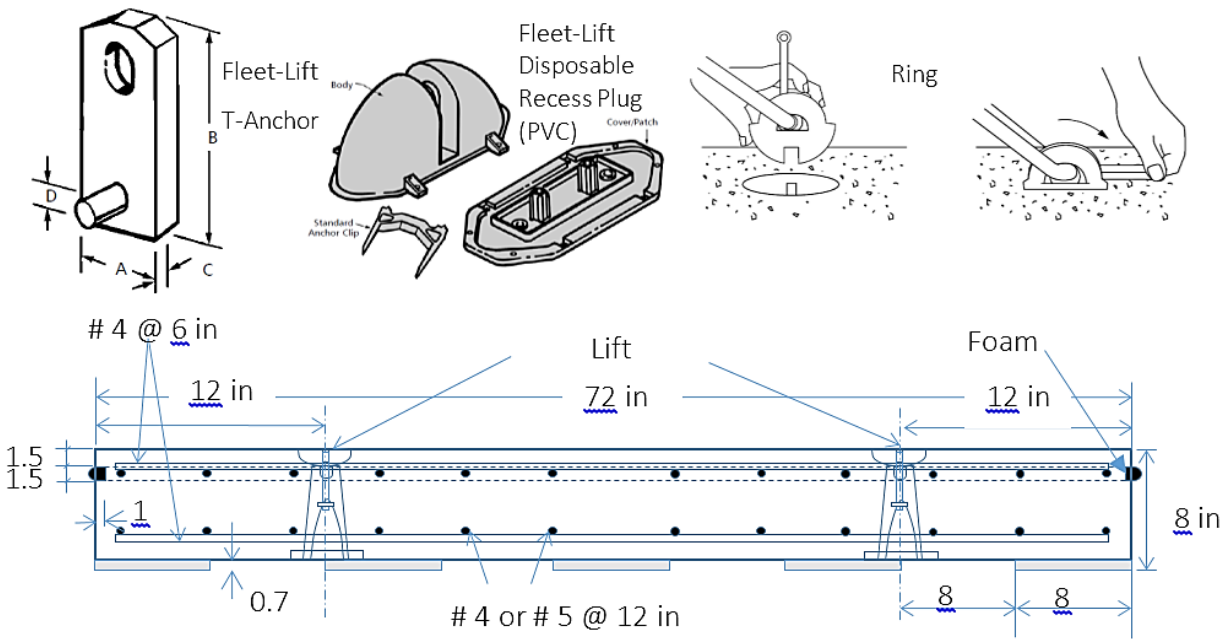


Figure 6.6: Precast slab design

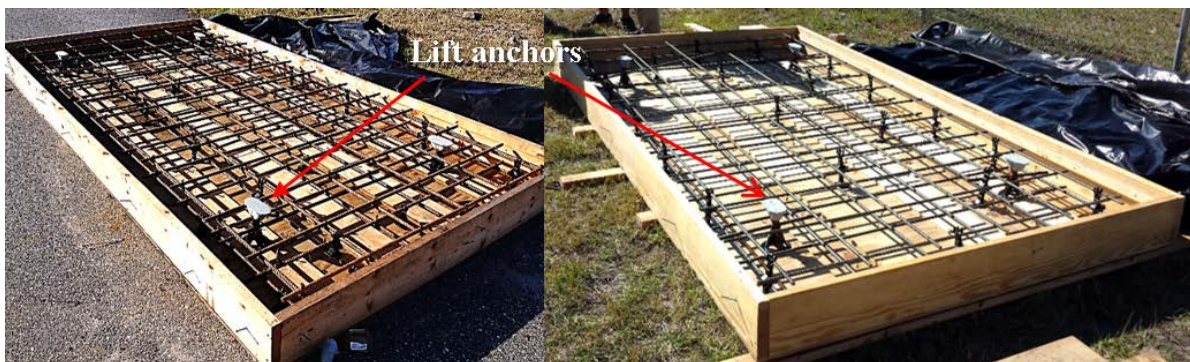


Figure 6.7: Construction of the precast panels

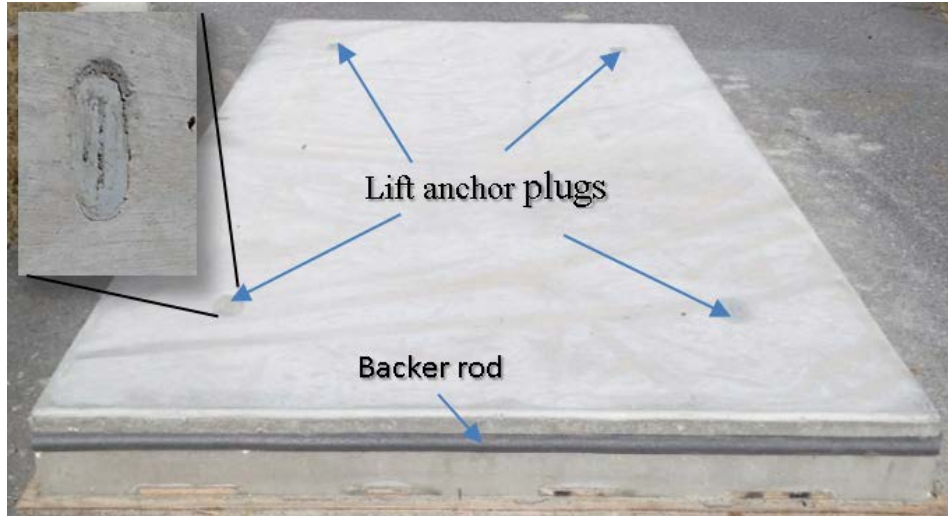


Figure 6.8: Locations of covered lift anchors

The panels were cast at the test track using 4,000 psi concrete supplied by a commercial concrete plant (Figure 6.9). The concrete was vibrated with emphasis on vibration around the lift anchors and the recessed components of the form to ensure that the panels would have firm lift anchors and perfectly shaped recessed areas. After casting, the forms were covered with plastic sheets for proper curing.



Figure 6.9: Casting of precast panel

The panels were designed to be robust to withstand multiple field applications. The bottom of each panel included four 8"x 3/4" recessed stripes along the bottom of the panels, as shown in Figure 6.10. The stripes were positioned along the long side of the panel bottom in order to be perpendicular to the direction of traffic. The recessed stripes were designed to improve the friction and interlock with the base to minimize panel shifting under the action of the moving traffic.

A 1.5" groove was indented along the sides of the panels. A 1.5" diameter backer rod was glued into the groove as shown in Figure 6.10. The backer rod extended about 3/4" outside the face of the concrete. The backer rod foam was preferred over rubber seals due to its relatively lower cost, more common use in paving projects, and ease of installation and replacement.

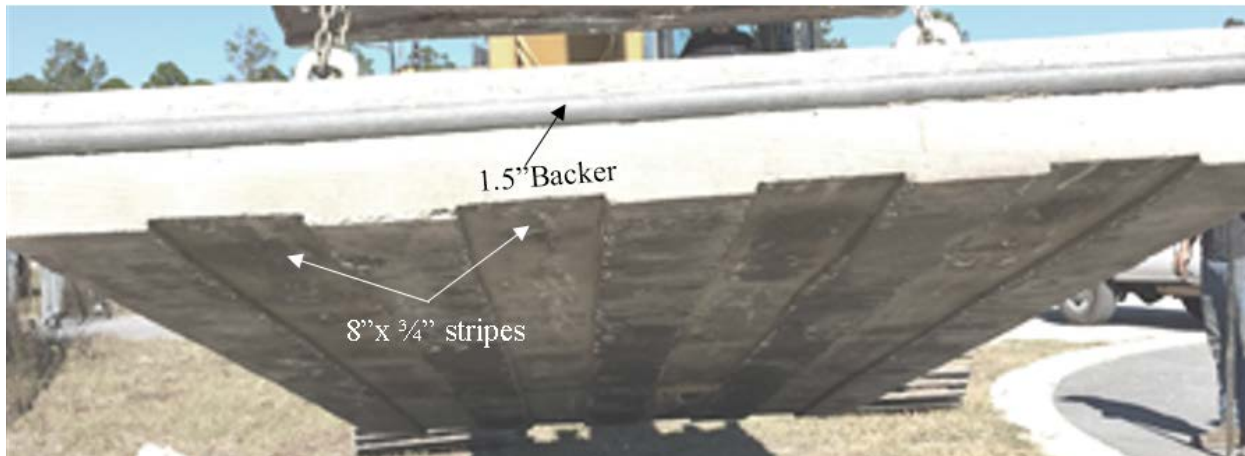


Figure 6.10: Striped panel bottom and backer glued baker rod along the panel sides

The backer rod was also intended to absorb minor impact of the panel sides and corners against the surrounding concrete, and thus preserve the structural integrity of the panels. Another possible benefit may be its joint sealing ability to minimize ingress of surface water during the temporary use of the panels in the replacement pits.

The protruding portion of the backer rod was lubricated with polymer gel to facilitate

insertion and removal of the panel in and out of the slab replacement pits. The polymer gel is degradable and an environmentally friendly lubricant (Figure 6.11). The lubricant that was prepared by adding 0.35 oz. of concentrated synthetic polyacrylamide polymer to 8 liters of water. The lubricant was prepared 24 hr. before its application to allow time for the viscosity of the gel to increase with time. The final product was a viscous water-based gel that could be used safely to reduce labor/material cost of replacing the backer rod every time the precast panel is used.

6.2.3 Installation of Precast Panels

The two precast slabs were cured until reaching the required concrete strength. After stripping off the panel side forms, installing the backer rod and removing the plastic covers from the lifting anchor recesses, the lift rings were clutched to the anchors. Using a steel chain, each panel was lifted from the base form, as shown in Figure 6.11.

An excavator was used to lift the panels and to install them in the test pit, as shown in Figure 6.12. The choice of using the excavator was due to its availability nearby at the recycling plant. On jobsites, the contractor may choose this or other lifting tractors or backhoes.



Figure 6.11: Lubricated backer rod



Figure 6.12: Rigging and maneuvering the precast panel

However, it is recommended to use a more efficient and steady lifting system of a backhoe, a tractor, or a forklift with a steel I-beam attachment, as shown in Figure 6.13. The service life of the precast panels is related to the methods and equipment used in storing, transporting, delivering, and installing of the panels. The precast panels are easily damaged if they are mishandled at any stage before or after their use.

Figure 6.13 show three different proposed rigging methods, which can be used to maneuver the precast panels in the field. These methods are as follows:

- A. *Use of a four-sling-lift*
- B. *Use of an equalizer beam*
- C. *Use of a spreader frame*

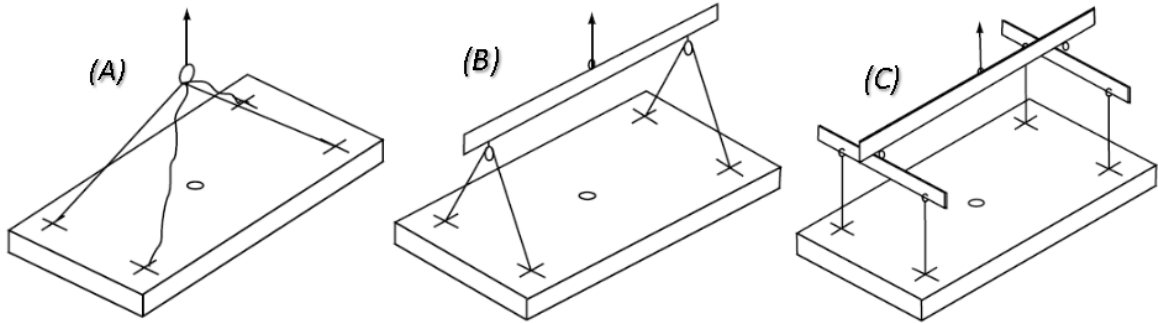


Figure 6.13: Alternative Rigging Methods

The first method (Figure 6.13a) provides more flexibility to adjust and rotate the panel while lowering it in the pit. This method was used to rig the precast panel at FSU test site, and it was found to be suitable to maneuver a 6' x 6' panel (Figure 6.14). However, the disadvantage of this method is the constant horizontal adjustment that is required of a larger precast panel when lowering it in the pit. The equalizer beam and the spreader frame methods provide better stability (Figure 6.13 b and c) in the rigging process, but the flexibility of rotating the panels is more restricted in these cases.



Figure 6.14: Use of a four-sling-lift method and a boom crane at FAMU-FSU test site

Prior to installation in the test pit at the test track; the panels went through multiple lifting and lowering cycles. These maneuvers were performed to test the robustness of the anchors, speed of the handling method, and the adequacy of the structural design of the panels.

After completing multiple handling and moving maneuvers, no cracks or damages were observed in both panels. The two panels were then lowered and positioned inside the replacement test pit as shown in Figure 6.15. The process of lowering each panel took about 10 min. to complete. A faulting of about ¼” was measured at the joints between panels and with the surrounding pavement. This faulting may be considered acceptable since the precast panels are temporary fillers in the slab replacement pits with installation period not exceeding one week.



Figure 6.15: Placement of the two precast panels

At jobsites and with the proper equipment, adequate tools, and practical experience, the process of installing the panels in slab replacement pits would not require more than 10 min. In addition, it should be noted that proper leveling of the surface of the soil underneath the precast

panels is important to establish a uniform contact area and to prevent any “rocking” action of the panels. A proper leveling tool would be recommended to ensure a uniformly leveled bottom of the pit. The leveling course, compacted by the weight of the panels and traffic, should remain in place prior to casting the replacement slab.

6.2.4 Instrumentation and test loading the panels

With the two precast panels installed in the test pit, eight LVDTs were placed at key locations on the surface of the panels as shown in Figure 17. The LVDTs were intended to measure panel movements under the truck wheel loads, and during the braking maneuver of the truck on the panels. The movements of the panels were monitored in the vertical and horizontal directions, and were recorded using a data acquisition system controlled by a laptop computer. Each LVDT was instantaneously monitored using external readout units placed on the two sides of the test section to obtain real time displacement readings during the load testing.

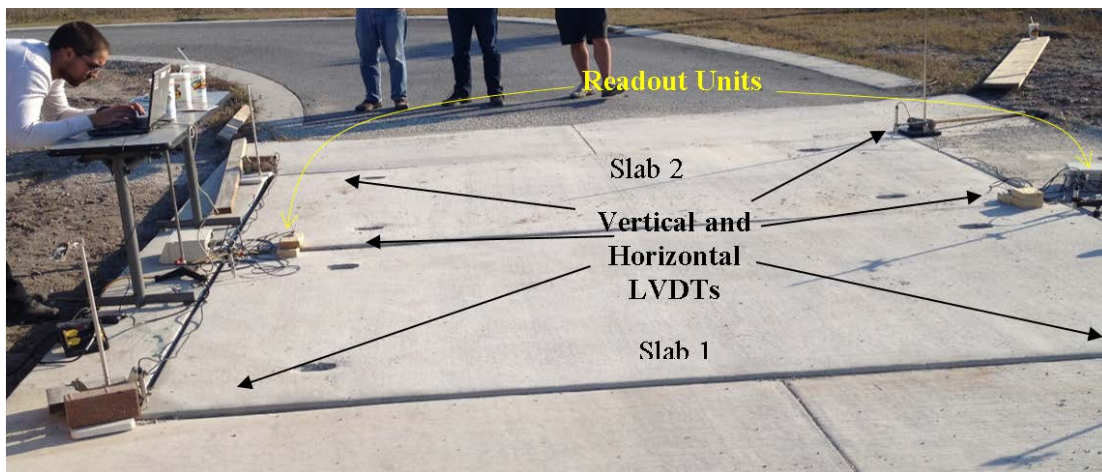


Figure 6.16: Instrumentation of the precast panels

A 60,000 lb. concrete pump truck was used to load the precast panels as shown in Figure 6.17. The wheel configuration included single and double tandem axles. According to the truck

specifications, the front axle carried $\frac{1}{4}$ (15,000 lb) of the total weight and the rear axles supported the remaining $\frac{3}{4}$ (45,000 lb) of the truck weight. This truck represents one of the heaviest on urban streets.

The truck made 50 passes on the panels. It traveled at a speed lower than 10 mph on the precast panels. The movements of the panels were being observed, and the vertical and horizontal displacement measurements were being measured by the LVDTs. During the initial passes, some seating of the panels was noticed. However, upon subsequent passes, no further seating was detected.

The real time measurements from the readout units were helpful to determine which corners of the two slabs were moving more than the other corners. The LVDTs readings showed that the upper right corner of the second slab was displacing slightly in a vertical direction more than the other corners. In general, the panels did not rock under the weight of the wheels. This was an indication of a stable support generated by the striped bottom configuration of the panels and the effect of their initial panel seating in the leveling course.

The truck made additional passes traveling at 10 mph and then suddenly braking on the panels. This braking maneuver was intended to verify whether the panels were shifting horizontally as the truck suddenly braked on the panels. However, no noticeable shifting was detected. This was an indication of friction and interlocking action between the stripes at the bottom of the panels at the leveling course. The LVDTs were simultaneously capturing the vertical and horizontal displacements. The initial readings from the LVDTs confirmed the observations of some minor and insignificant movements in the horizontal and vertical directions after several loading cycles. Results of the field tests were analyzed and compared with the numerical modeling

results. These results will be presented in chapter 7.



Figure 6.17: Front and rear view of the truck used in load testing of precast panels

6.2.5 Removal of Precast Panels from the test Pit

The precast panels were left in the test pit for a period of 4 weeks prior to their removal. A day prior to casting the replacement slab, the two panels were removed using the same excavator used in the original installation. The removal of both panels took less than 10 min. However, during lifting of the precast panels, the corner of one of the panels was chipped off as a result of an impact with the surrounding concrete (Figure 6.18). With proper equipment and experience, the removal of panels from the slab replacement pits should be accomplished in less than 5 min. without any damage to the sides of the panels or to the surrounding pavement. This experience brought attention to the need to use better and more effective handling methods, since the panels would be re-used multiple times in the rehabilitation projects.



Figure 6.18: Damage to one of the precast panels during removal

6.3 SCC Mix - Field Evaluation

The efforts prior to this task were focused on preparing an SCC mix with high workability, flow rate and high-early strength. These results were achieved and verified at the materials laboratory of the FAMU-FSU College of Engineering. The final mix design presented in chapter 5 is shown in Table 6.1. All mixes were batched in the lab using a 4ft³ concrete mixer. The workability of each mix was tested immediately after adding and thoroughly mixing the accelerator using the slump flow and T20 test methods according to ASTM C1611/C1611M-14.

Table 6.1: SCC final mix design

Ingredients	Mix lb/yd³	Description
Cement	830	Type I/II cement used – AASHTO M85
Coarse Aggregate	1625	Limestone grade size 57
Fine Aggregate	1224)	Silica sand
Mix Water	280	Mix water adjusted to aggregate moisture and water content in the accelerator admixture
W/C	0.34	
Admixtures	fl oz/yd³	

Workability Retainer	42	ASTM C 494/C 494M, Type S, specific performance admixture
HRWR - Polycarboxylate	50	ASTM C 494, Type A, water-reducing, and Type F, high- range water-reducing admixture
Accelerator	473	ASTM C 494 Type C, accelerating, and Type E, water- reducing and accelerating, and admixture.
Water Reducer & Retarder	42	ASTM C 494/C 494M, Type A, water-reducing, Type B, retarding, and Type D, water-reducing and retarding admixture

The 12' x 12' x 8" replacement slab at the test track pit required the preparation of 4 cu yd. of SCC mixed at a batch plant and transported to the jobsite. The research team were aware that conditions are quite different when batching the SCC mix at a batching plant as compared to laboratory conditions. The main difference is the large volume of the mix (4 cu. yd.) batched at the commercial batch concrete plant in a 10 cu yd. truck mixer compared to batching at a 4 cu. ft. in a university laboratory. Also, transportation time between the batch plant and test track was estimated between 45 to 60 min. This would affect the SCC workability. Also, upon arrival to the jobsite the accelerator would be added which requires special handling to the truck mixer to avoid quick setting of the concrete inside the mixer before discharging the entire load of concrete. The primary issues that had to be addressed in batching the SSC mix at the concrete plant were the following:

1. Maintaining workability over an extended period following the mixing of the accelerator in the SCC mix.
2. Impact of changing material sources.
3. Differences in moisture conditioning of materials at the concrete plant compared to the FAMU-FSU laboratory with respect to SCC plastic and hardened properties.
4. Determining the extent of workability loss in the SCC mix during the transportation period

from the plant to the jobsite.

5. Extent of workability retention after the addition of the accelerator at the jobsite.

6.3.1 Verification of Workability Retention at FAMU-FSU Laboratory

To address the above issues, tests on freshly mixed SCC were performed to evaluate the workability of the mix over a period of 60 min. after mixing in the accelerator. During slab the replacement process at jobsites the SCC mix has to be transported from the batch plant to the casting place. Transportation requires a considerable amount of time ranging from 45 to 60 min. At the jobsite, the accelerator is usually added to the truck mixer, followed by an additional mixing before casting the slabs. After casting the first slab, the truck mixer will be idle for a few min. and continue its revolutions in an agitation mode while traveling to the next slab.

To simulate the impact on the SCC workability as a result of truck idle time, it was decided to evaluate the slump flow of the mix for 60 min after addition of the accelerator. To verify the workability retention, laboratory tests were performed on two batches B1 and B2 using the same mix design in Table 6.2. The evaluation involved performing the slump flow and T20 tests at different time intervals over a period of 60 min. After completing the batching sequence and performing the initial slump flow test on the SCC mix, the speed of the revolving mixer was reduced to simulate a case of an idle truck mixer in an agitation mode. Also, the mouth of the mixer was covered with a plastic sheet to prevent evaporation of the mix water.

Concrete temperature inside the mixer was regularly monitored between the slump flow tests using an infrared thermometer device as shown in Figure 6.19. This was to determine if the addition of the accelerator would cause an increase in cement hydration while the concrete mix was in the agitation mode. A significant increase in concrete temperature would have indicated a

high level of hydration which would lead to loss of the concrete workability. The concrete temperature during this test period increased by only 2°F.



Figure 6.19: Temperature measurement of SCC mix

Table 6.2 shows the test results for the slump flow and T20 for B1 and B2. The slump flow was consistently retained above 20 inches, and the T20 was about 4 seconds or less for the duration of 60 min. The test results demonstrated the ability of the SCC mix to retain its workability for at least 45 to 60 min. after the addition of the accelerator maintaining a continuous and uninterrupted agitation of the mix.

Two possible explanations are offered for the workability retention ability of the SCC mix after the addition of the accelerator. First, the nonstop agitation of the mixes allowed the workability retainer, thig-range water reducer, and set retarder admixtures to reach their maximum impact. Second, the continuous agitation may have prevented an early negative impact of the accelerator on the SCC mix setting time and workability. This was further demonstrated by the stable temperature of the agitated concrete inside the mixer. However, after completing the slump flow

test, it was noticed that the remaining mix leftover in the wheelbarrow started immediately to lose its workability. This was another indication that the accelerator had an immediate and quick impact on the workability when the SCC mix became stagnant.

Table 6.2: Slump Flow and T20 Test results

Time	B1		B2			
	Slump Flow		T20	Slump Flow		T20
0 *	20	(480)	9	22	(550)	1
10	28	(710)	2	-----	-----	----
15	----	-----	----	24	(600)	2
20	29	(737)	2	-----	-----	----
25	-----	-----	----	27	(675)	3
30	28	(700)	2	-----	-----	----
35	-----	-----	----	29	(725)	3
40	26	(648)	3	-----	-----	----
50	22	(546)	4	-----	-----	----
60	15	(380)	> 10	29	(725)	3

** This test was performed after 6 min. from adding accelerator and remixing*

Also, during the slump flow tests, the SCC mix seemed to maintain good cohesion with no noticeable segregation as evident from Figure 6.20. The absence of any visible segregation may have been the result of using a proper dosage of the workability retaining admixture. This finding was even more interesting when considering the fact that grade 57 aggregate was used in the mix. This size of aggregate is considered by industry to be the upper limit of any coarse aggregate size allowed in SCC mixes before segregation will most likely occur.

Argos Ready Mix Company provided support to the research team by offering to supply the concrete for the replacement slab at the test track. The research team and Argos staff

conducted additional trial batches of the SCC mix at their concrete plant in Jacksonville. The aim was to repeat the workability retention performance of the SCC mix using materials from the Jacksonville area, before batching 4.5 cu. yd. mix quantity needed to cast the replacement slab at the test track.



Figure 6.20: Slump flow test

Using the SCC mix shown in Table 6.1, five 1.25 cu ft. trial batches were prepared and tested using the Argos concrete plant materials, equipment and testing lab, as shown in Figure 6.21. The five batches were necessary to prepare a sufficient quantity of concrete for the multiple slump flow tests and cast cylinders for subsequent compressive strength tests.



Figure 6.21: Trial batches at Argos concrete plant in Jacksonville

The same batching sequence was followed in all five-trial batches, using the same aggregates and cement. The as-batched water content had to be changed for the different batches, since the free moisture of the sprinkled aggregate-pile changed during the four-hour batching period. In addition, fine white material was present with the coarse aggregate obtained from the interior of the pile, which retained more free moisture compared to the free moisture content measured from the pile specimen. It was noticed that the fine aggregate in Jacksonville plant had different specific gravity than the aggregates used in the FAMU-FSU trial batches.

Variability in material moisture condition is to be expected during a production day at concrete plants. This presented a unique opportunity to test the flexibility of the designated SCC mix in achieving the same range of workability and early strength values at a production plant compared to a small mixture in a controlled environment of a university laboratory.

The ambient temperature during the five trial batches ranged from 75° F to 78° F and the concrete temperature in the mixer was about 80° F. All batches included the same accelerator with the exception of batch 1, where no accelerator was added. Also, due to the small size mixer, it was

not possible to prepare sufficient specimens for the workability and for all necessary strength tests.

The slump flow/T20 tests, as well as the 4 and 6 hr. compressive strengths tests were performed at the Argos plant laboratory, while the 9 hr. tests were performed at the FAMU-FSU laboratory. Results of the slump flow/T20 tests and the compressive strengths for the five trial batches are shown in Table 3.

Despite the variability in the moisture content of aggregates, the slump flow test results ranged from 20 to 30 inches. These measurements were retained for at least 40 min. after mixing with the accelerator and maintaining agitation of the SCC mix. The concrete temperature during the agitation period did not increase to indicate any significant hydration of the concrete inside the rotated mixer. This was another validation of the FAMU-FSU laboratory test results which showed when SCC was in continuous agitation mode, the concrete mix retained its workability.

Table 6.3: Test results at Argos plant trial batches

Batch No.	Slump Flow (in)		T20 (sec)	Compressive strength (psi)	
1*	28	(0)**	4	1,868	(9)**
	21	(30)	5.5		
2	30.5	(0)	4	4,863	(9)
	30	(10)	4		
3	28.5	(20)	3	1,212	(4)
	30	(30)	2	2,459	(6)
4	20	(30)	4	3,584	(6)
	27	(40)	4		
5	20	(0)	1	3,990	(6)
	14	(60)	14		

* No accelerator was added to the mix.

** Values in () are times in minutes after mixing for the slump flow test, or in hours for compressive strength tests.

The compressive strengths after 6 hr. for mixes 4 and 5 were greater than 2,200 psi required by the FDOT specification. In Mix 3, the compressive strength was much closer to the required FDOT strength. This was a result of the presence of excessive moist fines in the coarse aggregate. Nevertheless, the Jacksonville batch plant results proved that the SCC mix had the flexibility to accommodate variabilities in commercial concrete plants while still meeting the FDOT strength requirements. It should be noted that the 9-hour specimens in batches 1 and 2 were transported from Jacksonville to Tallahassee and tested at the FAMU-FSU labs due to the closing of the Argos lab at the end of that workday.

6.3.2 Casting of Replacement Slab in Test Pit at Test track

With the confidence generated in the SCC mix during the trial batches at the Argos plant, it was decided to batch a 4.5 cu yd. mix at the closest concrete plant to the test track using the SCC mix shown in Table 6.1. All the ingredients and the admixtures with the exception of the accelerator were batched in the same sequence of the trial batches at the plant. The mix water was adjusted to account for the free moisture in the plant aggregate. Also, a certain quantity of the mix water was withheld to partially account for the water content of the accelerator at the casting site, and to retain sufficient quantity in case the mix required more water to achieve the required workability at the site.

It was important to achieve an initial slump flow of at least 16 in at the batch plant in anticipation of some drop in the slump during transportation of the concrete to the test track. Once the accelerator was added, the slump was expected to elevate to a range from 20 in to 28 in. That would be have been sufficient to sustain the workability for at least 30 to 40 min. and to simulate a situation of multiple discharges and idle periods experienced by the truck mixers at jobsites.

The SCC ingredients for the 4.5 cu yd. mix were batched on April 10, 2015, at 9:30 AM when the ambient temperature at the concrete plant was 78° F. After mixing the ingredients, the slump flow was measured at 25 in and T20 at 4 sec. It took about 45 min. to transport the SCC mix to the test track. At the test track, a second slump flow was performed and measured 19 in. This was a reduction of about 6 in. from plant slump measurement. The accelerator was then added to the mixer, as shown in Figure 6.22, followed by 5 min. of remixing. A third slump flow test was performed and resulted in 21 in. spread in 5 seconds.

Immediately following the slump flow test, the truck discharged the SCC mix to fill the

12' x 12' x 8" replacement slab pit, as shown in Figure 6.23. The mix was cohesive and rushed down the mixer chute at a high velocity. No segregation was noticed as the mix moved swiftly and uniformly in all directions to fill the pit.

It took 3 min. to fill the entire test pit. Compared to conventional concrete casting with high-early strength mix, the SCC mix showed excellent performance at a much higher discharge rate with no segregation. Once it settled in the pit, the mix started to set quickly, and its temperature elevated rapidly.



Figure 6.22: Addition of the accelerator at the track



Figure 6.23: Discharging SCC mix in the pit to cast the replacement slab

It was not possible to attain a smooth surface finishing because of the lack of professional finishers at the site (Figure 6.24). However, on job sites with abundance of skilled labor and proper finishing equipment, the slab would have been poured and properly finished in less than 10 min. This fast rate of placement will contribute to a much higher productivity compared to conventional, low –slump, high-early strength, concrete mixes.

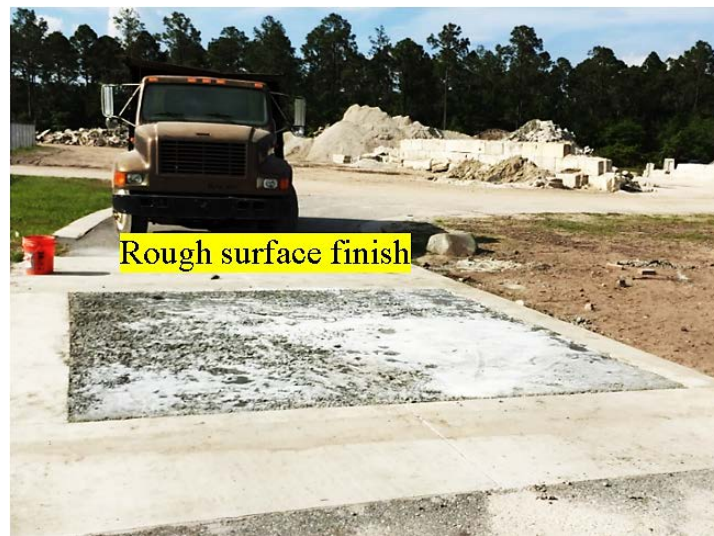


Figure 6.24: Surface finish of replacement slab

It is important to note that once the accelerator is added, the mixer has to continue in non-stop agitation mode, when not discharging concrete, with slightly higher revolution speed than conventional agitation speed, until completely discharging its SCC load. If the mixer is allowed to slow down or stop, the concrete will likely set inside the mixer and may require an elaborate and possibly expensive process to dislodge the hardened concrete from inside the mixer drum.

Managing the appropriate quantity of the accelerator and without holding the mix water in SCC mix for slab replacement is very important to achieve the full advantages of SCC mix use in

a replacement slab. Based on the team's experience, it is recommended that the amount of accelerator be reduced when the ambient temperature exceeds 85° F. This may not be an issue during cool night paving. However, in daytime paving under hot weather, an excess amount of accelerator could affect the mix performance with respect to a shorter setting time and rapid loss of workability. The high ambient temperature at the job site will increase in the rate of concrete hydration and the concrete temperature. This can be controlled by withholding a certain percentage of the accelerator from the mix without affecting the rate of early strength gain.

At the test track, six 6"x 12" cylinder specimens were cast to be tested at 4 and 6 hr. Also, the slab was covered with a plastic sheet to maximize curing and to achieve high-early strength, as shown in Figure 6.25. The temperature of the concrete was monitored intermittently, using an infrared laser thermometer and a thermal camera. The maximum surface temperature reached about 135° F.



Figure 6.25: Slab curing with plastic sheet

The six concrete cylinders were transported to Argos laboratory for testing. However, due to the limited access to the laboratory after work hours, only three cylinders were tested after 4 hr. The remaining 3 specimens were transported to FAMU-FSU labs, and were tested after 3 days. The average 4 hour compressive strength of the cylinders was 1,400 psi. The temperature measurements were used to estimate the compressive strength of the SCC at the test track using the maturity relationship of the mix, as will be explained in chapter 7.

6.3.3 Truck Loading of Replacement Slab

Six hours after SCC placement, the replacement slab was loaded using a 25,000 lb truck as shown in Figure 6.26. The truck had single front and double rear axles. The truck represents a typical heavy construction or utility truck on urban streets or county roads. The truck made 100 passes on the slab. During the truck laps, the slab was wetted frequently and checked for crack. No cracks were detected. The 100 passes were completed in about one hour. A final close examination of the slab surface did not reveal any damage or cracking in the slab.



Figure 6.26: Load testing of the replacement slab using a 25,000 lb truck

Following the truck loading, the slab was marked for core sampling later. Nine cores were obtained from different locations including the corners, edges and center of the slab. At the FAMU-

FSU laboratory, the cores were examined to determine if any segregation had taken place during casting of the slab. No segregation was detected as evident from the close up in Figure 6.27. However, minor bug holes were present on the surfaces of the cores. The samples were later tested at 28 days. The average strength of concrete at 28 days was 10,140 psi.



Figure 6.27: Core samples from the replacement slab – no sign of any segregation

6.4 Conclusions

The field tests demonstrated the efficiency of the proposed method of using temporary reusable precast panels and SCC mix. The method allows the preparation of a large number of replacement slab pits that would be fitted with temporary and re-usable precast panels. The panels would be retained for a short period ranging from one to seven days. Once the panels are removed from the pits, dowel bars are retrofitted, and then SCC mix is used to cast the replacement slabs in a shorter time compared to conventional high-early-strength concrete mixes.

The SCC mix can be duplicated at commercial concrete plants, transported to the site, and rapidly discharged to cast the replacement slabs without the need for manual spreading or vibrators.

A surface finishing equipment may be needed to properly finish the slab surface. The SCC mix was determined to be very cohesive during discharge. When batched properly, the SCC mix will not segregate, despite the use of grade 57 coarse aggregate in the mix. The cast slab showed no sign of shrinkage or thermal cracking. The compressive strength at 6 hr. exceeds by far the 2,200 psi strength required for lane opening. In fact, with this mix the concrete may reach the required strength in 4 to 5 hr., which would allow more time to achieve higher productivity.

CHAPTER 7

FILED TESTING AND MODELING

7.1 Introduction

Three field tests were performed in this study. Two of these tests were at the FAMU-FSU site and were described in chapters 4. The third field test was performed at the test track in Green Cove Springs as was described in chapter 6. These tests were conducted over an extended period at different locations, and the outcomes varied depending on the purpose of each field test. The tests are described in Table 7.1.

In this chapter, results and observations from the three test sites are presented and discussed. Additionally, the test results are compared with the analytical results obtained from Finite Element Analysis (FEA) using ANSYS 14.5. Material properties used in the FEA were assumed to be linear-elastic.

Table 7.1: Slab Replacement Field Tests

Location		Precast Slab Size	Test Pit Size	Leveling Course at the base	SCC Materials	Purpose of the Test
FAMU-FSU		One 6'x 6'x 9"	6'x 6'x 9"	Builder's Sand	Argos, Tallahassee	- Constructability and Performance of the precast slab in the test pit under traffic load
Green Cove Springs Test Track		Two 6'x 12'x 8"	12'-3"x 12'-3"x 8"	Fine Recycled Concrete	Argos, Jacksonville	- Constructability and Performance of the precast slabs in the test pit under traffic load - Workability retention and performance of the SCC mix in the field
FAMU-FSU		One 6'x 6'x 9"	6'x 6'x 9"	Builder's Sand	A-Materials, Tallahassee	- Workability retention and performance of the SCC mix in the field

7.2 Performance of the Precast Panels Under Truck Loads

7.2.1 Instrumentation of Panels at Green Cove Springs Test Track

At the Green Cove Springs test track, two 6'x 12'x 8" precast panels were fabricated on site and installed in a 12'-3"x12'-3"x 8" replacement-slab test-pit at the Green Cove Springs Test Track. The panels were subjected to 50 loading cycles of a 60,000 lb. concrete pump truck traveling at a speed less than 5 mph, to produce vertical displacement in the panels. Also, occasionally, the truck was making a braking maneuver to induce horizontal shifting of the panels.

Vertical and horizontal displacements were monitored during the repeated truck loading of the two precast panels using LVDTs. The displacements were also determined analytically using Finite Element Model, ANSYS 14.5. The objective of measuring the panel displacements was to determine the effectiveness of the proposed panel design in resisting movements under the truck loading, and to establish if impact occurs at the joints between the panels and with the surrounding pavement because of horizontal movement of the panels.

Eight Linear Variable Differential Transformers (LVDTs) were installed on the panels to measure the vertical and the horizontal displacements, as shown in Figures 7.1 and 7.2. Six LVDTs were positioned to measure vertical displacement panels. The LVDTs were connected to a data acquisition system and a laptop to capture and record the displacements. Two additional readout units were also used to provide real-time monitoring of the vertical and horizontal displacements. These instant readings from the units were helpful to guide the truck during loading and braking actions. Because of the proximity of the LVDTs to the truck wheels, the speed of the truck was maintained below 5 mph in order to avoid any accidental collision between the truck wheels and the LVDTs. The truck was guided on a specific path to keep it away from the LVDTs. Because

of the distance between the front and the rear axles, it was not possible to have the full truckload (60,000 lb.) on one panel at one time.

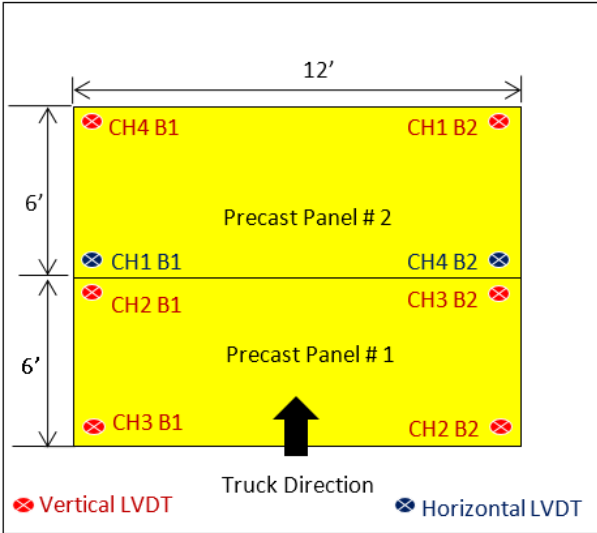


Figure 7.1: Schematic plan of instrumentation of the precast panels

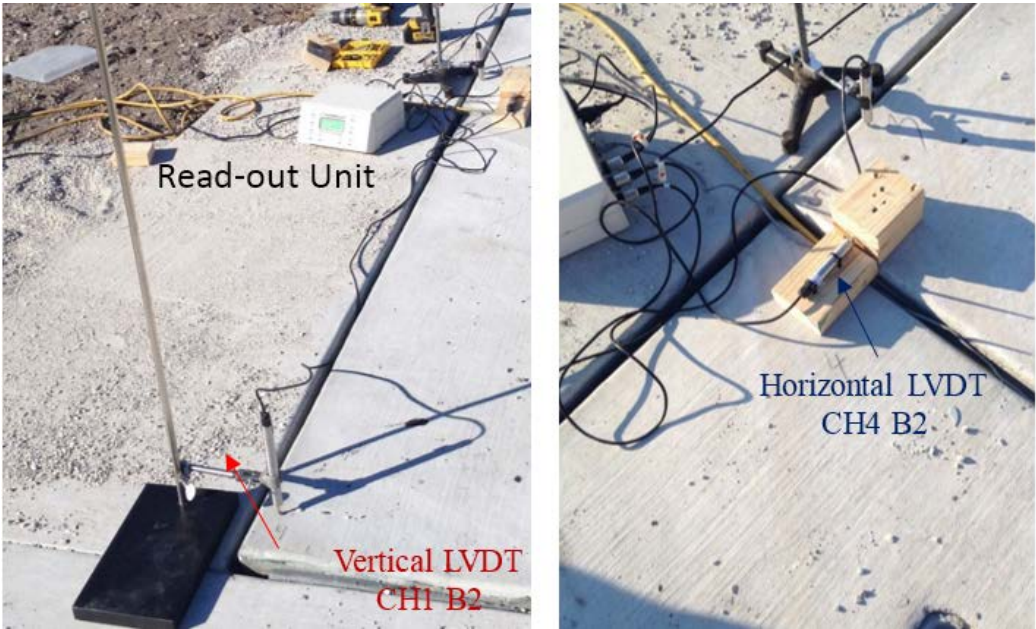


Figure 7.2: Vertical and horizontal LVDTs on the precast panels

7.2.2 Truck loading

As mentioned, a 60,000 lb. concrete pump truck was utilized to apply both vertical wheel loads and horizontal braking loads on the precast panels, as shown in Figures 7.3 and 7.4. The truck had a single axle under the cabin and tandem double axles in the back. The loading ratio of the front to back axles was 1:3. Accordingly, the vertical load on the front and rear axles were 15,000 lb and 45,000 lb respectively. Figuring out the load distribution pattern was necessary to simulate the proper boundary conditions and forces in ANSYS 14.5 finite element modeling.



Figure 7.3: Concrete pump truck loading precast panels



Figure 7.4: Configuration of LVDTs and wheel loads

During displacement monitoring, it was noticed that after a few loading cycles on the vertical displacements of the panels started to stabilize, an indication of firm seating of the panels in the pit. This was noticeable for measurements from LVDTs CH4-B1, CH2-B1, CH3-B1, CH3-B2, CH2-B2, and CH2-B2 as shown in Figure 7.5. The vertical displacement measurements averaged from 0.11 to 0.30 in. With respect to the horizontal displacement, it was noticed that driving the truck over the panels did not produce significant horizontal displacements (Figure 7.6). The horizontal displacement measurements were induced by the moving truck and averaged from 0.01 to 0.03 in. It should be noted that these displacements did not count for the horizontal displacements due to truck braking.

The profile of the vertical displacements is shown in Figure 7.7. These measurements suggest that the permanent settlement “panel seating” under traffic loads upon lane opening would almost cease after a few load repetitions from the passing trucks. It is possible that the reduction in the settlement rate after a few cycles was due to a combination of the heavy weight of the precast panels (8500 lb/panel) and multiple load application of the truck. Cyclic loading increased the compressibility of the soil, and hence increased the stiffness of the base layer underneath the slabs.

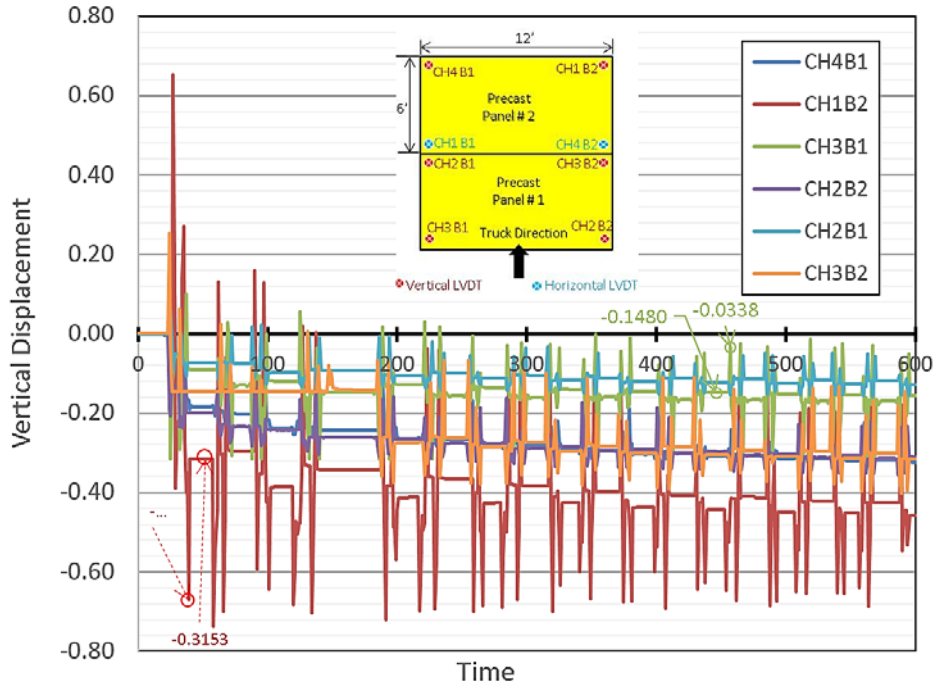


Figure 7.5: Vertical displacements of the two precast panels

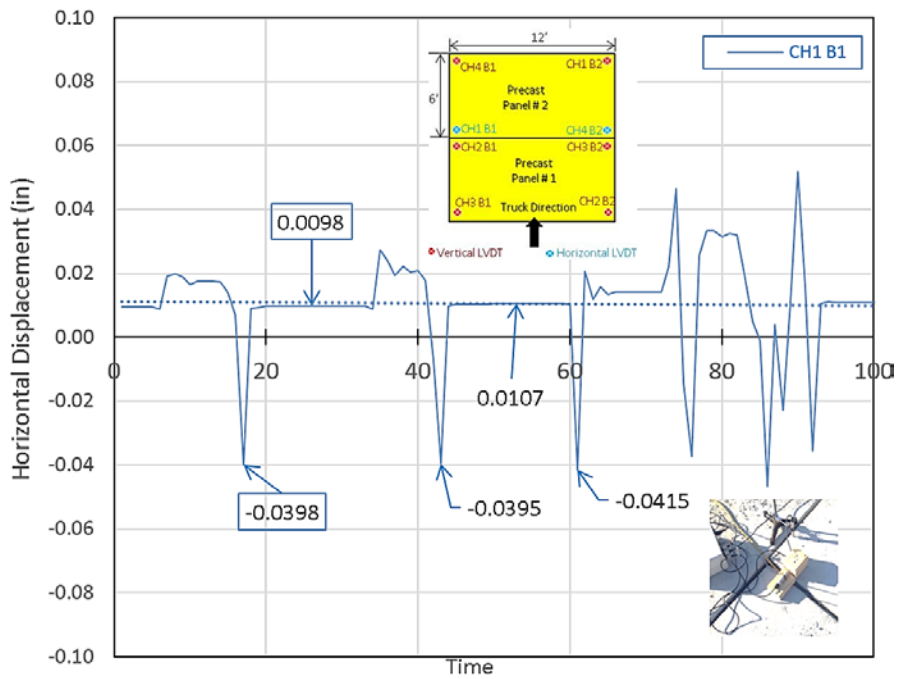


Figure 7.6: Horizontal displacement of precast panel 2

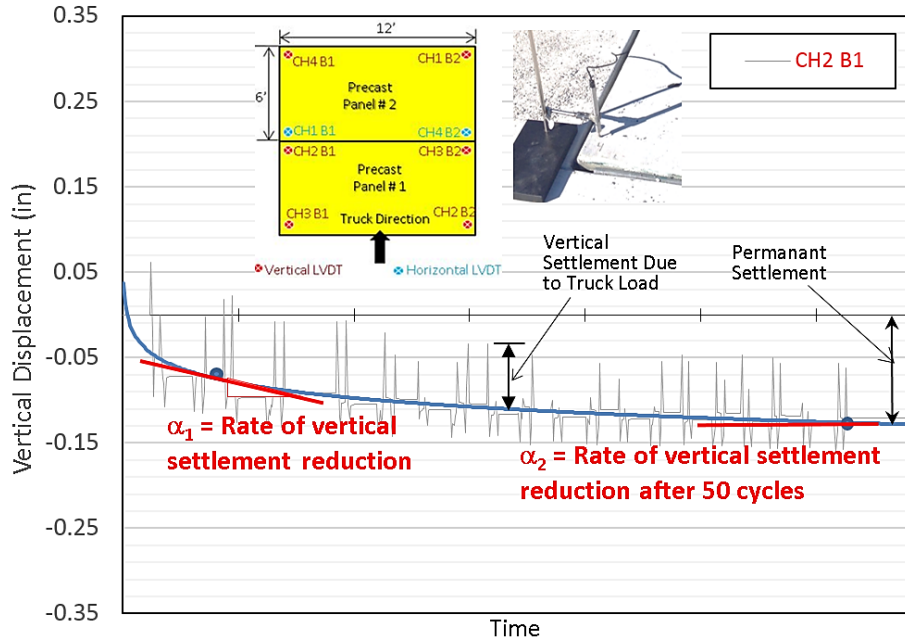


Figure 7.7: Profile of vertical displacement of precast panel 1

The joint faulting was less than 3/16" after the completion of the 50 loading cycles. This faulting is considered acceptable since the function of the panels in the proposed system will be as temporary placeholders prior to casting the permanent slab replacements. Also, it was noticed that there were no permanent vertical or horizontal displacements in the panels after sudden braking of the truck as indicated in Figures 7.8 and 7.9. This demonstrated the efficient design of the precast panels and stability of the leveling course. The four 8" wide recessed stripes at the bottom of each panel formed ridges on the surface fine recycled aggregate leveling course. These ridges provided interlocking action and frictional resistance at the interface between the panels and the base layer. Upon removing the precast panels, the striped impressions in the leveling course were intact indicating little, if any, horizontal shifting of the panels had occurred, as shown in Figure 7.10. This suggested the fine recycled aggregate layer experienced some densification and re-cementing during the repeated load application. This increased stiffness led to the reduction in the panel displacements.

The vertical and horizontal displacements due to sudden braking were about 0.18 in. and 0.03 in, respectively. The presence of the recessed stripes at the bottom of the panels and backer rod foam around the perimeters of the two panels may have contributed to the low horizontal displacements. It should be noted that the backer rod would most likely act as a cushion in case of any impact between the adjoining panels or at joints with the surrounding pavement.

This field demonstration validated the robustness of the precast panel design features. The reinforced panels would resist cracking during handling and multiple installations. The recessed stripes at panel bottom surface of the panel would contribute to more interlock and friction that would minimize horizontal movements. The backer rod would provide stability to the panels and preserve their structural integrity during multiple uses, as well as protect the surrounding concrete from damage during panel installation and from traffic action.

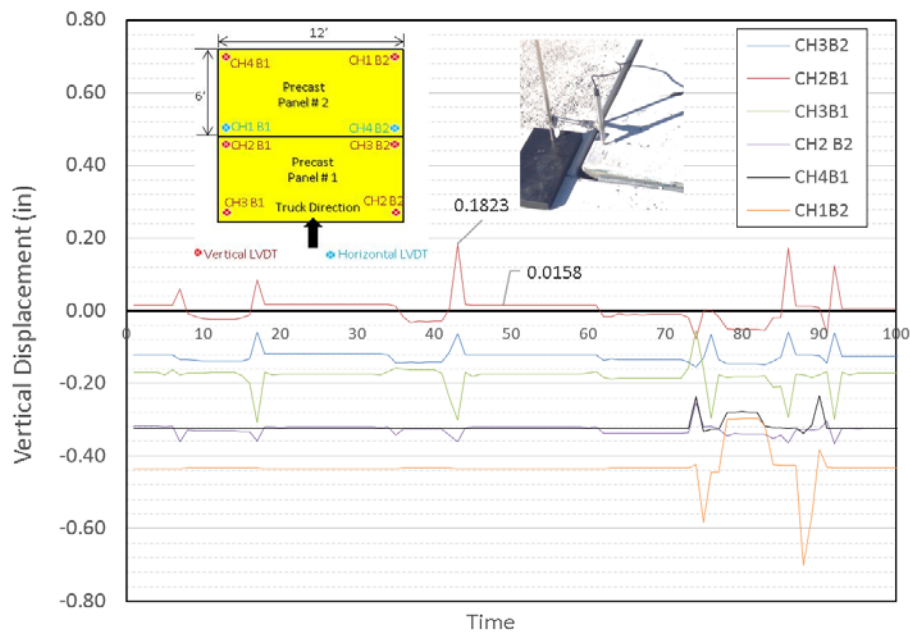


Figure 7.8: Vertical displacements in panels due to sudden braking

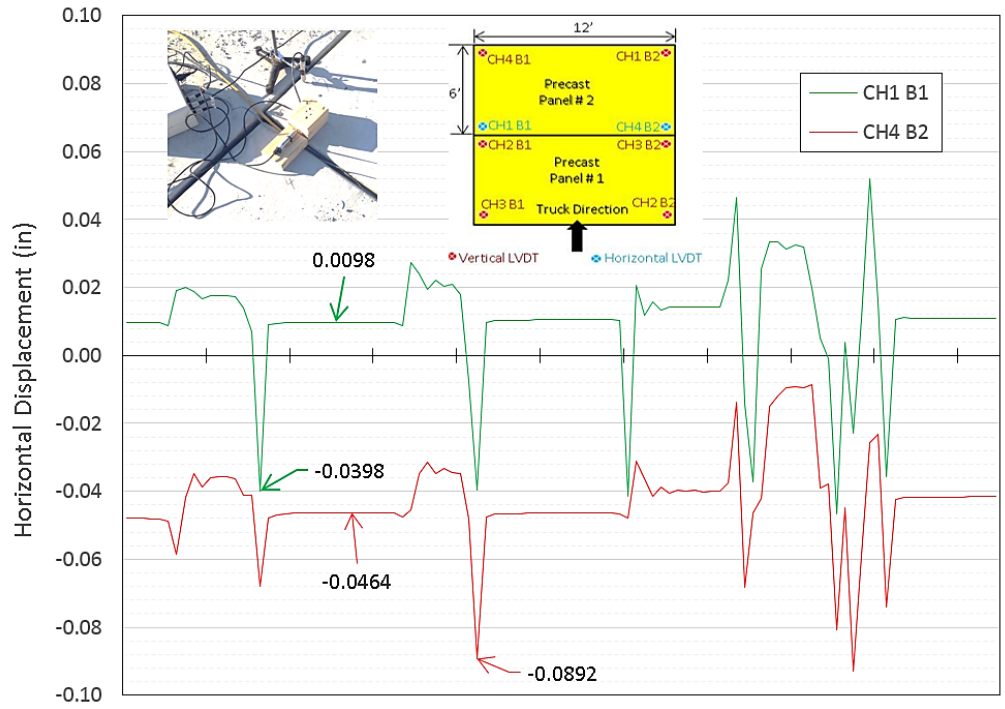


Figure 7.9: Horizontal displacements in panels due to sudden braking

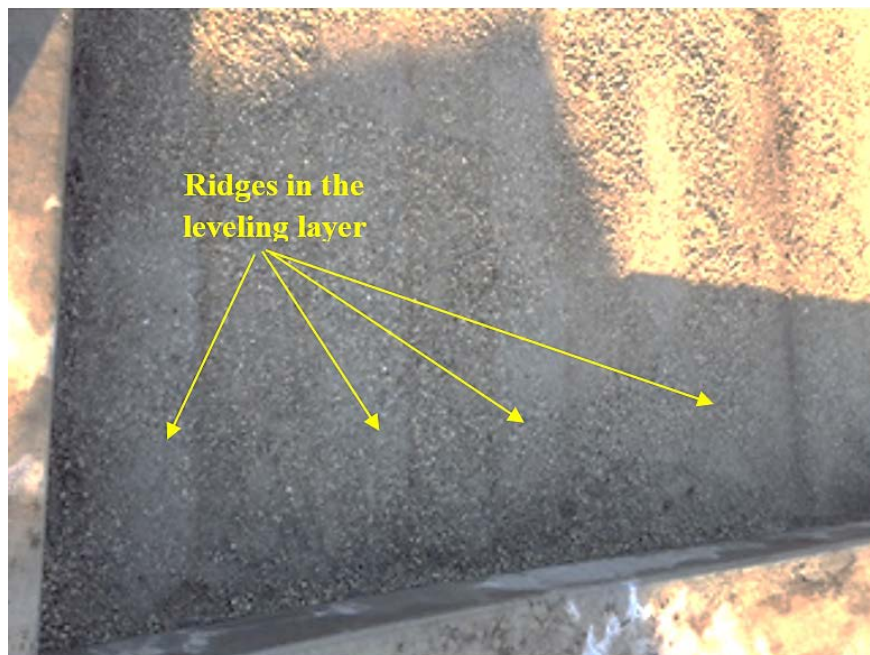


Figure 7.10: Imprints of ridged stripes on the surface of recycled aggregate leveling layer

7.2.3 Finite Element Analysis (FEA)

The finite element model ANSYS 14.5 used to predict the vertical and horizontal displacements in this task is the same model previously described in chapter 4 in predicting the deformation of the 6' x 6' x 9" precast panel at the FAMU-FSU site. Material properties in the FE model were assumed to be linear elastic. Therefore, permanent deformations of the soil underneath the slabs were not calculated from the analysis. Only elastic vertical and horizontal displacements were predicted from the model. The properties of the materials used in the FE model are shown in Table 7.2.

Table 7.2: Material properties in FE Model

Elements Properties	Concrete Slabs	Concrete Pavement	Base Layer	Subgrade Layer	Foam Gasket
<i>E</i>	2x10 ⁶ psi	2x10 ⁶ psi	4x10 ³ psi	1x10 ³ psi	50 psi
<i>μ</i>	0.2	0.2	0.35	0.4	0.4
<i>γ</i>	145 pcf	145 pcf	115 pcf	110 pcf	60 pcf

The loading conditions on the precast panels were modeled using only the wheel loads on the tandem-double rear axle of the truck as graphically displayed in Figure 7.11. The reason for not considering the front axle load was due to the dimensions of the panels, which did not accommodate both axles at the same time. Therefore, the heavier tandem axle was used in the model to apply the vertical and the horizontal loads as shown in Figure 7.12. The weight on each tire was applied as nodal forces on an approximate contact area of 6" x 6" for each tire.

The FE models were used to analyze the response of the panels under the wheel loads at locations similar to those used for the LVDTs in the field. The FE model consisted of 22,200 elements (Figure 7.12). The loads were applied assuming the rear-axle weight of 45,000 lb., which

was determined based on the 1:3 ratio of the front single axle to the rear tandem-double-axle of 60,000 lb. truck. The vertical and horizontal wheel loads were distributed on 32 nodal points at distances equal to the dimensions of the rear axle wheels.

Two models were developed to represent the two loading cases. The first model involved the application of vertical loads imposed by the weight of the truck on the tandem axle at the designated nodes. In the second model, the horizontal forces were added at the same nodes to simulate the condition of applying a sudden braking on the truck.

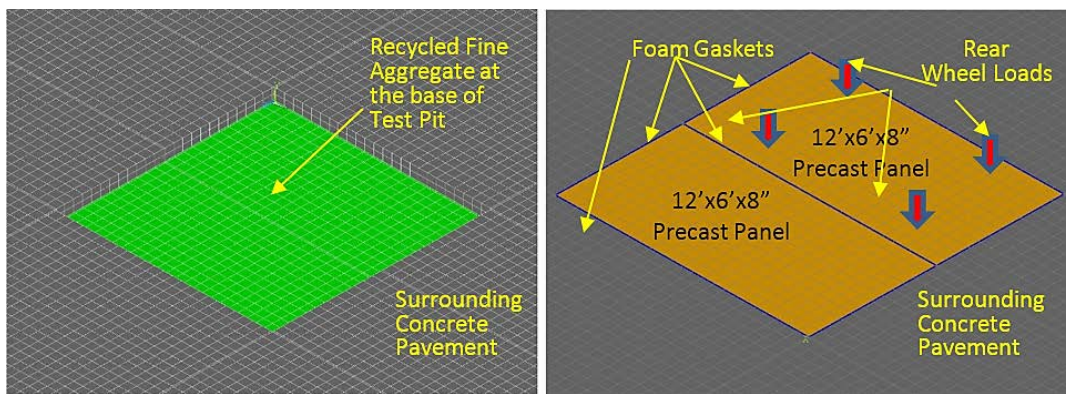


Figure 7.11: FEM of precast panels at Green Cove Springs test track

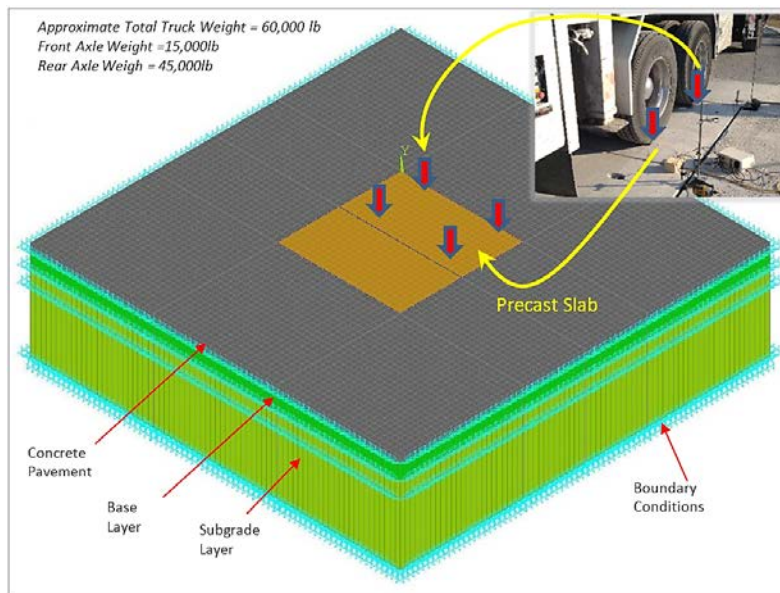


Figure 7.12: Load configuration of the FE models

The horizontal loads were calculated based on the friction coefficient given by Wang and Al-Qadi (2010) in Table 7.3. The rolling condition used in the current analysis was considered “Full Braking” and the friction coefficient (μ) was chosen to be 0.8. Accordingly, the horizontal force from the rear axil is as follows:

$$\text{Horizontal Force} = \text{Vertical Rear Axle Weight} \times (\mu) = 45,000 (0.8) = 36000 \text{ lb.} \quad (1)$$

Table 7.3: Friction coefficients at various rolling conditions ($\mu = 10\text{km/h}$) (Wang and Al-Qadi, 2010)

Rolling conditions	Friction coefficients	Maximum Contact Stresses			Maximum Stress Ratio
		Vertical	Transverse	Longitudinal	
Free rolling	$\mu = 0.3$	1056	223	65	1:0.21:0.06
	$\mu = 0.5$	1051	309	73	1:0.29:0.07
	$\mu = 0.8$	1067	391	81	1:0.37:0.08
Full Braking	$\mu = 0.3$	1053	14	316	1:0.02:0.30
	$\mu = 0.5$	1099	38	549	1:0.03:0.50
	$\mu = 0.8$	1144	73	915	1:0.06:0.80
Cornering (slip angle =1°)	$\mu = 0.3$	1157	277	73	1:0.24:0.06
	$\mu = 0.5$	1302	401	85	1:0.31:0.07
	$\mu = 0.8$	1432	485	95	1:0.34:0.07

Results from the finite element analysis of the vertical and horizontal displacements of the precast panels are shown in Figures 7.13 and 7.14. The maximum vertical displacement was predicted to be 0.11 in, and the maximum horizontal displacement was 0.02 in. These values were obtained by applying the wheel loads symmetrically on the modeled panels. In the field, however,

the truck wheel path may wander, which may result in larger displacements in the panels. This condition was not considered in the finite element analysis because of the fact that the actual path of the moving truck was restricted by the locations of the sensors on the panels.

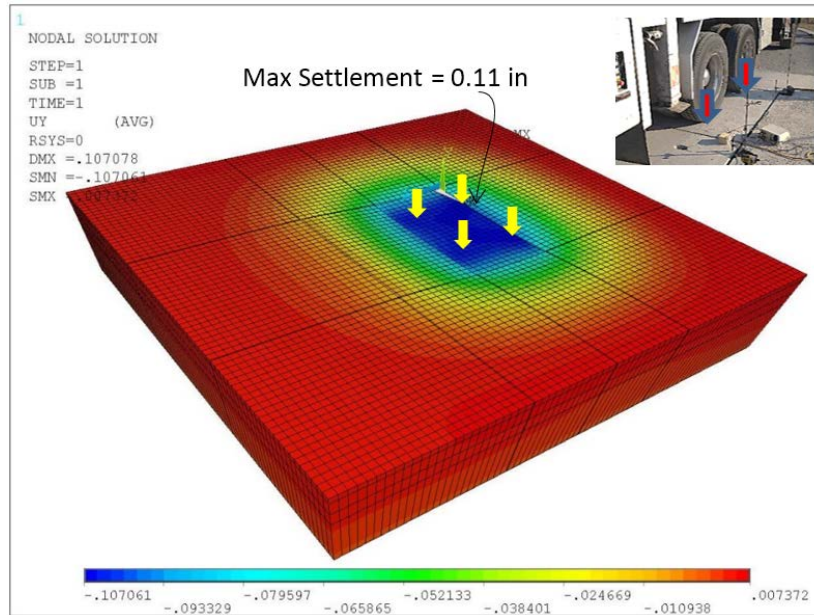


Figure 7.13: Vertical displacement of panel 2

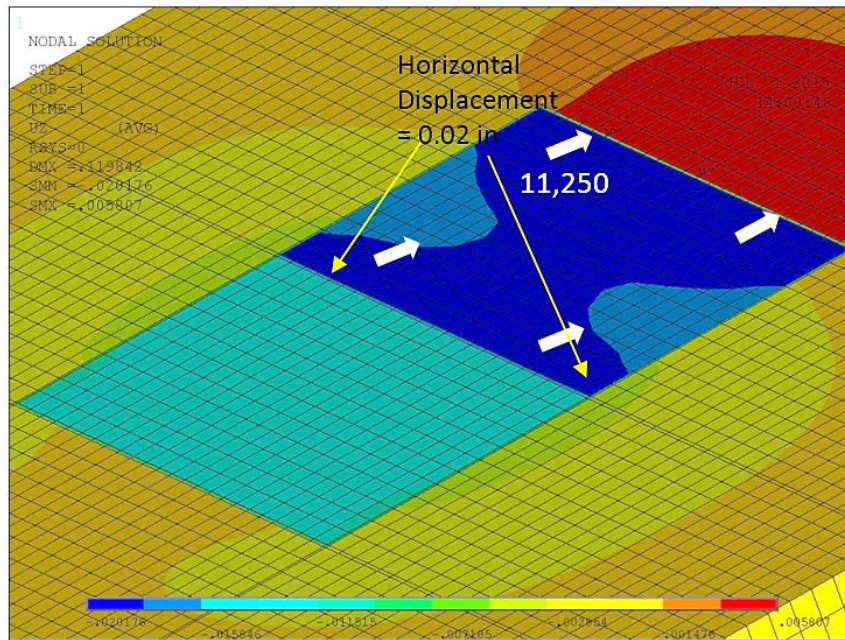


Figure 7.14: Horizontal displacement of panel 2

7.2.4 Field Test Measurements vs. Numerical analysis Results

The FEA results as compared with the actual LVDT measurements from the field load test are shown in Figures 7.15 to 7.19. Almost all the vertical measurements from the field showed the same pattern of settlement profile against the number of load cycles. The method of calculating the vertical settlements from each LVDT measurements was presented in Figure 7.7. Two types of vertical displacements were taking place simultaneously. The first type consisted of plastic settlement, which was decreased as the number of load cycles increased, and the second type was elastic settlement or recoverable vertical displacement, which followed the pattern of recurrent upward and downward spikes reflecting the movement of the truck over the panels. Also, the rate of vertical settlement (α_n) declined with the increase in the number of load cycles. This pattern indicated that the vertical settlements in the precast panels reached a stable condition after 50 cycles of loading. In other words, the soil underneath the panels experienced continuous compaction or permanent settlement under repeated loading. The average permanent settlement was about 0.225 in. The spikes shown in field measurements reflect the displacements from the repeated truck loading. These measurements indicated elastic vertical displacements of about 0.1 in. The maximum recorded vertical displacement was about 0.3 in. at the upper right corner of panel 2 (CH1 B2). At this particular location, it is believed that the leveling course was not graded properly which caused slight rocking in panel 2. Using a low cost leveling tool to even the surface could have eliminated such rocking in the precast panels. Proper leveling should be applied in all replacement pits, especially for pits wider than 6 ft. The precast panel at FAMU-FSU (6' x 6' x 9") test pit did not exhibit such rocking action during repeated load applications. In this test pit, a 6' long (2"x 4") straight edge and a torpedo level were used to level the builder's sand underneath the precast panel.

The FEA results showed that the maximum vertical displacement due to repeated truck loading was about 0.1 in. This value was comparable with the field measurements from the actual relationships of vertical displacement vs. number of load cycles. The FEA did not calculate any permanent settlement because of the elastic properties used in modeling the system.

The horizontal displacements due to sudden braking of the truck were also compared with the predicted results from the FEA (Figure 7.20). The field measurements showed an increase of 0.03 in. in the horizontal displacement and the FEA results predicted about 0.0096 in. displacement. The large field measurement was expected, because the FEA model did not simulate any sliding movement of the panels in the field.

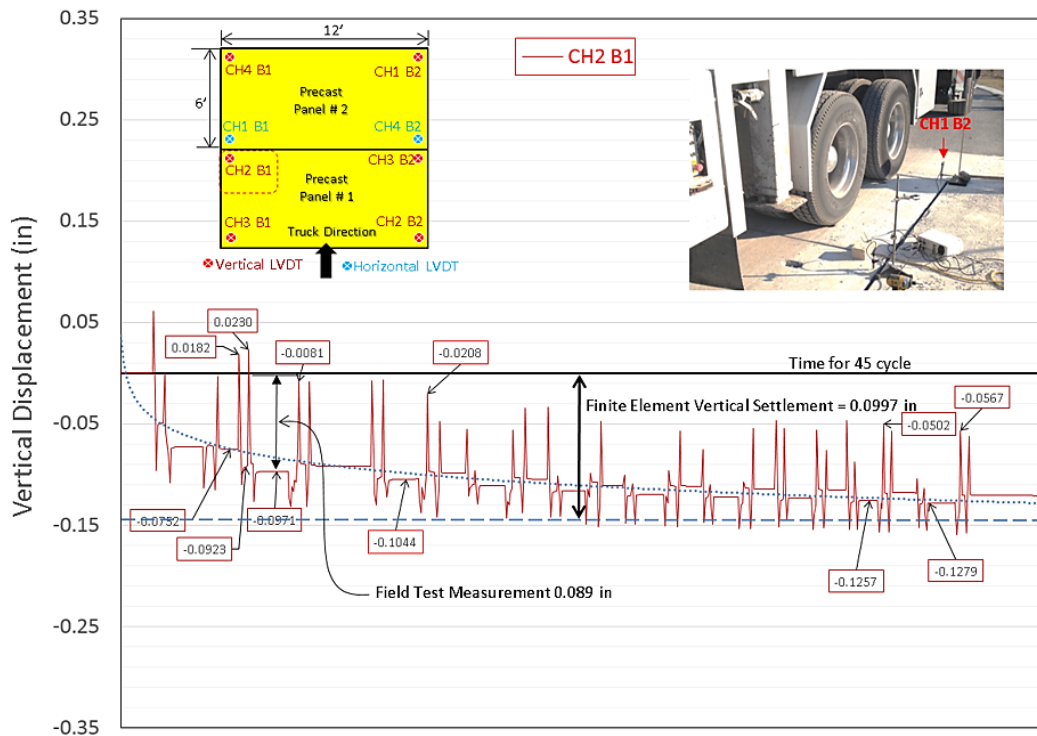


Figure 7.15: Vertical displacements from field and FEA results at CH2 B1

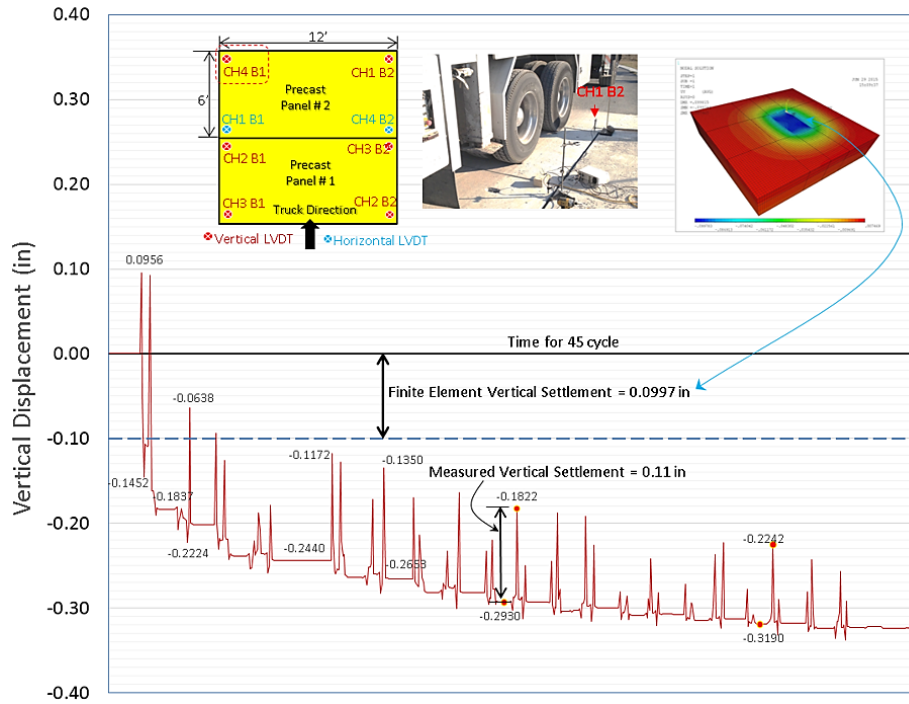


Figure 7.16: Vertical displacements from field and FEA results at CH4 B1

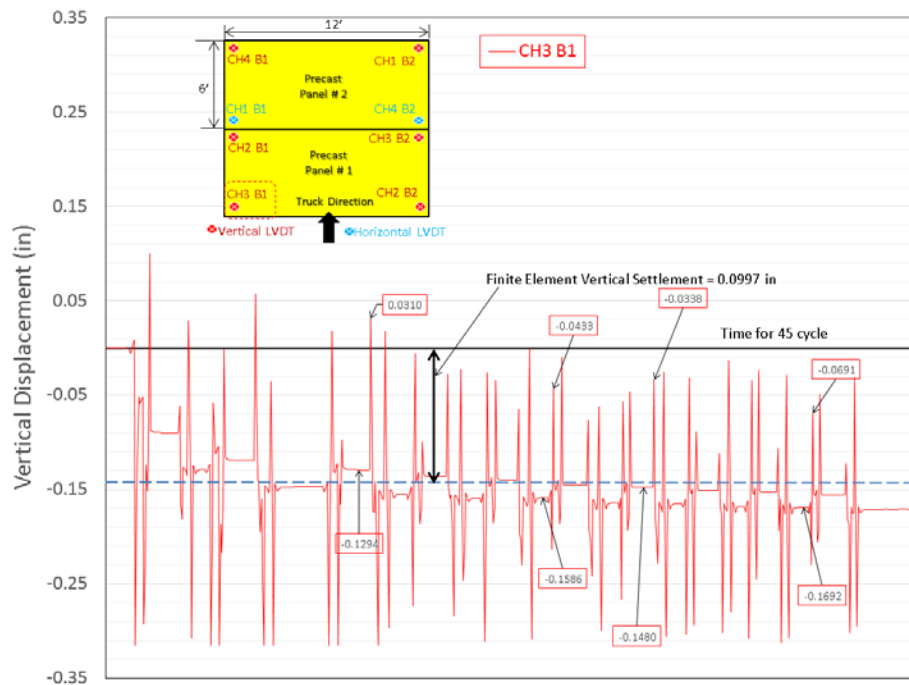


Figure 7.17: Vertical displacements from field and FEA results at CH3 B1

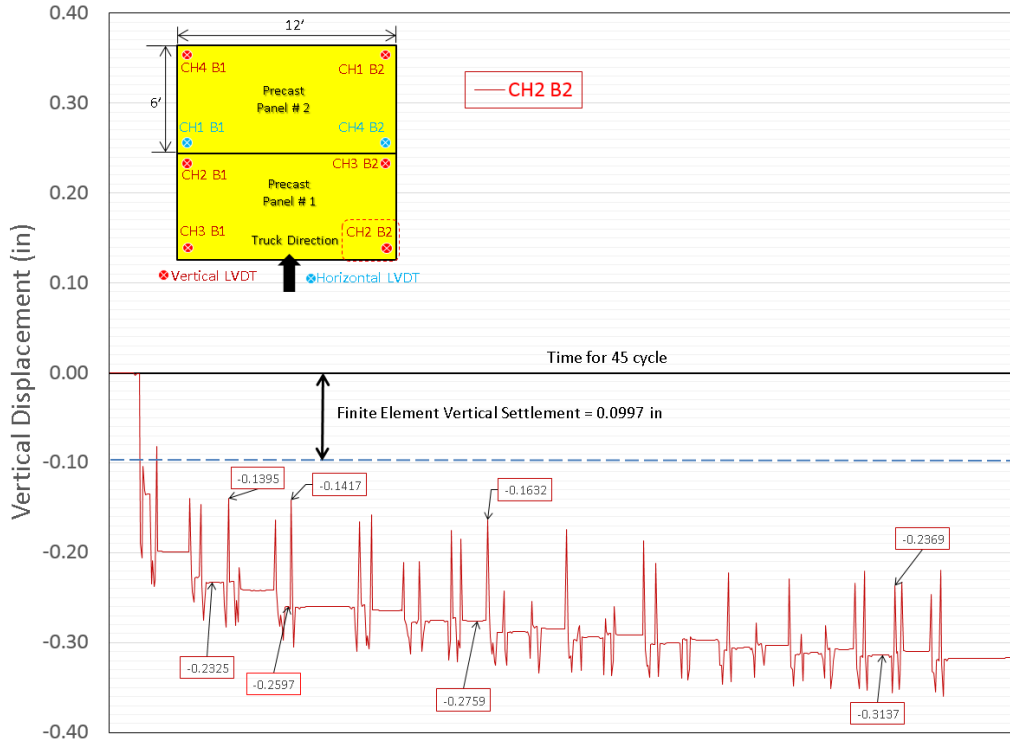


Figure 7.18: Vertical displacements from field and FEA results at CH2 B2

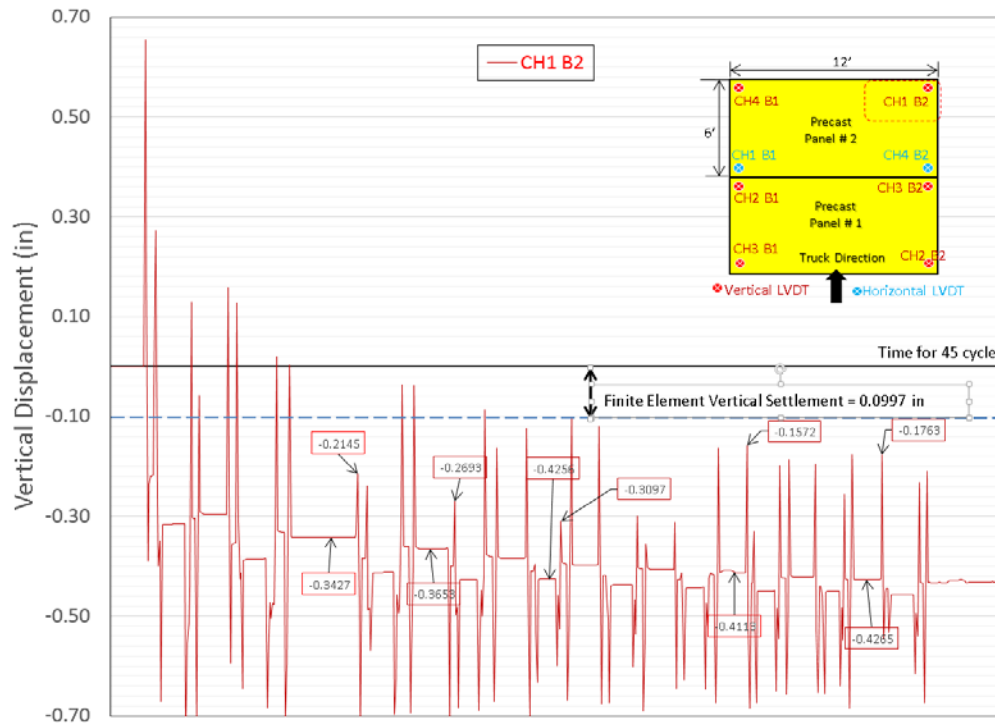


Figure 7.19: Vertical displacements from field and FEA results at CH1 B2

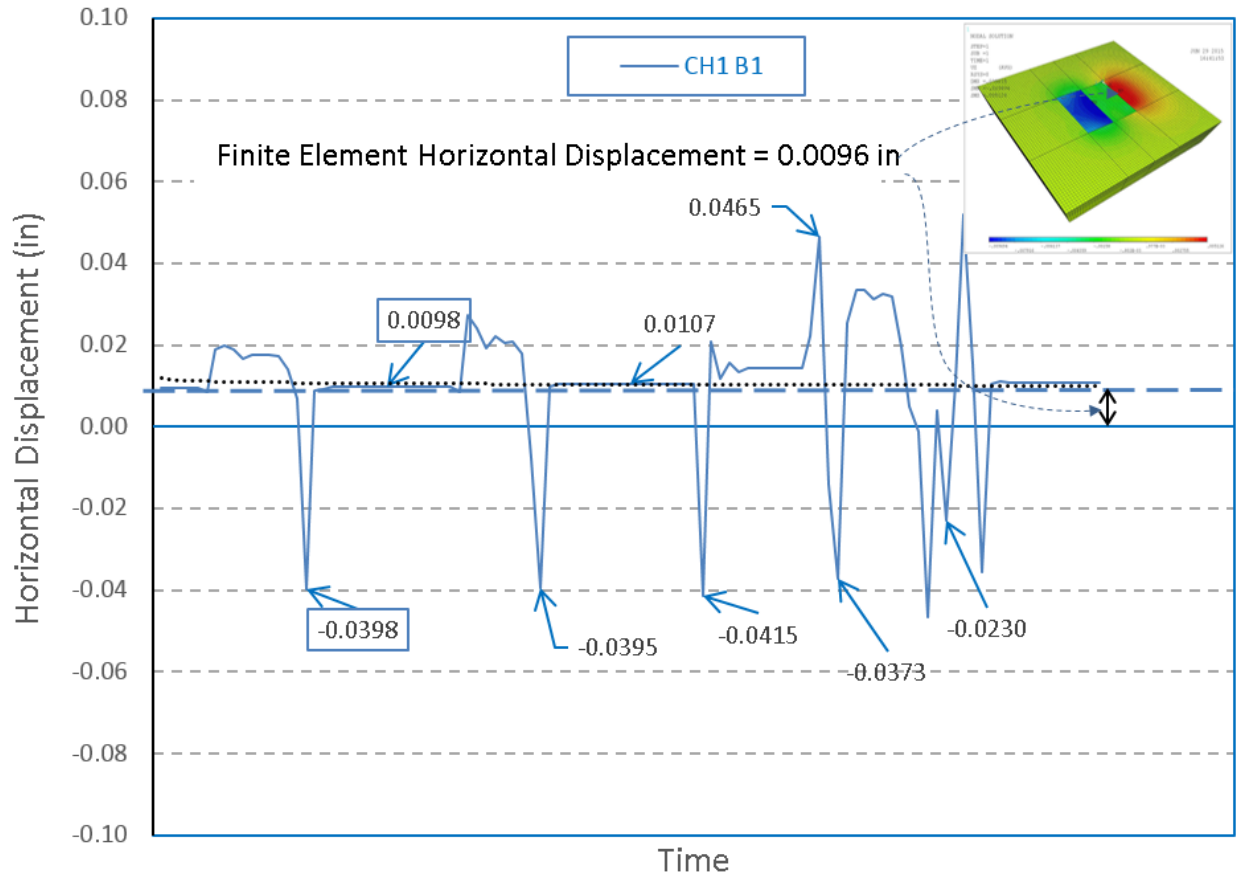


Figure 7.20: Horizontal displacements due to sudden braking in the moving load

Even with the differences between the field measurements and the FEA results, the horizontal displacements obtained from testing and FEA were relatively small, ranging from 0.01 and 0.03 in.

7.3 Maturity Measurements for SCC Mix

7.3.1 Concrete Maturity

It has been established that the strength of a given concrete mix is directly related to both its age and temperature history. At early ages, temperature has a strong effect on strength development.

In 1950, an approach was proposed to account for the combined effects of time and temperature on strength development of concrete. Later, it was proposed that the measured temperature history during the curing period could be used to compute a single factor that would be indicative of the concrete strength. Saul (1951) called this factor “maturity,” and proposed the well-known “maturity rule” for estimating the strength of concrete. The rule states that

“Concrete of the same mix at the same maturity (reckoned in temperature–time) has approximately the same strength whatever combination of temperature and time goes to make up that maturity.”

Bergstrom (1953) and Plowman (1956) validated Saul’s maturity rule. However, McIntosh (1956) and McIntosh (1962) reported cases where the rule could not be realized. Since then extensive research has been conducted and modifications have been introduced to improve the reliability of strength-temperature-time relationship of concrete maturity. Currently, the maturity method is viewed as a useful and simple approach to account for the complex combined effects of time and temperature on concrete strength development. This method provides a reliable estimate for in-place early-age strength of concrete during construction in lieu of destructive testing of field-cured specimens.

The traditional destructive testing method of field-cured cylinder specimens, cured in the same conditions as the structure, is used to schedule construction activities. These activities include removal of forms or reshoring, backfilling walls, schedule prestressing and post-tensioning operations, determining the time for opening the pavements or bridges to traffic, sawing joints, and to determine when protection measures can be terminated in cold weather. The maturity method would accomplish these objectives in a non-destructive manner

The maturity concept assumes that samples of a concrete mixture of the same maturity will have similar strengths, regardless of the combination of time and temperature yielding the

maturity. For example, concrete cured at a temperature of 50°F (10°C) for 7 days may have the same maturity index as concrete cured at 80°F (27°C) for 3 days and therefore would have similar strengths. An illustration of this concept is shown in Figure 7.21 (Nelson 2003).

The measured maturity index of in-place concrete, a function of temperature history and age, is used to estimate its strength development based on a pre-determined calibration of the time-temperature-strength relationship developed from laboratory tests for the same mix.

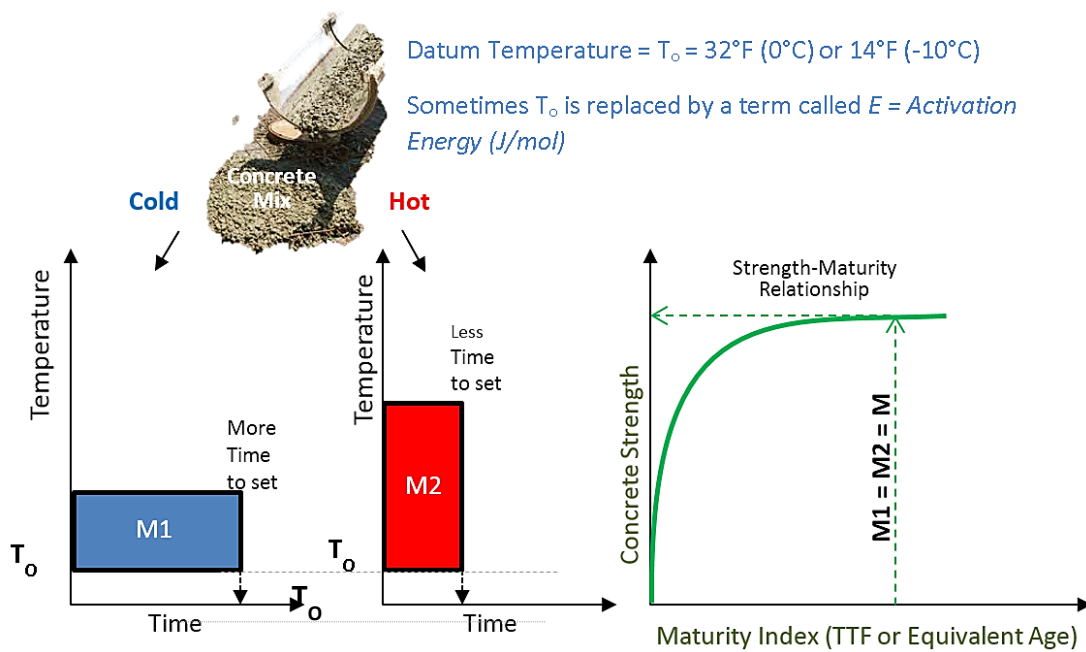


Figure 7.21: Strength-Maturity relationship concept (Nelson 2003)

The rate of strength development at early ages (Strength vs. Time) is determined from the rate increase in temperature (Temperature vs. Time). The procedure for estimating concrete strength using maturity concepts is described in ASTM C1074-11 “Standard Practice for Estimating Concrete Strength by the Maturity Method”. The temperature-time-strength relationship of a concrete mixture is developed in the laboratory by recording the variations in the

Temperature vs. Time and Strength vs. Time for concrete cylinders. This procedure establishes one of two maturity functions for that mix (Figure 7.22).

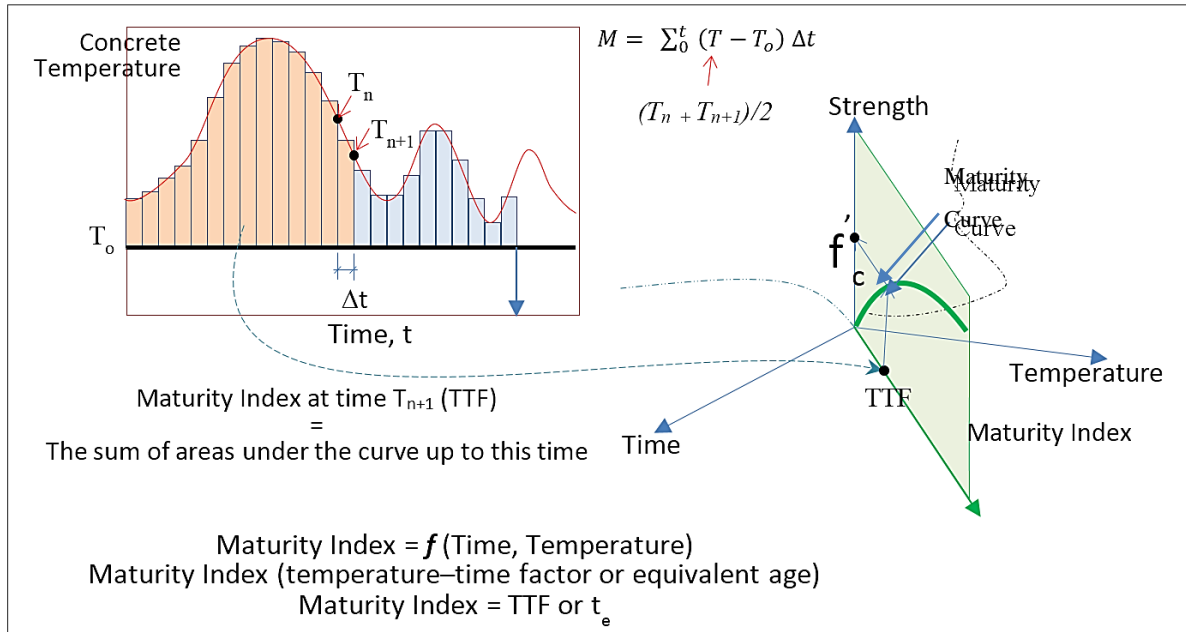


Figure 7.22: Strength vs. Maturity function/s

7.5.2 Maturity Functions

The term maturity was for the first time linked to the *product* of time and temperature. Saul (1951) suggested that maturity should be calculated with respect to a “datum temperature (T_o),” which is the lowest temperature at which strength gain is observed. Thus, maturity is computed from the temperature history using the following:

$$M = \sum_0^t (T - T_o) \Delta t \quad (2)$$

where

M = maturity* at age t

T = average temperature of the concrete during time interval Δt

T_o = datum temperature

This equation has become known as the Nurse–Saul function. Saul (1951) recognized that once concrete has set, it will continue to harden (gain strength) at temperatures below 0°C (32°F). Thus, he recommended a datum temperature of -10.5°C (13°F) for use in Equation 2. Plowman (1956) suggested a value of -12°C (11°F) for the datum temperature. Generally, a value of -10°C (14°F) has been used in subsequent applications of the Nurse–Saul function. Saul (1951) noted that the maturity principle was valid provided the concrete temperature did not reach about 50°C (122°F) within the first 2 hr. or about 100°C (212°F) within the first 6 h after the start of mixing. If the early-age temperature rise was excessive, the Nurse–Saul maturity function underestimated strength during the first few hours of treatment and the strength at later ages was adversely affected. Thus, Saul recognized important limitations of the maturity rule and the Nurse–Saul maturity function. It should be noted however, that the SCC mix used in this study never realized temperatures greater than 150°F in 4 hr. even during the hot summer conditions of 105°F ambient temperature.

The Nurse–Saul function can be used to convert a given temperature–time curing history to an “equivalent age” of curing at a reference temperature (T_r) as follows:

$$t_e = \frac{\sum(T-T_o) \Delta t}{(T_r-T_o)} \quad (3)$$

where

t_e = equivalent age at the reference temperature

T_r = reference temperature

In this case, equivalent age represents the duration of the curing period at the reference temperature that would result in the same maturity as the curing period at other temperatures. The equivalent age concept, originally introduced by Rastrup (1954) is a convenient method for using

other functions besides equation to account for the combined effects of time and temperature on strength development. Equation 3 can be written as follows:

$$t_e = \sum \alpha \Delta t \quad (4)$$

where

$$\alpha = \frac{(T-T_0)}{(T_r-T_0)} \quad (5)$$

The ratio α , which is called the “age conversion factor,” has a simple interpretation: it converts a curing interval Δt to the equivalent curing interval at the standard reference temperature.

An example of how to use the age conversion factor is shown in Figure 7.23.

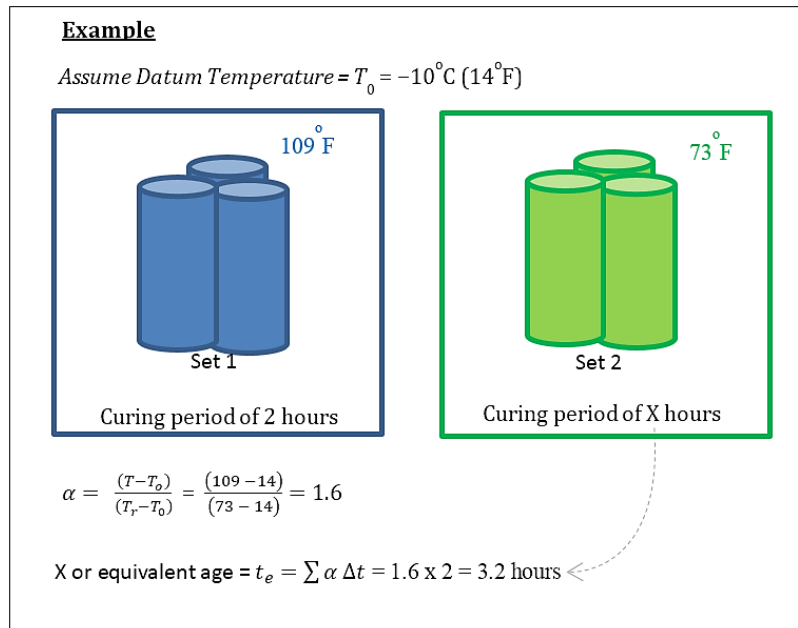


Figure 7.23: Age conversion factor and equivalent age concept

Rastrup (1954) proposed the following function for equivalent age derived from a well-known axiom in physical chemistry which states that the reaction velocity is doubled if the temperature is increased by 10°C .”

$$t_e = \sum \left(2^{\frac{T-T_r}{10}} \right) \Delta t \quad (6)$$

For example, a curing period at 43°C (109°F) is equivalent to four times the same curing period at 23°C (73°F).

Wastlund (1956) reported, however, that subsequent studies at the Swedish Cement and Concrete Research Institute showed that over a wide temperature range the Rastrup function was not as accurate as the Nurse–Saul function in representing the effects of time and temperature.

Weaver and Sadgrove (1971) used the equivalent age concept to develop a manual for formwork removal times under various temperature conditions. They suggested the following new expression to calculate the equivalent age at 20°C (68°F):

$$t_e = \frac{\sum (T+16)^2}{1296} \Delta t \quad (7)$$

Sadgrove (1975) suggested that equation 7 gave better strength estimates at low maturity values than the Nurse–Saul function (equation 4) and at later maturities, the Nurse–Saul function was more accurate than equation 7.

Copeland et al. (1962) suggested that the effects of temperature on the early rate of hydration of cement could be described by the Arrhenius equation. The Arrhenius equation is a formula for the temperature dependence of reaction rates. Freiesleben Hansen and Pedersen (1977) suggested the following expression for equivalent age based on the Arrhenius equation:

$$t_e = \sum_0^t e^{\frac{-E}{R} \left[\frac{1}{273+T} - \frac{1}{273+T_r} \right]} \Delta t \quad (8)$$

where

t_e = equivalent age at the reference curing temperature

T = average temperature of concrete during time interval Δt , °C

T_r = reference temperature, °C

E = activation energy, J/mol. (*Equivalent term to datum temperature*)

R = universal gas constant, 8.3144 J/ (mol K)

The exponential function in equation 8 is the age conversion factor and is expressed in terms of the absolute temperature. The exact shape of the curve describing the variation of the age conversion factor with temperature depends on the value of E , which according to Freiesleben Hansen and Pedersen had the following values:

for $T = 20^\circ\text{C}$ (68°F) $E = 33,500 \text{ J/mol}$

for $T < 20^\circ\text{C}$ (68°F) $E = 33,500 + 1470 (20 - T) \text{ J/mol}$

7.3.2 Strength–Maturity Relationships

Several functions can be used to determine concrete strength from a maturity index.

Nykanen (1956) suggested an exponential strength–maturity relationship as follows:

$$S = S_\infty(1 - e^{-kM}) \quad (9)$$

Where

S = compressive strength

S_∞ = limiting compressive strength

M = maturity index

k = a constant

The limiting compressive strength is a function of the water–cement ratio. The constant k is related to the initial rate of strength development. According to Nykanen, the value of k is expected to depend on the water–cement ratio and the type of cement.

Plowman (1956) noted that when strength was plotted as a function of the logarithm of maturity (based on the Nurse–Saul function) the data would fit a straight-line trend. Therefore, he suggested the following strength–maturity relationship:

$$S = a + b \log(M) \quad (10)$$

The constants a and b are related to the water–cement ratio of the concrete and the type of cement.

Bernhardt (1956) suggested a hyperbolic strength–maturity relationship. A similar function was independently proposed by Goral (1956) to describe the development of strength with age at a constant temperature. Later, Committee 229 of the American concrete Institute (ACI) adopted the same function to estimate concrete strength at different ages. Chin (1971) proposed the same function and described a procedure to evaluate the function for given data. The hyperbolic strength–maturity function can be expressed in the following form:

$$S = \frac{M}{\frac{1}{A} + \frac{M}{S_{\infty}}} \quad (11)$$

Where

M = maturity index

S_{∞} = limiting strength

A = initial slope of strength–maturity curve

7.3.3 Developing Laboratory SCC Maturity Relationship

To predict concrete strength from the maturity index in the field, it is required to establish the compressive strength (f'_c) vs. maturity index (TTF) relationship under controlled conditions in the lab. In this task, two mixes were prepared to establish the strength-maturity relationships using the same SCC mix design. The difference between the two mixes was the source of the materials. As it was mentioned previously, the first SCC mix was developed using Argos materials in Tallahassee and Jacksonville. In the second mix, Anderson-Materials (A-Materials) in Tallahassee were used. Although both concrete suppliers provided cement type I/II, the hydration rates of the two cements were different. According to A-Materials, their cement hydrates faster than the same type from Argos. Also, the two fine aggregates had different specific gravities. Additionally, A-Materials coarse aggregate was noticed to contain more fines than Argos. Therefore, it was decided to establish two maturity relationships for the same mix design.

The laboratory test procedures were conducted based on the ASTM C1074-11 (Standard Practice for Estimating Concrete Strength by the Maturity Method). The curing process of the prepared specimens was in accordance to ASTM C31. Although this standard method was originally specified for field curing of concrete specimens, two thermal insulation bags were used under controlled laboratory conditions. Each of the bags contained ½" of insulating cooler foam within its walls. The floorboard inside each bag was ½" smooth melamine. Another ½" plywood board was also added at the bottom of each bag to provide additional insulation for the cured specimens. The bags were placed in FAMU-FSU materials laboratory under a controlled temperature of 78°F and relative humidity of 60% for the duration of curing prior to testing. Measurements of the ambient lab temperature, and relative humidity and temperature inside the

thermal bags, as well as the temperature inside two concrete cylinders were continuously monitored and recorded. All concrete specimens for compressive testing including the two cylinders for temperature measurements were maintained in their covered molds inside the bags until time of testing. The two control cylinders were instrumented with embedded thermocouples at their centers and connected to Humboldt maturity meter placed outside the thermal bag (Figure 7.24).



Figure 7.24: Curing bag with temperature monitoring devices

The early strength requirements of the SCC mix necessitated the monitoring of the compressive strength development during the first few hours after casting of specimens. The compression tests were performed on at least two specimens at ages 3, 4, 6, 9, 12, and 24 hr. and 3, 7, 14 and 28 days. At the time of testing, the average maturity index for the instrumented specimens was recorded every 1/2 hr. during the first 48 hr. and then every hour for the remainder of the curing period. The maturity meter had a RAM which allowed the recording unit to store the readings for the duration of testing. The recorded measurements were then downloaded for further analysis.

Also, 2'x2'x4" slabs were cast from the two mixes and instrumented with embedded thermocouples similar to the control concrete cylinders in the thermal bags. The concrete temperatures were simultaneously recorded from the control specimens and the slabs (Figure 7.25).



Figure 7.25: Instrumented small-scaled slab

7.3.4 Thermal Devices Used in Maturity Testing

Additional thermal devices were also used to record the temperature measurements at various time intervals. These devices included the following as shown in Figures 7.26 and 7.27

- 1- External immersion thermocouple probes
- 2- Infrared laser thermometer
- 3- Thermal camera (FLUKE)
- 4- Thermal camera (FLIR)

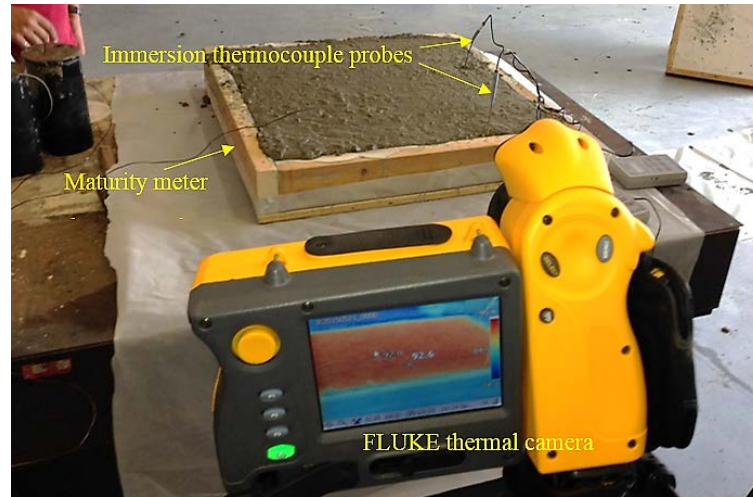


Figure 7.26: Temperature measuring devices

The purpose of using other temperature measuring devices besides the maturity meter was to explore the possibility of developing strength-maturity relationships in a non-traditional way by monitoring the temperature remotely without using invasive sensors. Using embedded thermocouples and a data logger has become a conventional maturity method used in the field. However, the recent advancements in hardware and software technologies have made it possible to use systems/devices that are equal, if not more efficient than the traditional maturity meter.

Presently, the smartphones have become virtually miniature computers. When a specific external device is added, and an associated software application is downloaded to certain smartphones, the setup can become a standalone maturity system and testing device. For example, a mini infrared camera can be assembled from a plug-in device model FLIR-ONE, FLIR App, and an iPhone. This inexpensive device could replace industrial grade infrared cameras such as Fluke Ti50FT IR FlexCam as shown in Figure 7.27.



Figure 7.27: FLIR-ONE and Smartpone

In this study, both a FLAIR plug-in camera and an industrial infrared camera model FLUKE Ti50 were used. To verify the accuracy of the temperature measurements a laser infrared device and immersion thermal probes were also used. Readings from of these devices were recoded with time. After the completion of the maturity test, measurements from all the devices were downloaded to an Excel spreadsheet to develop the strength-maturity relationships graphically as displayed in Figure 7.28.

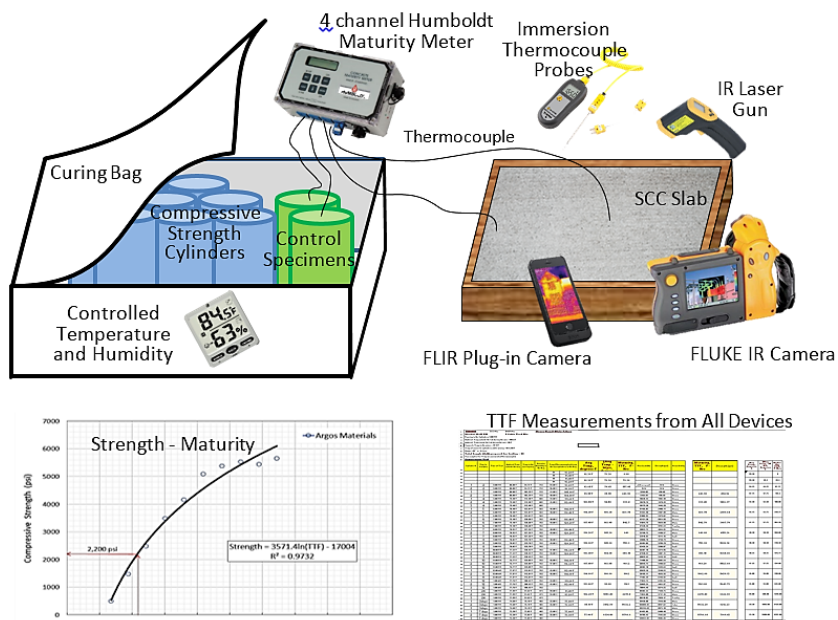


Figure 7.28: Strength-Maturity relationship from all thermal devices

The maturity test results of compressive strength vs. maturity index from all the thermal devices used in this study were determined using the Nurse–Saul function (Equation 2). As can be seen from the results in Figure 7.29, the different methods to determine maturity index (TTF) of the SCC mix using Argos materials showed an excellent agreement. The best fitting relationship shown in the Figure is expressed as follows:

$$\text{Strength} = 2,310 \ln (\text{TTF}) - 10,244 \quad (R^2 = 0.97) \quad (12)$$

This relationship was used to predict the compressive strength of the SCC mix used in casting the replacement test pit at Green Cove Springs test track. As it was described in Report 5, concrete specimens were prepared in the field to determine the early age compressive strength at 4 and 6 hr. Because of the long distance between the test track and the Argos laboratory in Jacksonville, it was not possible to test the specimens on time. Therefore, the FLIR plug-in thermal camera was used to record temperature vs. time relationship using the iPhone. The records consisted of images and video clips.

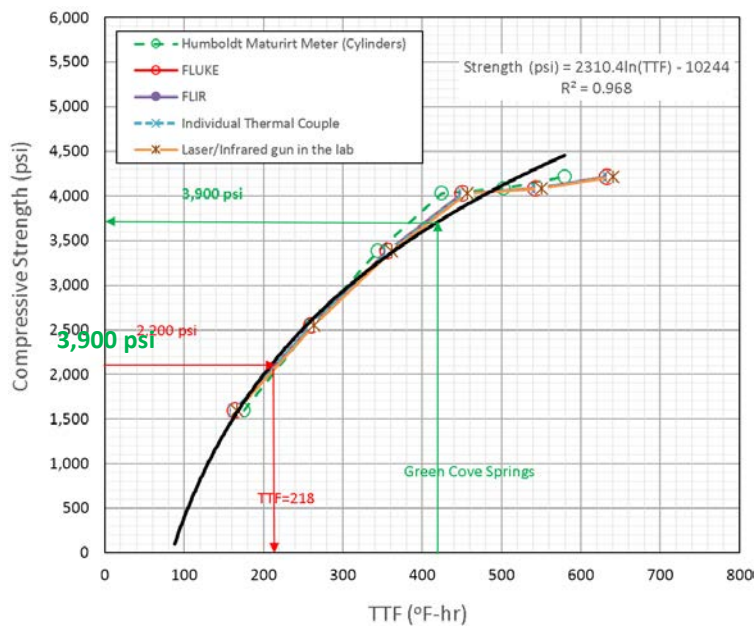


Figure 7.29: Strength-Maturity relationships from various measuring devices

Each image showed the surface temperature and the corresponding time. Data obtained from this method was downloaded and the concrete strength was predicted after 4 hr. and 6 hr. from casting the slab. The maturity index was determined as the product of the average temperatures at one-hour time intervals. The datum temperature used in the calculation was 14°F. At 4 hr. the TTF was found to be 428, which corresponded to a compressive strength of 3,900 psi. Although the predicted compressive strength provided a good reason to start load testing, it was decided to wait until 6 hr. before applying 100 load cycles of 20,000 lb. truck load on the replaced slab.

7.3.5 Novel Method for Concrete Maturity

The use of thermal cameras in maturity measurements is possible if both the temperature reading and the time can be recorded. Also, it is necessary to determine whether the sensitivity of the camera is capable of capturing accurate temperatures comparable to those obtained from embedded thermocouples. In concrete pavement replacement applications, the time and space are important. The space is usually constrained by the construction equipment and the MOT devices. Therefore, measurement of the early age strength of the concrete is needed to allow timely lane opening to traffic. The conventional maturity meter is a common method used in the field to determine the early strength without resorting to sample testing. However, a maturity meter needs a prior calibration, installation of wired sensors, which are inserted in zones near the slab edges. Also, measurements are limited by the number of channels in the data logger. Once it is in place to measure the temperature history, the maturity meter cannot be moved from one slab to another.

A fast and accurate wireless technique for measuring the maturity of the replaced concrete slabs would add to the cost effectiveness of the new slab replacement system. Thermal cameras can provide full records of the development of concrete temperature vs. time. These records can

be captured in image or video formats with time. Additionally, the thermal images have other advantages over the traditional maturity meter. These advantages include the following:

- 1- Provide a remote technique to record temperature vs. time
- 2- Full thermal image of the pavement slab showing detailed temperature variation over the entire area rather than one or two points
- 3- The effect of the surrounding pavement on the temperature development in the replacement slab
- 4- Real-time effect of using different curing methods on the concrete maturity
- 5- Ability to store the data for further analysis
- 6- Smartphone devices with thermal attachments can provide CPU capability to calculate real-time maturity of the concrete at unlimited locations on the concrete slab and average all the readings for more accurate measurements.

7.3.6 Thermal Measurements at Test Track

During the field test in Green Cove Springs test track, the ambient air temperature before casting the SSC mix in the test pit was 89°F. Images from the test pit at that time indicated the cooling effect of water spraying on the leveling course where the temperature immediately dropped to 83°F as shown in Figure 7.30.

After casting the test pit, the thermal images showed a gradual increase in the concrete surface temperature. By examining the real time images, it was noticed that the variations in the surface temperature were consistent between the high values near the center and the low values at the edges. The difference in surface temperature near the center and the edge was about 28°F as shown in Figure 7.31. It was not determined if these temperature changes would lead to future thermal cracking. The SCC slab in Green Cove Springs did not show any shrinkage or thermal

cracking after few days from casting and truck loading. These results from the thermal images could be used to explain why some replaced slabs using conventional high-early strength concrete mixes experience early shrinkage or thermal cracks at early age. Shrinkage and thermal cracking are common problems encountered when casting slabs with mixes with high cement contents.

To minimize the effect of temperature variation across the surface of the SCC slab, the replacement slab was covered with plastic sheeting. It was noticed that covering the slab would produce a more uniform temperature across the entire surface area (Figure 7.32). Also, it was noticed that plastic sheeting would preserve the concrete temperature and improve its maturity and strength development. Although the weather was not windy on that day, when the plastic cover was removed, the uncovered surface temperature started to drop rapidly, and the pattern of blotchy color-coded temperature at different locations was more noticeable as shown in Figure 7.33.

During the second field test at the FAMU-FSU site, Anderson-Materials were used in the mix. The compressive strength was predicted using the maturity index method. The FLIR thermal camera was used to record the temperature of the slab at different time intervals. Additionally, immersion thermocouple probes were inserted in the slab for verification. The test site was located close to the materials laboratory; therefore, cylinders were cast to be tested for f'_c at 4, 6, 9, 12, and 24 hr. Additional samples were prepared to determine f'_c up to 28 days.

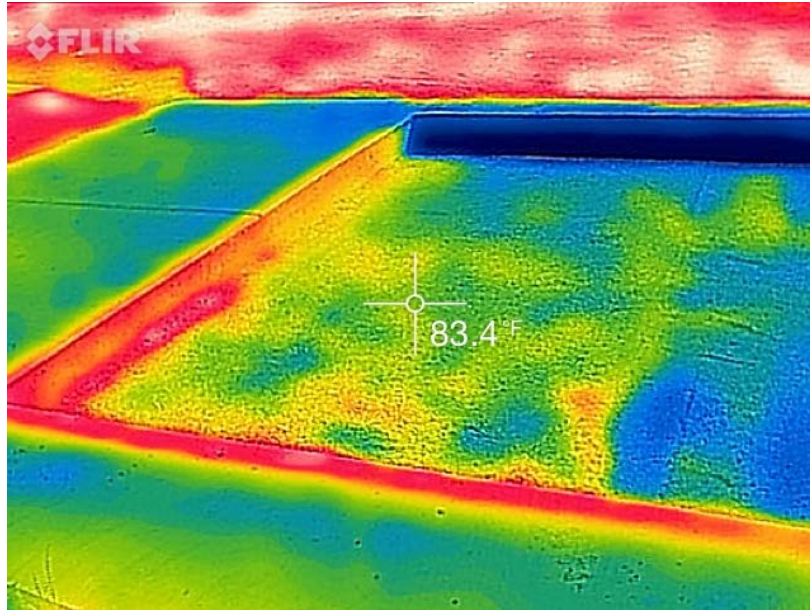


Figure 7.30: Initial temperature at the bottom of test pit before pouring the SCC mix

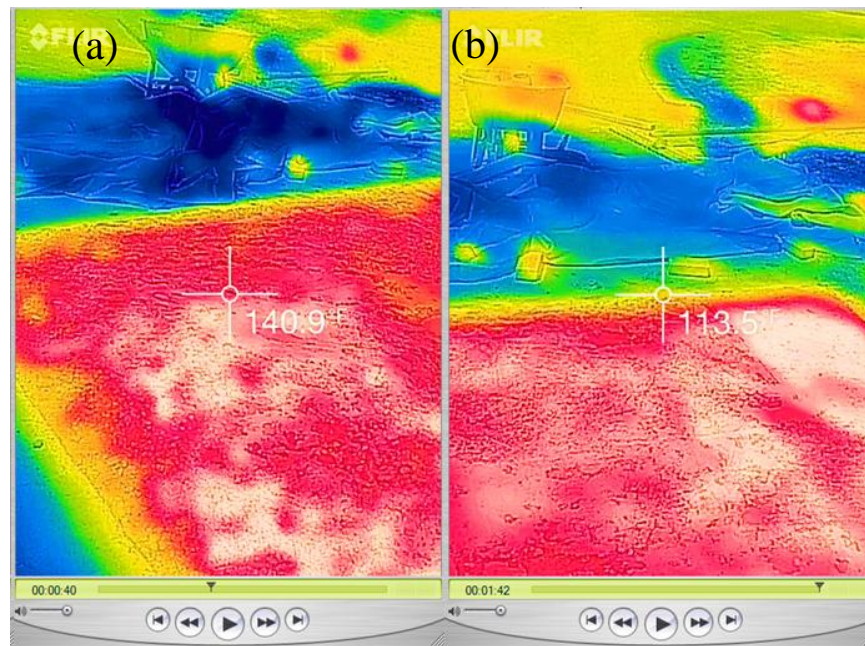


Figure 7.31: Temperature gradient of the SCC slab 4 hr. after casting,
 (a) Surface temperature at interior of slab,
 (b) Surface temperature at edge of slab

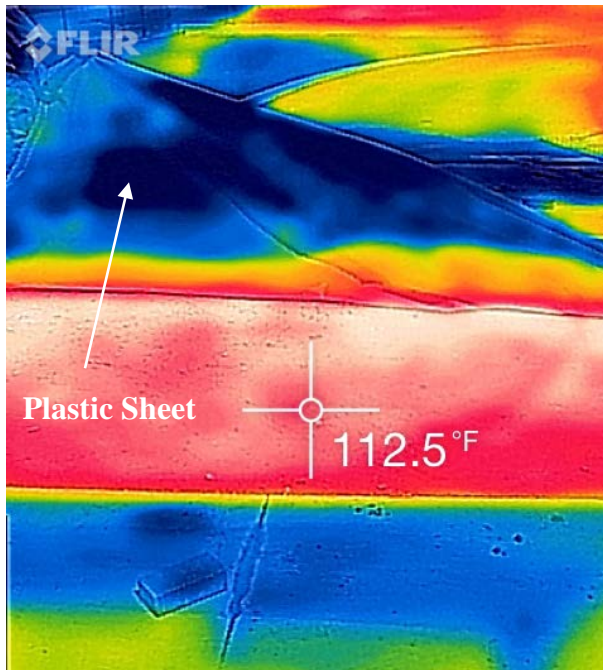


Figure 7.32: Using plastic sheeting to cover SCC slab

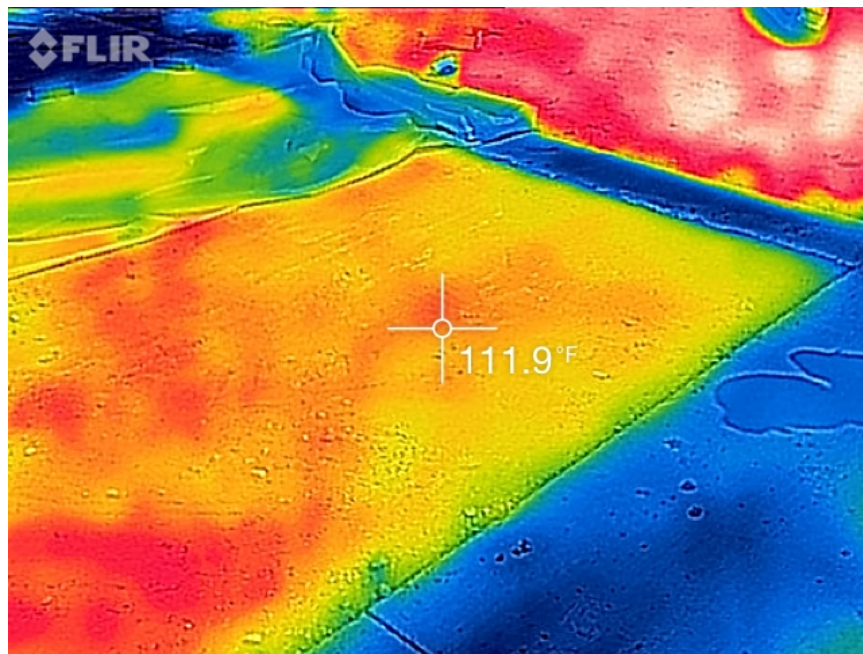


Figure 7.33: Exposing the slab to existing weather conditions

Several thermal images were captured of the truck during concrete mixing at the test site, before and after the addition of the accelerators. It was noticed that the addition of the accelerator caused a slight increase in the drum temperature. This was obvious from the heat generated at

drum opening as shown in Figure 7.34. The drum continued to rotate during the testing time to minimize any possibility of early setting of the SCC mix. As mentioned in report 5, the continuous agitation of the SCC mix is important to prevent any loss of workability and stiffening of the mix.

The maturity index using the Anderson-Materials SCC mix was about 390 for an early compressive strength of 2,200 psi. This maturity index was higher than the SCC mix using Argos materials. The maturity index at the Green Cove Springs was 218. This difference was expected because of the variations in the materials used in both mixes. Moreover, using the same cement Type I/II, it was expected that cement provided by Anderson-Materials would be slower in hydration during the initial setting. However, a few hours from casting, the slab temperature started to rise and then maintained its high values for a longer time than the cement provided by Argos (Figure 34). The temperature after 6 hr. reached 154°F, which resulted in a maturity index of 840. The TTF value corresponded a compressive strength of 3,900 psi (Figure 7.36). This strength value is certainly much higher than the current specification requirement for slab replacement at lane opening time.

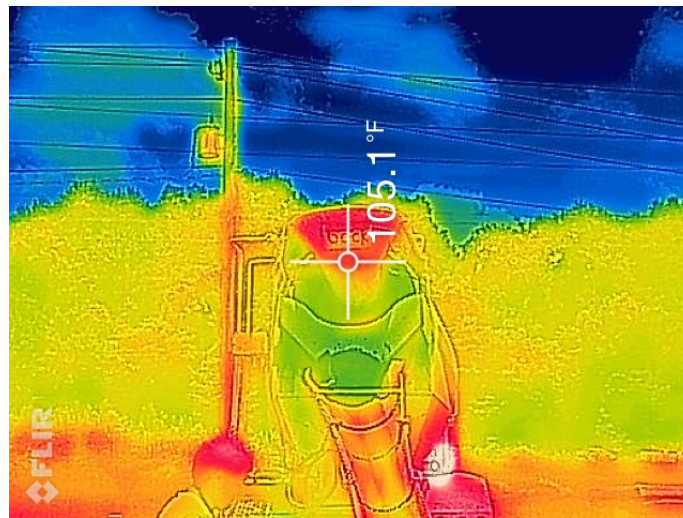


Figure 7. 34: Detecting temperature increase after adding the accelerator

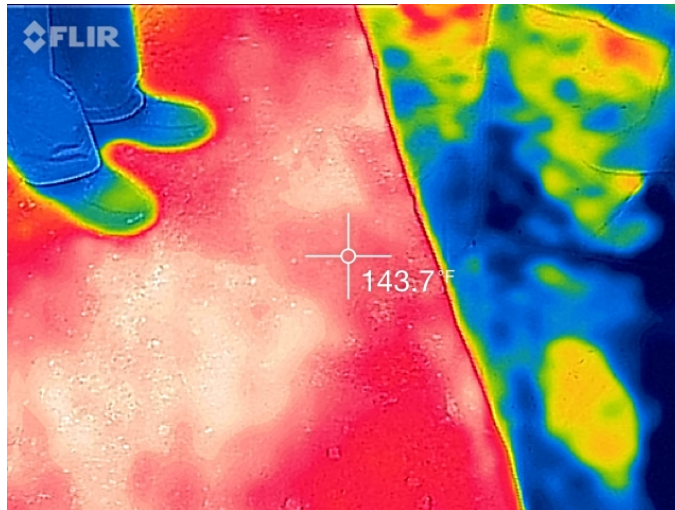


Figure 7.35: Temperature of the SCC mix in the test pit (FAMU –FSU Site)

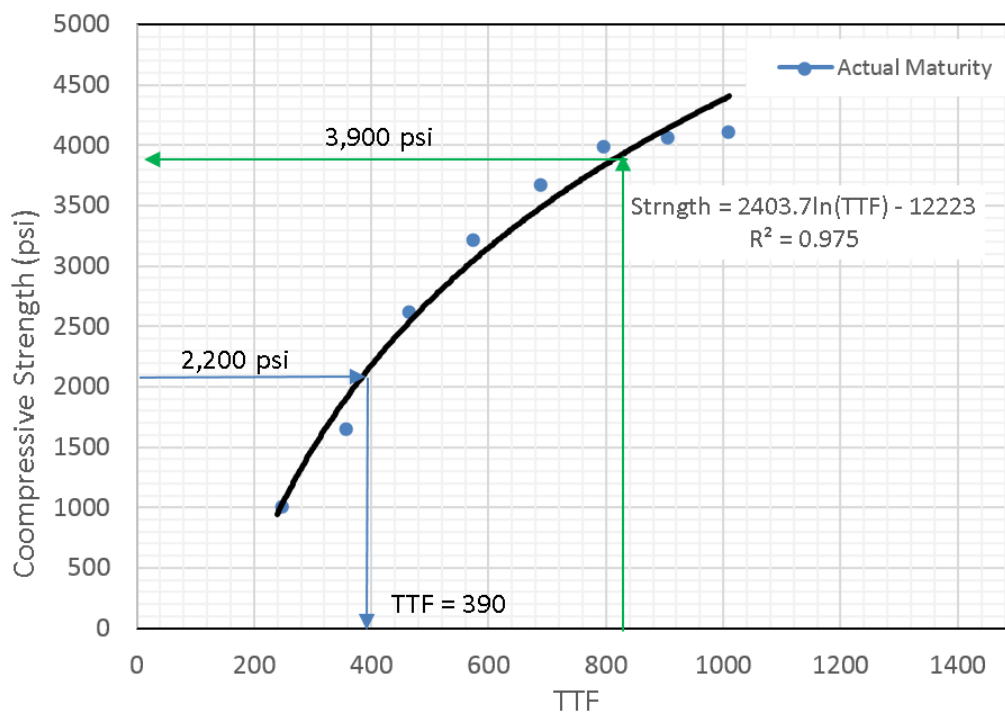


Figure 7.36: Strength-Maturity relationship of SCC mix using Anderson materials

CHAPTER 8

CONSTRUCTION GUIDELINES AND SPECIFICATIONS

8.1 Introduction

The Florida Department of Transportation has been rehabilitating old and distressed concrete pavements on highways and roadways in Florida as part of its maintenance and rehabilitation program. The pavement rehabilitation projects primarily involve replacement of severely cracked and shattered slabs, as well as grinding, sealing cracks and resealing joints. The main construction challenge on heavily congested urban highways such as Miami, Tampa, Orlando and Jacksonville, as well as on some city streets and county roads is lane closures to allow for slab replacements. Lane closures limit flow of traffic and force accelerated construction activities and movement of equipment in tight spaces.

The lane closures are mostly limited to nighttime. The window for lane closures in a majority of project is from 9:00 PM to 5:00 AM. The eight-hour construction window includes 1.5 to 2 hr. for setting up and dismantling maintenance of traffic (MOT) devices and the remaining 6 to 6.5 hr. for removing distressed sections and casting replacement panels and slabs. The FDOT requires the specimens for lane-opening strength-test be obtained from the last slab cast during the closure period. As such, the last slab has to be placed at least 3 to 4 hr. prior to the scheduled lane opening time. During this short period, the concrete must reach the FDOT required strength to allow opening the lane to traffic.

The work involved in removing and replacing the panels/slabs is as follows:

1. Saw cutting around the perimeter of the distressed area.
2. Removing the distressed segment or full slab.

3. Restoring the base surface from any damage or distortion.
4. Drilling new dowel holes in the adjoining concrete.
5. Cleaning and injecting epoxy into the dowel holes.
6. Installing new dowel bars in the holes and waiting for the epoxy to cure.
7. Discharging concrete in the replacement pit.
8. Spreading and vibrating the concrete.
9. Applying surface vibration and finishing of the replacement panel or slab
10. Curing the replacement panel or slab until opening the lane to traffic

In some cases, the contractors would cut around the deteriorated concrete and leave the segment in place to be removed and replaced during the following construction night.

The short window for actual construction limits contractor's production, considering the number of steps involved in removing the segments or full slabs, preparing the open pits and casting the panels or slabs. A survey of contractors and project engineers presented in chapter 3, as well as information from two recent rehabilitation projects on I-95 in Miami, showed that the volume of concrete cast per construction night ranges from 25 to 50 cu. yds. This represents 12 to 25 (6' x 12' x 9") panels or 4 to 8 (20' x 12' x 9") slabs cast per night. The low production rate requires more MOT nights and higher prices for the low volume of concrete produced per construction night. These factors contribute to longer construction time and higher cost for concrete rehabilitation projects.

Some contractors may attempt to extend the nightly construction period to as close as possible to the lane opening time in order to increase their production. This action requires the concrete mix to be designed and produced to develop the required lane-opening strength in a much shorter period by using higher dosage of cement and/or accelerators, and/or reducing the w/c of the mix. In such

cases, as have been observed by the research team, the replacement slabs would develop longitudinal or transverse cracks shortly after casting, due to high thermal and shrinkage stresses. This situation often leads to disagreements on the cause of the distress and the party responsible for the repair, and often ends up costing the FDOT and/or the contractor significant expenses.

The research team has developed an innovative method using temporary precast panels and an effective SCC mix to accelerate the slab replacement process; increase contractor productivity; extend the time required for the concrete to cure and develop the required strength; reduce MOT days; shorten project construction time, and reduce construction cost. The method may also reduce or eliminate premature cracking of replacement panels/slabs.

This chapter includes a description of precast panel design and preparation, SCC mix details and properties, design and specification requirements, construction guidelines and application criteria, as well as construction speed and cost benefits, and implementation challenges.

8.2 Summary of New Method

The Precast Panel-SCC method for accelerated slab replacement involves the following steps:

1. Precast concrete panels as are used as temporary fillers or “place holders” in the open replacement pits after removing the deteriorated segments of the pavement slab and drilling the new dowel holes in the adjacent concrete.
2. Within a period not to exceed one week, the precast panels are removed from the pits.
3. New dowels are inserted in the epoxy-filled hole.
4. The SCC mix is then discharged in the pit to cast the permanent replacement panels.
5. The removed precast panels are transported to the next pavement section to be re-used in newly prepared replacement pits.

6. This process is repeated until all deteriorated concrete segments identified in the plans/surveys are removed and replaced using the SCC mix.

8.3 Project Design Requirements

Some modifications to FDOT Standard Index 308 would be required to facilitate the use of the proposed method, as well as to accelerate removal and replacement of the panels. It is recommended that Index 308 be modified to include standard dimensions of slab segments that need to be removed and replaced. Based on the length of slab crack, the proposed replacement segment would be 6', 8', 10' or 12' long, and the width would be equal to the width of the slab. If the crack extends beyond 12 feet, the entire slab would be replaced. This recommendation assumes that the slabs are 20' long, as is the case in older pavements. It should be noted that Index 308 requires that a minimum 6' section of the existing slab remain in place. The standard dimensions of segments to be removed from 15-ft slabs would be 6', 8' and 10' long, and the width would equal to the width of the slab. A minimum 5' section of the existing slab would remain in place to assure the structural integrity of the 15-ft slabs. Cracks longer than 10' would require removing and replacing the entire 15-ft slab.

8.4 Design of Precast Panels

Two standard concrete precast panels are proposed, including (5'-9" x 11'-9" x 9"), called (Panel A), and a (3'-9" x 11'-10½" x 9"), called (Panel B). Individually or combined, these panels would fit in standard replacement pit sizes (6' x 12'), (8' x 12'), (10' x 12') or (12' x 12'). This assumes that the dimensions of the full size slabs are 20' x 12' x 9". Design details of assumed 9" thick precast panels are shown in Figures 8.1 to 8.6.

In case of a single or multiple severe cracks that extend beyond 12', full slab replacement would be required to meet the criteria in Standard Index 308. For 15' long slabs, severe cracks that extend beyond 10' would require full slab replacement. The panel thickness (T) will be based on the nominal thickness of the existing pavement. However, it is recommended that the nominal pavement thickness (T) be determined more precisely from core samples and used in the design of the precast panels.

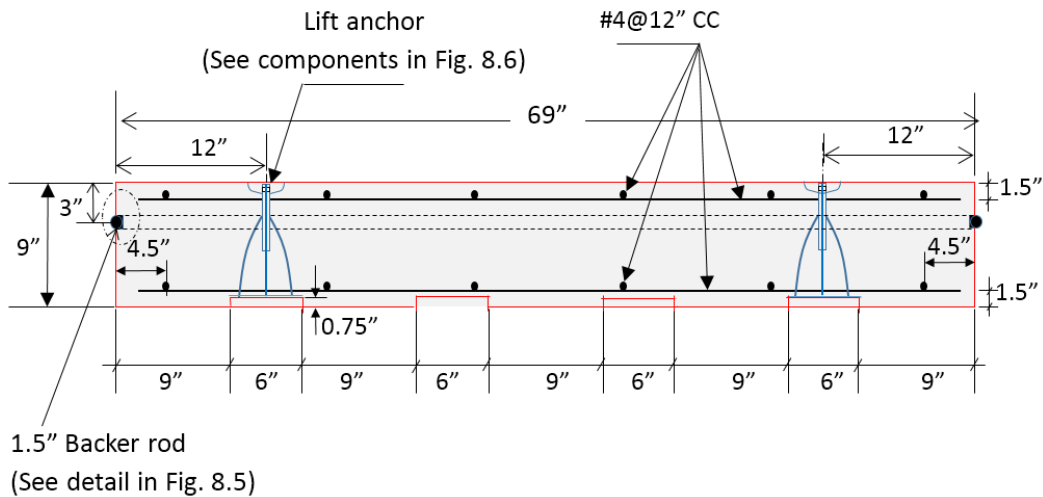


Figure 8.1: Design of (5'-9" x 11'-9" x 9") Panel A

Note: Used in 6' x 12' (single panel) and 12' x 12' replacement pits (two panels). Also used in combination with 3'-9" x 11'-9" (Panel B) in 10' x 12' pits.

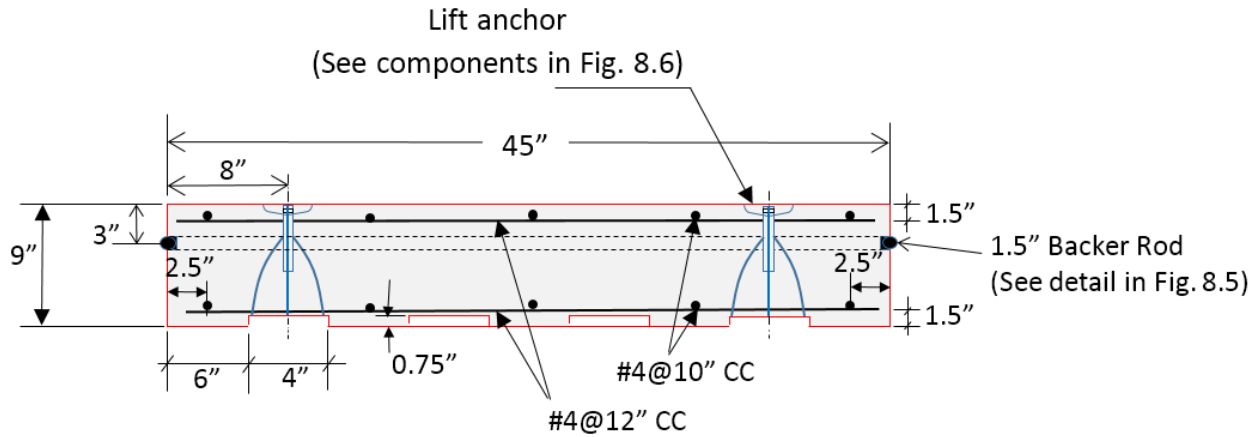


Figure 8.2: Design of (3'-9" x 11'-9" x 9" Panel B

Note: Used in 8' x 12' (two panels) replacement pits. Also used in combination with 5'-9" x 11'-9" (Panel A) in 10' x 12" pits.

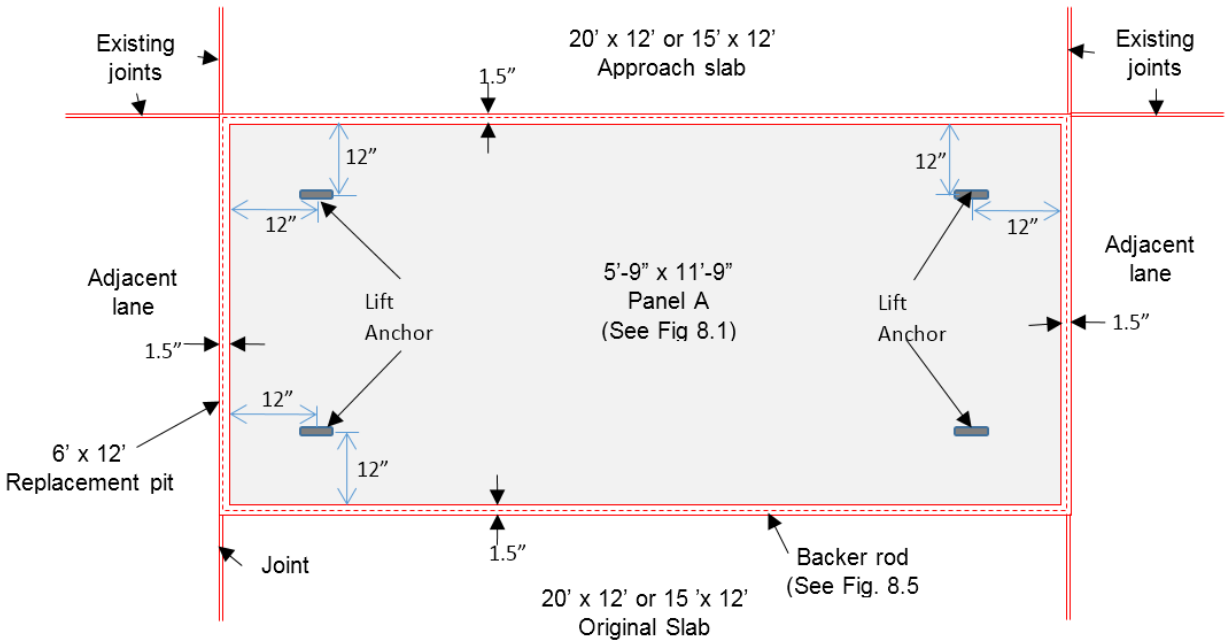


Figure 8.3: Placement of Panel A in 6' x 12' replacement pit

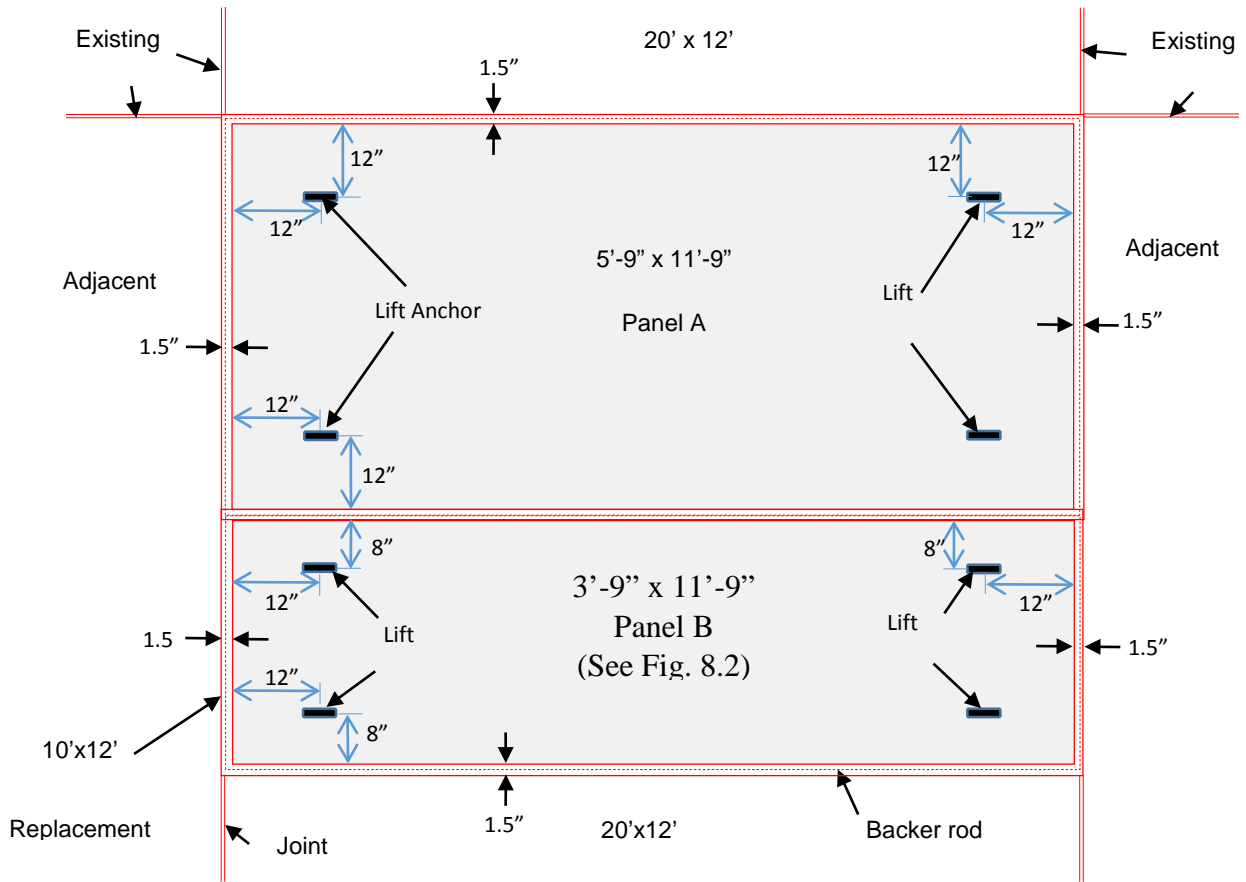


Figure 8.4: Placement of Panels A&B in 10' x 12' pit

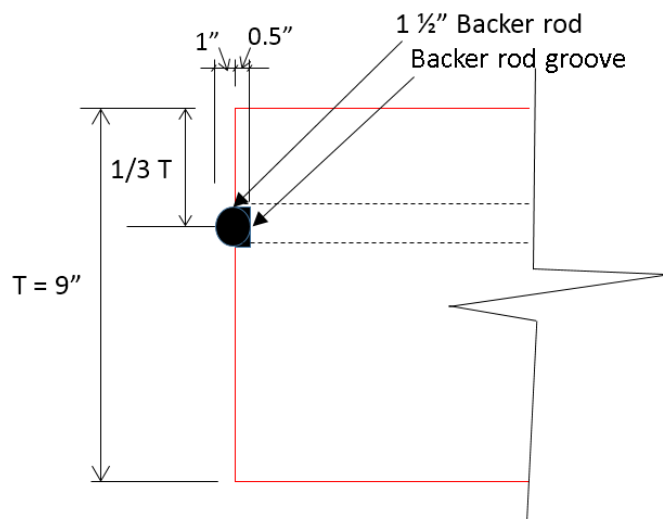


Figure 8.5: Backer rod details

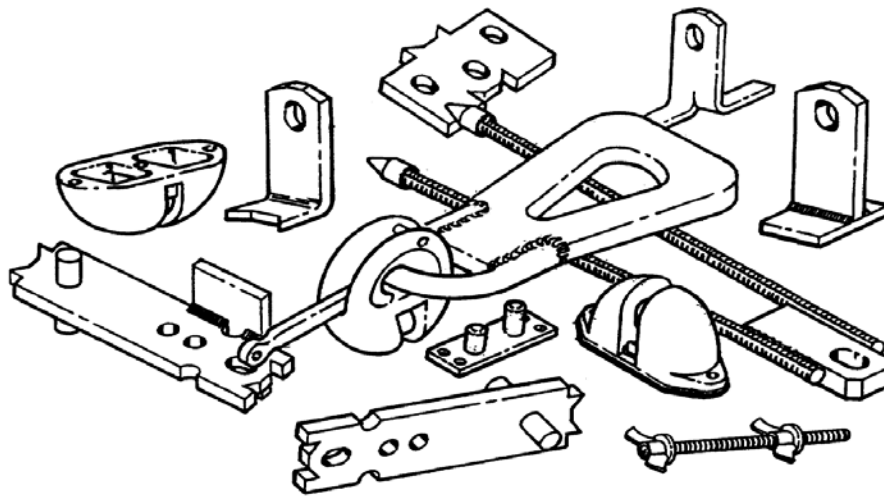


Figure 8.6: Components of lift anchor assembly

8.4.1 Reinforcement and Lift anchors

The concrete precast panels are reinforced, as shown in Figure 8.1 and 8.2, with top and bottom mats using # 4 rebars. A 1½” concrete cover would be provided for each mat. Four lift anchors are included. The components of the proposed lift anchor are shown in Figure 8.6. Details of the panel components are shown in Figure 8.7. The components include two mats of reinforcement, four wood boards along the bottom of the form to produce recessed stripes in the panels, and four lift-anchor assemblies.

Details of the lift anchor assembly and clutch, and connection to the panel reinforcement are shown in Figure 8.8. It should be emphasized that the lift anchor assemblies must be firmly tied to the reinforcing bars and positioned at suitable locations to ensure steady lifting and maneuvering of the panels. Contractors may use other types of lift anchor systems that suit their lift equipment.



Figure 8.7: Reinforcement and form design



Figure 8.8: Details of Lift Anchor installation and clutch connection

8.4.2 Alternate detail options

The two precast concrete panels prepared by the research team for demonstration are shown in Figure 8.9. The panels had 90° “square” corners, and 1.5” Styrofoam backer-rod gaskets along the sides of the panels. However, the user may wish to consider curved or “round” corners, and stopping the backer rod gasket 2 inches short of each corner tip. This configuration will provide better corner protection against corner spalling, and will reduce stripping of the backer rods during installation and removal of the panels. In addition, the width of the recessed stripes may be reduced, if desired, to further increase panel grip of the base and to improve its stability under traffic.



Figure 8.9: Demonstration panels showing backer rod and bottom recessed stripes

The precast panels can be prepared at the contractor's yard or fabricated at a precast plant in quantities based on the number of panels anticipated for use during the project. The strength of the concrete mix used to cast the panels must be at least 4,000 psi. The concrete would be vibrated and panel surfaces properly finished and textured with broom finish. Lightweight aggregate may be used as partial replacement of normal weight aggregate in the concrete mix. However, prior to their use, the panels should be tested for structural stability and robustness, and they should be approved by the project engineer.

8.5 Self-Consolidating Concrete Mix

Concrete mixes used for slab replacement include much higher cement content and lower w/c than in normal concrete mixes. High dosage of accelerating admixture is also used. The purpose of the concrete mix with such ingredients is to produce high-early strength that meets or exceeds the FDOT's strength requirement at lane opening time. The slump may reach six inches to allow sufficient workability during concrete discharge. The concrete requires manual spreading, internal vibration and finishing. It would normally take at least 15 and 20 min. to place 6' x 12' and 12' x 12' panels, respectively. When the length of time to cast the replacement panel is added to the time needed to remove the deteriorated segment, restore the base and retrofit new dowel bars, the production rate of replacement panels would be severely limited.

The research team developed a highly efficient mix that closely mimics the fresh properties of SCC mixes, and reaches an early strength similar to concrete mixes used in slab replacements. The proposed mix is shown in Table 8.1. It is identified as an SCC mix due to its high slump flow, which allows rapid discharge and filling of the replacement pit without the need for manual distributions and internal vibration of the mix, and without exhibiting any segregation. However,

it should not be confused with SCC mixes used in structural applications and should not be specified as such. This mix contains coarse aggregate grade 57 with nominal maximum size of 1”, which is favored by contractors for pavement slab construction. Also, the use of accelerating admixture to achieve a high-early strength will also cause rapid drop in slump as soon as the mix becomes stationary.

However, the SCC mix developed in this research managed to maintain a high slump flow for a period of 60 min. after adding the accelerator, as shown in Table 8.2. This was accomplished by continuous and uninterrupted agitation of the mix for the entire testing period. In field applications, the SCC mix would allow multiple replacements of 6’ x 12’ or other size panels until the entire 4 to 8 cu. yd. load of concrete is discharged without setting inside the mixer. Again, it should be stressed that the mixer drum must be in continuous agitation mode, when not discharging, and at a higher revolution rate than in conventional mixes.

Table 8.1: Proposed SCC Mix Design

Ingredients	Mix lb/yd³	Description
Cement	830	Type I/II cement used – AASHTO M85
Coarse Aggregate	1625	Limestone grade size 57
Fine Aggregate	1224	Silica sand
Mix Water	280	Mix water adjusted to aggregate moisture and water content in the accelerator admixture
W/C	0.34	
Admixtures	fl Oz/yd³	
Workability Retainer	42	ASTM C 494/C 494M, Type S*, specific performance admixture

HRWR - Polycarboxylate	50	ASTM C 494, Type A, water-reducing, and Type F, high- range water-reducing admixture
Accelerator	473	ASTM C 494 Type C, accelerating, and Type E, water- reducing and accelerating, and admixture.
Water Reducer & Retarder	42	ASTM C 494/C 494M, Type A, water-reducing, Type B, retarding, and Type D, water-reducing and retarding admixture

**Must be approved prior to use*

Table 8.2: Slump Flow and T20 Test results

Time Min	B1			B2		
	Slump Flow		T20	Slump Flow		T20
	in	(mm)	(sec)	in	(mm)	(sec)
0 *	20	(480)	9	22	(550)	1
10	28	(710)	2	-----	-----	----
15	----	-----	----	24	(600)	2
20	29	(737)	2	-----	-----	----
25	-----	-----	----	27	(675)	3
30	28	(700)	2	-----	-----	----
35	-----	-----	----	29	(725)	3
40	26	(648)	3	-----	-----	----
50	22	(546)	4	-----	-----	----
60	15	(380)	> 10	29	(725)	3

* This test was performed after 6 min. from adding accelerator and remixing

Several trial batches of the SCC mix were prepared at the FAMU-FSU laboratory. Compressive strength test results at different hours within the first 24 hr. period are shown in Table 8.3. The strength results starting at 4 hr. exceeded the 2,200 psi strength that is currently required by the FDOT at lane opening time. The same mix was also produced at two commercial concrete plants and showed similar strength results. With the mix test results being validated in plant and

field applications, the team is confident that the mix can be used for slab replacements in rehabilitation projects. It should be mentioned that the mix ingredients such as cement, accelerator, and w/c may be adjusted for hot and cold weather or when slightly lower early strength is desired.

Table 8.3: Compressive strength during the first 24 hr.

Time (hour)	Compressive strength	
	psi	(MPa)
4	3,762	(26)
6	4,886	(34)
9	5,784	(40)
12	6,135	(42)
24	7,828	(54)

8.6 Specification Requirements

The benefit of the proposed highly flowable SCC mix is to accelerate casting of replacement panels by rapid discharge, reduction or elimination of manual spreading and internal vibration and with no segregation. Also, the SCC mix would achieve the required early strength at lane opening time in accordance with the latest version of specification 353. It should be emphasized that the material properties, mix design and function of the SCC mix for slab replacement are different from SCC mixes used in structural elements.

It is recommended that specification 353 be amended to allow the use of the SCC mix with the following requirements:

- a. Self-Consolidating Concrete (SCC) mix would be allowed to be used to cast replacement slabs. Grade 57 aggregate may be used in the SCC mix. Other grades such as 67, 89 or a blend of these aggregate may also be used.

- b. For SCC mix design approval in the laboratory, the mix would have an initial slump flow (ASTM C1611) of 15” to 20” and T20 of 5 to 10 seconds prior to addition of the accelerator. After the addition of the accelerator and remixing, the mix slump flow would not be less than 20” and segregation shall not occur. Also, the mix must maintain a slump flow not less than 15” without segregation during a period of 45 min. after mixing the accelerator.
- c. For production mixes, the slump flow of the approved SCC mix would be tested at the jobsite prior to the addition of the accelerator. The slump flow shall be 15” to 20” with a T20 of 5 to 10 seconds and without segregation. No further slump flow tests would be required after addition of the accelerator and remixing.
- d. The mix design in Table 8.1 may be used as a guide in the specification but not as a prescriptive requirement. This will allow the contractor and concrete producer to optimize the mix according to the specific work and weather conditions.
- e. During discharge of the concrete in the replacement pit, monitor flow of the mix. If the flow in the pit slows down considerably, apply manual spreading of the concrete and use internal vibrators to properly distribute and compact the concrete, and avoid segregation.
- f. After addition of the accelerator to the mix and remixing, maintain the mixer in agitation mode (when not discharging concrete). The speed of revolution during agitation may be higher than that used for conventional concrete mixes. The agitation of the mix must be continuous and without interruption until the entire concrete load is discharged.
- g. Reject the concrete if the mix exhibits segregation at discharge or while flowing in the pit during the casting of the slab. Remove the segregated concrete from the replacement pit.

- h. The strength of the SCC mix at lane opening would meet the strength requirement of the latest version of specification 353.
- i. A Maturity Curve would be developed for the SCC mix and used to determine the opening strength. Compressive strength cylinders would also be prepared and used for concrete acceptance as required in specification 353.

8.7 Construction Guidelines

8.7.1 Installation of Precast Panels

1. Review project design plans to identify slab segments requiring replacement. Perform a survey of the project site to validate severity of the distress conditions in the affected slabs, and mark areas requiring removal and placement.
2. Determine the nominal thickness of the pavement using information from the core length data in the geotechnical report, and if necessary, obtain additional cores for thickness verification.
3. Prepare the necessary number of concrete precast panels.
4. As a guide, the suggested concrete volume required to prepare the necessary number of precast panels for a rehabilitation project would be 5% of the total volume of concrete to be replaced (as shown in the project plans). However, the exact number of Panels A and B (section 8.4), and the proportion of the number of each panel to the total number of panels would be best assessed by the contractor and dictated by the project plan sheets. Factors such as robustness of the fabricated panels, installation procedure and type of panel handling equipment may determine the required number of panels to be prepared for the project.

5. The removed and replaced segments would have standard dimensions specified in section 8.3. The width of the affected segment would be equal to the width of the existing slab. Make sure to follow other design requirements of Standard Index 308.
6. Saw cut the cracked or deteriorated segment of the slab using the standard dimensions specified in section 8.3. Remove the segment from the remainder of the slab.
7. When the extent of the deterioration or cracking exceeds 12' in a 20-foot slab or 10' in a 15-foot slab, remove the entire slab.
8. If disturbed, restore the base by leveling and compaction to ensure proper density of base in the replacement pit.
9. Measure the depth of the pit. If the depth is longer than the thickness of the precast panels, place an approved leveling course on the base. The leveling course material can be fine recycled concrete (Figure 8.10), builder sand, Geosynthetic mats or any other suitable material approved by the project engineer. The goal is to elevate the panels to a level not lower than $\frac{1}{4}$ " from the elevation of the surrounding area. If the depth of the pit is less than the panel thickness, trim the base surface. Use a straightedge with a leveling device to produce an even surface of the leveling course or the trimmed base (whichever applies).
10. Retain the leveling course material in the pit when casting the replacement slab. The leveling course would become an integral part of the base for the replacement slab.
11. Drill holes in the sawed face of the existing concrete, as shown in the plans, to anchor in the new dowel bars. Use a hand drill or the more preferred Gang drills to prepare the holes as shown in Figure 8.11. Ensure proper horizontal and vertical alignment of the holes. The open pit is now ready to receive the temporary precast panel(s).

12. Use a backhoe, crane or similar equipment with a telescopic extension boom that can be adjusted in elevation and horizontal reach. Its lifting capacity has to exceed 10 tons. Use four metal chains hooked to the lift anchors to maneuver the panels. Figure 8.12 shows a few possible lifting methods.
13. Lift each precast panel from the transport truck, then move and position it above the panel replacement pit. Lubricate the backer rod gasket to facilitate its installation and removal. Carefully lower the panel inside the pit, making sure that the gap between the surrounding concrete and the panel edges stays fairly uniform, as shown in Figure 8.13.
14. Follow steps 11 to 13 to install the second panel in the pit when the length of the pit is 8', 10' or 12', as shown in Figure 8.14.
15. With the panels in place, the lane can be opened to allow flow of traffic, as illustrated in Figures 8.15 and 8.16 respectively. The backer rod gasket and configured bottom of the slab will provide panel stability, minimizing major shifting of the panels under traffic.
16. The panels can stay in the replacement slab pits for up to 7 days.
17. Prior to casting the replacement slabs, carefully lift the precast panels from the replacement pits (Figure 8.17). Place them on the flat bed of a transport truck, and haul away to the next closed roadway section to be re-used.
18. Discard and replace any severely damaged precast panel. A spall larger than a 4" x 4" x 1", or a crack wider than 0.25 in, or multiple cracks in a panel constitute a "severely damaged" panel.

19. To retrofit the new dowel bars, first clean the drilled holes using compressed air to remove any debris and dust. Then, apply an FDOT approved epoxy, starting at the back of the hole as shown in Figure 8.18. Ensure the epoxy fills the entire hole.
20. Insert each dowel through an epoxy-retention plastic disk. With a twisting motion, push the bar into the epoxied hole while pressing the plastic disc against the hole (to prevent escape of the epoxy), and ensuring that the dowel is surrounded by the epoxy (Figure 8.19). Repeat the process in all open pits to prepare for SCC casting. Upon curing of the epoxy, the slab will be ready for casting.
21. There is no need to remove the leveling material from the bottom of the replacement pits prior to casting the slab. The compaction from the weight of the panels and the moving traffic are sufficient to provide proper density to the thin leveling course. The material would become an integral part of the base beneath the new replacement slabs.



Figure 8.10: Fine recycled material for base leveling course



Figure 8.11: Drilling new holes for dowel bars with a Gang drill

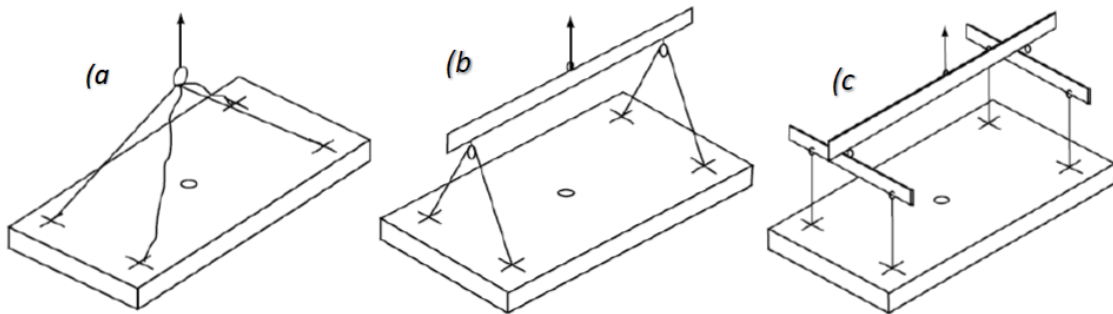


Figure 8.12: Possible methods for moving, installing and lifting precast panels



Figure 8.13: Installation of the first precast panel using a backhoe



Figure 8.14: Installation of second panel



Figure 8.15: Two precast panels temporarily filling a 12' x 12' x 8" slab replacement pit



Figure 8.16: Allowing vehicles on the temporary precast panels



Figure 8.17: Removing temporary precast panels from the replacement pit



Figure 8.18: Application of epoxy starting from the back of the hole



Figure 8.19: Insert new dowel bars fitted with a retention disk to prevent epoxy leak

8.7.2 Casting the Replacement Slabs

1. Ensure the dowel bars have been firmly anchored in their holes, Figure 8.20. Upon arrival of the truck mixer to the jobsite obtain a concrete sample and perform the slump flow test (Figure 8.21).
2. Add the accelerating admixture to the mixer as shown in Figure 8.22. After remixing the SCC, discharge the mix in the pit as shown in Figure 8.23. Due to the speed of discharge and flow, there will not be a need to distribute or vibrate the mix. However, at any time during discharge and placement, if the flow of the mix becomes too slow, consider manual distribution and internal vibration of the mix.
3. Observe any signs of segregation during concrete placement. Remove the concrete from the pit if segregation is observed.

4. Upon completion of the slab casting, stop the SCC discharge but continue the agitation of the mix without interruption. It is suggested that the revolution speed of the mixer while in agitation mode be higher than in normal concrete mixes with no accelerators.
5. Immediately after completing placement of the concrete, apply a swift surface finish using a roller or vibratory screed, as shown in Figure 8.24. Do not allow the concrete to set prior to applying the surface finish.
6. Continue casting the next replacement slabs until the truck mixer is emptied. Do not stop the mix agitation at any time before the entire concrete load is discharged.
7. Cure finished the slabs according to specification 353 using an FDOT approved curing product. Avoid curing the slabs with water spray during the early curing hours to prevent thermal shock. In cold weather, consider covering the slabs with curing blankets.
8. When the maturity test shows that the required strength has been reached, open the lane to traffic (Figure 8.25).



Figure 8.20: Replacement slab pit ready for concrete placement



Figure 8.21: Slump Flow test



Figure 8.22: Add accelerator to the SCC mix at the jobsite



Figure 8.23: Replacement slab casting with SCC mix



Figure 8.24: Final surface finish with Roller screed



Figure 8.25: Allowing traffic on replacement slab after reaching required strength

8.8 Criteria for Applying the Precast Panel-SCC Method

The proposed Precast Panels-SCC method for accelerating slab replacement is most useful when applied in the following cases:

1. Volume of concrete used for slab replacement is at least 1,000 cu. yds.
2. Limited window for construction during nighttime or daytime.
3. Significant premature cracking has been observed when using conventional high-early-strength concrete mixes with excessive cement and/or accelerator.
4. Closely spaced distressed slab segments that require removal and replacement.
5. When the cost-benefit analysis favors the use of this method. Examples of cost savings are shown in section 8.9.

Other favorable factors to use the proposed method include, close proximity of the ready mixed plant and contractor's storage yard to the project site, as well as a well-planned MOT that provides adequate space for positioning and movement of the construction/transportation equipment needed for the method.

8.9 Project Time and Cost savings

The proposed Precast Panels-SCC method has the potential to increase the contractor's production by at least 25% to 30%. The increased production will reduce MOT time, shorten project construction time, and reduce contractor costs. This will ultimately result in project time and cost savings to the FDOT, contractors, and the travelling public.

During demonstration of the method at the Green Cove Springs test track, the FAMU-FSU research team managed to achieve the following completion times:

1. Installation of a each precast panel - 10 min.
2. Removal of each panel – 5 min.
3. Casting a 12' x 12' x 8" replacement slab using SCC mix – less than 3 min. with no segregation.
4. Concrete strength reached a minimum 2,200 psi after 4 hr.

No cracking was observed on the slab when 100 passes of a 25,000 lb truck were applied after 6 hr. from slab casting.

The benefits of the method can be fully realized when executed as follows:

1. ***First lane closure*** - The contractor would remove as many deteriorated panels as possible without being concerned about casting any panels. He then prepares the holes for the new dowel bars and restores the base, if necessary. This would be followed by

placing the precast panels in the open slab replacement pits. A suitable leveling course may be needed to raise the surface elevation of a panel to near or equal to the surface elevation of the surrounding concrete area. During this lane closure the contractor's productivity may reach at least 40 to 50 (6' x 12' x 9") panels.

2. ***Second Lane closure*** – The contractor moves through the section of the prior lane closure, and would pick up the temporary precast panels to haul them away to the next section. The dowel bars would then be installed in the epoxied holes. Once epoxy sets, the pit would be ready for casting. The truck mixers would start filling the pits by discharging the SCC mix at a high flow rate. No workers would normally be needed to spread or vibrate the mix. A two-man team would apply a finishing roller screed on the freshly cast replacement slab. The contractor's production during the second lane closure can easily reach a minimum 50 (6' x 12' x 9") panels or 100 cu. yds. This would also allow sufficient time for the concrete to reach the lane opening strength without the need to use concrete mixes with excessive quantities of cement and accelerator.

The MOT time, and the cost for MOT devices and traffic control procedures will be drastically reduced. Based on analysis of the FDOT 2015 bid costs for concrete rehabilitation projects, the MOT and road uses (lane rental) costs can reach 18% to 21% of the total construction budget. As such, any time and cost savings realized from reducing the MOT would benefit the FDOT, contractor and, ultimately, the taxpayers.

There would also be cost savings to the contractor from reducing the number of workers needed to cast the replacement slabs. This cost saving can be used to fund the fabrication and handling of the precast panels. Also, any additional cost of the SCC mix will most likely be offset by the reduced cost of concrete from the increase volume needed to cast the large number of

replacement slabs during each lane closure period. When the added productivity, and reduced labor and materials costs are realized, the proposed method would be appealing to contractors and concrete producers, which would produce savings the FDOT.

8.9.1 Illustration of Time and Cost Savings

Two FDOT rehabilitation projects, were evaluated to illustrate the cost and time savings as a result of using the Precast Panels-SCC method. These projects were awarded in January (Project A) and December (Project B) of 2015 to rehabilitate sections of I-95 in Miami, Dade County. Time and cost information as well as the net savings for Projects A (Example 1) and B (Example 2) are shown in Tables 8.4 and 8.5, respectively.

In performing the evaluation in Tables 8.4 and 8.5, our team considered the combined cost of 17 MOT related bid items, contract time and road user cost, and cost of Item 353 (Slab replacement concrete). The savings in time and cost of MOT and lane rental (user cost) was estimated conservatively at 25%. This saving can be attributed to at least 80% to 100% increase in the number of panels removed and replaced per lane closure, each night. This added productivity will result in less MOT days and devices, and law enforcement monitoring.

The reduction in the price of Item 353 (concrete for replacement slab) was estimated conservatively at 10%. The reduction in cost is due to increase in the volume of concrete produced by approximately 100% per each lane-closure. Also, it is a result of using less workers to prepare and finish the replacement slabs. However, the 10% reduction in the cost of Item 353 would probably be offset by the increase in cost of the SCC mix, as well as the added cost to fabricate, transport and handle the precast panels at the jobsite.

As a result of using the Precast Panel-SCC method to accelerate slab replacement in the two projects, the total project savings of \$996,714 (5.7%) in cost and 105 days (25%) in completion time would have been achieved in project A, and \$773,958 (4.5%) and 109 days (25%) in Project B. Other intangible cost savings include, reduced potential for premature cracking of the replacement slabs, and less accidents in the work zone as a result of reduced MOT days, which can save lives and property.

It is suggested that the FDOT include in the project announcements, the cost as well as the estimated project completion time or user cost (lane-rental) days. This will encourage the contractors to consider this method to save time and cost, and achieve a competitive advantage in the bidding process. The result will be lower cost to the FDOT, taxpayers and the contractor. The other and more important benefit to the contractor is the added competitive advantage as a result of moving away from the outdated and slow conventional method for slab replacement, which had often resulted in premature cracking of replacement slabs.

The increased productivity and cost savings will depend on the contractor's means and methods; use of proper and efficient installation equipment; attention to the installation and SCC casting details; as well as smart construction scheduling and worker utilization. It also depends on the experience of the concrete plant personnel in producing appropriate SCC mixes, and managing mix properties with and without accelerators.

The savings estimates used in the two examples were rather conservative. The research team is convinced that with wide use of the Precast Panel-SCC method, and strong competition among the contractors in utilizing efficient methods and equipment, the savings will increase, and the quality and long term performance of the replacement slabs will be significantly better.

Table 8.4: Cost and time savings in rehabilitation Project A (Example 1)

Item	Project A Bid price	Time/cost Saving with Precast- SCC	Added Cost Using Precast - SCC	Cost Reduction (-) or Increase (+)
MOT (17 Items)	\$1,478,855	25%	N/A	- \$369,714
Lane Rental (Days)	418 d x \$6,000/d = \$2,508,000	25%	N/A	- \$627,000
Slab replacement concrete (Item 353)	10,568 CY x \$650/CY = \$6,869,688	10% (Cost)	N/A	- \$686,969
SCC mix & Precast Panels		N/A	\$686,909	+ \$686,969
Total Cost Difference				\$996,714
Total Project Cost	\$17,314,516			
Reduced project Cost	\$16,317,802			
Total Cost Saving %	5.7 %			
Total Time Saving	105 days (25%)			

Table 8.5: Cost and time savings in rehabilitation Project B (Example 2)

Item	Project B Bid price	Time/cost Saving with Precast- SCC	Added Cost Using Precast- SCC	Cost Reduction (-) or Increase +
MOT (17 Items)	\$485,833	25%	N/A	- \$121,458
Lane Rental	435 d x \$6,000/d = \$2,610,000	25%	N/A	- \$652,500
Slab replacement concrete (Item 353)	10,653CY x \$685/CY = \$7,297,237	10% (Cost)	N/A	- \$729,724
SCC mix & Precast Panels		N/A	\$729,724	+ \$729,724
Total Cost Difference				\$773,958
Total Project Cost	\$17,042,000			
Reduced Project Cost	\$16,268,042			

Total Cost Saving %	4.5%			
Total Time Saving	109 days (25%)			

8.10 Challenges and Opportunities

The new method will be very effective in shortening the construction time for slab replacements, resulting in faster completion of rehabilitation projects and significant cost savings. The time and cost savings will be most realized when, appropriate panel lifting equipment is used by trained operators; experienced concrete plant operators to batch and adapt the SCC mix to the weather and MOT conditions; and a concrete casting crew that is quick and efficient. Maintaining speed, efficiency and care in construction will produce the best results that would by far exceed the productivity using conventional slab replacement process.

Here are some of the potential challenges and solutions:

8.10.1 Robustness of precast panels under traffic

The concrete precast panels were reinforced with double mats of #4 reinforcing bars spaced 12” or less in both directions (Figures 8.1 and 8.2). The panel lift anchors were those typically used in heavy precast bridge and wall segments. The team tested the robustness of the panels at the Green Cove Springs test track and FAMU-FSU test pit under slow-moving heavy trucks and validated the soundness of the panel design and structural integrity. Of course, it would have been more ideal to test the panels under normal traffic traveling at 50 or 60 mph. However, due to limited project budget, and unavailability of preplanned rehabilitation projects to allow testing of the panels, prevented the demonstration of panel performance on a Florida road or highway. However, the research team has validated and are fully confident in the structural integrity of the

panels and the lift anchors. There is no doubt that the heavily reinforced panels would perform as intended under any combination of traffic weights and speed. There will not be a need to change the design or configuration of the panels upon implementation of the method in any future rehabilitation projects. Barring any accidental drop of the panels during transportation and handling, each precast panels would be re-used at least 15 times prior to any damage that may require panel replacement.

The most vulnerable areas of a panel are the corners, as shown in Figure 8.26. Panel corners may spall and/or break away after multiple uses. Also, when using improper lifting equipment or gross mishandling of the panel installation can lead to corner breaks. To improve the robustness of the corners, the team modified the designs of Panels A and B as shown in Figures 8.1 and 8.2. The backer rod groove around the perimeter of the panels was lowered from 1.5” to 3” below the panel surface. Also, it is suggested to make the shape of the corners round instead of a sharp 90°-angle. This design will provide more resistance to spalling. It is recommended that a precast panel be replaced when a spall or chipped area is larger than 4” x 4”x 1”.

The most likely maintenance performed on the panels at jobsites would be re-attaching or replacing the backer rods when they are stripped off the panel or become damaged from multiple installations. This maintenance can be minimized with proper fabrication of the panel, including designing an appropriate backer rod groove that allows ½ of the gasket cross section to be inserted and cemented inside the groove. An appropriate cementing material must also be used that is compatible with the Styrofoam material of the backer rod. Also, stopping the backer rod gasket 2 inches short of each corner tip will reduce stripping of the backer rods during installation and removal of the panels.



Figure 8.26: Damage to panel corner and stripping of backer rod gasket

8.10.2 Production of the SCC Mix and management of its properties

The workability of the SCC mix must be high during casting and finishing of the replacement slabs. Such high workability must be maintained until the entire concrete load is discharged from the truck mixer. The mix must also develop the required strength at lane opening time. These contrasting mix criteria require plant and truck operators that are well versed in SCC mix design and production.

Weather and jobsite conditions may dictate fast action to adjust the properties of the SCC mix in order to achieve the required results. It is extremely important to maintain the mixer at a continuous and uninterrupted agitation mode after adding the accelerator at the jobsite and remixing. Failure to follow this recommendation may result in rapid setting of the mix inside the mixer drum. Also, when the flow of the mix becomes too slow, the contractor must deploy manual spreading and internal vibration of the mix to prevent segregation and strength deficiency in the slab.

8.10.3 Agency and industry acceptance

The team has a firm belief that the proposed Precast Panels-SCC method to accelerate slab replacement will result in significant project savings with respect to time and cost. As in the cases of many previous innovative construction methods, some contractors may have reservations and difficulty in initially accepting the new methods. They tend to feel comfortable with their long-standing construction means and methods for slab replacement, despite the fact that a significant number of them experience low production (Chapter 3- Industry Survey) in rehabilitation projects. Also, by attempting to increase productivity through mix modifications, they risk creating stress conditions in the concrete that induce premature cracking in the replacement slabs.

It is a known fact that production has not improved much over the past years despite advances in admixtures and the use of high-early strength mixes. Also, premature cracking of newly cast replacement slabs is a common problem in most rehabilitation projects. This problem has led to additional repair costs to the contractor and/or the department. Applying this method will resolve the low productivity issue and premature distress problems.

Some modifications may be needed to successfully implement the Precast Panels-SCC method. These modifications include the use of efficient lifting equipment, training of contractor personnel, and the use of experienced concrete plant and truck operators. Some changes are also needed in the FDOT design, material specification, and contract requirements, as explained earlier, to facilitate its wide implementation.

CHAPTER 9

CONCLUSIONS, RECOMMENDATIONS AND IMPLEMENTATION PLAN

9.1 PROJECT SUMMERY

Slab replacement is a major activity in any concrete pavement rehabilitation project. According to a survey of industry and FDOT shown in Chapter 3, the contractors' productivity in slab replacements has been very low, ranging between 25 to 50 cu. yd. during the lane closure period. The low number of slab replacements completed during the closure period is due to the short window available to complete the multiple time consuming activities required for each slab replacement. In an effort to increase productivity, the concrete mix is often designed to achieve the lane opening strength requirement of 2,200 psi in the shortest possible time to enable placing more slabs during a lane closure period. This requires the use of excessive quantities of cement and/or accelerators to achieve the required strength. A likely consequence of such action has been the development of premature cracking in many newly replaced slabs.

This project was initiated with the objective to develop a method using temporary reusable precast panels and self-consolidating concrete (SCC) to accelerate the slab replacement process. The ultimate goal of the method is to increase contractors' productivity, reduce maintenance of traffic (MOT) and construction completion time, reduce cost and minimize premature cracking. The two components of this method, namely, reinforced precast panels and SCC mix were designed, prepared, and tested in the lab, and then demonstrated their viability in the field. Construction criteria, detailed guidelines and specifications were also developed to facilitate implementation of this method in concrete pavement rehabilitation projects.

The method involves installing one or two precast panels in the replacement slab pit after removing the deteriorated section of the original slab. The panels are kept as placeholders for a few days and then removed. The open pit is then cast using SCC mix to form a permanent replacement slab.

The method was developed and tested and is summarized in the following steps:

1. Remove the deteriorated section of the pavement slab.
2. Drill holes for the new dowel bars in the appropriate sides of the replacement pit, then clean and patch the holes with tape.
3. If the depth of the resulting pit does not match the thickness of the precast panels, add a leveling course to the bottom of the pit or, otherwise, grub the bottom, whichever applies to achieve the desired depth.
4. Install one or two precast panels in each slab replacement pit. The precast panels would remain in the pit for a short period of time ranging from one to seven days.
5. Remove the precast panel(s) and transport to the next segment of the project for re-installation.
6. Remove the tape that covered the dowel holes and fill the holes with epoxy.
7. Insert and anchor the new dowel bars in the epoxied holes.
8. Cast the replacement slab using the SCC mix,
9. Level, finish and cure the slab surface.
10. Repeat the construction sequence (Steps 1 to 9) until completing the required slab replacements for the project.

9.2 CONCLUSIONS

9.2.1 Temporary Reusable Precast Panels

1. Two 6'x 12'x 8" panel were designed using double mats of no. 4 and no. 5 reinforcing bars. Both designs showed similar robust performance in laboratory and field demonstrations.
2. The imbedded backer rod gasket along the sides of the panels facilitated installation in and removal of panels from the replacement slab pits. Lubricating the gaskets expedited the installation process. The gasket also would soften any impact of the panels against the surrounding concrete and prevent damage to both sides.
3. Maintaining a 1.5" gap between the panels and the surrounding concrete facilitated installation of panels inside the replacement slab pits.
4. The recessed stripes along the bottom surface of the panels provided stability and strong interlock with the base to resist panel shifting under traffic.
5. The panels displaced 3/16" vertically and had very low horizontal displacement when subjected to 50 load repetitions from a passing 60,000 lb truck. This faulting is considered acceptable since the panels are temporary place holders and would remain in the pit for only a few days.
6. The installation time for each panel was approximately 10 min. and its removal was 5 min. With more dedicated lifting and maneuvering equipment, these times can be shortened further.

9.2.2 Self-Consolidating Concrete (SCC) Mix

1. An innovative SCC mix was developed for slab replacements in concrete pavements. The high flow rate of the SCC mix for rapid discharge and finish without segregation will

increase productivity of contractors during lane-closure time and will reduce maintenance of traffic (MOT) time.

2. The SCC mix using Type I/II cement, 57 grade aggregate, silica sand, low w/c as well as a combination of HRWR, workability retainer and accelerator produced a highly workability mix for rapid discharge and shorter casting time, and exceeded the 2,200 psi strength required by the Florida DOT for lane opening. This SCC mix is a departure from conventional SCC mixes used in structural applications.
3. The SCC mix design was highly effective for casting a slab replacement in the field without the need for compaction. This will potentially save time and labor.
4. The concrete workability was retained for at least 60 minutes after adding and mixing the accelerator. The workability retention will allow the concrete in truck mixers to maintain a high workability rate during truck idle times between successive concrete placements and achieve rapid discharge during casting of isolated replacement slabs.
5. Vibrated and nonvibrated samples cast from the same SCC mix showed very small differences in compressive strength and weight. As a result, no concrete vibration was needed during slab placements or in preparing cylinder samples.
6. There was no aggregate segregation in any of the batched mixes despite high workability and the use of grade 57 aggregate in the mix.
7. There was no segregation in placement of the SCC mix in a 12' x 12' x 8" replacement slab pit.
8. It took less than three min. to completely cast a 12' x 12' x 8" replacement slab.
9. Adjustments to the admixture dosage rates may be necessary when the SCC mix is specified for longer concrete transportation periods, when the admixture source changes.

10. Adjustments in the mix cement content and/or accelerator dosage rate may be necessary when the ambient temperature is higher than 85°F or lower the 50 °F to maintain high workability and agency-required strength for lane-opening.
11. Strength of the SCC mix at 6 hr. greatly exceeded the required 2,200 psi strength for lane opening.
12. It is very importance to maintain the truck mixer in agitation mode (when not discharging concrete), non-stop, and at a slightly higher speed than conventional agitation. This will prevent premature setting of the SCC mix after addition of the accelerator at the jobsite.
13. Immediate leveling and finishing of the cast slab will be required due to rapid loss of SCC workability upon discharge in the replacement slab pit.

9.3 RECOMMENDATIONS

9.3.1 General

This method is most cost effective and efficient when:

1. The volume of concrete specified in the contract bid is more than 1000 cu. yds.
2. Limited window for lane closure is specified, especially during nighttime.
3. Significant premature cracking is observed using conventional concrete mixes with excessive amount of cement and accelerator to achieve required strength in less than 4 hr. from the lane opening time.
4. Many deteriorated slabs that require removal and replacement are located in close proximity of each other.
5. The cost benefit analysis favors the use of this method.

Other favorable factors include close proximity of the concrete batch plant and contractor's storage yard to the project site, and safety concerns of having too many workers at slab replacement sites.

9.3.2 Temporary Reusable Precast Panels

1. Revise FDOT Standard Index 308 for 20' long slabs to require the designer to use only four standard dimensions for the deteriorated area to be removed. These dimensions shall be, 6' x 12', 8' x 12', 10' x 12' and 12' x 12'. Cracks that exceed 12' shall require replacement of the entire slab. For 15' long slabs, use three standard dimensions, 6' x 12', and 8' x 12' and 10' x 12'. Cracks exceeding 10' would require replacing the entire slab.
2. Revise FDOT specification 353 to allow the use of precast panels approved by the engineers as temporary fillers of slab replacement pits.
3. Prepare reusable precast panels in two dimension, 6' x 12' x T and 4' x 12' x T. Determine the thickness (T) of the panels from the average thickness of representative pavement cores. These panels would fit individually or in a set of two in the proposed standard pits recommended in (1) for Index 308.
4. Use the panel design developed in this project or a similar design that produces panels that are robust during handling and transportation, stable under traffic, and structurally sound for multiple uses.
5. The precast panels may be reinforced and cast at the contractor's yard or fabricated in a precast plant and delivered to the contractor. The precast panels may be pre-tensioned and can be made using lightweight concrete (after testing).

6. Prepare sufficient number of panels from the two dimension in (2) based on the anticipated productivity per lane closure, proportions of the various standard pit dimensions shown in (1), and the anticipated number of panels that have to be replaced due to damage.
7. Maintain a 1.5” gap between the panels and surrounding concrete to facilitate installation and removal of the panels. This can be achieved by increasing the dimensions of the replacement slab pit or shortening the dimensions of the panels.
8. When the depth of a replacement slab pit is different from the thickness of the precast panels by more than 0.25”, add a leveling course material or grub the base (whichever condition exists) to allow the surface elevation of the installed panel to match that of the surrounding concrete. At the contractor’s option, approved fine recycled concrete, builder sand or geosynthetic mats may be used as a leveling course.
9. Retain the leveling course in place when casting the replacement slab. Revise FDOT specification 353 to allow retention of the leveling course when temporary precast panels are used. .
10. Use efficient equipment to handle the panels at the jobsite, including, loading and unloading, as well as installing and removing. Equipment options include, a crane, excavator bucket or a tractor with a telescopic extension boom that can be adjusted in vertically or horizontal reach, or a similar machines capable to lifting up to a 10 ton weight.
11. Replace a precast panel when upon multiple uses becomes severely damaged. A severe damage includes a crack wider than 0.25” or multiple cracks developed in the panel, or

when a spall larger than 4" x 4" is formed in the panel. Revise specification 353 to include this item.

9.3.3 Self-Consolidating Concrete (SCC) Mix

1. Modify FDOT specification 353 to allow the use of SCC mix in slab replacements. Allow the use of 67 or 57 grade aggregates and accelerator admixture in the SCC mix.
2. Use the SCC mix design developed in this project or an equivalent mix that produces a minimum 20" slump flow immediately after addition of the accelerator. Make adjustments in specification 353 to reflect this property.
3. The SCC mix must maintain a high slump flow for quick discharge and no vibration, and develop a minimum strength of 2,200 psi at lane opening.
4. There will not be a need for internal vibration during casting of the replacement slab using the highly workable SCC mix.
5. Use manual distribution of the concrete and apply internal vibration if the flow of the SCC mix appears to have decreased significantly.
6. When the SCC mix exhibits segregation, remove the concrete from the pit and adjust the mix. Revise specification 353 to include this item.
7. Consider starting the roller or surface vibratory screed to achieve a smooth surface finish while the concrete is being discharged in the replacement slab pit or as soon as the pit is filled. Delaying the surface finish may present challenges to proper surface finish as the mix will harden rapidly as the mix is settled in place.
8. Upon addition of the accelerator to the truck mixer, maintain the mixer at a continuous and no-stop agitation mode (when not discharging concrete). Increase the revolution

speed of the mixer to ensure that the high workability of the mix is maintained, until its entire concrete load has been discharged.

9. When the full slab is removed, the SCC mix may be used to cast a new slab without the need to include the precast panel component of the method.
10. Make adjustments to the mix ingredients when encountering cold or hot weather or when sources of the admixture are changed. Refer to this note in the revised specification 353 when SCC mix is used in slab replacement.

9.4 IMPLEMENTATION PLAN

The method developed in this project and described in the report will result in higher productivity, shorter MOT and project completion time, as well as lower project cost. It may also minimize premature cracking of replacement slabs. It is acknowledged that old methods that contractors had been following in replacing slabs may be difficult to change. However, the research team has and will continue to provide information and guidance on the details and merits of the method.

The recent efforts by the authors to present and promote the method included, a presentation made at the 2016 Construction conference (2016 FTBA Construction Conference). This was followed by another presentation to an interested Tampa contractor who attended the FTBA Conference session. Also, a technical paper was presented and has been published for the 2015 Transportation Research Board (TRB) (Armaghani et al, 2015). A second paper was also presented at TRB 2016 (Armaghani et al. 2016). A technical paper will also be presented and published at the 2016 International Conference on Concrete Pavement (Armaghani et al 2016).

The team partnered and communicated with the concrete industry, contractors and materials suppliers. This interaction has helped not only to secure materials, large SCC mixes and specialty equipment for field applications, but also raised interest of the industry in the proposed method. In conversations with individual contractors, they have shown interest in the method, and some have even started to use components or general concepts of the method and achieved good results with respect to higher productivity, shorter completion time and more cost savings.

The implementation of the method is an option of the contractors and within his “means and methods”, however, the Florida DOT can assist and encourage the rapid implementation of the method by making changes to the design, and material outlined in the above recommendations. It is also recommended that the FDOT should ask for project completion time and project cost, as criteria for contractor selection. This will encourage many contractors to seriously consider the proposed method realizing that the time and cost savings by utilizing this new method may offer a competitive advantage in their bids. The research team can help the FDOT in the training contractor personnel, producers and inspectors of these projects, and also be present at the construction sites when the slabs are being replaced. Chapter 8 of this report can be used as a guideness for the contractor personnel, producers, and inspectors.

There is no doubt that the contractors and concrete producers can make adjustments in the SCC mix design, selecting the right type of equipment to handle the precast slabs, and setting the time schedule to complete the slab replacement. These actions will result in more cost savings, better productivity, less cracking problems, and longer lasting replacement slabs. The ultimate beneficiary if the proposed method is successfully implemented will be the FDOT and the taxpayers.

REFERENCES

1. American Concrete Pavement Association, Guidelines for Full-Depth Repair, TB002P, Skokie, IL, 1995.
2. American Concrete Pavement Association, The Concrete Pavement Restoration Guide – Procedures for Preserving Concrete Pavement, TB020P, Skokie, IL, 1997.
3. Armaghani, J. Tawfiq, K, Squillacote, S and Bergin, M., Accelerated Slab Replacment Using Self- Consolidating Concrete. Transportation Research Record: Journal of the Transportation Research Board of the National Academies, No. 2508, Washington D. C., 2015, pp. 93-101.
4. Armaghani, J. Tawfiq, K, Squillacote, S and Bergin, M., Accelerated Slab Replacment Using Temporary Precast Slabs and Self- Consolidating Concrete. Presentation at the Meeting of the Transportation Research Board of the Natioanl Academies. Washington D.C., 2016.
5. Armaghani, J., Accelerated Slab Replacment Using Temporary Precast Slabs and Self- Consolidating Concrete. Presentaion at the 2016 Florida Transportation and Builders Association (FTBA) Construction Conference, Orlando, Februry 9-10, 2016.
6. Armaghani, J. Tawfiq, K, Squillacote, S and Bergin, M., Accelerated Slab Replacment Using Temporary Precast Slabs and Self- Consolidating Concrete. Paper Accepted for Presentation and Publication at the Proceeding of the 11th International Conference on Concrete Pavements, San Antonio, Texas, August 28-31, 2016.
7. Buch, N., Barnhart, V., and Kowli, R., Precast Concrete slabs as Full-Depth Repairs- Michigan Experience, Transportation Research Record 1823, TRB, National research Council, Washington D.C., 2003, pp. 55-63.
8. David K. Merritt, B. Frank McCullough, Ned H. Burns, and Anton K. Schindler, “The Feasibility of Using Precast Concrete Panels to Expedite Highway Pavement Construction. Report No. FHWA/TX-01/1517-1, February 2000.
9. Elkins, Gary Eugene, B. F. McCullough, and Ronald W. Hudson. *Precast Repair of Continuously Reinforced Concrete Pavement*, Research Report 177-15, Center for Transportation Research, The University of Texas at Austin, May 1979.
10. Esmaelkhanian, B., Feys, D., Khayat, K., and Yahia, A., New Test Method to Evaluate Dynamic Stability of Self-Consolidating Concrete, ACI Materials Journal, Vol. 111, No. 3, May-June 2014.
11. Florida Department of Transportation, Standard Specification for Road and Bridge

- Construction, Section 353, Concrete Pavement Slab Replacement, 2013.
12. Florida Department of Transportation, Design Standards, Index 308, 2010.
 13. Hall, K., and S. Tayabji, Precast Concrete Panels for Repair and Rehabilitation of Jointed Concrete Pavements. Tech brief IF-09-003. FHWA, U.S. Department of Transportation, Washington, D.C., 2008
 14. Khayat, K. Mitchell, D., Self-Consolidating Concrete for precast, Prestressed elements, National Cooperative Highway research Program, NCHRP Report 628. Transportation Research Board, TRB, Washington, D.C. 2009.
 15. Kosmatka, S., and Panarese, W., Design and Control Of Concrete Mixtures, 13th Edition, Portland Cement Association, Skokie, Illinois.
 16. Lee, D. H. "Features of Prestressed Concrete Runway." Civil Engineering and Public Works Review (London), Vol. 54, No. 640, pp. 1291-1292, November 1959.
 17. McCullough, B. Frank, "Review of FHWA Prestressed Concrete Pavement Implementation," Unpublished report, January 1984.
 18. Merritt, D., McCullough, F., Burns, N., Precast Prestressed Concrete Pavement Pilot Project near Georgetown , Texas, Transportation Research Record 1823, TRB, National research Council, Washington D.C., 2003, pp. 11-17.
 19. Neil D. Cable, N. H. Burns, and B. Frank McCullough, "New concepts in prestressed concrete pavement," Research Report 401-2, Texas State Department of Highways and Public Transportation; December 1985.
 20. Ouchi M., Nakamura S. Osterberg T., Hallberg S., & Lwin M. (2003). Applications of Self-Compacting Concrete in Japan, Europe and the United States. *ISHPC*, pp. 1-20.
 21. Precast Concrete Pavement Systems for Rapid Pavement Repair and Replacement: Basic Information and Commentary Developed by the AASHTO TIG on Precast Concrete Paving Systems, June 2008.
 22. Ray, G. K. "Prestressed Pavement Slab - Patuxent River Naval Air Station, Md." Highways Bureau, P.C.A. Preliminary Report, November 27, 1953.
 23. Simonsen, J. E. Research Report # R-968 - Development of Procedures for Replacing Joints in Concrete Pavement, August 1975, Michigan Department of Transportation.
 24. Simonsen, J. E. , Research Report # R-1020 - Development of Procedures for Replacing Joints in Concrete Pavement, August 1975, Michigan Department of Transportation.

25. Stein, B., Kramer, B., Kumar, T., Pyle, T., and Shatnawi, S., Rapid Strength Concrete for Rehabilitation and Improvement of Pavements, First International Conference on Pavement Preservation. 2001.
26. Stott, J. P. "prestressed Concrete Roads." Roads and Road Construction (London), Vol. 33, No. 388, pp. 114-116, April 1955.
27. Super Slab, Fort Miller Inc., www.fortmiller.com.
28. Tayabji, S., Buch, N., and Kohler, E., "Precast Concrete Pavements: Current Technology and Future Directions," 9th International Conference on Concrete Technology and Future Directions, San Francisco California, 2008.
29. Tayabji, Shiraz, N. Buch, and D. Ye. "Performance of Precast Concrete Pavements." Reston, VA: ASCE Proceedings of the First Transportation and Development Institute Congress; March 13-16, 2011, Chicago, Illinois, American Society of Civil Engineers, 2011.
30. Tayabji, S., Ye, D., and Buch, N., "Precast Concrete Pavement Technology," SHRP 2, Report S2-R05-RR-1, Transportation Research Board, Washington D.C., 2013.
31. Tayabji, S., Fugro, D., and Buch, N., Precast Concrete Pavement Technology, SHRP 2 Report S2-R05-RR-1, Transportation Research Board, Washington D.C., 2013.
32. Tia, M., and Kumara, W., Evaluation of Early Strength Requirement of Concrete for Slab Replacement using APT, UF Final Report, FDOT Project RPWO # 83, Gainesville, Florida, March 2005.
33. Transportation Research Board. 1974. "Reconditioning High-Volume Freeways in Urban Areas," Synthesis of Highway Practice No. 25, National Cooperative Highway Research Program, Washington, D. C.
34. Wang, K., Shah, S, White, D., Gray, J., Voigt, T., Gang, L., Hu, J., Halverson, C., and Pekmezci, B., Self-Consolidating Concrete – Application for Slip-Form Paving: Phase I (Feasibility Study), Center for Portland Cement Concrete Paving Technology, Iowa State University, Report No. TPF-5(098), November 2005.
35. Wang, K., Shah, S, Grove, J., Gray, J., Taylor, P., Weigand, P., Hu, J., Steffes, B., Lomboy, G., Quanji, Z., Gang, L., and Tregger, N., Self-Consolidating Concrete – Application for Slip-Form Paving: Phase II, National Concrete Pavement Technology Center for, Iowa State University, Report No. DTFH61-06-H-00011, May 2011.
36. Yang, F. Self-Consolidating Concrete, CE 241, Report #1, University of Berkley California, March 2004.