

PERFORMANCE CRITERIA RECOMMENDATIONS FOR  
MORTARS USED IN FULL-DEPTH PRECAST CONCRETE  
BRIDGE DECK PANEL SYSTEMS

by

Donald P. Scholz

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Dr. Carin L. Roberts-Wollmann, Chairperson  
Department of Civil and Environmental Engineering

Dr. Thomas E. Cousins  
Department of Civil and Environmental Engineering

Dr. Rodney T. Davis  
Virginia Transportation Research Council

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## ABSTRACT

The use of full-depth precast concrete bridge deck panels is becoming more and more attractive to transportation authorities throughout the country. In comparison to conventional cast-in-place decks, precast decks are of higher quality, allow for the bridge to be opened to traffic in less time and are easier to maintain, rehabilitate, and replace. This ultimately results in lower costs for transportation authorities and less disruption for the motoring public. Unfortunately, the use of precast deck panel systems is hindered by the lack of design standardization and information regarding the performance of such systems. This research focuses on a key element of the system, the mortar or grout, which is used to connect the precast panels to the bridge girders by filling the space in the horizontal shear pockets and the haunches. Several essential mortar characteristics were identified and investigated in order to create a specification that indicates required performance criteria for mortars. This specification can be used to determine whether particular mortars or grouts are suitable for use in a full-depth precast concrete bridge deck panel system.

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## CHAPTER 1: INTRODUCTION

### 1.1 Full-Depth Precast Concrete Bridge Deck Panels

The civil engineering community is constantly introducing new construction techniques in order to reduce costs and manage time more effectively. When it comes to bridges, the use of precast concrete deck panels in lieu of cast-in-place decks affords many advantages. Assembly of a precast deck panel system is easier and takes less time than a conventional cast-in-place deck which involves formwork and the daunting task of ensuring a high-quality concrete placement and curing over the entire area of a bridge. Naturally, precast concrete can be held to higher quality standards since it is placed in the controlled environment of a precasting yard. Because precast deck panel assembly is quick and there is no fresh concrete to require a long curing period, the bridge can be opened to traffic in much less time. Precast deck panels can be repaired and replaced on an individual basis, simplifying the maintenance and rehabilitation process. This results in less time lost for the motoring public due to lane closures and detours.

Once the girders are positioned, a precast deck panel system can be installed in four steps. Initially, the precast panels are set in place along the length of the bridge. The panels are typically 7 to 10 in. deep, up to 40 ft wide and 10 ft long. They account for the full depth of the structural deck and span the entire width of the bridge. Leveling devices are used to adjust the elevation of the panels. Secondly, the panels are connected to each other using a mortar or grout, and are then longitudinally post-tensioned. Thirdly, the panels are connected to the girders through a series of shear connector blockouts or pockets. Once again, a mortar or grout is used to fill these horizontal shear connector pockets and the haunch between the deck panels and girders. Lastly, barriers and an optional wearing surface can be placed on the deck panels before opening the bridge to traffic. A schematic of a full-depth precast concrete bridge deck panel system is presented in Figure 1.1. The system has been used with concrete bridge girders as well as steel bridge girders.



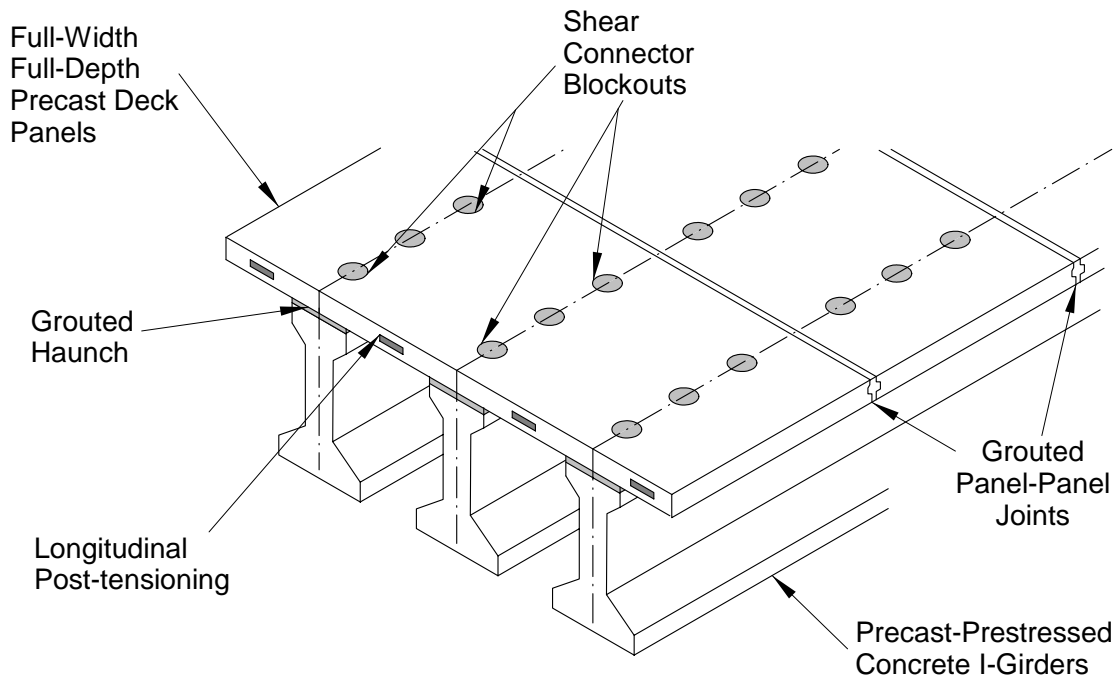


Figure 1.1: Full-Depth Precast Concrete Bridge Deck Panel System

The precast deck panel system has been used in many regions of the United States over the past fifty years, however, their use pales in comparison to the use of conventional cast-in-place decks. This can be attributed to the lack of standardization among deck panel design details. Variables which need to be evaluated to achieve an optimum design include:

- Panel to panel connection details including:
  - Ideal mortar properties
  - Post-tensioning details
- Panel to girder connection details including:
  - Horizontal shear connection pocket spacing, size and geometry
  - Ideal mortar properties
  - Panel and girder surface preparations
- Evaluation of various wearing surface options

## **1.2 Research Objective and Scope**

The scope of this research is investigating mortars and surface preparations for horizontal shear connections between precast concrete panels and concrete girders. A current National Cooperative Highway Research Program (NCHRP) project (No. 12-65) is studying panel to panel connection details, thus they will not be included in this research. The goal is to develop a specification that will indicate required performance of essential mortar properties in order to determine whether a particular grout is suitable for use in a precast deck panel system. This will be accomplished by identifying grout material properties that are crucial to ensuring a panel to girder connection of high initial quality. These properties will then be evaluated with standard tests approved by the American Society for Testing and Materials (ASTM) as well as tests designed to represent how a mortar functions in a precast deck panel system. Each property will be paired with one ASTM test and one representative test. Four mortars will be assessed with and without a pea gravel aggregate extension for a total of eight different grouts. These candidate grouts have been carefully selected from a list of highway patching materials approved by VDOT. Four types of surface preparations for panels and girders will also be investigated in conjunction with the ASTM tests. The research objectives are:

- Identify essential mortar properties
- Identify appropriate ASTM tests and design representative tests
- Evaluate properties of eight mortars using ASTM and representative tests
- Determine advantages/disadvantages of using an aggregate extension in grouts
- Recommend minimum performance criteria for each mortar property
- Evaluate four types of surface preparations for panels and girders
- Develop a design specification for the use of mortars in full-depth precast concrete bridge deck panel systems

## **1.3 Thesis Organization**

Chapter 2 presents previous research on precast bridge deck panels, noting the shortage of specific information regarding mortars and their role in the system. Chapter 3 discusses the properties of mortars that are vital to ensuring a high quality horizontal

shear connection between girders and panels. Chapter 4 describes the ASTM tests and representative tests used in this project as well as the candidate grouts. Chapter 5 presents results and analysis of all of the experiments. Chapter 6 presents a summary and conclusions of the research and provides recommendations for future research. Chapter 7 proposes a performance specification for mortars used in full-depth precast concrete bridge deck panel systems.

## CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

### 2.1 Precast Concrete Bridge Deck Panel System Background

Full-depth precast concrete bridge deck systems have been in use in the United States since the early 1970s. Bridges in Virginia that currently utilize the system include the Route 7 bridges over Route 50 in Fairfax, the Route 229 bridge over Big Indian Run in Culpeper, the Route 235 bridge over Douge Creek in Fairfax, and the Woodrow Wilson Bridge which carries Interstate 95/I-495 over the Potomac River into Maryland (Issa, et al. 1995a; Babaei, et al. 2001). All of these bridges originally had cast-in-place decks which were replaced by precast concrete deck panels after 40 to 50 years of service, except for the Wilson Bridge deck, which was replaced after 20 years of service. VDOT selected a precast system for each bridge in part because of the minimization of construction-induced traffic delays. Table 2.1 presents details about the use of precast deck panels for these bridges.

Table 2.1: Select Uses of Precast Deck Panels in Virginia

Bridge Name and Location	Design	Girders	Mortar Description	Longitudinal Post Tensioning
Route 7 Bridges, Fairfax	Composite	Steel (Plate)	rapid setting cementitious	Yes
Route 229 Bridge, Culpeper	Composite	Steel (Rolled)	high early strength non-shrink	No
Route 235 Bridge, Fairfax	Composite	Steel (Rolled)	non-shrink	No
W. Wilson Bridge, Potomac	Composite	Steel (Rolled)	high early strength polymer concrete	Yes

An analysis was conducted to compare the costs of a traditional cast-in-place deck with a precast panel alternative for the Route 7 bridges project in Fairfax. While it was estimated that the cast-in-place deck would run \$250,000 less than the precast system in construction costs, the precast system would save the motoring public over \$2,000,000 in user-related costs. (Babaei, et al. 2001) These costs stem from the fact that using a cast-in-place deck would require the bridges to be completely closed for 4 months, while the

precast system could be installed panel by panel at night. The bridge could remain open during the day, and the total construction time would only be 1½ months. In the invaluable interest of time, precast concrete deck panel systems are becoming more and more attractive to departments of transportation around the country.

While precast bridge deck panels have been utilized in new construction as well as in rehabilitation of deteriorated cast-in-place decks, their use has been somewhat restricted by the limited knowledge base of design specifications and construction procedures. While more unified methods in panel design are emerging, an aspect of the system that has certainly been given little attention is the mortar or grout. This material is ultimately responsible for the connection between the precast deck panels and the bridge girders and must be held to high standards to ensure composite action between the structural components. While the importance of this system detail is undeniable, current procedures for selecting grouts are vague at best. The following section investigates previous research on precast deck systems, noting their discussion of mortars and grouts.

## **2.2 Precast Concrete Bridge Deck Panel Literature Review**

Biswas (1986) reported on the use of full-depth precast deck systems in some New York, Pennsylvania, Maryland, New Jersey, Illinois and California bridges. Included were system details regarding panel dimensions, transverse joints, post-tensioning, panel to panel connections and panel to girder connections. Numerous types of materials were used to fill the haunches and shear pockets such as epoxy/sand mixes, non-shrink grouts, latex modified concrete, polymer grouts and calcium aluminate cement mortars. He noted the importance of the mortar to the system's performance but admitted that their material properties are not always readily available. Some research was conducted on the strength and durability of a silica-sand epoxy mortar with varying moisture contents to cyclic loading and freeze-thaw cycles. He reported that with increasing temperature, the number of load cycles to failure decreased parabolically as did its flexural resistance with increasing freeze-thaw cycles.

Issa, et al. (1995a) surveyed state departments of transportation around the country and found that 14 have used a precast deck panel system in one or more of their bridges. Most were used for deck rehabilitation. They also conducted their own field

investigations of precast deck panels in 11 states. (Issa, et al. 1995b) The researchers reported on system details similar to Biswas, but also included information about how well various components had performed over the life of the system. While cracking and leaking were observed in some, they concluded that precast panel systems have, as a whole, performed exceptionally well. Most DOTs reported using a “high strength non-shrink grout” but details about these mortars are limited. The researchers expressed interest in adopting a high early strength material to be used to fill the pockets and haunches as well as the transverse joints. Issa, et al. (1998) then developed finite element models based on their findings to determine the ideal amount of longitudinal post-tensioning to use in the system.

Yamane, et al. (1998) developed a full-depth, precast, prestressed concrete bridge deck system. They created a finite element model and then built a full-scale prototype with three 20 ft long panels over two girder lines spaced at 8 ft. They selected a rapid-set non-shrink grout called Set<sup>®</sup> 45 based on research done by Master Builders, Inc., who also manufactures the product. This research will be discussed in section 2.3. Yamane indicated that there may be other products suitable for use in a precast deck panel system, listing Five Star, Tamstech, Fosroc and Sika as possible manufacturers. During the cyclic load tests of the panels system, water was ponded over a panel to panel connection to see if leakage would occur at the interface. No such behavior was observed.

Culmo (2000) reported on the successful implementation of two precast bridge deck panel systems in Connecticut. The first bridge consisted of six spans and used a full bridge closure approach. It was completed in 7 weeks. The second bridge consisted of 34 spans and used a weekend bridge closure approach since the bridge was along a major traffic artery. It was completed in 6 months. Connecticut developed their own deck panel system design based on practices in other states. They utilized a high strength, non-shrink grout to fill the transverse joints as well as the shear pockets and haunches. As is the case for so many other projects, specific details regarding this material’s properties were not available. However, the precast decks were reported to be in excellent condition after 8 years of service.

While most precast concrete bridge deck panel systems utilize a high strength non-shrink grout, details about specific material properties are vague. Little effort is

made to identify specific properties that are important for a mortar to function well in a precast deck system, let alone set criteria for those properties. “High early strength” and “non-shrink” are commonly used to describe an ideal mortar, but how high and how early is sufficient for this system? What limits should be placed on shrinkage? In order to ensure a quality precast deck system, ideal mortar properties should be established so that suitable products may be selected for use in the system.

## 2.3 Mortars and Grouts

### 2.3.1 Current Specification

The current specification for mortars used in deck panel systems is ASTM C 1107 (2002): Standard Specification for Packaged, Dry Hydraulic-Cement Grout. This standard is really geared towards grouts that are used as a base material to support machinery. In this situation, the grout must remain at a constant thickness over time and, therefore, the specification places strict limits on change in height. Three classifications are established based on how a grout adjusts its volume to control its height change. Grade A grout adjusts its volume by expanding before hardening, Grade B grout expands after hardening, and Grade C uses a combination of pre-and post-hardening expansion. Performance requirements are summarized in Table 2.2.

Table 2.2: Performance Requirements for Grouts per ASTM C 1107

Compressive Strength (ASTM C 109)	Height Change (ASTM C 827 and C 1090)			
	Grade A	Grade B	Grade C	
1000 psi @ 1 day				
2500 psi @ 3 days	Max 4.0%	Max n/a	Max 4.0%	@ Final Set
3500 psi @ 7 days	Min 0.0%	Min n/a	Min 0.0%	
5000 psi @ 28 days	Max n/a	Max 0.3%	Max 0.3%	@ 1, 3, 14
	Min 0.0%	Min 0.0%	Min 0.0%	and 28 days

This specification does not address properties that are important to deck panel grouts such as tensile strength, bond strength, shrinkage, flow and resistance to chlorides and sulfates from road debris. Furthermore, the compressive strength requirements are

far below what should be expected of deck panel grouts. High early strengths are desired so that bridges may be open to traffic within hours of the grout pour. For instance, requiring 2000 psi within 2 hours would be more appropriate. It is apparent that a new specification needs to be developed to address the unique needs of mortars and grouts utilized in a precast bridge deck panel system.

### **2.3.2 Literature Review**

Gulyas, et al. (1995) of Master Builders Technologies (MBT) reported on the importance of grouts to transfer load between precast, prestressed concrete box beams and other structural elements. Shrinkage and bond loss led to leakage and general degradation of systems as reported by two regional Precast/Prestressed Concrete Institute (PCI) associations. These maintenance issues could be avoided if more attention were given to grouts in bridge design. Gulyas also pointed out that the specification for non-shrink mortars, ASTM C 1107, does not address shrinkage or bond strength. The researchers developed a program to evaluate two types of grouts through component and composite testing. Component testing involved evaluation of basic grout properties such as compressive strength, tensile strength, and height change. Composite testing involved creating small concrete keyway assemblies, filling them with mortar and then testing them in direct tension, vertical shear and longitudinal shear.

MBT tested two types of grouts: a generic non-shrink grout and a magnesium ammonium phosphate ( $\text{Mg-NH}_4\text{-PO}_4$ ) mortar manufactured and distributed by Master Builders as Set<sup>®</sup> 45 Hot Weather. They reported that the Set<sup>®</sup> 45 performed much better than the non-shrink grout, with an average 300% higher failure loads in the three types of composite tests. The failure mode for the non-shrink grout specimens was bond failure along the interface, while for the Set<sup>®</sup> 45 specimens it was a substrate failure through the concrete keyway. The Set<sup>®</sup> 45 also outperformed the non-shrink grout in component tests, with higher compressive and tensile strengths and smaller height changes. Gulyas reported on unpublished MBT research conducted in the past that utilized slant shear cylinder tests (ASTM C 882) and drying shrinkage tests (ASTM C 157 with 3 in. square cross section bars). They showed that Set<sup>®</sup> 45 and Set<sup>®</sup> 45 extended 50% with a 3/8 in. pea gravel exhibited high bond strength to concrete (1000-2000 psi) and very low drying



shrinkage compared to a 0.32 water-cement ratio concrete (100 microstrain at 28 days). Overall, the researchers concluded that keyway composite tests should be used to evaluate non-shrink mortars that are being considered for use in box beam systems. They also noted that special attention should be given to removing carbonation and other undesirable accumulation from concrete surfaces that can adversely affect the bonding capabilities of the grout. The Mg-NH<sub>4</sub>-PO<sub>4</sub> Set<sup>®</sup> 45 Hot Weather was recommended for use in these box-beam bridge systems. Gulyas used straightforward methods to qualify mortars based on system-specific configurations. A similar approach could be adopted to qualify mortars for precast bridge deck panel systems.

Nottingham (1996) reported on the performance of grouts used in precast deck systems for bridges and docks in Alaska. He traced most problems to weak grout, poor joint details and inconsistent grouting procedures, noting that the grouting operation is often “controlled chaos.” Since grout specifications were vague and performance was suffering, more detailed qualifications and procedures were developed over time. Nottingham recommended using the Master Builders Set<sup>®</sup> 45 or a similar product whose properties would meet those presented here in Table 2.3.

Table 2.3: Nottingham’s Recommended Grout Specifications

<b>Compressive Strength</b> (No test method specified)	1200 psi @ 6 hrs. 4500 psi @ 1 day 6500 psi @ 28 days
<b>Flexural Strength</b> (ASTM C 78, air cured)	550 psi @ 1 day 600 psi @ 28 days
<b>Slant Shear Bond</b> (ASTM C 882)	2500 psi @ 28 days
<b>Freeze-thaw Resistance</b> (ASTM C 666, A modified)	RDF of 80%
<b>Scaling Resistance</b> (ASTM C 672, 25 cycles)	0 scaling rating
<b>Shrinkage</b> (ASTM C 596)	0.03% @ 28 days
<b>Sulfate Resistance</b> (ASTM C 1012)	0.10% @ 28 weeks

Nottingham also provided recommendations for installation procedures. These specifications are a big step in standardizing the performance of grouts in precast deck

system design, which has largely neglected their importance in the past. However, the method of determining these performance levels appears subjective and should be investigated more closely with laboratory testing. Important grout characteristics not addressed include its flow capabilities and its early age compressive strength (1-2 hrs) which is vital when a bridge must be opened to traffic in a short amount of time.

## 2.4 Horizontal Shear Transfer and Push-Off Tests

### 2.4.1 Codes and Specifications

ACI 318 (2002), AASHTO Standard Specification for Highway Bridges (1996), and AASHTO LRFD Bridge Design Specifications (1998) present three different design methods for horizontal shear transfer between a precast girder and a cast-in-place deck slab. These methods for normal weight concrete are summarized below:

ACI 318-02:  $V_u \leq \phi V_{nh}$

$$\text{If } V_u > \phi 500b_v d, \quad V_{nh} = \mu A_v f_y < 0.2f'_c A_c \text{ and } 800A_c \text{ (lbs.)} \quad (2.1)$$

$$\text{If } V_u < \phi 500b_v d, \quad V_{nh} = 80b_v d \text{ (lbs.)} \quad (2.2)$$

for clean, roughened surface with no steel reinforcement, and  
for clean, smooth surface with minimum reinforcement

$$V_{nh} = (260 + 0.6A_v f_y / (b_v s)) b_v d \leq 500b_v d \text{ (lbs.)} \quad (2.3)$$

for clean, roughened surface with reinforcement provided

$$\text{minimum reinforcement area, } A_{vh} = 0.75 \sqrt{f'_c} b_v s / f_y \geq 50 b_v s / f_y \text{ (in}^2\text{)} \quad (2.4)$$

AASHTO Standard Specifications:  $V_u \leq \phi V_{nh}$

$$V_{nh} = 80b_v d \text{ (lbs.)} \quad (2.5)$$

for clean, roughened surface with no steel reinforcement

$$V_{nh} = 350b_v d \text{ (lbs.)} \quad (2.6)$$

for clean, roughened surface with minimum reinforcement

$$V_{nh} = 330b_v d + 0.4A_v f_y d / s \text{ (lbs.)} \quad (2.7)$$

for clean, roughened surface with greater than minimum reinforcement

$$\text{minimum reinforcement area, } A_{vh} = 50b_v s / f_y \text{ (in}^2\text{)} \quad (2.8)$$

AASHTO LRFD Specifications:  $v_{uh}A_{cv} < \phi V_n$

$$v_{uh} = V_u/(b_v d) \text{ (psi)} \quad (2.9)$$

$$V_n = cA_{cv} + \mu(A_{vh}f_y + P_c) \text{ (lbs.)} \quad (2.10)$$

where, in all three design methods,

$V_u$  = factored vertical shear force, lbs.

$v_{uh}$  = factored horizontal shear stress, psi

$V_{nh} = V_n$  = nominal horizontal shear resistance, lbs.

$A_{vh}$  = area of horizontal shear steel reinforcement, in<sup>2</sup>

$f_y$  = yield strength of horizontal shear steel reinforcement, psi

$s$  = spacing of horizontal shear steel reinforcement, in.

$b_v$  = width of interface, in.

$A_{cv} = b_v s$ , in<sup>2</sup>

$d = d_v$  = effective depth to tension reinforcement or prestressing strands, in.

$\mu$  = friction coefficient = 1.0 for concrete with clean, roughened surface

$c$  = cohesion factor = 100 psi for clean, roughened surface

$P_c$  = permanent compressive force normal to shear interface, lbs.

All three methods use a similar concept in that shear strength is the sum of the cohesion between the materials plus a friction coefficient times a clamping stress. The clamping stress is a function of the amount of steel reinforcement across the interface. It is important to restate that these design equations were developed for a cast-in-place concrete slab bonding to a precast concrete girder. Horizontal shear resistance for a precast deck panel system that has two precast concrete elements bonded with a mortar or grout is not specifically addressed in any design specification.

#### **2.4.2 Push-Off Tests**

Today's design specifications for horizontal shear transfer are based on the shear friction concept, which describes the behavior of a cracked material or an interface between two elements. As the two sides of the cracked material attempt to shear past each other, their motion is resisted by friction. Additionally, the crack dilates, separating the materials. In concrete, this dilation is resisted by steel reinforcement which bridges the interface. The provided area of steel,  $A_{vf}$ , is assumed to be loaded to its yield strength,  $f_y$ , and causes a net compressive force to act normal to the interface. The

friction force along the interface is equal to a friction coefficient,  $\mu$ , times the normal force,  $A_v f_y$ . This concept is illustrated in Figure 2.1.

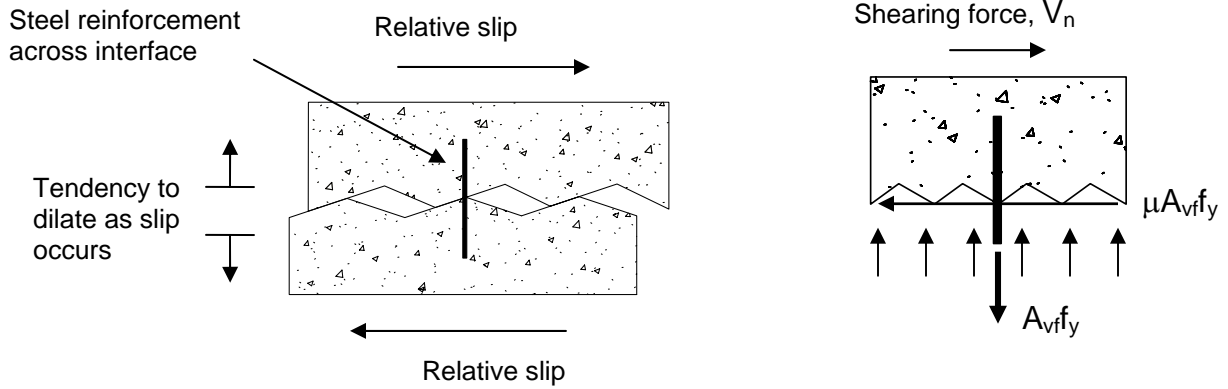


Figure 2.1: Shear Friction Concept

The shear friction concept has been modeled in laboratory experiments by means of the push-off test. An L-shaped concrete specimen is precast with steel reinforcing extending from the lower leg. Then an inverted L-shaped specimen is cast on top of the precast specimen and the combined unit is loaded in direct shear along the interface. A typical push-off specimen is shown in Figure 2.2.

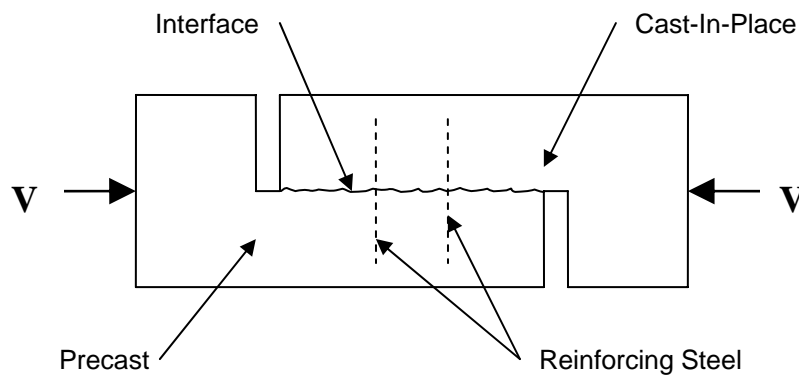


Figure 2.2: Classic Push-Off Test Specimen

These tests were used extensively by Birkeland (1966), Mast (1968), and Mattock (1969, 1972 and 1976) to quantify horizontal shear capacity between a precast and cast-in-place concrete interface. These tests were modified by Shim, et al. (2000, 2001) to investigate shear transfer between a steel girder and precast concrete slab that were joined with steel studs and a mortar. They used three mortars with different compressive strengths and found that the shear strength of the system increased as the compressive strength of the mortar increased, but this parameter was not the focus of their research.

Menkulasi and Roberts-Wollmann (2002, 2003) modified the push-off test to represent a precast deck panel system with a haunch space between two precast L-shaped specimens and a shear pocket blockout in the deck side specimen. They performed three series of 12 push-off tests with three varying parameters, summarized in Table 2.4

Table 2.4: Menkulasi and Roberts-Wollmann Push-Off Test Parameters

Haunch Height	Shear Connectors	Mortar Type
1 in.	no connectors	Latex-modified mix
2 in.	1 # 4 bar	Set <sup>®</sup> 45 Hot Weather extended 50%
3 in.	2 # 4 bars	
	1 # 5 bar	
	2 # 5 bars	

Menkulasi and Roberts-Wollmann also investigated the use of shear keys formed into the girder side specimen as well as post-installed hooked rebar and Dayton Richmond anchors. They found that the Set<sup>®</sup> 45 Hot Weather performed slightly better than the latex-modified mix and that the haunch height did not significantly affect the shear capacity of the system. The researchers compared their tests results to the ACI, AASHTO Standard and AASHTO LRFD design equations for horizontal shear strength and found that the AASHTO LRFD method was the best predictor of the precast deck panel system's behavior. Menkulasi and Roberts-Wollmann also developed best fit and lower bound design equations for horizontal shear strength based on their data.

$$v_{nh} = 160 + 0.51(A_{vh}f_y + P_n)/(b_v s) \text{ (psi)} \quad \text{[best fit]} \quad (2.11)$$

$$v_{nh} = 80 + 0.51(A_{vh}f_y + P_n)/(b_v s) \text{ (psi)} \quad \text{[lower bound]} \quad (2.12)$$

Their push-off test configuration and results were utilized extensively in the current research project to investigate how different types of mortars affect the horizontal shear capacity of a precast concrete deck panel system.

## **2.5 Background and Literature Review Summary**

This chapter has presented background information on precast concrete deck panels systems. It is evident that the mortar or grout has been largely overlooked in the implementation of these systems, despite their importance to the system's overall performance. The current specification for mortars does not address the properties that are essential to ensuring a high quality connection between the precast girders and the precast deck panels. Establishing performance criteria and developing a more appropriate specification will ensure that suitable products will be selected for use in these systems. Identifying mortars that are suitable for use in these systems will be more straightforward and the structural integrity of the precast deck panel systems will increase dramatically.

## CHAPTER 3: IDENTIFICATION OF MORTAR PROPERTIES ESSENTIAL TO PRECAST DECK PANEL SYSTEMS

### 3.1 General Mortar Properties

There are many types of performance-based properties that separate one mortar from another. The properties that are important to precast bridge deck panel systems can be organized into three basic categories: strength, durability and constructability. These properties are summarized in Table 3.1.

Table 3.1: General Performance-Based Mortar Properties

Strength	Durability	Constructability
Compressive	Shrinkage	Work Time
Tensile	Freeze/Thaw	Set Time
Bond	Sulfate Resistance	Flow
	Chloride Ingress	

#### 3.1.1 Strength

In order to open a bridge utilizing a precast deck panel system to traffic as soon as possible, rapid mortar strength gain is of utmost importance. Most mortars used for highway patching are rated for a compressive strength of 2500 psi in two hours. This is certainly an impressive statistic, but it is important to note that these mortars are usually used to fill shallow cracks and small areas of weathered concrete. In a precast deck panel system, the grout needs to fill an area as deep as the deck itself, between 7 in. and 10 in., as well as the haunch between the deck and girders, which can range from 1 to 3 in. For such a deep and voluminous pour, it is customary to use a pea gravel aggregate extension, which allows the mortar to pour more like concrete and to extend the yield volume of the mortar, reducing costs. Using the proper aggregate extension is vital to ensure that the reduction in initial compressive strength is not too great, and that the consistency of the mortar does not become too thick, hindering its ability to flow through the confines of the haunch. The goal of using a mortar in a precast deck panel system is to achieve a

compressive and tensile strength similar to that of the deck concrete. This will ensure a fairly uniform structural consistency in the deck and more importantly, sufficient composite action between the deck and the girders.

Bond or adhesion between the grout and the concrete of the deck and girder is important to ensure sufficient horizontal shear strength of the deck panel system. Currently, ACI 318-02, AASHTO Standard and AASHTO LRFD provide design equations for horizontal shear strength between a precast girder and a cast-in-place deck, which involves one shear plane. However, they do not provide design equations for horizontal shear strength between two precast members, which involves two shear planes, one between the grout and deck and one between the grout and girder. Menkulasi and Roberts-Wollmann (2002, 2003) have proposed equations for horizontal shear resistance in precast concrete deck panels on concrete girders based on their research. For the case where no shear connectors are used, the peak shear stress across the two plane interface was between 115 and 225 psi.

### **3.1.2 Durability**

Most mortars and grouts under consideration for use in precast deck panel systems are considered non-shrink. This does not mean that the mortar does not shrink; rather, it shrinks a very small amount. Differential shrinkage between the grout and the precast concrete must be limited to ensure that cracks are not formed along the interface, reducing the horizontal shear capacity of the system. Mortar shrinkage can also lead to cracks at the shear pocket interface. This could allow water and deicing agents to seep through the deck, which has been known to cause significant damage to the girders.

Freeze/thaw resistance measures a material's ability to withstand cold/warm cyclic temperature changes. Sulfate resistance and chloride ingress are properties that describe a material's permeability when exposed to sulfates and chlorides such as deicing chemicals and other road debris. While these are all important characteristic for long-term durability in sections of the country with varying temperatures throughout the year, it is not vital in ensuring a high initial quality for horizontal shear connections and will not be investigated in this research.



### **3.1.3 Constructability**

Since most candidate mortars boast high early strength gain, constructability can be a concern. Most grouts specify that mixing, placing and finishing must be completed within 10 to 15 minutes. To ensure a high quality horizontal shear connection, the grout must completely fill the shear pockets and distribute evenly through the haunches. If a grout's workability is poor and the initial set time low, it is very possible that its ability to flow will be adversely affected. Achieving a balance between high early strength and flow capability is critical.

### **3.2 Mortar Properties Investigated in This Research**

The performance-based mortar properties that have been identified as important to ensuring a horizontal shear connection of high initial quality are:

- Compressive Strength
- Tensile Strength
- Shrinkage
- Flow
- Workability
- Bond Strength

The eight candidate mortars will be used to evaluate these properties and determine optimal performance criteria for a precast bridge deck panel system.

## CHAPTER 4: DESCRIPTION OF ASTM TESTS, REPRESENTATIVE TESTS AND CANDIDATE MORTARS

Four candidate mortars were analyzed through a series of tests in order to investigate the properties identified in Chapter 3. They were evaluated as neat mortars (no aggregate extension) and as extended mortars, using a 3/8 in. pea gravel aggregate extension. A corresponding 4000 psi nominal concrete batch was prepared for each grout. The concrete was needed as a base material for many of the experiments as it represented the concrete girder and concrete deck panel. Mixing information for each mortar and concrete are provided at the end of this chapter.

### 4.1 Compressive Strength

The compressive strength for each mortar was obtained in accordance to ASTM C109 (2002): Standard Test Method for Compressive Strength of Hydraulic Cement Mortars Using 2-in. Cube Specimens (modified). Since an important characteristic of a mortar is early strength gain, compressive strengths were obtained at one hour, two hours, one day and seven days (see Figure 4.1). Three cubes were tested at each time interval, and the reported strength is the average of the three cubes.



Figure 4.1: Typical 2 in. Cube Specimens After Testing per ASTM C 109

## 4.2 Tensile Strength

### 4.2.1 ASTM C 496

The tensile strength for each mortar was obtained in accordance to ASTM C 496 (1996): Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. This test method applies a splitting compressive load along the sides of a cylinder. A splitting tensile strength can then be calculated based on the cylinder's dimensions and the maximum applied load. In this research, 4 in. by 8 in. cylinders were used to obtain splitting tensile strengths at one day and seven days (see Figure 4.2). Two cylinders were tested at each time interval, and the reported strength is the average of the two cylinders.



Figure 4.2: Typical Split Cylinder Specimen After Testing per ASTM C 496

### 4.2.2 Representative Calculation: Mohr's Circle

While no representative test was conducted for tensile strength of the mortars, a simple Mohr's circle approach was used to obtain a minimum tensile capacity for a mortar bonding to a precast girder and precast panel. Two stress states were evaluated: 1) pure shear stress between panel and girder, and 2) shear stress and tensile stress in a negative moment region of a continuous girder.

### 4.2.2.1 Pure Shear Stress

Two natural shear planes occur in the haunch between the girder and the deck panel. The mortar must be able to cohere to both concrete elements and resist the horizontal shear forces acting along each interface. While resisting these stresses, the mortar must not fail in diagonal tension. The mortar needs to have a tensile capacity higher than the required mortar/concrete bond strength to ensure that a crack is not formed within the mortar itself. This concept is illustrated in Figure 4.3

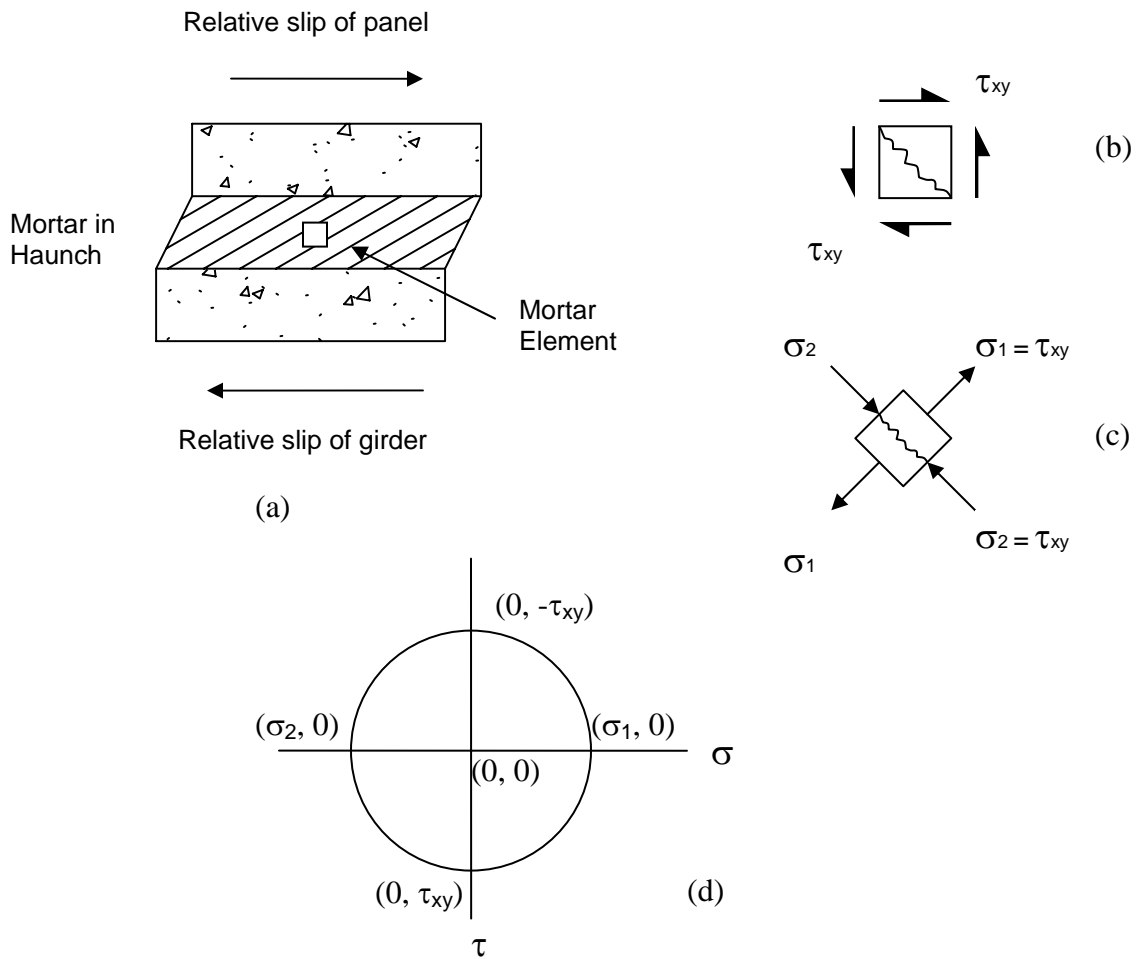


Figure 4.3: Pure Shear Stress: Mortar in Haunch (a), In-Plane Shear Stresses (b), Principal Stresses (c), and Mohr's Circle (d)

Since the mortar is subjected to pure shear stress,  $\tau_{xy}$  (Figure 4.3b), the principal stresses,  $\sigma_1$  and  $\sigma_2$ , act  $45^\circ$  from this plane and are equal in magnitude to the shear stress (Figure 4.3c). The tensile stress is equal to  $\sigma_1$ , and Mohr's circle (Figure 4.3d) is centered at (0, 0). With little or no steel reinforcement present across the haunch, the clamping stress, or normal force acting through the haunch, is low. For clamping stresses between 0 psi and 100 psi, the AASHTO LRFD design equation assumes a horizontal shear strength that varies linearly between 100 psi and 200 psi. The mortar must resist at least this amount of stress in tension to guarantee that the failure mode of the system is not a diagonal tension crack through the mortar. Therefore, the minimum tensile capacity of the mortar is 200 psi.

#### **4.2.2.2 Shear Stress And Tensile Stress**

A more critical stress state is located at the interior supports of a continuous girder. Longitudinal post-tensioning has been used to counteract the tensile stresses induced in the deck at these negative moment regions. Issa, et al. (1998) recommended a minimum post-tensioning of 450 psi in order to keep the deck panels in compression for a continuous girder bridge. It can be assumed that tensile stresses present at this location must be equal and opposite to the required compressive post-tensioning. The tensile stress in the mortar in the haunch would be less than that in the deck because of the varying strain distribution throughout the composite girder and deck panel. Since this distribution varies depending on the size and spacing of the girders, the thickness of the deck and haunch, and the compressive strengths of the deck and girder, 450 psi was conservatively taken as the tensile stress in the mortar. A shear stress of 200 psi is also assumed at this location, as discussed in section 4.2.2.1. A mortar element and Mohr's circle for this stress state is illustrated in Figure 4.4. Vertical compressive stresses caused by the weight of the deck panel are conservatively neglected since they are extremely small ( $< 1$  psi for an 8 in. deck) compared to the tensile stresses and shear stresses caused by the applied loads. Mohr's circle is centered at 225 psi (Figure 4.4b), which is the average normal stress,  $\sigma_{avg}$ ; the radius, R, is approximately 300 psi. The principle stresses are 525 psi ( $\sigma_1$ ) and -75 psi ( $\sigma_2$ ).

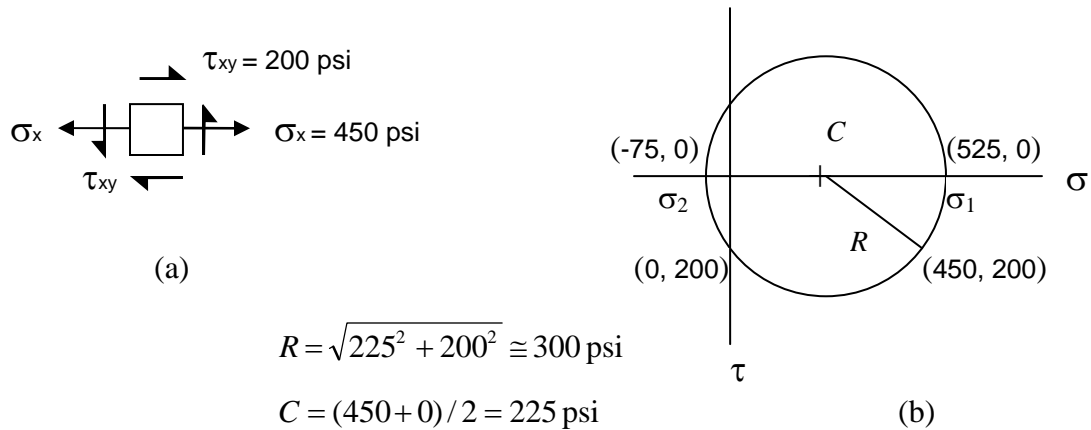


Figure 4.4: Shear and Tensile Stress: Mortar Element (a), and Mohr's Circle (b)

In order to prevent diagonal tension cracking at this location, the mortar needs to have a tensile strength equal to the principle stress of 525 psi. However, this number is conservative, and calculations should be carried out to obtain the actual stresses in the mortar for each specific bridge configuration.

### 4.3 Shrinkage

#### 4.3.1 ASTM C 157

Shrinkage for each mortar was obtained over a 28 day period in accordance to ASTM C 157 (1999): Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete (modified). Mortar was placed in rectangular prism bar molds 11.25 in. long with nickel alloy studs inserted at each end. A 10 in. gage distance between studs is considered the original length value in shrinkage calculations. Neat mortars, or mortars without an aggregate extension, were tested using 1 in. square cross section bars. Mortars with an aggregate extension were tested using 3 in. square cross section bars (see Figure 4.5). A length comparator measured the outside distance between studs in order to determine shrinkage over time.



Figure 4.5: Neat Mortar (bottom) and Aggregate Extended Mortar Shrinkage Bars

Shrinkage bars were allowed to cure in laboratory ambient air conditions. This allowed them to experience slight temperature and humidity changes as would be the case for mortars used in a bridge deck panel system. An environmentally controlled chamber would not accurately represent these conditions. Since the coefficient of thermal expansion for each grout is low, and the laboratory temperature did not vary greatly, temperature effects did not greatly alter the shrinkage values. Four shrinkage bars were prepared for each neat mortar while three shrinkage bars were prepared for each aggregate extended mortar. Three shrinkage bars were also prepared for each corresponding concrete batch. ASTM C 596 (2001) is a similar specification which can also be used to determine shrinkage of mortars.

#### **4.3.2 Representative Test: Shear Pocket with Ponding**

A critical location of a precast deck panel system in which mortar shrinkage could affect the girder-panel connection is the shear pocket. Most mortars are specified as “non-shrink”, which does not mean that they do not shrink at all, but that they do not shrink very much. It was important to assess the validity of this ambiguous terminology. Relative shrinkage differences between the concrete and the mortar could cause cracking along the interface, which could result in less bond strength and the leaking of water

through the panel. Minimizing leaking is especially important in areas of cold weather climate so that deicing agents do not seep through the deck and attack the bridge girders.

To model relative shrinkage of concrete and mortar in a shear pocket, a 12 in. by 12 in. by 4 in. deep block of concrete was cast with a centered 6 in. diameter circular cutout. After the concrete had cured for at least 28 days, mortar was poured into the 6 in. pocket. Then after the mortar cured, a thin layer of water was ponded over the entire 12 in. by 12 in. area. This test is illustrated in Figure 4.6 and Figure 4.7. Careful observations were made regarding cracks between the mortar and concrete and water leaking through the interface. Two specimens were created for each candidate mortar.

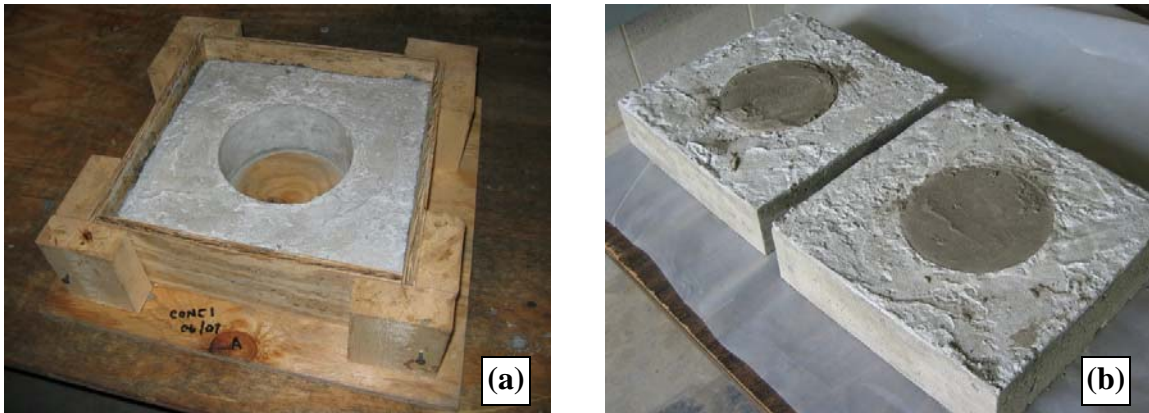


Figure 4.6: Shear Pocket Specimen Before (a) and After (b) Filling with Mortar



Figure 4.7: Shear Pocket Specimen with Water Ponding



#### **4.4 Flow and Workability**

Each candidate mortar was mixed according to manufacturer recommendations. The process starts with an initial water amount, to which the mortar powder is added while the batch is mixed. When approximately 80% of the powder is added, an additional specified amount of water is supplied to the mix, which significantly improves its workability. For batches with a pea gravel aggregate extension, all of the aggregate for each batch is placed in the mixing container with the initial water before any powder is added. Since the required yield volume for these experiments was small compared to what would be needed for an actual precast panel system, standard 50 lb. bags of mortar were used along with a medium-speed drill and paddle mixer. Observations regarding each candidate mortar's workability and set time were recorded.

Some mortars are available in bulk bags weighing from 2500 to 3000 pounds. In the field, two methods of mixing and placing grout are common. One is using a large rotating mixer and placing the mortar with a pushcart. The cart has a lever-controlled release mechanism to allow the grout to be poured into the shear pockets through an opening in the bottom of the cart. The second method is mixing the grout with a ready-mix truck and then pumping the grout into the shear pockets with a large diameter hose.

##### **4.4.1 ASTM C 1437 and ASTM C 230**

Flow characteristics for each mortar were measured in accordance to ASTM C 1437 (2001): Standard Test Method for Flow of Hydraulic Cement Mortar (modified). Specifications for the flow table and truncated flow cone are found in ASTM C 230 (1998): Standard Specification for Flow Table for Use in Tests of Hydraulic Cement. The test setup is shown in Figure 4.8.



Figure 4.8: Truncated Flow Cone and Drop Table

Immediately after the mortar was mixed, the proper amount was placed in the flow cone. After the cone was completely filled and the table was wiped clean of any stray mortar, the cone was lifted vertically to allow the mortar to slump under its own self weight. The horizontal spread was measured at its widest and narrowest dimension. This information was used to calculate the average percent increase of the mortar's original diameter of 4 in. This allows for quantification of the mortar's ability to flow under its own power, without the help of vibration or any external force. Once these measurements were obtained, the table was dropped 10 times within 15 seconds. This is a modification to the standard test method which calls for 25 drops within 15 seconds. The reason for this modification is because these particular types of mortars tend to flow better than the average mortars for which this test method is intended. Twenty-five drops would result in the mortar spreading across the entire 10 in. diameter of the table and the purpose of the test would be lost. It is important to measure how each mortar flows when forced by vibration or some other method. Once again, the horizontal spread was measured at its widest and narrowest dimension in order to calculate an average percent increase of the mortar's original diameter.

#### 4.4.2 Representative Test: Haunch Flow Mockup

The following setup was designed to model a deck panel's shear pockets and haunch through which the mortar must flow. A 4 in. thick rectangular concrete block was formed in plywood formwork that was 5 in. high. The concrete was given a trowel smooth finish. The block measured 1 ft wide by 2 ft long (see Figure 4.9a). A plywood cover was fixed over the base formwork with one "shear pocket" at each end of the block (see Figure 4.9b). The 2 ft spacing represents a typical spacing for shear pockets in a precast deck panel system, while the 8 in. pocket height represents a typical deck thickness. The 1 in. difference between the top of the concrete block and the bottom of the plywood cover represents a minimum haunch height between girder and panel through which the mortar would have to flow. It is normal to encounter this tight haunch space near the mid-span of a precast, prestressed girder due to camber.

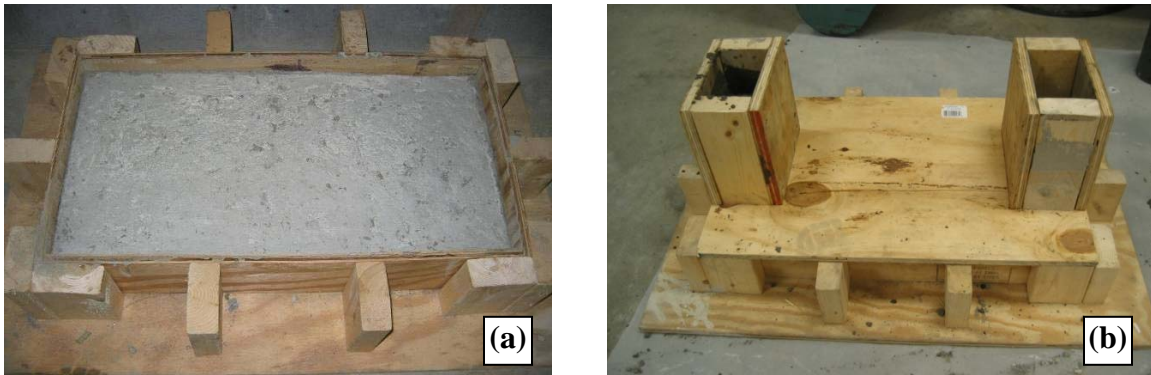


Figure 4.9: Haunch Flow Mockup Before (a) and After (b) Placement of Cover

After the mortar was tested in the truncated flow cone, it was immediately poured down the left shear pocket and allowed to flow across the haunch. The objective of this experiment is to see how well each mortar flows through a tight haunch spacing, forced only by the hydraulic head pressure provided by the height of the shear pocket. The grout must be able to completely fill the haunch space and then flow up the adjacent shear pocket. In the construction of a precast deck panel system, the grout should be poured in successive pockets, starting at mid-span of a girder and working towards the

supports. This takes advantage of the girder's camber and helps the grout flow through the haunch. If the bridge is inclined, the mortar should be poured downhill. After one day, the plywood cover and shear pockets were removed. Qualitative observations were made based on the ability of the grout to completely fill the haunch and rise into the adjacent shear pocket. A good flow and a poor flow are illustrated in Figure 4.10.

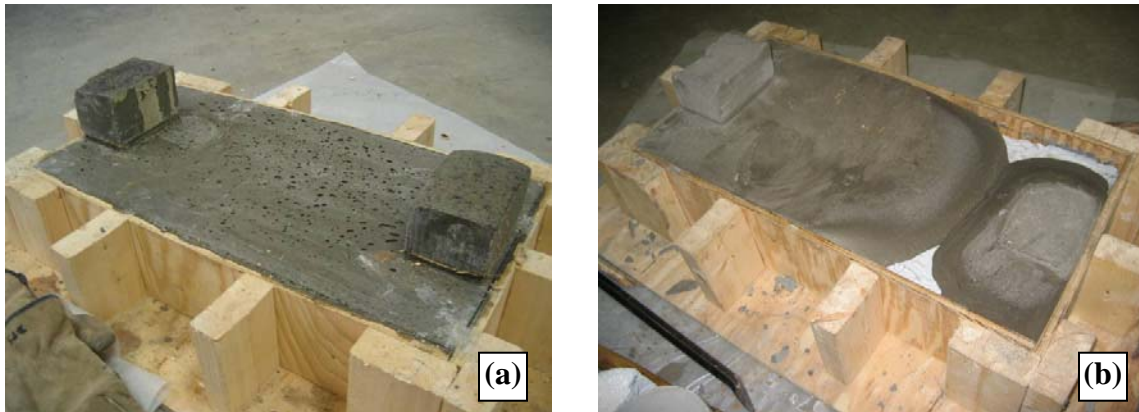


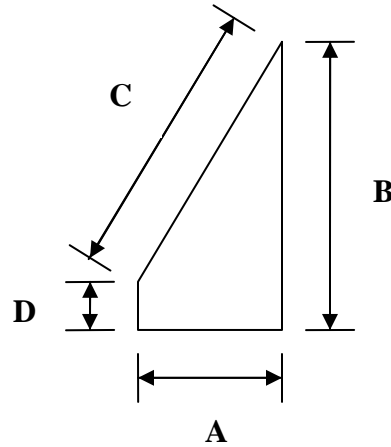
Figure 4.10: Good (a) and Poor (b) Grout Flow Through Haunch Mockup

## 4.5 Bond Strength

### 4.5.1 ASTM C 882

The bond strength of each candidate mortar was investigated in accordance to ASTM C 882 (1999): Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear (modified). This test method calls for two halves of a 3 in. by 6 in. cylinder to be created by slicing the cylinder at 30° from the vertical. One concrete half cylinder and one mortar half cylinder are to be bonded together using an epoxy resin and then the completed cylinder system is to be tested in compression to determine the bond strength of the epoxy resin. For the purpose of this research, 4 in. by 8 in. cylinders were used. The lower portion of the cylinder was made of concrete. The candidate grout was poured over top of the concrete base to complete the cylinder. The full cylinder was then tested in compression to determine the bond strength of the grout

to the concrete. Figure 4.11 presents the dimensions of the half cylinders used in the ASTM standard and the dimensions used in this research.



Dimension	3 in. x 6 in. Cylinder	4 in. x 8 in. Cylinder
A: Diameter	3.000 in.	4.000 in.
B: Height	5.598 in.	7.464 in.
C: Slant Height	6.000 in.	8.000 in.
D: Base Height	0.400 in.	0.536 in.

Figure 4.11: Slant Cylinder Schematic and Dimensions

In order to create concrete specimens in this fashion, plastic cylinder molds were filled with Plaster of Paris to supply rigidity. After one day, the cylinders were sliced in the specified orientation and the plaster was removed. The sliced cylinders were then placed in formwork to support the cylinder during the concrete pour (see Figure 4.12).



Figure 4.12: Sliced 4 in. x 8 in. Cylinders for Slant Cylinder Tests

The slanted dimension of the cylinder form rested in a horizontal position in order to prepare the surface of the concrete in four different manners: a) smooth, b) exposed aggregate, c) raked, and d) raked and sandblasted. Three cylinders for each type of surface condition were formed in order to investigate optimal surface preparations for the precast girders and precast deck panels. A trowel was used to obtain the smooth surface. The exposed aggregate surface was obtained by spraying the fresh concrete with a surface retarder which slows down the set time of the cement paste. After two hours, the top layer of cement paste was removed with a steel brush, exposing the concrete aggregates. A screw was used to obtain the raked surface, grooving an amplitude of  $\frac{1}{4}$  in. The appropriate specimens were sandblasted within a 24 hour period prior to pouring the grout. All four surface preparations for the concrete slant cylinder halves are shown in Figure 4.13.



Figure 4.13: Slant Cylinder Concrete Surface Preparations:  
Smooth (a), Exposed Aggregate (b), Raked (c), and Raked and Sand Blasted (d)

A total of 12 concrete half cylinders were prepared for each candidate mortar. After they cured for at least 28 days, they were inserted into a whole 4 in. by 8 in. cylinder mold. Then the mortar was poured into the mold to complete the cylinder (see Figure 4.14). Cylinders were tested in compression in order to investigate the early bond strength of each grout. Neat mortar cylinders were tested one day after the pour and aggregate extended mortars were tested two days after the pour. Observations were made regarding whether the cylinder failed along the shear plane or if failure was due to significant cracking in the grout or concrete.



Figure 4.14: Completed Slant Shear Cylinder

#### **4.5.2 Representative Test: Push-Off Test**

A push-off test was used to investigate the ability of a grout to resist horizontal shear loads in the haunch between a precast girder and precast deck panel. These tests have been used extensively in the past to investigate shear capacity between new concrete cast over precast concrete and were used recently by Menkulasi (2002) to investigate two precast elements with a grouted interface. The push-off tests for this research were performed at a later time than the series of grout tests that were explained earlier in this



chapter. This allowed for the push-off tests to be modified based on the results of the grout series tests. The best surface preparations were determined for the beam side and slab side specimens and the three best-performing candidate grouts were selected to be used in the push-off tests.

For each test, two L-shaped concrete blocks were formed, one representing the girder and one representing the deck panel slab. The specimens were then oriented as shown in Figure 4.15 and the shear pocket and haunch were filled with the mortar. The specimen was then loaded directly along the center line of the haunch to failure. A small normal force was also provided to simulate the clamping stress that is supplied by the tributary weight of a deck panel per girder spacing as well as other dead loads.

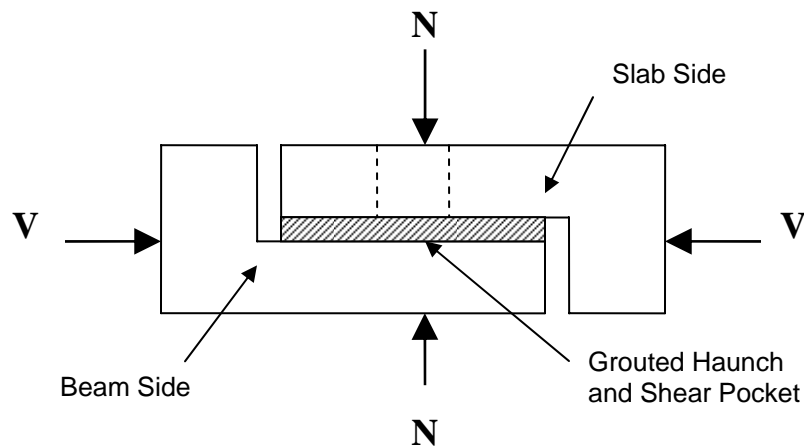
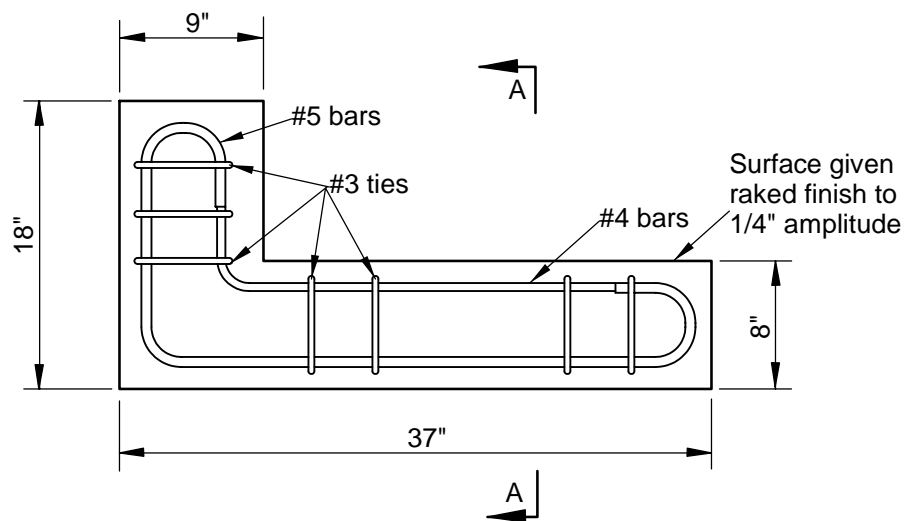


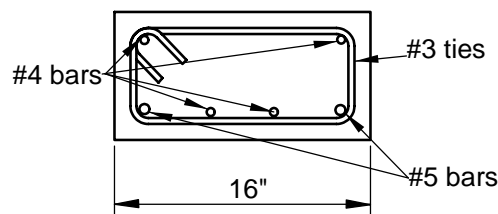
Figure 4.15: Typical Push-Off Test Setup

### 4.5.2.1 Specimen Details

The beam side specimen's dimensions and reinforcing details are provided in Figure 4.16. The specimen was poured in the orientation shown. This simulates the pour orientation for a precast concrete girder, where the top of the girder is exposed to the air. No shear connectors were used in these tests in order to solely investigate the horizontal shear strength provided by the mortar.



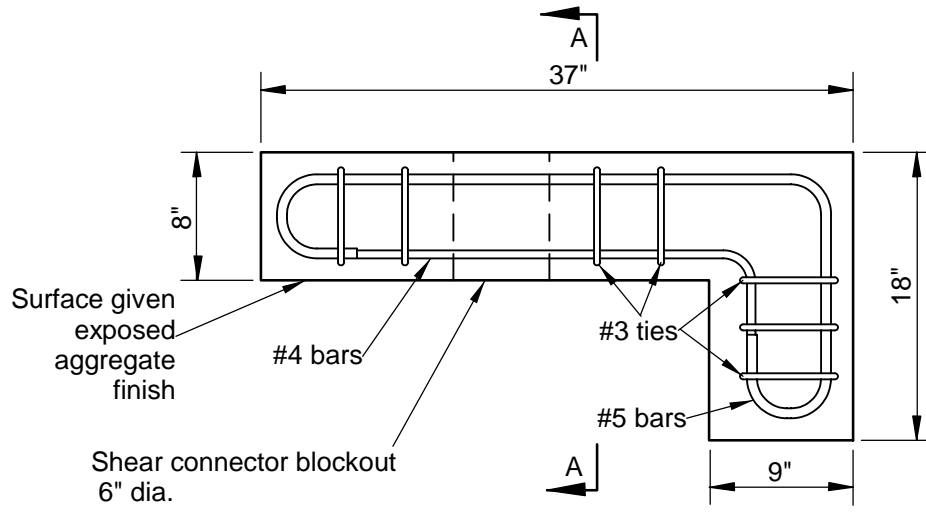
(a) Side View



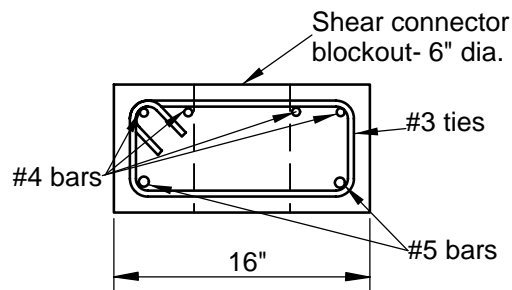
(b) Section A-A

Figure 4.16: Beam Side Specimen Details

The slab side specimen's dimensions and reinforcing details are provided in Figure 4.17. Again, the specimen was poured in the shown orientation to simulate a true deck panel pour, where the bottom of the slab rests against formwork. A 6 in. diameter cylinder was used to form the shear pocket.



(a) Side View



(b) Section A-A

Figure 4.17: Slab Side Specimen Details

Based on the results of the series of grout tests, optimal surface conditions were determined for the push-off specimens. A raked surface was selected for the beam side, with a rake amplitude of  $\frac{1}{4}$  in. (see Figure 4.18a). This is the conventional surface preparation for precast concrete bridge girders, although it may not be feasible if self-consolidating concrete is used. An exposed aggregate finish was selected for the bottom of the slab side (see Figure 4.18b). This surface preparation has been recommended for precast deck panels in the past. In order to achieve this surface condition, a coating of retarder was painted on the bottom of the formwork. One day after the concrete was poured, the slab specimens were removed from their forms. The bottom of the specimens were hosed and brushed to remove the cement paste layer and expose the aggregate.

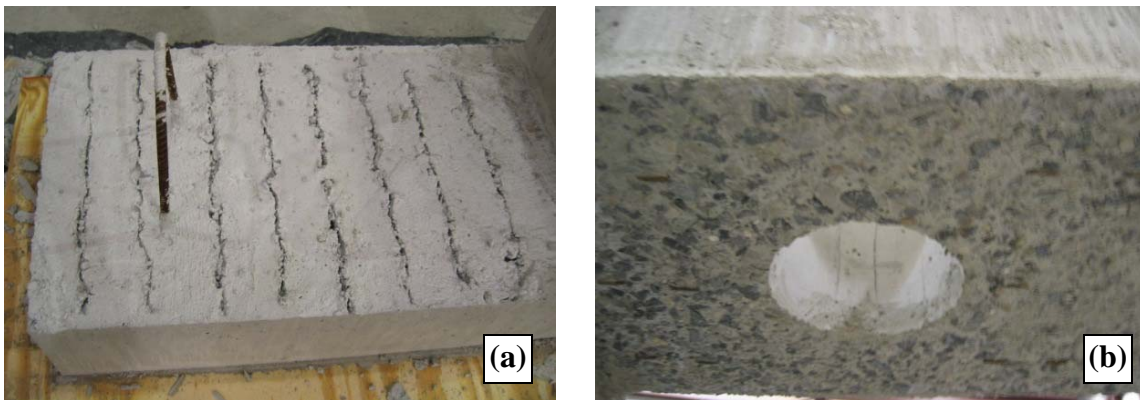


Figure 4.18: Beam Side (a) and Slab Side (b) Push-Off Specimen Surface Preparation

One difference between these push-off tests and the push-off tests performed by Menkulasi is the orientation of the specimen during the test. The previous tests were performed with the beam and slab elements resting on their side. The grout was poured through the side of the interface, not through the shear pocket. It was decided to arrange these push-off tests in an upright position to better simulate the actual condition of a precast deck panel resting above the precast girder. A 1.5 in. haunch space was used; the specimens were also placed 1.5 in. apart horizontally in order to allow for sufficient relative displacement of the slab side and beam side during testing. Formwork was placed around the interface and the grout was poured through the shear pocket. The completed push-off specimen was tested two days later (see Figure 4.19).



Figure 4.19: Complete Push-Off Specimen with Grouted Interface

#### 4.5.2.2 Test Setup

The push-off test setup consisted of two hydraulic rams, a roller-plate system, two end buttresses, two load cells to monitor loads and two potentiometers to monitor displacements. The setup is shown in Figure 4.20.

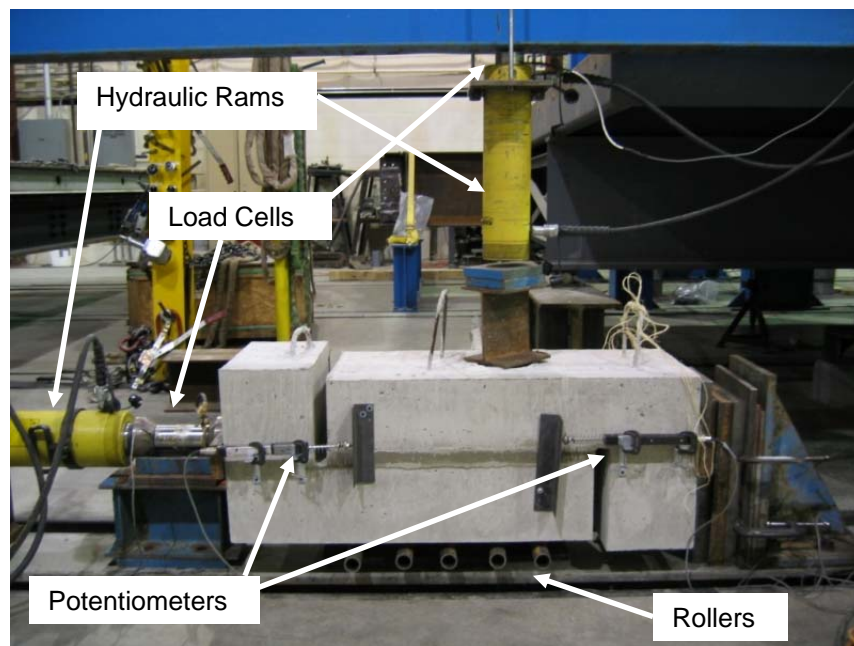


Figure 4.20: Push-Off Test Setup

The vertical ram applied force through load cell #1 in order to provide a normal force across the bonded interface. The horizontal ram applied force through load cell #2 to a rectangular plate. That plate pushed against the beam side specimen and was centered with the haunch. The beam side rested on a roller-plate system that allowed it to displace relative to the slab side. The slab side was fixed in place by an end buttress and an identical rectangular plate that was also centered with the haunch. Two potentiometers monitored the relative displacements of the slab and beam specimens, with one affixed to each specimen. Since there was no shear reinforcement, it was expected that once the initial cohesion bond failed, the interface would experience a large slip and would not be able to sustain load. Potentiometer #1 (right side) measured displacement of the beam relative to the slab, and potentiometer #2 measured the displacement of the slab relative to the beam. End plate and potentiometer configurations are shown in Figure 4.21. Load cell and potentiometer details are provided in Table 4.1.

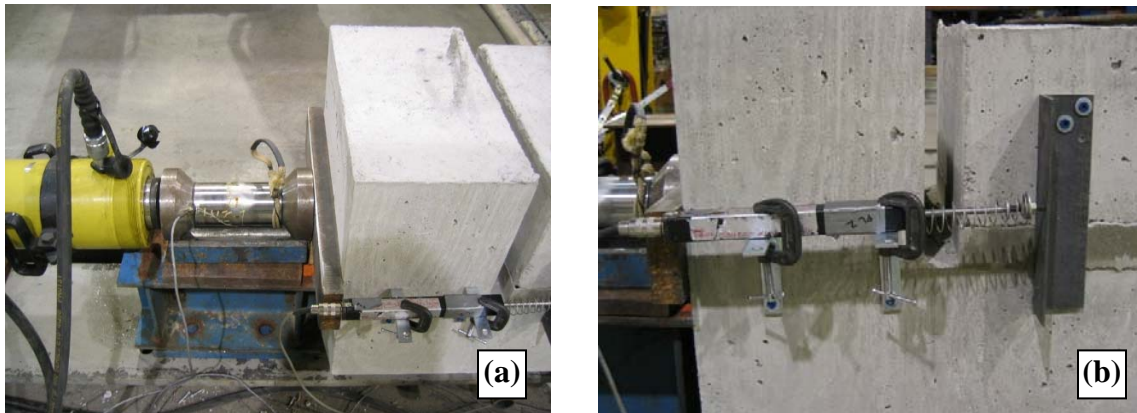


Figure 4.21: Load Cell #2 with End Plate Configuration (a) and Potentiometer #2 (b)

Table 4.1: Load Cell and Potentiometer Details

Monitoring Device	Capacity	Accuracy
Load Cell #1	50 kips	0.050 kips
Load Cell #2	150 kips	0.200 kips
Potentiometer #1	4 in.	0.0001 in.
Potentiometer #2	4 in.	0.0001 in.

#### **4.5.2.3 Test Procedure**

The vertical hydraulic ram was used to apply an initial load of 2500 lbs. which is approximately the tributary weight of an 8.5 in. deck panel with a 2 ft pocket spacing on girders spaced at 10 ft. As the horizontal load increased, the grout interface expanded vertically due to a basic Poisson's effect. This caused the normal force in the vertical ram to increase. Once the vertical load reached 4000 lbs., it was reduced to the original 2500 lb. loading. The horizontal shear loading was increased steadily over a ten minute period until the bonded interface failed. The load was then increased until the specimen would not accept any more load or the horizontal space between the specimens closed. Observations were made regarding whether the interface failed between the grout and beam specimen or between the grout and slab specimen.

#### **4.6 Candidate Mortars and Corresponding Concrete**

A list of pre-qualified concrete repair mortars was obtained from VDOT and four were selected for investigation in this research. ThoRoc<sup>®</sup> 10-60 Rapid Mortar is a Degussa Building Systems product. It was previously marketed by Fosroc as Patchroc<sup>®</sup> 10-60 Rapid Mortar. SikaQuick<sup>®</sup> 2500 is a relatively new material that was introduced in 2003 by Sika Corporation of Lyndhurst, New Jersey, and has become popular among DOTs. Five Star<sup>®</sup> Highway Patch is distributed by Five Star Products, Inc. of Fairfield, Connecticut. Set<sup>®</sup> 45 is distributed by Master Builders, Inc. of Cleveland, Ohio, a Degussa Company. Set<sup>®</sup> 45 Hot Weather was selected because it allows for longer working time in elevated temperature conditions. All of these products are identified as rapid hardening, high early strength gain repair mortars. ThoRoc<sup>®</sup> 10-60, SikaQuick<sup>®</sup> 2500 and Five Star<sup>®</sup> Patch are all cement-based, while Set<sup>®</sup> 45 Hot Weather is magnesium-phosphate based. Water and aggregate extension amounts used in this research were based on manufacturer recommendations and vary for each product. Table 4.2 provides mixing information for each product.

For each series of grout tests, a corresponding batch of concrete was prepared at least 28 days in advance. This concrete is a nominal 4000 psi mix design. Component quantities by weight are provided in Table 4.3. In addition to the slant cylinders and 3 in. square cross section shrinkage bars, 4 in. by 8 in. cylinders were also prepared for

determination of compressive and tensile strength of the concrete at the time of the grout tests. Compressive strength was obtained in accordance to ASTM C 39 (2002): Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Tensile Strength was obtained in accordance to ASTM C 496 (1996): Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.

Table 4.2: Candidate Mortars and Mixing Information

ID No. and Product Name		Mixing Quantities per 50 lb. Bag					Cost per bag, \$
		Initial Water, pints	Additional Water, pints	Aggregate Extension, %	Aggregate Extension, lbs.	Yield Volume, cu. ft.	
Neat Mortar	1. ThoRoc <sup>®</sup> 10-60 Rapid Mortar	5.50	1.00	0	0	0.43	12.75
	2. SikaQuick <sup>®</sup> 2500	5.00	0.50	0	0	0.43	13.75
	3. Five Star <sup>®</sup> Highway Patch	5.00	1.00	0	0	0.40	20.50
	4. Set <sup>®</sup> 45 Hot Weather	3.25	0.50	0	0	0.39	24.00
Extended Mortar	5. ThoRoc <sup>®</sup> 10-60 Rapid Mortar	5.50	1.00	50	25	0.57	12.75
	6. SikaQuick <sup>®</sup> 2500	5.00	0.50	50	25	0.60	13.75
	7. Five Star <sup>®</sup> Highway Patch	5.00	1.00	80	40	0.66	20.50
	8. Set <sup>®</sup> 45 Hot Weather	3.25	0.50	60	30	0.58	24.00

Table 4.3: Concrete Mix Quantities

Component	Quantity
Type I/II Portland Cement	46.00 lb.
Coarse Aggregate (angular)	125.12 lb.
Fine Aggregate	92.70 lb.
Water	21.60 lb.
Air Entrainer	10.2 ml
Retarder	13.0 ml
<b>Yield Volume</b>	<b>1.95 cu. ft.</b>



## 4.7 Test Summary

Table 4.4 summarizes the types and number of ASTM tests and representative tests used in this research to evaluate the properties of each candidate mortar. Table 4.5 summarizes the types and number of ASTM tests used to evaluate the properties of each corresponding concrete.

Table 4.4: Test Summary for Each Candidate Mortar

<b>Test</b>	<b>No.</b>
<b>Compressive Strength</b>	
ASTM C 109: 2 in. Cubes	
1 hour	3
2 hours	3
1 day	3
7 days	3
<b>Tensile Strength</b>	
ASTM C 496: Split Cylinders	
1 day	2
7 days	2
<b>Shrinkage</b>	
ASTM C 157: Shrinkage Bars	
Neat mortars (1 in.)	4
Extended mortars (3 in.)	3
Shear Pocket Ponding	2
<b>Flow</b>	
ASTM C 1437: Flow Cone	1
Haunch Mockup	1
<b>Bond Strength</b>	
ASTM C 882: Slant Shear Cylinder	
Smooth	3
Exposed Aggregate	3
Raked	3
Raked and Sand Blasted	3
Push-Off Test	
Mortar A	2
Mortar B	2
Mortar C	2

Table 4.5: Test Summary for Each Corresponding Concrete

<b>Test</b>	<b>No.</b>
<b>Compressive Strength</b>	
ASTM C 39: 4 in. x 8 in. Cylinders	2
<b>Tensile Strength</b>	
ASTM C 496: Split Cylinders	2
<b>Shrinkage</b>	
ASTM C 157: Shrinkage Bars (3 in.)	3

## CHAPTER 5: PRESENTATION OF RESULTS AND ANALYSIS

### 5.1 Compressive Strength: ASTM C 109

Each candidate mortar lived up to its claim as a high early strength material. Discrepancies exist in exactly how high and how early each manufacturer specifies their product. Test results are presented in Table 5.1 and Figure 5.1. Most mortars achieved 2000 psi in two hours. ThorRoc 10-60 (1) had the highest compressive strength at each of the one hour, two hour, one day and seven day periods. Set<sup>®</sup> 45 HW extended (8) and SikaQuick<sup>®</sup> 2500 extended (6) exhibited the lowest compressive strength for one hour and two hour periods and for one day and seven day periods, respectively. In all cases, the extended mortars did not gain as much strength as the corresponding neat mortars. While these comparative measures are useful, it is more important to examine whether each mortar was able to attain a strength at each period that is suitable for a precast deck panel system. Set<sup>®</sup> 45 HW (4 & 8) displayed its ability to remain workable for a longer period of time, and gained a significant amount of strength by the end of the first day. Five Star<sup>®</sup> Patch (3 & 7) displayed a significant strength gain in the second hour. These characteristics could be viewed as attractive since a one hour strength that is too high could hinder mixing and pouring in the field. This topic will be addressed further in section 5.4: Flow and Workability.

Table 5.1: Compressive Strengths per ASTM C 109

Mortar	Compressive Strength, psi			
	1 hr.	2 hr.	1 day	7 day
1 ThorRoc <sup>®</sup> 10-60	<b>2700</b>	<b>3030</b>	<b>5210</b>	<b>6380</b>
2 SikaQuick <sup>®</sup> 2500	1700	2250	3540	4710
3 Five Star <sup>®</sup> Patch	910	2810	5080	5820
4 Set <sup>®</sup> 45 HW	420	2050	4930	4930
5 ThorRoc <sup>®</sup> extended	<b>1860</b>	2370	3150	5040
6 SikaQuick <sup>®</sup> extended	1020	1170	1900	2550
7 Five Star <sup>®</sup> extended	-	<b>2730</b>	<b>4490</b>	<b>5440</b>
8 Set <sup>®</sup> 45 HW extended	-	230	2650	4180

**Bold** values indicate the highest values for neat and extended mortars at each time period.

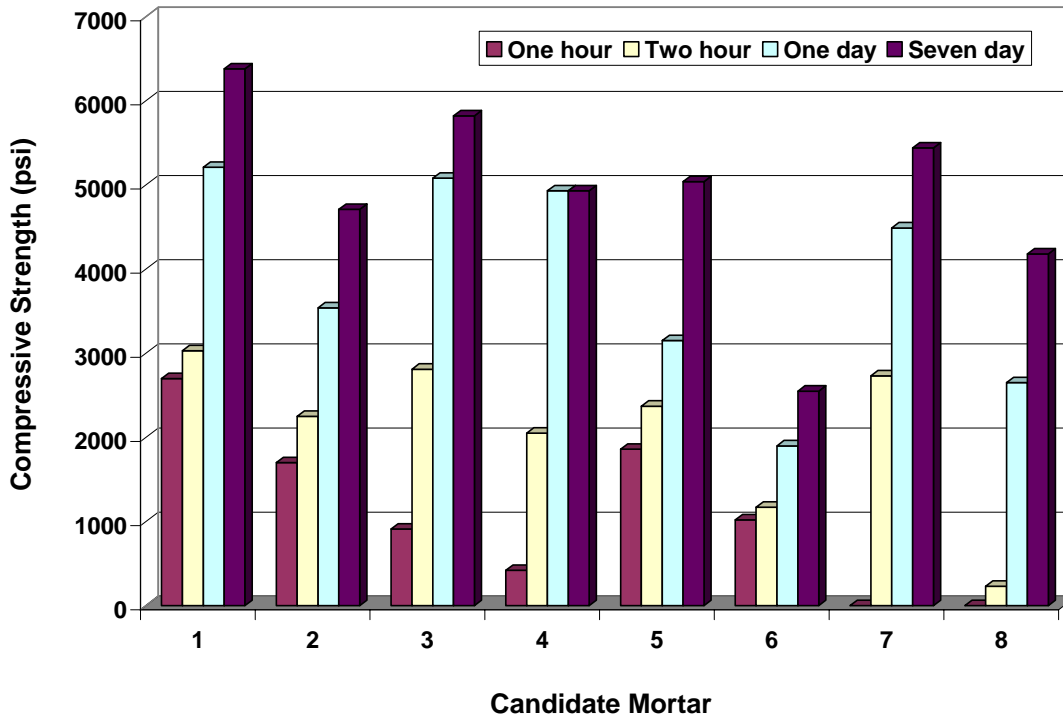


Figure 5.1: Compressive Strengths per ASTM C 109

## 5.2 Tensile Strength: ASTM C 496

Each candidate mortar achieved a 200 psi split tensile strength by one day. Every mortar except SikaQuick<sup>®</sup> 2500 (2 & 6) achieved 400 psi by seven days. Only the ThoRoc<sup>®</sup> (1) and Five Star<sup>®</sup> (3 & 7) products achieved 525 psi by seven days. Test results are presented in Table 5.2 and Figure 5.2.

Table 5.2: Splitting Tensile Strengths per ASTM C 496

Mortar		Tensile Strength, psi	
		1 day	7 day
1	ThoRoc <sup>®</sup> 10-60	385	<b>540</b>
2	SikaQuick <sup>®</sup> 2500	255	340
3	Five Star <sup>®</sup> Patch	<b>485</b>	530
4	Set <sup>®</sup> 45 HW	380	410
5	ThoRoc <sup>®</sup> extended	410	510
6	SikaQuick <sup>®</sup> extended	280	335
7	Five Star <sup>®</sup> extended	<b>445</b>	<b>555</b>
8	Set <sup>®</sup> 45 HW extended	330	415

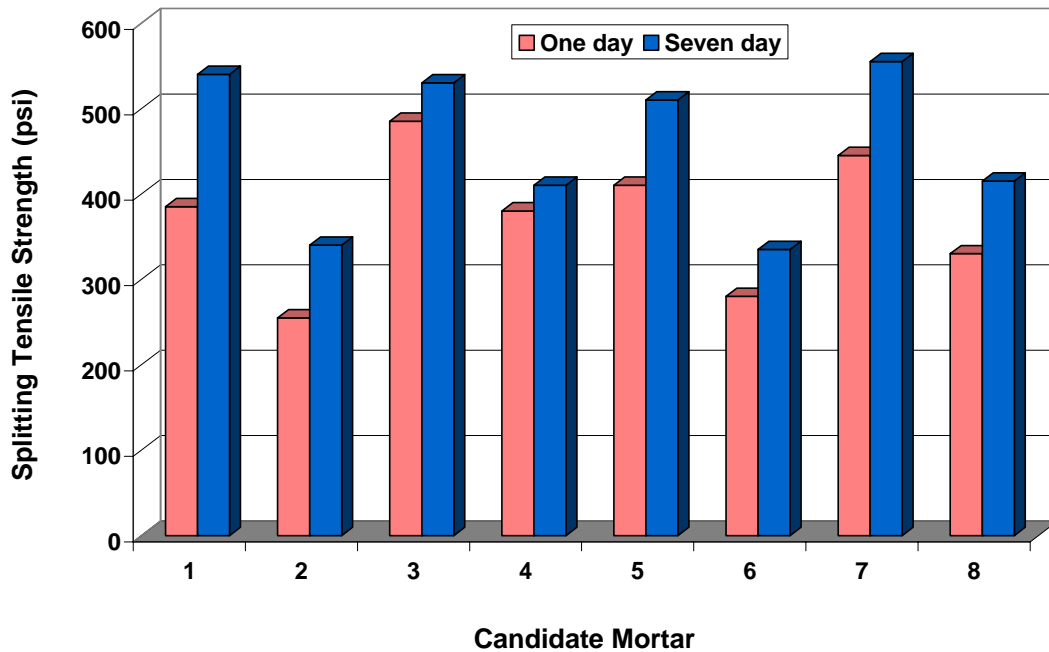


Figure 5.2: Splitting Tensile Strengths per ASTM C 496

None of the mortars exhibited a significant strength increase between one and seven days, as they all achieved at least 70% of their seven day strength in the first day. The tensile strength of the extended mortars remained fairly consistent with their neat mortar counterparts, with seven day strengths varying by 6% at most. They did not consistently display lower tensile strengths as was the case for compressive strength.

### 5.3 Shrinkage

#### 5.3.1 ASTM C 157

Shrinkage was measured for each mortar over a 28 day period. ASTM specifies that neat mortars and extended mortars must be analyzed separately since the shrinkage bars are different sizes. Ideally, the mortar should shrink at a rate similar to the deck panel concrete in order to minimize differential shrinkage and the potential for cracking. Mokarem (2002) recommended 0.03% - 0.04% (300 - 400 microstrain) as a target shrinkage range for concrete. Typical 28 day shrinkage values for the 4000 psi concrete mix used in this research were in this range. Of the eight candidate mortars, Five Star<sup>®</sup>

Patch (3 & 7) and Set<sup>®</sup> 45 Hot Weather (4 & 8) performed the best, exhibiting a shrinkage of less than 0.04% (400 microstrain) for both the neat and extended mortars. The SikaQuick<sup>®</sup> 2500 (2) bars were especially difficult to remove from the forms, resulting in local cracking. The results for this mortar are displayed with an asterisk (\*) since they may not be representative of true shrinkage values. Results for neat mortars are presented in Table 5.3 and Figure 5.3, and results for extended mortars are presented in Table 5.4 and Figure 5.4. Shrinkage values for all candidate mortars are presented in inches, % shrinkage, and microstrain.

Table 5.3: 28 Day Shrinkage for Neat Mortars per ASTM C 157

Mortar	28 Day Shrinkage		
	in.	%	με
1 ThoRoc <sup>®</sup> 10-60	0.0076	0.076	760
2 SikaQuick <sup>®</sup> 2500*	0.0080*	0.080*	800*
3 Five Star <sup>®</sup> Patch	<b>0.0029</b>	<b>0.029</b>	<b>290</b>
4 Set <sup>®</sup> 45 HW	0.0034	0.034	340

Based on 1 in. x 1 in. x 11.25 in. shrinkage bars. Gage Length = 10 in.

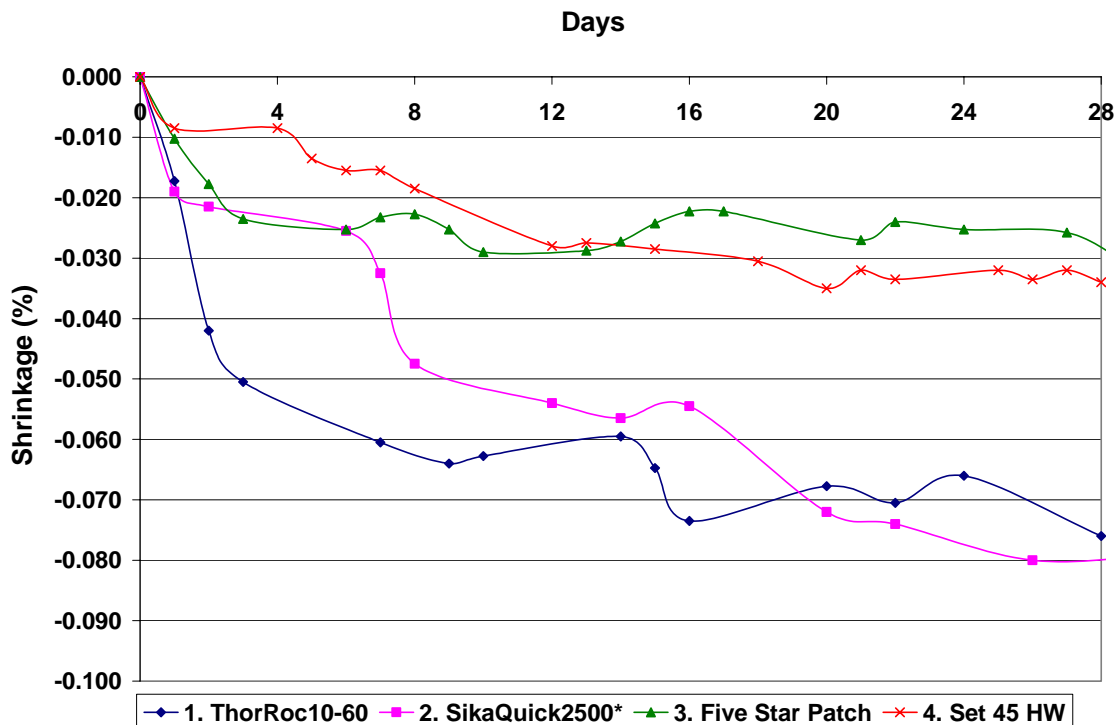


Figure 5.3: 28 Day Shrinkage for Neat Mortars per ASTM C 157

Table 5.4: 28 Day Shrinkage for Extended Mortars per ASTM C 157

Mortar		28 Day Shrinkage		
		in.	%	$\mu\epsilon$
5	ThoRoc <sup>®</sup> extended	0.0064	0.064	640
6	SikaQuick <sup>®</sup> extended	0.0089	0.089	890
7	Five Star <sup>®</sup> extended	0.0036	0.036	360
8	Set <sup>®</sup> 45 HW extended	<b>0.0018</b>	<b>0.018</b>	<b>180</b>

Based on 3 in. x 3 in. x 11.25 in. shrinkage bars. Gage Length = 10 in.

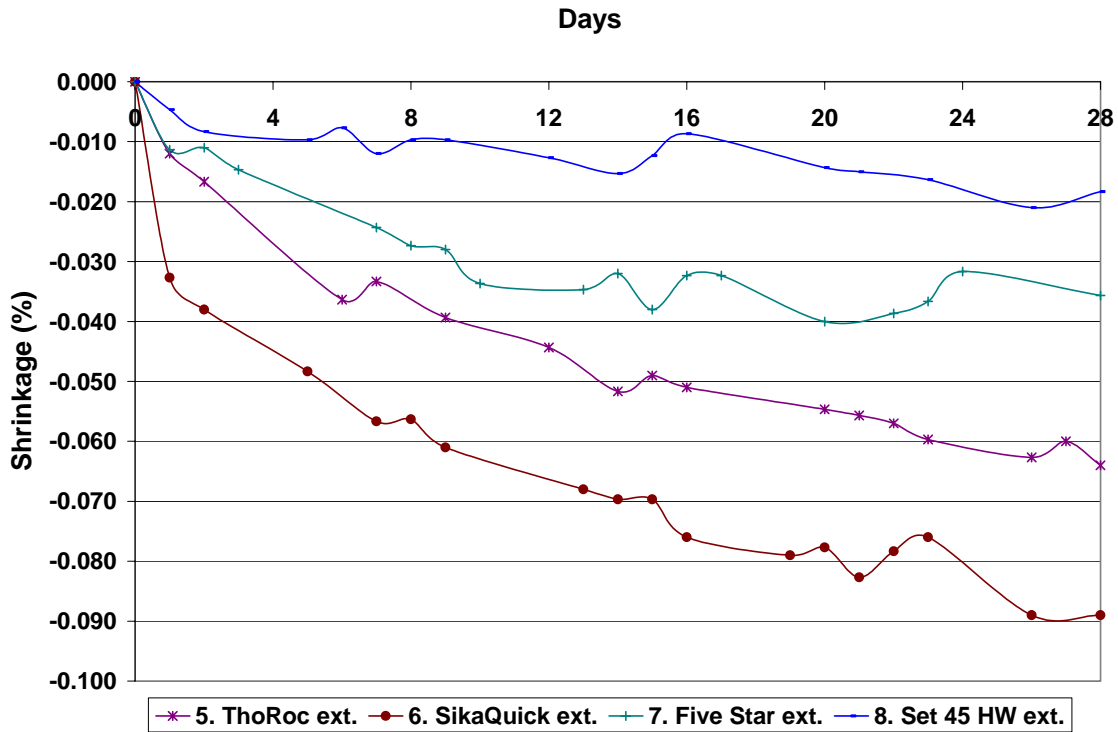


Figure 5.4: 28 Day Shrinkage for Extended Mortars per ASTM C 157

### 5.3.2 Comparisons Between Neat and Extended Mortars

In comparing all of the shrinkage data, the neat mortars for SikaQuick<sup>®</sup> 2500 (2) and Five Star<sup>®</sup> Patch (3) displayed less shrinkage than their corresponding extended mortars (6 & 7). This is counter-intuitive. For the same size specimen, an increasing presence of aggregate should result in decreasing shrinkage values because the aggregate tends to restrain the shrinkage of the cement paste. However, two different size specimens were used in this research (1 in. and 3 in.). According to W. Morrison, ASTM

C 157 technical committee contact person (personal communication, November 2, 2004), ASTM does not supply a method for comparing shrinkage values between different size specimens, but would be interested in developing a specific correlation.

ACI 209R (1992): Prediction of Creep, Shrinkage and Temperature Effects in Concrete Structures presents a unified method for correcting ultimate shrinkage values,  $(\epsilon_{sh})_u$ , based on deviations from normal conditions. The variable in this investigation that affects direct comparison of shrinkage between neat and extended mortars is the difference in size of the shrinkage bar specimens. ACI 209R provides two correction factors based on member size; it is up to the designer to decide which to use, but both may not be used together. The first correction factor is based on volume-surface ratio, with 1.5 in. considered standard. The second correction factor is based on a minimum average specimen thickness, with 6 in. considered the minimum. Therefore, if a specimen has a volume-surface ratio other than 1.5 in., or an average thickness less than 6 in., the ultimate shrinkage value,  $(\epsilon_{sh})_u$ , may be multiplied by either of the appropriate correction factors. The equations for calculating these correction factors are presented below.

$$\gamma_{vs} = 1.2 \exp(-0.12 v/s) \quad (5.1)$$

where  $\gamma_{vs}$  = volume-surface correction factor

$v/s$  = volume-surface ratio of specimen, in.

$$\gamma_h = 1.23 - 0.038h \quad (5.2)$$

where  $\gamma_h$  = average thickness correction factor during first year of drying

$h$  = average thickness of specimen, in. (< 6 in.)

The corrected ultimate shrinkage value may then be used in the common time-ratio equation to estimate shrinkage at a given time. For seven day moist cured concrete,

$$(\epsilon_{sh})_t = (t / (35 + t)) \gamma_{sh} (\epsilon_{sh})_u \quad (5.3)$$



where  $(\epsilon_{sh})_t$  = shrinkage at time t

t = time in days after seven day moist cure period

$\gamma_{sh}$  = shrinkage correction factor (in this case, either  $\gamma_{vs}$  or  $\gamma_h$  )

$(\epsilon_{sh})_u$  = ultimate shrinkage value

If specific local information is unavailable, ACI 209R allows an average ultimate shrinkage value of 780 microstrain to be used.

Since the intent is to compare recorded shrinkage values for different size specimens, and not to predict such values, the correction factor shall be used on the right hand side of the equation so that the recorded shrinkage values for each mortar will be divided by the appropriate correction factor. The volume-surface ratio correction factor has been selected to modify the recorded shrinkage values for this research. Volume-surface ratio is calculated per unit length based on the cross section of a given specimen.

For a 1 in. x 1 in. shrinkage bar,

$$v/s = (1 * 1) / (4 * 1) = 0.25$$

$$\gamma_{vs} = 1.2 \exp(-0.12 * 0.25) = 1.165$$

For a 3 in. x 3 in. shrinkage bar,

$$v/s = (3 * 3) / (4 * 3) = 0.75$$

$$\gamma_{vs} = 1.2 \exp(-0.12 * 0.75) = 1.097$$

The recorded shrinkage values were divided by the appropriate correction factors in order to compare the normalized values between neat mortars and extended mortars. The corrected values are presented in Table 5.5.

Table 5.5: 28 Day Shrinkage with Volume-Surface Ratio Correction Factor

Mortar	$\Delta L$ , in.	$\gamma_{vs}$	Corrected Shrinkage, $\Delta L / \gamma_{vs}$		
			in.	%	$\mu\epsilon$
1 ThorRoc <sup>®</sup> 10-60	0.0076	1.165	0.0065	0.0653	653
5 ThorRoc <sup>®</sup> extended	0.0064	1.097	0.0058	0.0584	584
2 SikaQuick <sup>®</sup> 2500	0.0080	1.165	0.0069	0.0687	687
6 SikaQuick <sup>®</sup> extended	0.0089	1.097	0.0081	0.0812	812
3 Five Star <sup>®</sup> Patch	0.0029	1.165	0.0025	0.0249	249
7 Five Star <sup>®</sup> extended	0.0036	1.097	0.0033	0.0328	328
4 Set <sup>®</sup> 45 HW	0.0034	1.165	0.0029	0.0292	292
8 Set <sup>®</sup> 45 HW extended	0.0018	1.097	0.0016	0.0164	164

Despite the volume-surface ratio correction factor proposed by ACI 209R, SikaQuick<sup>®</sup> 2500 (2) and Five Star<sup>®</sup> Patch (3) still displayed less shrinkage than their corresponding extended mortars (6 & 7). While this normalization of shrinkage values did not reverse the trend for SikaQuick<sup>®</sup> 2500 (2 & 6) and Five Star<sup>®</sup> Patch (3 & 7), it did provide a more uniform method to directly compare shrinkage between neat mortars and extended mortars that were obtained using different size specimens.

### 5.3.3 Representative Test: Shear Pocket with Ponding and Differential Shrinkage

All eight candidate mortars performed well in shear pocket conditions. No cracking was observed and no water was able to seep through the mortar/concrete interface. It is unlikely that a precast deck panel would be placed on a bridge before it has achieved its specified 28 day strength. Some concrete shrinkage would have already occurred at this time. For a circular interface, the concrete will shrink inward, causing the interface to contract. This is evidenced by a restrained shrinkage test, AASHTO PP34: Standard Practice for Estimating the Cracking Tendency of Concrete, in which concrete shrinks around a steel ring, causing compressive stresses in the ring (Mokarem 2002). If the mortar is then poured at this 28 day period, both the concrete and mortar will be shrinking towards the center of the circular interface, but at different rates. This is illustrated in Figure 5.5

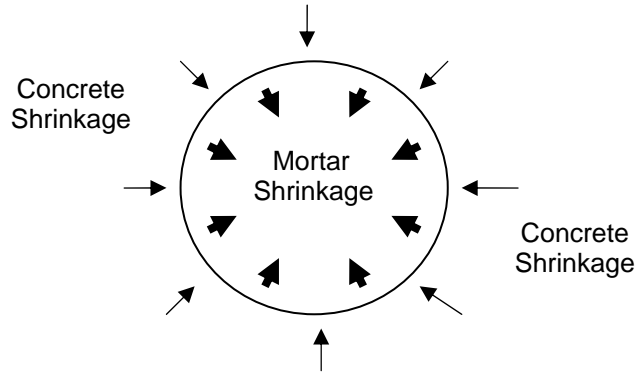


Figure 5.5: Differential Concrete and Mortar Shrinkage at Shear Pocket Interface

The corrected mortar shrinkage values are plotted along with a volume-surface ratio corrected average shrinkage curve for the eight corresponding concrete batches in Figure 5.6. Differential shrinkage, which is the difference in shrinkage values between a mortar and the concrete at any time, is presented in Figure 5.7. The mortar will be shrinking relative to the concrete's 28 day shrinkage value, so a 28 day mortar shrinkage corresponds to a 56-day concrete shrinkage and so on.

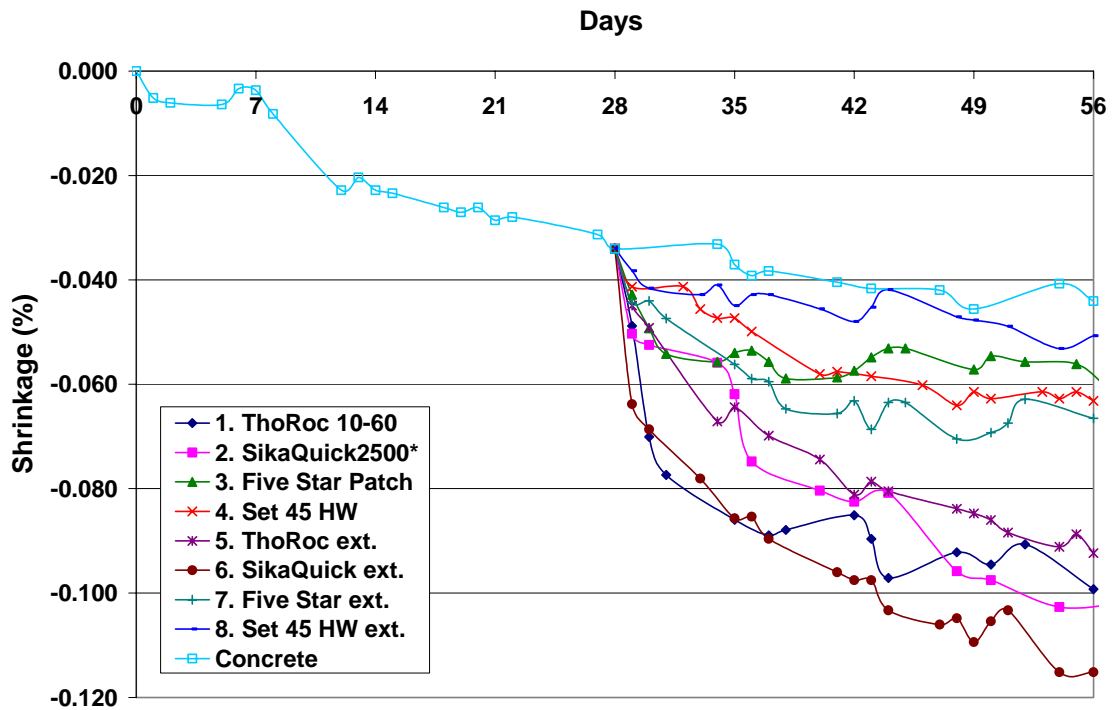


Figure 5.6: Shrinkage for Candidate Mortars and Base Concrete

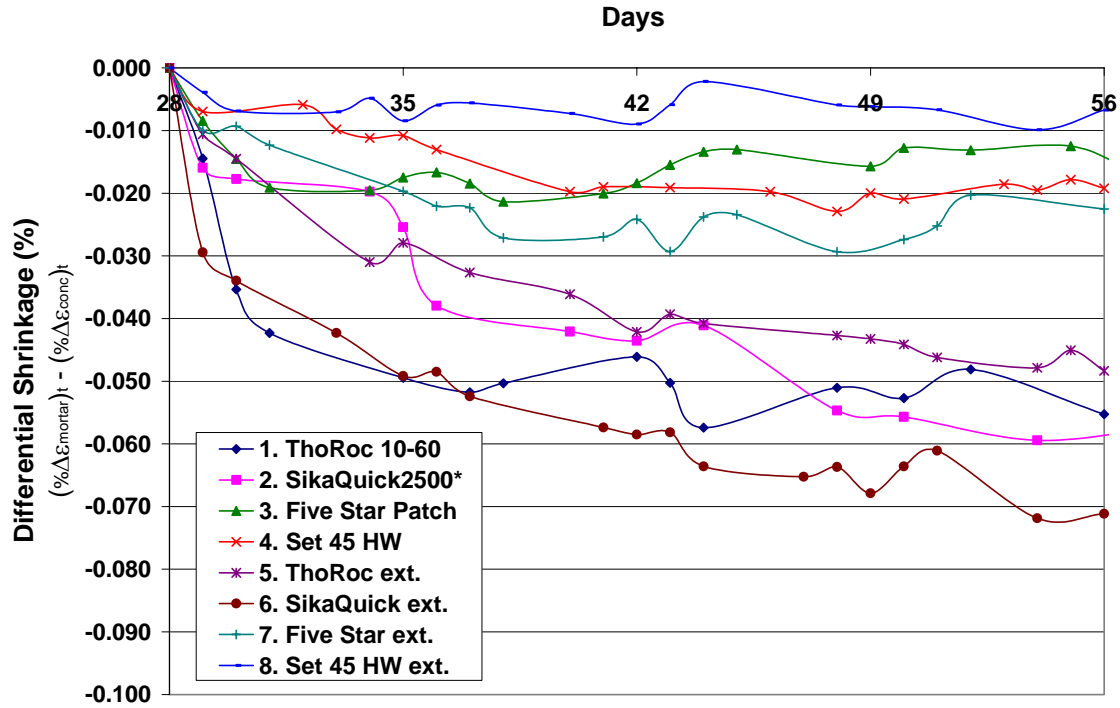


Figure 5.7: Differential Shrinkage Between Candidate Mortars and Base Concrete

The concrete’s corrected average 28 day shrinkage was 0.034% (340 microstrain) and its corrected average 56 day shrinkage was 0.044% (440 microstrain). The largest differential between concrete shrinkage and mortar shrinkage was 0.072% (720 microstrain), occurring at the 54 day period with SikaQuick® 2500 extended (6). Even this large difference was not great enough to cause cracking or allow the passage of water through the shear pocket interface.

Studies have suggested that in order for water to carry chlorides through a crack in concrete, the crack width must be at least 0.012 in. Other studies have suggested widths as small as 0.004 in. (Keller, 2004). If it is assumed that the mortar is able to shrink enough to break its bond from the concrete, the mortar/concrete interface can be modeled as a crack. The concrete is assumed to have little or no shrinkage to maximize the differential shrinkage between the materials. The maximum allowable crack width can be used to calculate a corresponding shrinkage strain for the mortar. In the case of a circular shear pocket, the crack width equals the shrinkage strain times the radius of the circle as shown in equation 5.4.

$$w_{cr} = \varepsilon r \quad (5.4)$$

where  $w_{cr}$  = crack width, in.

$\varepsilon$  = shrinkage strain,  $\mu\varepsilon$

$r$  = radius of shear pocket, in.

A worst-case scenario would be encountered using the smallest allowable crack size of 0.004 in. and the largest shear pocket, which could be up to a 12 in. diameter (6 in. radius). The shrinkage strain that would cause this crack size in this situation is 667  $\mu\varepsilon$ :

$$\varepsilon = (0.004 \text{ in.}) / (6 \text{ in.}) = 667 \mu\varepsilon$$

The shrinkage strain that would cause the smallest allowable crack size for the 6 in. diameter (3 in. radius) shear pocket used in this research is 1334  $\mu\varepsilon$ :

$$\varepsilon = (0.004 \text{ in.}) / (3 \text{ in.}) = 1334 \mu\varepsilon$$

This approach shows that the largest differential shrinkage in the shear pocket representative test of 720  $\mu\varepsilon$  is too small to cause a crack large enough to allow water to pass. However, mortar shrinkage should at least be limited to 667  $\mu\varepsilon$  in order to ensure that water does not leak through the mortar/concrete interface of a large shear pocket.

#### **5.4 Flow and Workability**

Observations were made regarding the workability of each candidate mortar based on the degree of effort required to mix each product as well as their work time and initial set time. Work time was measured from the start of mixing until workability began to decrease. At this time, the product begins its initial hardening. Initial set time was measured from the start of mixing until the product was no longer workable. The product had attained its initial hardened state at this time. This information, along with observations regarding each product's consistency as well as their performance in the haunch flow mockup representative test are presented in Table 5.6. Flow results from the

ASTM C 1437 (2001) truncated flow cone tests are presented in Table 5.7 and Figure 5.10.

ThoRoc<sup>®</sup> 10-60 (1) was difficult to mix and had a short set time. Although its flow cone results were favorable, it did not flow well through the haunch. Its very high one hour strength compromised its ability to flow because the mortar achieved its initial set too quickly. When the grout failed to emerge from the haunch, the remainder was poured down the opposite pocket to see if a two directional flow could sufficiently fill the space. As expected, this procedure did not give good results as two air pockets were formed as seen in Figure 5.8.



Figure 5.8: ThoRoc<sup>®</sup> 10-60 (1) Flow Through Haunch Mockup

This reaffirmed the importance of pouring mortar in one direction in a precast bridge deck panel system, rather than working inward from two points. ThoRoc<sup>®</sup> 10-60 extended 50% (5) was also difficult to mix and did not perform as well on the drop table as the neat mortar (1). However, since the aggregate extension prolonged the mortar's set time and reduced the one hour compressive strength, it remained workable for a longer period of time and, therefore, flowed slightly better through the haunch. However, the flow was still undesirable because it was very slow and the mortar did not completely fill the corners or rise into the adjacent shear pocket. Photographs of the haunch flow test for ThoRoc<sup>®</sup> extended (6) can be found in Appendix A.

SikaQuick<sup>®</sup> 2500 (2) was easy to mix, displayed good flow cone results and flowed well through the haunch. While its flow cone performance was almost identical to the ThoRoc<sup>®</sup> 10-60 (1), its work time was longer and its one hour compressive strength lower, enabling it to flow for a longer period of time. SikaQuick<sup>®</sup> 2500 extended 50% (6) was fairly easy to mix and flowed almost as well as the neat mortar (2). One observation from all of the extended mortars is that they had difficulty filling the sharp corners at the end of the haunch mockup. This should not be a problem in a precast deck panel system because the haunch is continuous along the length of the girder and such end corner conditions are uncommon. Photographs of the haunch flow tests for both SikaQuick<sup>®</sup> 2500 mortars (2 & 6) can be found in Appendix A.

Five Star<sup>®</sup> Patch (3) was easy to mix and spread over the entire area of the drop table under its own weight. It flowed easily through the haunch. Of all the candidate mortars, its light color best matched the color of concrete. This is a good characteristic because blending in with the concrete deck panel can reduce the patchwork appearance of the riding surface if an additional wearing surface is not applied to the deck. Five Star<sup>®</sup> Patch extended 80% (7) was almost impossible to mix with such a high recommended aggregate extension. Its flow suffered because of this, but its strength gain was surprisingly similar to the neat mortar (3). A lower aggregate extension ratio would certainly be more suitable for use in a precast deck panel system. Both Five Star<sup>®</sup> Patch mortars (3 & 7) actually remained bonded to the plywood cover of the haunch flow test upon its removal from the base. The concrete slab was given a smooth finish, so these mortars were able to form a better bond to the porous plywood. This behavior was not viewed as either positive or negative since the purpose of the test was to observe flow and not bond. Photographs of the haunch flow tests for both Five Star<sup>®</sup> Patch mortars (3 & 7) can be found in Appendix A.

Set<sup>®</sup> 45 Hot Weather (4) was extremely easy to mix and flowed very well on the drop table and through the haunch (see Figure 5.9). Compared with all candidate mortars, it remained workable for the longest period of time. Aesthetically, its dark color does not match the concrete at all. Set<sup>®</sup> 45 Hot Weather extended 60% (8) was initially difficult to mix with a high aggregate extension, but as the powder was added, it achieved a consistency similar to that of the neat mortar (4). It did not flow as well as the neat

mortar (4) but did flow the best of all of the extended candidate mortars. Photographs of the haunch flow test for Set<sup>®</sup> 45 HW extended (8) can be found in Appendix A. The ability to perform well in high temperature conditions is a very attractive feature of Set<sup>®</sup> 45 Hot Weather. The prolonged work time can also be taken advantage of in normal temperature conditions.



Figure 5.9: Set<sup>®</sup> 45 Hot Weather (4) Flow Through Haunch Mockup

Table 5.6: Candidate Mortar Workability Observations

Mortar	Work Time, min.	Initial Set Time, min.	Consistency	Haunch Flow Observation
1 ThoRoc <sup>®</sup> 10-60	8	16	Thick	poor
2 SikaQuick <sup>®</sup> 2500	15	24	Medium	good
3 Five Star <sup>®</sup> Patch	18	30	Medium	good
<b>4 Set<sup>®</sup> 45 HW</b>	<b>28</b>	<b>44</b>	Runny	<b>very good</b>
5 ThoRoc <sup>®</sup> extended	10	19	Thick	fair
6 SikaQuick <sup>®</sup> extended	21	29	Medium	<b>good</b>
7 Five Star <sup>®</sup> extended	15	26	Thick	fair
<b>8 Set<sup>®</sup> 45 HW extended</b>	<b>24</b>	<b>35</b>	Medium	<b>good</b>

Work Time is the time from when mixing begins until workability begins to decrease.

Initial Set Time is the time from when mixing begins until the mortar is no longer workable.



Table 5.7: Truncated Flow Cone Spread Values per ASTM C 1437

Mortar	Initial		After 10 Drops		Total Diameter Increase, %
	Average Spread, in.	Diameter Increase, %	Average Spread, in.	Additional Diameter Increase, %	
<b>1</b> ThoRoc <sup>®</sup> 10-60	7	75	<b>10</b>	43	<b>150</b>
<b>2</b> SikaQuick <sup>®</sup> 2500	7	75	9.5	36	138
<b>3</b> Five Star <sup>®</sup> Patch	<b>10</b>	150	<b>10</b>	0	<b>150</b>
<b>4</b> Set <sup>®</sup> 45 HW	9.5	138	<b>10</b>	5	<b>150</b>
<b>5</b> ThoRoc <sup>®</sup> extended	5	25	8.5	70	113
<b>6</b> SikaQuick <sup>®</sup> extended	6.5	63	8.5	31	113
<b>7</b> Five Star <sup>®</sup> extended	5	25	8.5	70	113
<b>8</b> Set <sup>®</sup> 45 HW extended	<b>7.5</b>	88	<b>9</b>	20	<b>125</b>

Initial Flow Cone Diameter = 4 in.

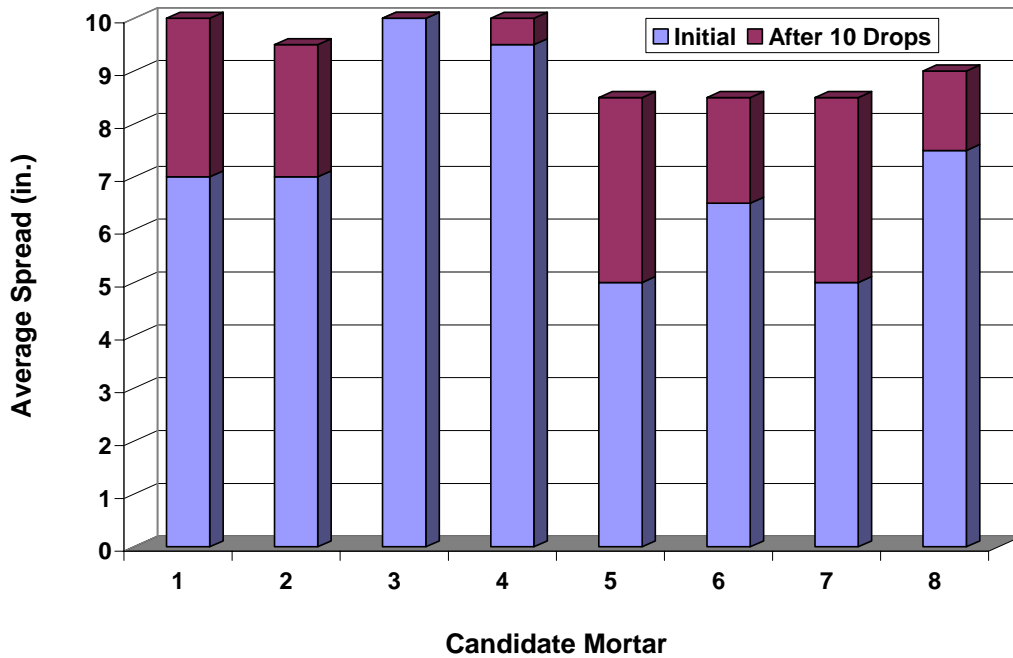


Figure 5.10: Truncated Flow Cone Spread Values per ASTM C 1437

## 5.5 Bond Strength

### 5.5.1 ASTM C 882

Slant shear cylinder tests provided a method of analyzing each candidate mortar's ability to bond to concrete with various types of surface preparations. Two modes of failure were common in these tests:

- 1) clean shearing of mortar/concrete bond along slanted interface (Figure 5.11a)
- 2) mortar and/or concrete cracking before interface bond failure
  - a) mortar cracking was not too severe and it was possible to load the specimen until the bonded interface failed (Figure 5.11b)
  - b) mortar cracked and split in a vertical manner so that it was not possible to continue loading the specimen (Figure 5.11c)



Figure 5.11: Slant Shear Cylinder Failure Modes

In each case, the maximum load was recorded and converted to stress by dividing by the elliptical area of the bonded interface. For a 4 in. by 8 in. cylinder sliced at a 30° angle, the interface is a 4 in. by 8 in. ellipse and the area is  $\pi*(4/2)*(8/2) = 25.133 \text{ in}^2$ . ASTM suggests reporting the results of these tests simply as load divided by area. However, the objective of using this test in this research project is to investigate shear stress. Therefore, the maximum load was multiplied by the cosine of 30° to obtain the true shear stress component acting along the bonded interface. Results for the slant cylinder tests are presented in Table 5.8 and Figure 5.12. A loading at which many mortars began to crack was between 10000 lbs. and 15000 lbs. This is equal to an interface shear stress between 345 psi and 515 psi.

Table 5.8: Slant Cylinder Bond Strength with Varying Concrete Surface Preparations

Mortar	Shear Stress with Varying Surface Preparation, psi			
	Smooth	<b>Exposed Aggregate</b>	Raked	Raked and Sand Blasted
1 ThoRoc® 10-60	<i>540</i>	<i>540</i>	630	<b>650</b>
2 SikaQuick® 2500	1240	<b>1400</b>	1190	670
3 Five Star® Patch	950	<b>1810</b>	1540	<i>720</i>
4 Set® 45 HW	<i>520</i>	<i>470</i>	<b>630</b>	<i>560</i>
5 ThoRoc® extended	1490	<b>1730</b>	1320	1450
6 SikaQuick® extended	<b>980</b>	850	750	730
7 Five Star® extended	1380	1680	1210	<b>1700</b>
8 Set® 45 HW extended	500	<b>950</b>	640	820

Values in *italics* represent significant mortar cracking associated with failure mode 2.

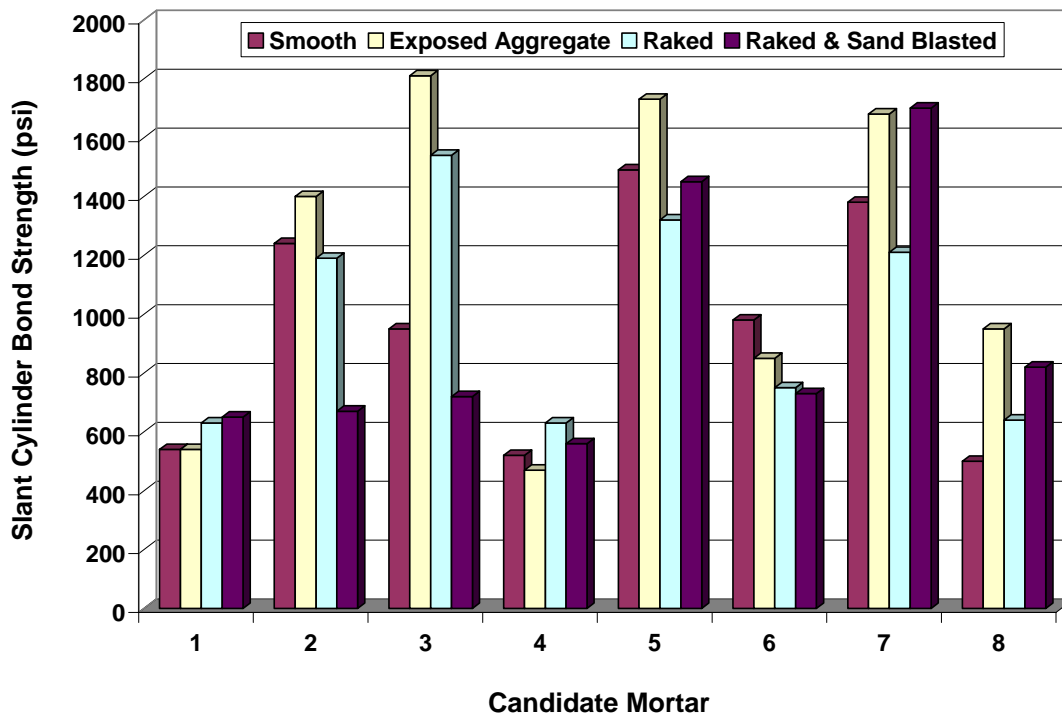


Figure 5.12: Slant Cylinder Bond Strength with Varying Concrete Surface Preparations

Of all candidate mortars, Five Star<sup>®</sup> Patch (3) displayed the highest bond strengths for exposed aggregate and raked surfaces, while Five Star<sup>®</sup> Patch extended (7) and ThoRoc<sup>®</sup> 10-60 extended (5) displayed the highest bond strengths for raked/sand blasted and smooth surfaces, respectively. Generally, the extended mortars performed slightly better than the neat mortars. The exposed aggregate preparation provided the best bonding surface for four of the eight mortars and was second best for two mortars. The smooth interface performed slightly better than anticipated, providing the worst or second worst bond strength for only half of the candidate mortars. With such a featureless surface, the smooth interface was expected to provide the least bond strength for each mortar. Whether sand blasting would increase the bonding performance of a raked surface was of particular interest in these tests. Only for Five Star<sup>®</sup> Patch extended (7) did the raked and sand blasted surface display a significant advantage over the raked surface. The raked surface displayed a much higher bond strength than the raked and sand blasted surface for SikaQuick<sup>®</sup> 2500 (2) and Five Star<sup>®</sup> Patch (3). However, for the other five candidate mortars, the two surface preparations displayed very similar bond

strengths. So while it is possible for sand blasting to increase the bonding capability of a raked concrete surface, it has shown to be ineffective in almost 90% of these tests. For the trouble and cost that is involved with sand blasting, it may not be a worthwhile venture if the concrete surface is already raked.

### 5.5.2 Push-Off Tests

Based on the performance of the candidate mortars in the property specific tests, three were selected for further investigation through a series of push-off tests. The objective was to form a correlation between slant shear cylinder tests and performance of the mortar in horizontal shear at the girder/deck panel interface. Five Star<sup>®</sup> Patch (3) and Set<sup>®</sup> 45 HW (4) were selected based on their excellent constructability and shrinkage performance as well as their ability to gain strength quickly after the first hour. The slant shear cylinders for Five Star<sup>®</sup> Patch (3) performed much better than the Set<sup>®</sup> 45 HW (4), which should predict a better performance in the push-off tests. Set<sup>®</sup> 45 HW extended (8) was selected based on its overall performance as the best extended mortar. Additionally, this same mortar (8) was used in push-off tests by Menkulasi, so comparisons could be made regarding how well the mortar fared in the two different push-off test configurations. With the exposed aggregate and raked surfaces performing best in the slant shear cylinder tests, it was decided to use these preparations for the push-off test specimens (see Figure 4.18). The beam side was given a raked finish, as is done traditionally, and the slab side was given an exposed aggregate finish. Menkulasi used the same surface preparations for his push-off tests. Two push-off tests were conducted for each of the three mortars.

Results of the push-off tests are presented in Table 5.9. Clamping stress is defined as the sum of the applied normal force and the force provided by the steel reinforcement divided by the area of the interface. Since there was no steel reinforcement crossing the interface, the clamping stress is simply the vertical load,  $P_n$ , divided by the interface area,  $b_v s$ .

Table 5.9: Push-Off Test Results

Mortar		$V_{peak}$ , lbs	$P_n$ , lbs	$A_{cv}$ , in <sup>2</sup>	$v_{peak}$ , psi	cl, psi	Slip, in.	Failure Plane	$f'_{c,}$ Grout, psi	$f'_{c,}$ Conc., psi
3 Five Star <sup>®</sup> Patch	A	33500	3850	424	79.0	9.1	0.0091	slab	4480	3830
	B	35600	4700	316	112.7	14.9	0.0153	slab	4480	3830
4 Set <sup>®</sup> 45 HW	A	43200	3420	424	101.9	8.1	0.0078	beam	3780	3830
	B	42700	2500	424	100.7	5.9	0.0096	beam	3780	3830
8 Set <sup>®</sup> 45 HW ext.	<b>A</b>	<b>50500</b>	4050	424	<b>119.1</b>	9.5	0.0178	beam	3780	3830
	B	44000	2700	424	103.8	6.4	0.0149	beam	3780	3830

$V_{peak}$  = shear load at failure, lbs.

$v_{peak}$  = shear stress at failure, psi

$P_n$  = normal force at failure, lbs.

cl = clamping stress at failure, psi

$A_{cv} = b_v s$  = area of interface, in<sup>2</sup>

slip = maximum slip at failure, in.

Set<sup>®</sup> 45 HW extended (8) provided the highest shear resistance along the interface, followed by Set<sup>®</sup> 45 HW (4) and then Five Star<sup>®</sup> Patch (3). In each case, the specimen was not able to sustain much or any load after the bond failure. Additionally, the slip occurring immediately after failure was greater for specimens that took higher peak shear loads. This is illustrated in the load-slip plot in Figure 5.13. All three candidate mortars performed in a similar fashion to the push-off tests conducted by Menkulasi. The six push-off tests from this research were added to Menkulasi's results on a shear stress verses clamping stress plot which is found in Figure 5.14. Five of the six tests performed in this research were predicted conservatively by Menkulasi's lower bound equation for nominal horizontal shear resistance. Menkulasi's lower bound and best fit equations (Eqs. 2.11-2.12) as well as the AASHTO LRFD design equation (Eq. 2.10) are also illustrated in Figure 5.14.

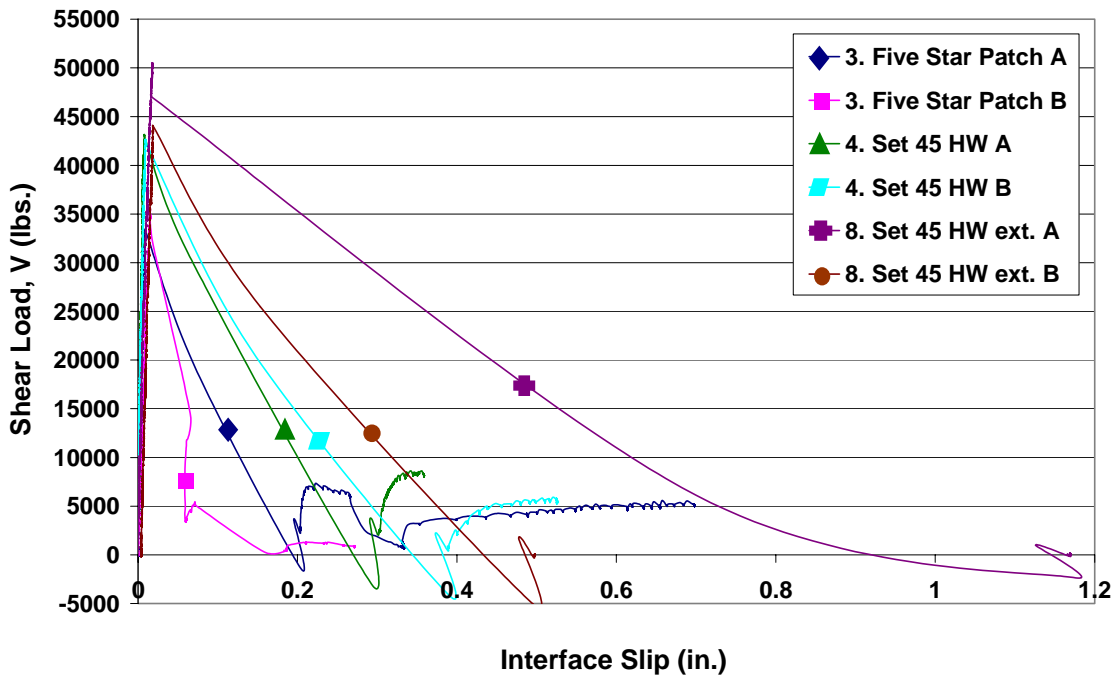


Figure 5.13: Push-Off Test Shear Load vs. Interface Slip

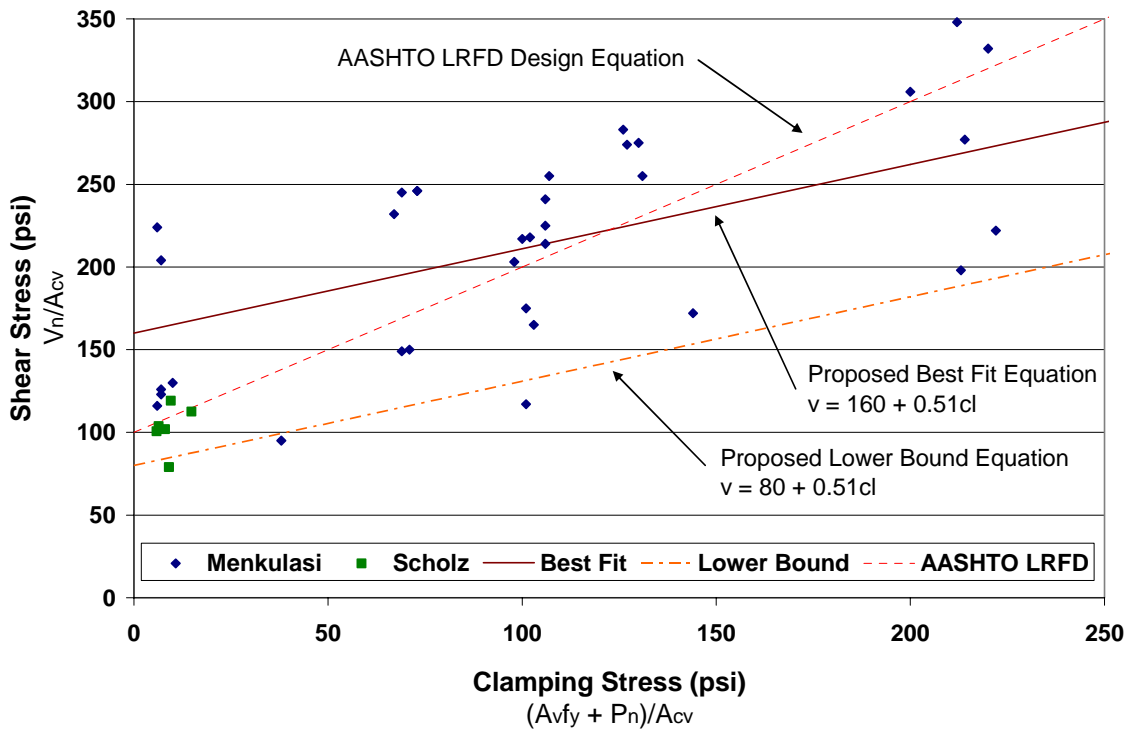


Figure 5.14: Shear Stress vs. Clamping Stress for Push-Off Tests

### 5.5.3 Correlations Between Slant Shear Cylinder Tests and Push-Off Tests

Five Star<sup>®</sup> Patch (3) exhibited the best interface bond in the slant cylinder tests, but fared worst of the three mortars used in the push-off tests. Also, the slant cylinders did not correctly predict whether the beam/mortar interface or the slab/mortar interface would fail in the push off tests. For Five Star<sup>®</sup> Patch (3), the slant cylinders displayed a higher bond with an exposed aggregate concrete finish, but the push-off tests failed along the exposed aggregate preparation of the slab-side specimen. Both Set<sup>®</sup> 45 HW (4 & 8) slant cylinder tests showed similar results for the exposed aggregate and raked finish, however all of the push-off tests failed along the raked beam interface. The slant shear cylinder tests did not accurately predict the outcome of the push-off tests. Individual slant cylinder tests were tabulated in a similar fashion to the push-off test results and then plotted along with the push-off test points on the shear stress versus clamping stress graph. Shear stress and clamping stress for the slant cylinders are simply the components of the compressive force,  $F$ , which act along the bond interface ( $F\cos(30^\circ)$ ) and normal to the bond interface ( $F\sin(30^\circ)$ ), respectively. These values are presented in Table 5.10. Figure 5.15 illustrates that the horizontal shear resistance for the slant cylinder tests were not in the range of the push-off tests.

Table 5.10: Individual Slant Shear Cylinder Test Results for Each Mortar

Mortar	Cylinder	Load, lbs.	$V_{peak}$ , lbs.	$P_n$ , lbs.	$A_{cy}$ , in <sup>2</sup>	$V_{peak}$ , psi	$cl$ , psi	$f'_c$ Grout, psi
3 Five Star <sup>®</sup> Patch	Raked 1	45500	39404	22750	25.133	1567.8	905.2	5080
	Raked 2	44000	38105	22000	25.133	1516.2	875.4	5080
	Ex. Agg. 2	52550	45510	26275	25.133	1810.8	1045.5	5080
4 Set <sup>®</sup> 45 HW	Raked 1	17500	15155	8750	25.133	603.0	348.2	4930
	Raked 2	17500	15155	8750	25.133	603.0	348.2	4930
	Raked 3	20000	17321	10000	25.133	689.2	397.9	4930
8 Set <sup>®</sup> 45 HW ext.	Raked 1	19500	16887	9750	25.133	671.9	387.9	3230
	Raked 2	18500	16021	9250	25.133	637.5	368.1	3230
	Raked 3	17500	15155	8750	25.133	603.0	348.2	3230

Terms as defined in Table 5.9



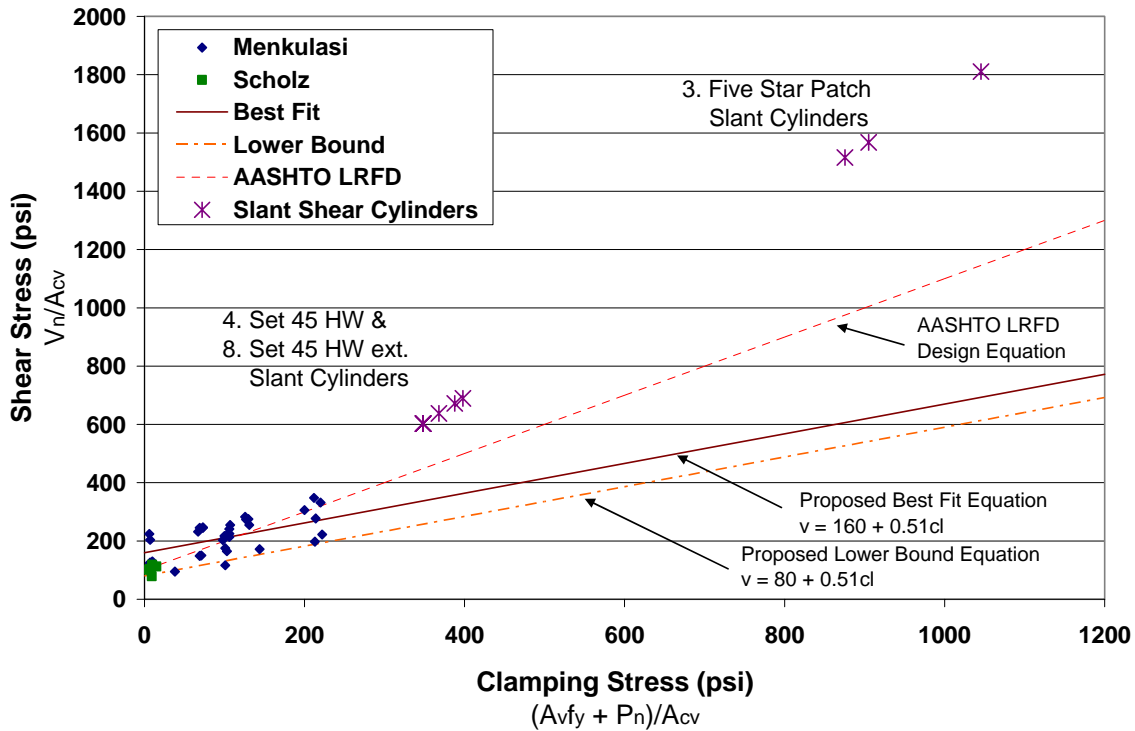


Figure 5.15: Shear Stress vs. Clamping Stress with Slant Shear Cylinders

Since the shear stress and clamping stress for the slant cylinder tests are purely a function of their geometry, the results will always plot along a line with a slope of  $\cos(\theta)/\sin(\theta)$  and a y-intercept of 0; in these tests, the slope of the line is  $\cos(30^\circ)/\sin(30^\circ) = 1.732$ . One possible means of better correlating slant shear cylinder tests to push-off tests would be to prepare cylinders with three different slant geometries, for instance, 30, 45 and 60 degrees. The results of these three tests could be plotted on the same shear stress versus clamping stress plot and a best fit line could be established. If the slope of that line resembled the general trend of push-off tests, even with a different y-intercept, the two tests could be correlated with a ratio of the slopes.

Another approach to correlating the slant shear cylinder tests and push-off tests is to calculate cohesion factors based on the AASHTO LRFD design equation for horizontal shear, which states that horizontal shear load resisted by an interface equals the sum of its cohesion plus the clamping load times a friction coefficient, as shown in equation 5.5.

$$V_n = cA_{cv} + \mu(A_{vf}f_y + P_c) \quad (5.5)$$

where  $V_n = V_{peak}$  = nominal shear resistance of the interface, kips

$c$  = cohesion factor, ksi

$A_{cv}$  = area of interface, in<sup>2</sup>

$\mu$  = friction coefficient = 1.0 for concrete with clean, roughened surface

$A_{vf}$  = area of steel reinforcement crossing interface, in<sup>2</sup>

$f_y$  = yield stress of steel reinforcement crossing interface, ksi

$P_c = P_n$  = normal force acting across interface, kips

With no steel reinforcement, and solving for cohesion factor,  $c$ , equation 5.5 simplifies to

$$c = (V_n - P_c) / A_{cv} \quad (5.6)$$

The results of the cohesion factor calculations using the AASHTO LRFD design equation are presented in Table 5.11. For each candidate mortar, the average slant cylinder cohesion factor was divided by the average push-off cohesion factor to obtain a multiplying factor between the two types of tests.

Table 5.11: Cohesion Factors for Push-Off Tests and Slant Shear Cylinder Tests

Mortar		$V_{peak}$ , kips	$P_n$ , kips	$A_{cv}$ , in <sup>2</sup>	$c$ , ksi	Push-Off Average	Cylinder to Push-Off Ratio
3 Five Star <sup>®</sup> Patch	Push-Off A	33.5	3.8	424	0.070	<b>0.084</b>	8.25
	Push-Off B	35.6	4.7	316	0.098		
	Slant Cyl. Avg.	41.0	23.7	25	<b>0.692</b>		
4 Set <sup>®</sup> 45 HW	Push-Off A	43.2	3.4	424	0.094	<b>0.094</b>	2.84
	Push-Off B	42.7	2.5	424	0.095		
	Slant Cyl. Avg.	15.9	9.2	25	<b>0.268</b>		
8 Set <sup>®</sup> 45 HW ext.	Push-Off A	50.5	4.0	424	0.110	<b>0.104</b>	2.59
	Push-Off B	44.0	2.7	424	0.097		
	Slant Cyl. Avg.	16.0	9.3	25	<b>0.268</b>		

The AASTHO LRFD design method assumes a cohesion factor of 0.1 ksi for normal weight concrete cast against normal weight concrete with a clean, roughened surface, while the equivalent factor in ACI 318 and the AASHTO Standard Specification

is taken as 0.08 ksi. All three mortars achieve the ACI and AASHTO Standard cohesion factors for horizontal shear strength, but only the Set<sup>®</sup> 45 HW extended (8) was able to achieve the AASHTO LRFD value. While the slant cylinder cohesion factor was a similar 2.6 and 2.8 times greater than the push-off cohesion factor for the Set<sup>®</sup> 45 HW tests (4 & 8), it was 8.25 times greater for the Five Star<sup>®</sup> Patch tests (3). This discrepancy is too large to create a solid correlation between slant shear cylinders tests and push-off tests using this AASHTO LRFD cohesion factor approach. Slant shear cylinder tests may not be representative of horizontal shear strength in the haunch.

Best fit equations for shear stress versus clamping stress were calculated for each of the candidate mortars based on their push-off tests and slant shear cylinder tests. As is the case for the AASHTO LRFD design equation, these equations represent the values for friction coefficient,  $\mu$ , and cohesion factor,  $c$ , for each mortar. The general form is given in equation 5.7.

$$v = c + \mu(cl) \quad (\text{psi}) \quad (5.7)$$

The friction coefficient represents the slope of the line, while the cohesion factor represents the y-intercept. The best fit equations for the three candidate mortars based on the slant shear cylinder tests and push-off tests are provided in equations 5.8 – 5.10. The AASHTO LRFD equation and Menkulasi’s best fit equation are provided in equations 5.11 – 5.12. Figure 5.16 illustrates how these equations compare to each other.

$$v = 75.5 + 1.65cl \quad (\text{psi}) \quad [3. \text{Five Star}^{\text{®}} \text{Patch best fit}] \quad (5.8)$$

$$v = 90.4 + 1.49cl \quad (\text{psi}) \quad [4. \text{Set}^{\text{®}} 45 \text{HW best fit}] \quad (5.9)$$

$$v = 99.5 + 1.46cl \quad (\text{psi}) \quad [8. \text{Set}^{\text{®}} 45 \text{HW ext. best fit}] \quad (5.10)$$

$$v = 100 + 1.00cl \quad (\text{psi}) \quad [\text{AASHTO LRFD equation}] \quad (5.11)$$

$$v = 160 + 0.51cl \quad (\text{psi}) \quad [\text{Menkulasi best fit}] \quad (5.12)$$

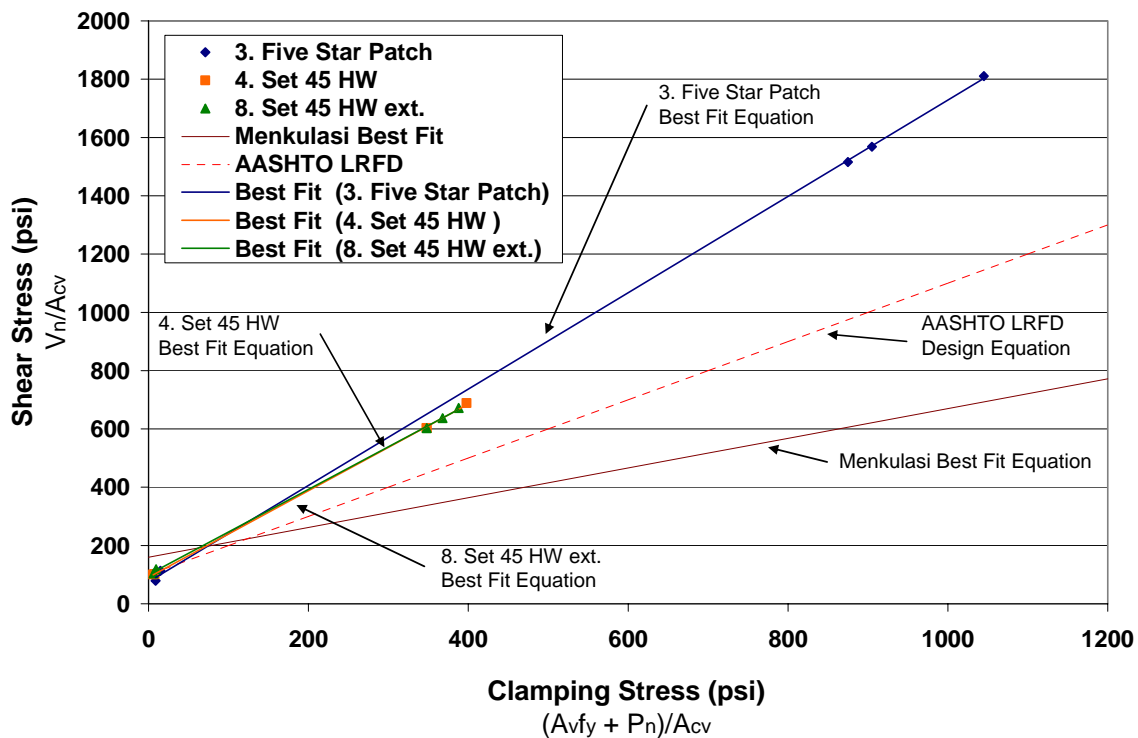


Figure 5.16: Best Fit Equations for Mortars Based on Slant Cylinder and Push-Off Tests

In comparing equations 5.8 – 5.12, it is apparent that the best fit equations for the candidate mortars based on slant shear cylinders tests and push-off tests have a lower cohesion factor (y-intercept), but a higher friction coefficient (steeper slope) compared to the AASHTO LRFD design equation and Menkulasi’s best fit equation for push-off tests. One approach to investigating these discrepancies is to analyze the definition of clamping stress. When steel reinforcement is provided across the shear interface, the  $A_s f_y$  term dominates the clamping stress value and the normal force term,  $P_n$ , can be conservatively neglected. It is assumed that the reinforcement yields in this situation, but that assumption may not always hold true. Most of the reinforcement in Menkulasi’s tests did not reach the yield stress at the time of interface cracking. The actual stress in the reinforcement at this time would more accurately be represented as  $\epsilon_s E_s$ , which is the strain in the reinforcement multiplied by the modulus of elasticity of steel. This approach was applied to Menkulasi’s data for the Set<sup>®</sup> 45 HW extended (8) push-off tests, and a new best fit equation was determined as shown in equation 5.13.

$$v = 115 + 1.45cl \quad (\text{psi}) \quad [\text{New Menkulasi best fit, Set}^{\text{®}} 45 \text{ HW ext.}] \quad (5.12)$$

The clamping stress values for most of the data decreased, since the reinforcement had not yielded. This caused the data points to shift to the left, increasing the slope of the best fit line, and bringing the slant shear cylinders more in line with the best fit equation for the push-off tests. The new push-off data and best fit equation for Set<sup>®</sup> 45 HW extended (8) are illustrated along with the corresponding slant shear cylinders in Figure 5.17.

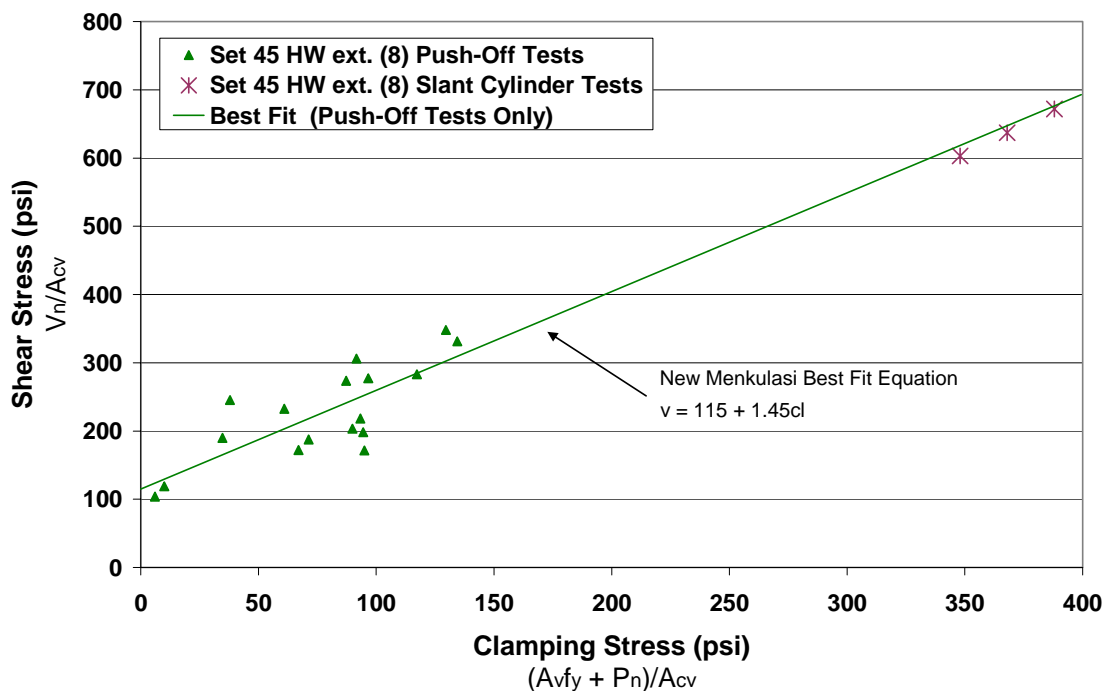


Figure 5.17: New Best Fit Equation for Push-Off Tests for Set<sup>®</sup> 45 HW ext. (8)

The cohesion factor (y-intercept) and friction coefficient (slope) from this new best-fit line is very similar to those established for Set<sup>®</sup> 45 HW extended (8) based on the slant shear cylinders and push-off tests conducted in this research (equation 5.10). A linear correlation could be established for this particular mortar based on these findings. However, this adjustment is limited because it does not address the Five Star<sup>®</sup> Patch (3), whose excellent performance in slant cylinder tests was not reflected in the push-off tests.

Further research must be carried out before a definite correlation can be established between slant shear cylinders tests and push-off tests. The use of the steel yield stress,  $f_y$ , in the clamping stress term should also be evaluated to determine the accuracy of the assumption that the reinforcing steel yields during horizontal shear transfer.

## CHAPTER 6: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

### **6.1 Mortar Research Summary**

A series of ASTM standard tests and representative deck panel system tests were performed on four candidate mortars with and without a pea gravel aggregate extension to determine suitable performance criteria for a precast concrete bridge deck panel system. These tests investigated essential mortar properties including compressive strength, tensile strength, shrinkage, workability, flow, and bond strength. The objective was to correlate mortar performance between the ASTM and representative tests so that a design specification could be developed and used in the selection of mortars for a precast concrete bridge deck panel system.

### **6.2 Conclusions and Recommendations**

#### **6.2.1 Compressive Strength**

It was evident that a very high early compressive strength can hinder the ability of a mortar to flow. This is unacceptable in all cases, because it is of utmost importance that the haunch and shear pockets are completely filled with mortar in order to ensure the best connection between the girder and precast deck panel. From a construction standpoint, it is very unlikely that a transportation authority would desire to open a bridge to traffic only one hour after the start of the mortar pour, although it could be more feasible in a deck replacement situation. In addition to the amount of time it takes to pour the mortar throughout the length of the bridge over multiple girder lines, there are many other tasks to accomplish before a bridge could be opened. These tasks include the placement of barriers, removal of temporary traffic control devices, general cleanup, and dispersion of personnel. In most cases, a high one hour strength would not be critical, and would most likely be detrimental. Strength gain in the second hour would be more appropriate if the panel system is being utilized to rehabilitate a deteriorated deck and partial or nighttime bridge closures are employed. A high two hour compressive strength would ensure that the bridge could be opened to traffic as soon as possible. Therefore, it is recommended that the mortar gain no strength within the first hour, and gain a minimum two hour

compressive strength of 2000 psi in accordance to ASTM C 109. These early strength parameters should ultimately be determined by the engineer-of-record for each specific use of the deck panel system. A high two hour strength may not be critical if the panel system is used in conjunction with new bridge construction or full lane closures. A recommended minimum one day compressive strength is 4000 psi and a recommended minimum seven day compressive strength is 5000 psi. This high compressive strength is desirable so that the mortar is consistent with the precast concrete deck panels. Deck panel compressive strength can range from 4000 psi to 6000 psi.

Since not all manufacturers will specify compressive strengths for their products at these exact time intervals, alternate criteria needs to be established as well. Any alternate criteria used in specifications must be stricter than the original criteria so that manufacturers are not tempted to omit information in order to meet standards. In lieu of two hour compressive strength, a recommended minimum three hour compressive strength is 3000 psi. In lieu of seven day compressive strength, a recommended minimum 28 day compressive strength is 6000 psi.

### **6.2.2 Tensile Strength**

To ensure that a mortar does not exhibit diagonal tension cracking in haunch conditions, a recommended splitting tensile strength for one day is 200 psi and for seven days is 400 psi in accordance to ASTM C 496. A recommended alternate criteria is 600 psi at 28 days in lieu of the seven day criteria. It may be difficult to ensure that diagonal tension cracking does not occur in the mortar at negative moment regions of a continuous girder. A detailed analysis of the stresses in the haunch at these locations should be carried out for each specific bridge configuration. It is also possible that a manufacturer may not specify a splitting tensile strength. In this case, criteria should be established based on a relationship between compressive strength and tensile strength. A common assumption for concrete is that tensile strength is approximately equal to 1/10 of the compressive strength. For each of the candidate mortars investigated in this research, the tensile strength ranged from 1/8 to 1/14 of the compressive strength. In order for these alternate criteria to be stricter than the original criteria, 1/15 was selected as a multiplier



to estimate the splitting tensile strength from the compressive strength. Specific details can be found in Chapter 7.

### **6.2.3 Shrinkage**

All four neat mortars and four extended mortars performed well in the shear pocket tests, with no cracks forming or water seepage through the interface. However, 28 day shrinkage values for ThoRoc<sup>®</sup> 10-60 (1 & 5) and SikaQuick<sup>®</sup> 2500 (2 & 6) were in excess of 0.06% (600 microstrain), which may be large enough to cause cracking and leaking when large diameter shear pockets are used. Optimal shrinkage values for a precast deck panel system should be in line with Five Star<sup>®</sup> Patch (3 & 7) and Set<sup>®</sup> 45 HW (4 & 8), which displayed more favorable results throughout the series of ASTM and representative tests, and were within the target shrinkage range of concrete (Mokarem, 2002). Therefore, a recommended maximum 28 day shrinkage is 0.04% (400 microstrain) in accordance to ASTM C 157 or ASTM C 596. This maximum is recommended for both neat mortars (1 in. square cross section prisms) and extended mortars (3 in. square cross section prisms).

### **6.2.4 Flow and Workability**

It has been recommended that the mortar gain no strength in the first hour to ensure that it does not set too quickly and adversely affect its flow. Work time and initial set time should not be less than 15 minutes and 30 minutes, respectively, although longer times are preferred. Additionally, it is recommended that a mortar be tested on site, immediately after mixing, in accordance with ASTM C 1437 (modified). It is recommended that the mortar achieve a self weight average spread of 7 in. and a 9 in. average spread after ten drops on a standard drop table specified by ASTM C 230 (modified from 25 drops).

### **6.2.5 Bond Strength**

The slant shear cylinder tests (ASTM 882) may not be representative of horizontal shear strength as they did not accurately predict the mortars' performance in push-off tests. A definite correlation was not identified between the two types of tests. However,

a mortar should be able to provide a cohesion factor of at least 100 psi (0.1 ksi) in order to meet the assumed cohesion factor used in the AASHTO LRFD Specifications. Further research should be carried out in order to correlate horizontal shear strength in haunch conditions with slant shear cylinder tests or another type of bond strength test. This would allow for performance criteria to be established in order to qualify candidate mortars and grouts for use in a precast deck panel system based on bond strength.

#### **6.2.6 Aggregate Extension and Water Content**

The use of an aggregate extension with the candidate mortars in this research did not significantly hinder each mortar's performance. Therefore, an aggregate extension is suitable for mortars used in a precast deck panel system. Advantages to using an aggregate extension include increasing the mortar's yield volume, lengthening the mortar's work time, and achieving a consistency similar to that of concrete. It is recommended that the aggregate be 3/8 in. pea gravel and that the extension be no greater than 50% by weight. This research has shown that a greater extension hinders the mortar's workability and flow capability. A 50% or less extension can slow the set of the mortar and extend its work time, which is a valuable feature for a precast deck panel pour. It is recommended that the specified maximum water content be used for each mortar. The product should be added to the specified minimum water amount, and when approximately 80% of the product has been added, additional water should be supplied to meet the specified maximum water content. This use of additional water aids the mortar's workability and flow without significantly compromising strength gain. The water content should never exceed the maximum content specified for each mortar, and water should never be added once pouring has commenced in an attempt to increase its workability.

#### **6.2.7 Properties Not Investigated in This Research**

Nottingham (1996) recommended criteria for some durability-based mortar properties that were not investigated in this research (see Table 2.3). These recommendations were applied to the proposed performance specification in Chapter 7.

### 6.2.8 Additional Recommendations

- Sand blasting did not significantly increase the bonding capabilities of a concrete surface which had already been raked to an amplitude of ¼ in. It may be unnecessary to perform this time-consuming and expensive task in this situation.
- A ¼” raked surface preparation is suitable for the top flange of a conventional concrete girder. Surface preparations to provide adequate bond between the mortar and self-consolidating concrete should be investigated. It is recommended that an exposed aggregate surface preparation be applied to the bottom of the precast concrete deck panels.
- Mortars should be poured continuously along girder lines starting from the center of each span and working towards the supports. This takes advantage of the girders’ camber so that the mortar is flowing in a downhill manner. If the bridge is inclined, the mortar should be poured downhill.
- Based on their performance throughout this research, Five Star<sup>®</sup> Highway Patch (3) and Set<sup>®</sup> 45 Hot Weather (4) are suitable for use in a precast concrete bridge deck panel system. Five Star<sup>®</sup> Highway Patch extended (7) and Set<sup>®</sup> 45 Hot Weather extended (8) also performed very well, but were hindered in constructability considerations due to their high aggregate extensions. If their extensions were reduced to 50% by weight, it is expected that both extended products (7 & 8) would be suitable for use in a precast deck panel system. Although Five Star<sup>®</sup> Highway Patch (3 & 7) and Set<sup>®</sup> 45 Hot Weather (4 & 8) are more expensive than ThoRoc<sup>®</sup> 10-60 and SikaQuick<sup>®</sup> 2500, transportation authorities should realize that using mortars that are suitable for this application is critical to ensuring a properly functioning deck system, even at higher initial construction costs. Using less-expensive mortars that are inappropriate for use in a precast deck panel system could be devastating to the structural integrity of the bridge and could force a very costly rehabilitation in the future.

### 6.3 Recommendations for Future Research

- Slant shear cylinder tests (ASTM 882) should be performed with three slant geometries in order to investigate how the interface bond is affected with varying shear stress to clamping stress ratios. Recommended slant angles are 30, 45 and 60 degrees from vertical. It may be possible to correlate a best fit line from these tests with horizontal shear strength in push-off tests, as explained in section 5.5.3. If ASTM 882 is used to qualify mortars based on bond strength, special attention should be given to the concrete surface preparation used in the test. Different types of surface preparations will result in varying bond strength results. Therefore, the test method should specify the use of one specific surface preparation so that results can be compared directly.
- A specific correlation should be developed between shrinkage measured by 1 in., 3 in. and 4 in. square cross section rectangular prisms. ASTM C 157 specifies the use of these different prism sizes with regard to the aggregate size used in mortars and concretes. By measuring shrinkage of the same products in three different size specimens, a correlation could be established and included in the ASTM test method. This would provide a much more precise way to compare shrinkage between neat mortars, extended mortars, and concrete.

# CHAPTER 7: PROPOSED PERFORMANCE SPECIFICATION

## FOR MORTARS USED IN FULL-DEPTH PRECAST

### CONCRETE BRIDGE DECK PANEL SYSTEMS

This performance specification is intended to qualify mortar or grout products for use in a precast concrete bridge deck panel system. Section 1 through Section 7 are intended to evaluate a product based on accompanying technical data, while Section 9 is intended to evaluate a product on site at the time of the pour. Section 8 provides mixing procedures.

#### **1. Product Composition**

**1.1 Neat Mortars:** The product shall be composed of all fine particles and have a consistency of a powder. Water shall be the only additive required.

**1.2 Extended Mortars:** A 3/8 in. pea gravel aggregate extension may be used in conjunction with a neat mortar. The extension shall not exceed 50% by weight. The aggregate shall comply with the current state-of-art specification for pea gravels.

**1.3 Neat and extended mortars** must comply with the specifications set forth in Section 2 through Section 9.

#### **2. Compressive Strength**

**2.1** The product shall meet the following time-based criteria for compressive strength based on ASTM C 109:

- 1 hour: No strength
- 2 hour: Determined by engineer-of-record based on construction procedure.
- 1 day: Minimum 4000 psi
- 7 day: Minimum 5000 psi

**2.2** If a 7 day compressive strength is not available for a product, the following criteria shall be used:

- 28 day: Minimum 6000 psi

#### **3. Splitting Tensile Strength**

**3.1** The product shall meet the following time-based criteria for splitting tensile strength based on ASTM C 496:

- 1 day: Minimum 200 psi
- 7 day: Minimum 400 psi

**3.2** If a 7 day splitting tensile strength is not available for a product, the following criteria shall be used:

- 28 day: Minimum 600 psi

**3.3** If no splitting tensile strength information is available for a product, the following criteria shall be used:

- 1 day compressive strength divided by 15 must be greater than 300 psi
- 7 day compressive strength divided by 15 must be greater than 400 psi
- 28 day compressive strength divided by 15 must be greater than 500 psi (in lieu of 7 day strength)

#### **4. Shrinkage**

**4.1** The product shall meet the following criteria for shrinkage based on either ASTM C 157 or ASTM C 596. Neat mortars shall be evaluated with 1 in. square cross section prisms and extended mortars shall be evaluated with 3 in. square cross section prisms. The criteria shall remain the same regardless of test prism size.

- 28 day: Maximum 0.04% (400 microstrain)

#### **5. Sulfate Resistance**

**5.1** The product shall meet the following criteria for sulfate resistance based on ASTM C 1012. Neat mortars shall be evaluated with 1 in. square cross section prisms and extended mortars shall be evaluated with 3 in. square cross section prisms. The criteria shall remain the same regardless of test prism size.

- 28 week: 0.10% (1000 microstrain)

#### **6. Freeze-Thaw Resistance**

**6.1** The product shall meet the following criteria for freeze-thaw resistance based on ASTM C 666, Procedure A:

- 300 Cycles: Minimum 80% Durability Factor

#### **7. Scaling Resistance**

**7.1** The product shall meet the following criteria for scaling resistance based on ASTM C 672:

- 25 Cycles: 0 Scaling Rating (no scaling)

#### **8. Mixing Procedure**

**8.1** If an aggregate extension is used, the aggregate shall be added to the initial water content before any powder is added.

**8.2** The powder shall be added to the specified minimum water content. An additional water amount shall be supplied after approximately 80% of the product has been added to the initial water. This additional water amount may be specified by the manufacturer or may be taken as the difference between the specified maximum water content and the specified minimum water content. The specified maximum water content for a specific product shall not be exceeded. No water shall be added to the product once pouring has commenced.

#### **9. Flow**

**9.1** The product shall be tested according to 9.2 on site, after mixing and immediately before pouring the product.

**9.2** The product shall be tested on a standard flow table specified by ASTM C 230. The testing procedure shall follow ASTM C 1437 with the following modifications:

- The average diameter of the product shall be measured after the mold is lifted to determine the product's flow under its own self weight.
- The table shall then be dropped 10 times in 15 seconds.
- The average diameter of the product shall be measured after the 10 drops
- If either the self weight or 10 drops causes the product's diameter to exceed the diameter of the table, then that measurement shall be recorded as the diameter of the table.

**9.3** The product shall meet the following criteria for flow based on the procedure in 9.2:

- Minimum average diameter from self weight flow: 7 in.
- Minimum average diameter after 10 drops: 9 in.

## REFERENCES

AASHTO (1996). *AASHTO Standard Specifications for Highway Bridges, 16<sup>th</sup> Ed.*, American Association of State Highway and Transportation Officials, Washington, D.C.

AASHTO (1998). *AASHTO LRFD Bridge Design Specification, 2<sup>nd</sup> Ed.*, American Association of State Highway and Transportation Officials, Washington, D.C.

ACI Committee 209 (1992). *Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures (Reapproved 1997)*, American Concrete Institute, Farmington Hills, MI.

ACI Committee 318 (2002). *Building Code Requirements for Structural Concrete (ACI 310-02)*, American Concrete Institute, Farmington Hills, MI.

ASTM C 39 (2001). "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," *Annual Book of ASTM Standards*, ASTM International, Vol. 04.02, West Conshohocken, PA, 2003.

ASTM C 109 (2002). "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. Cube Specimens)," *Annual Book of ASTM Standards*, ASTM International, Vol. 04.01, West Conshohocken, PA, 2003.

ASTM C 157 (1999). "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete," *Annual Book of ASTM Standards*, ASTM International, Vol. 04.02, West Conshohocken, PA, 2003.

ASTM C 230 (1998). "Standard Specification for Flow Table for Use in Tests of Hydraulic Cement," *Annual Book of ASTM Standards*, ASTM International, Vol. 04.01, West Conshohocken, PA, 2003.

ASTM C 496 (1996). "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," *Annual Book of ASTM Standards*, ASTM International, Vol. 04.02, West Conshohocken, PA, 2003.

ASTM C 596 (2001). "Standard Test Method for Drying Shrinkage of Mortar Containing Hydraulic Cement," *Annual Book of ASTM Standards*, ASTM International, Vol. 04.01, West Conshohocken, PA, 2003.

ASTM C 882 (1999). "Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete," *Annual Book of ASTM Standards*, ASTM International, Vol. 04.02, West Conshohocken, PA, 2003.

ASTM C 1107 (2002). "Standard Specification for Packaged Dry, Hydraulic-Cement Grout (Nonshrink)," *Annual Book of ASTM Standards*, ASTM International, Vol. 04.02, West Conshohocken, PA, 2003.

ASTM C 1437 (2001). "Standard Test Method for Flow of Hydraulic Cement Mortar," *Annual Book of ASTM Standards*, ASTM International, Vol. 04.01, West Conshohocken, PA, 2003.

Babaei, K., Fouladgar, A., and Nicholson, R. T. (2001). "Nighttime Bridge Deck Replacement with Full Depth Precast Concrete Panels at Route 7 over Route 50, Fairfax County, Virginia," *Proceedings of the 80<sup>th</sup> Annual Meeting of the Transportation Research Board*, Paper No. 01-0196, Washington, D.C., January 7-11, 2001.

Birkeland, P. W. and Birkeland H.W. (1966). "Connections in Precast Concrete Construction," *ACI Journal*, American Concrete Institute, Vol. 63, No. 3, March 1966, pp. 345-368.

Biswas, M. (1986). "Precast Bridge Deck Design Systems," *PCI JOURNAL*, Precast/Prestressed Concrete Institute, Vol. 31, No. 2, March-April 1986, pp. 40-94.

Culmo, M. P. (2000). "Rapid Bridge Deck Replacement Using Full Depth Precast Concrete Slabs," *Transportation Research Record*, Transportation Research Board, No. 1712, Construction 2000, Paper No. 00-1220.

Gulyas, R. J., Wirthlin, G. J., and Champa, J.T. (1995). "Evaluation of Keyway Grout Test Methods for Precast Concrete Bridges," *PCI JOURNAL*, Precast/Prestressed Concrete Institute, Vol. 40, No. 1, January-February 1995, pp. 44-57.

Issa, M.A., Idriss, A. T., Kaspar, I. I., and Khayyat, S. Y. (1995a). "Full Depth Precast and Precast, Prestressed Concrete Bridge Deck Panels," *PCI JOURNAL*, Precast/Prestressed Concrete Institute, Vol. 40, No. 1, January-February 1995, pp. 59-80.

Issa, M.A., Yousif, A. A., Issa, M. A., Kaspar, I. I., and Khayyat, S. Y. (1995b). "Field Performance of Full Depth Precast Concrete Panels in Bridge Deck Reconstruction," *PCI JOURNAL*, Precast/Prestressed Concrete Institute, Vol. 40, No. 3, May-June 1995, pp. 82-107.

Issa, M.A., Yousif, A. A., Issa, M. A., Kaspar, I. I., and Khayyat, S. Y. (1998). "Analysis of Full Depth Precast Concrete Bridge Deck Panels," *PCI JOURNAL*, Precast/Prestressed Concrete Institute, Vol. 43, No. 1, January-February 1998, pp. 74-85.

Keller, W. J. (2004). "Effect of Environmental Conditions and Structural Design on Linear Cracking on Virginia Bridge Decks," unpublished Masters Thesis, Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA.



Mast, R. F. (1968). "Auxiliary Reinforcement in Concrete Connections," *ASCE Journal, American Society of Civil Engineers*, Vol. 94, No. ST6, June 1968, pp. 1485-1504.

Mattock, A. H., Hofbeck, J. A., and Ibrahim, I. O. (1969). "Shear Transfer in Reinforced Concrete," *ACI Journal*, American Concrete Institute, Vol. 66, No. 2, February 1969, pp. 119-128.

Mattock, A.H., Johal, L., and Chow, H.C. (1975). "Shear Transfer in Reinforced Concrete with Moment or Tension Acting Across the Shear Plane," *PCI JOURNAL*, Precast/Prestressed Concrete Institute, Vol. 20, No. 4, July-August 1975, pp. 76-93.

Mattock, A.H., Li, W. K., and Wang, T.C. (1976). "Shear Transfer in Lightweight Reinforced Concrete," *PCI JOURNAL*, Precast/Prestressed Concrete Institute, Vol. 21, No. 1, January-February 1976, pp. 20-39.

Menkulasi, F. (2002). "Horizontal Shear Connectors for Precast Prestressed Bridge Deck Panels," unpublished Masters Thesis, Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Menkulasi, F. and Roberts-Wollmann, C. L. (2003). "Horizontal Shear Connections for Full-Width, Full-Depth Precast Concrete Bridge Deck Panels on Prestressed I-Girders," unpublished Structural Engineering and Materials Final Report, No. CE/VPI-ST 03/14, Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Mokarem, D. W. (2002). "Development of Concrete Shrinkage Performance Specifications," unpublished Masters Thesis, Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Nottingham, D. (1996). "Joint Grouting in Alaskan Bridges and Dock Decks," *Concrete International*, American Concrete Institute, Vol. 18, No. 2, February 1996, pp. 45-48.

Shim, C. S., Kim, J. H., Chang, S. P., and Chung, C. H. (2000). "The Behavior of Shear Connections in a Composite Beam with a Full-Depth Precast Slab," *Proceedings of the Institute of Civil Engineers, Structures and Buildings*, Vol. 140, February 2000, pp. 101-110.

Yamane, T., Tadros, M. K., Badie, S. S., and Baishya, M. C. (1998). "Full Depth Precast, Prestressed Concrete Bridge Deck System," *PCI JOURNAL*, Precast/Prestressed Concrete Institute, Vol. 43, No. 3, May-June 1998, pp. 50-66.

## APPENDIX A: HAUNCH FLOW MOCKUP

Appendix A contains photographs of the haunch flow mockup tests for all eight candidate mortars.



Figure A1: ThoRoc<sup>®</sup> 10-60 (1) Haunch Flow Mockup



Figure A2: ThoRoc<sup>®</sup> 10-60 extended (5) Haunch Flow Mockup



Figure A3: SikaQuick® 2500 (2) Haunch Flow Mockup



Figure A4: SikaQuick® 2500 extended (6) Haunch Flow Mockup



Figure A5: Five Star<sup>®</sup> Patch (3) Haunch Flow Mockup



Figure A6: Five Star<sup>®</sup> Patch extended (7) Haunch Flow Mockup



Figure A7: Set<sup>®</sup> 45 Hot Weather (4) Haunch Flow Mockup



Figure A8: Set<sup>®</sup> 45 Hot Weather extended (8) Haunch Flow Mockup

## APPENDIX B: CORRESPONDING CONCRETE DATA

Appendix B contains compressive strength, tensile strength and shrinkage data for each corresponding concrete batch.

Table B1: Corresponding Concrete Data

	<b>ASTM C 39</b>	<b>ASTM C 496</b>	<b>ASTM C 157</b>	
	Compressive Strength, psi	Tensile Strength, psi	28 day Shrinkage, %	56 day Shrinkage, %
Concrete 1	5450	650	0.037	0.048
Concrete 2	5290	640	0.029	0.040
Concrete 3	4910	550	0.039	0.047
Concrete 4	4700	590	0.052	0.063
Concrete 5	4720	570	0.050	0.058
Concrete 6	5570	610	0.037	0.052
Concrete 7	4830	560	0.044	0.053
Concrete 8	4620	510	0.054	0.064



## APPENDIX C: PRODUCT DATA SHEETS

Appendix C contains the product data sheets for the four candidate mortars that were evaluated in this research.

ThoRoc<sup>®</sup> 10-60 Rapid Mortar Data Sheet, Copyright © 2003 Degussa

SikaQuick<sup>®</sup> 2500 Data Sheet, Copyright © 2003 Sika Corporation

Five Star<sup>®</sup> Highway Patch Data Sheet, Copyright © 2001 Five Star Products, Inc.

Set<sup>®</sup> 45 and Set<sup>®</sup> 45 HW Data Sheet, Copyright © 2003 Degussa

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# 10-60 RAPID MORTAR

Very rapid-setting cement-based mortar

PRODUCT DATA

3 03930 **Concrete Rehabilitation**

### Description

10-60 Rapid Mortar is a one-component shrinkage-compensated very rapid-setting cement-based mortar. It is designed for horizontal concrete surfaces where high early strength gain is required.

### Yield

0.43 ft<sup>3</sup> (0.012 m<sup>3</sup>) per 50 lb (22.7 kg) bag

When extended 50%:  
0.57 ft<sup>3</sup> (0.016 m<sup>3</sup>)

When extended 100%:  
0.77 ft<sup>3</sup> (0.022 m<sup>3</sup>)

### Packaging

50 lb (22.7 kg) bags  
2,500 lb (1,134 kg) bulk bags

### Shelf Life

1 year when properly stored

### Storage

Store and transport in unopened containers at 60 to 80° F (16 to 27° C) in clean, dry conditions.

### Features

- Extra low permeability
- Very rapid setting
- Excellent resistance to freeze/thaw cycling
- Nongypsum based
- Shrinkage compensated
- Can be extended up to 100% by weight with 3/8" (10 mm) aggregate
- Proprietary cement blend

### Benefits

- Helps prevent chloride intrusion
- Structures can be opened to vehicular traffic in 1 hour; epoxy coated in as little as 4 hours
- Outstanding durability
- Volume stability
- Minimizes cracking from drying shrinkage; reduces stress at the bond line
- Economical; high yields
- Bonds to carbonated and noncarbonated concrete substrates

### Where to Use

#### APPLICATION

- Applications requiring high early-strength gain
- Structural concrete repairs
- Repairing industrial floors
- Bridges
- Parking decks
- Airport runways

#### LOCATION

- Horizontal surfaces
- Interior or exterior

#### SUBSTRATE

- Concrete

### How to Apply

#### Surface Preparation

#### CONCRETE

1. Concrete must be structurally sound and fully cured (28 days).
2. Saw cut the perimeter of the area being patched into a square with a minimum depth of 1/2" (13 mm).
3. Remove all unsound concrete and roughen the surface to a minimum 1/4" (6 mm) profile amplitude.
4. Remove all laitance, oil, grease, curing compounds, and other contaminants that could prevent adequate bond.
5. The concrete substrate should be saturated surface-dry (SSD), without standing water, before application.



## Technical Data

### Composition

10-60 Rapid Mortar is a blend of cement, graded aggregate, shrinkage-compensating agents, and set-control additives.

### Compliances

- ASTM C 928

### Test Data

The following results were obtained with a water / powder ratio of 5.5 pints (2.6 L) of water to 50 lbs (22.7 kg) of 10-60 Rapid Mortar at 73° F (23° C).

PROPERTY	RESULTS	TEST METHODS
<b>Fresh wet density</b> , lb/ft <sup>3</sup> (kg/m <sup>3</sup> )	130 (2,082)	ASTM C 138
<b>Set time</b> , min, at 72° F (22° C)		ASTM C 191
Initial	16	
Final	28	
<b>Working time</b> , min	8	
<b>Length change</b> , % (µstrain)		ASTM C 928
Drying shrinkage	-0.05 (-500)	
Wetting expansion	+0.03 (+300)	
<b>Coefficient of thermal expansion</b> , in/in/° F (cm/cm/° C)	7.0 x 10 <sup>-6</sup> (12.6 x 10 <sup>-6</sup> )	CRD C 39
<b>Modulus of elasticity</b> , psi (GPa)	4.4 x 10 <sup>6</sup> (19.5)	ASTM C 469
<b>Rapid chloride permeability</b> , coulombs	< 300	ASTM C 1202
<b>Freeze/thaw resistance</b> , % RDM, at 300 cycles	100	ASTM C 666, (Procedure A)
<b>Scaling resistance</b> , at 25 cycles	0 rating; no scaling	ASTM C 672
<b>Slant shear bond strength</b> , psi (MPa)		ASTM C 882, modified <sup>1</sup>
1 day	2,300 (16)	
28 days	2,600 (18)	
<b>Splitting tensile strength</b> , psi (MPa)		ASTM C 496
1 day	400 (3)	
28 days	450 (3)	
<b>Flexural strength</b> , psi (MPa)		ASTM C 348
1 day	700 (5)	
28 days	850 (6)	
<b>Compressive strength</b> , psi (MPa), 2" cubes		ASTM C 109
1 hr	2,000 (14)	
2 hrs	3,000 (21)	
1 day	6,500 (45)	
28 days	8,000 (55)	
<b>Compressive strength</b> , psi (MPa), 3 by 6" cylinders, at 28 days	7,400 (51)	ASTM C 39

<sup>1</sup>No bonding agent used; mortar scrubbed into substrate.

All application and performance values are typical for the material, but may vary with test methods, conditions, and configurations.

#### REINFORCING STEEL

1. Remove all oxidation and scale from the exposed reinforcing steel in accordance with ICRI Technical Guideline No. 03730 "Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion."
2. For additional protection from future corrosion, coat the prepared reinforcing steel with Zincrich Rebar Primer or install Corr-Stops® CM.

#### MIXING

1. Add 5-1/2 pints (2.6 L) of clean water to the mixing container for each bag of 10-60 Rapid Mortar. If required, add the correct amount of aggregate to the mixer. Add the powder to the water while continuously mixing with a slow-speed drill and paddle, mortar mixer, or other forced action mixer.
2. Mix for a minimum of 3 minutes until fully homogeneous.
3. Additional water may be added up to a maximum of 1 pint (0.47 L) per bag of 10-60 Rapid Mortar.

#### AGGREGATE EXTENSION

1. For repair areas 2 – 4" (51 – 102 mm) in depth, the minimum recommended addition is 15 – 25 lbs (6.8 – 11.4 kg) of 3/8" (10 mm) washed, graded, rounded, SSD, low-absorption, high-density aggregate per 50 lb (22.7 kg) bag.
2. For areas greater than 4" (102 mm) in depth, the minimum recommended addition is 25 – 50 lbs (11.4 to 22.7 kg) of 3/8" (10 mm) washed, graded, rounded, SSD, low-absorption, high-density aggregate per 50 lb bag.
3. The maximum aggregate extension is 50 lbs (22.7 kg) of pea gravel per bag.
4. The performance of 10-60 Rapid Mortar depends on the type, condition, and amount of aggregate added. Rely on trials, testing, and previous experience to determine aggregate suitability.

#### Application

1. Apply the mixed material onto the prepared saturated surface-dry (SSD) substrate by gloved hand, trowel, or screed. Ensure proper consolidation of the mortar and compaction around reinforcing steel. Minimum application thickness is 1/2" (13 mm).
2. Finish the completed repair, as required, taking care not to overwork the surface.
3. A maximum of 15 minutes should be allowed to mix, place, and finish 10-60 Rapid Mortar at 70° F (21° C).

#### Clean Up

Clean tools and equipment with clean water immediately after use. Cured material must be removed mechanically.

#### Curing

1. Proper curing is extremely important. Cure 10-60 Rapid Mortar immediately after finishing. Use a water-based curing compound that complies with ASTM C 309.

#### For Best Performance

- Minimum ambient, surface, and material temperature is 40° F (4° C) and rising.
- Do not mix longer than 5 minutes.
- Minimum application thickness is 1/2" (13 mm).
- Consult coating supplier for overcoating requirements.
- Make certain the most current versions of product data sheet and MSDS are being used; call Customer Service (1-800-433-9517) to verify the most current version.
- Proper application is the responsibility of the user. Field visits by Degussa personnel are for the purpose of making technical recommendations only and are not for supervising or providing quality control on the jobsite.

#### Health and Safety

##### 10-60 RAPID MORTAR

#### Caution

10-60 Rapid Mortar contains crystalline silica, Portland cement, hydraulic cement, and lithium carbonate.

#### Risks

Product is alkaline on contact with water and may cause injury to skin or eyes. Ingestion or inhalation of dust may cause irritation. Contains free respirable quartz, which has been listed as a suspected human carcinogen by NTP and IARC. Repeated or prolonged overexposure to free respirable quartz may cause silicosis or other serious and delayed lung injury.

#### Precautions

KEEP OUT OF THE REACH OF CHILDREN. Prevent contact with skin and eyes. Prevent inhalation of dust. DO NOT take internally. Use only with adequate ventilation. Use impervious gloves, eye protection and if the TLV is exceeded or if used in a poorly ventilated area, use NIOSH/MSHA approved respiratory protection in accordance with applicable federal, state and local regulations.

#### First Aid

In case of eye contact, flush thoroughly with water for at least 15 minutes. SEEK IMMEDIATE MEDICAL ATTENTION. In case of skin contact, wash affected areas with soap and water. If irritation persists, SEEK MEDICAL ATTENTION. Remove and wash contaminated clothing. If inhalation causes physical discomfort, remove to fresh air. If discomfort persists or any breathing difficulty occurs or if swallowed, SEEK IMMEDIATE MEDICAL ATTENTION.

Refer to Material Safety Data Sheet (MSDS) for further information.

#### Proposition 65

This product contains material listed by the state of California as known to cause cancer, birth defects, or other reproductive harm.

#### VOC Content

0 lbs/gal or 0 g/L

**For medical emergencies only,  
call ChemTrec (1-800-424-9300).**

#### Degussa Building Systems

889 Valley Park Drive  
Shakopee, MN, 55379

www.degussabuildingsystems.com

Customer Service 800-433-9517

Technical Service 800-243-6739

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**Product Data Sheet**  
Edition 8.2003  
Identification no. 746  
SikaQuick 2500

## SikaQuick® 2500

Very rapid hardening,  
repair mortar

<b>Description</b>	SikaQuick 2500 is a 1-component, very rapid hardening, early strength gaining, cementitious, patching material for concrete.
<b>Where to Use</b>	<ul style="list-style-type: none"> <li>■ Use on grade, above, and below grade on concrete.</li> <li>■ Highway overlays and repairs.</li> <li>■ Structural repair material for concrete roadways, parking structures, bridges, dams and ramps.</li> <li>■ Full depth patching repairs.</li> <li>■ Economical patching material for horizontal repairs of concrete and mortar.</li> </ul>
<b>Advantages</b>	<ul style="list-style-type: none"> <li>■ Very rapid hardening as defined by ASTM C-928.</li> <li>■ Allows application of an epoxy coating within 4 hours (73°F/50%R.H.).</li> <li>■ Freeze/thaw resistant.</li> <li>■ Easy to use, labor-saving material.</li> <li>■ Contains no added chlorides.</li> <li>■ Not gypsum-based.</li> <li>■ High early strength.</li> <li>■ Fast-setting.</li> <li>■ Open to foot traffic in 45 minutes; to vehicle traffic in 1 hour (at 73°F).</li> <li>■ Easily applied to clean, sound substrate.</li> <li>■ Not a vapor barrier.</li> </ul>
<b>Coverage</b>	Approximately 0.43 cu. ft. When extended with 25-30 lbs. of 3/8 in. gravel yield is approximately 0.60-0.63 cu. ft.
<b>Packaging</b>	50-lb. multi-wall bag.

### Typical Data (Material and curing conditions @ 73°F (23°C) and 50% R.H.) (Water/powder = 0.12)

<b>Shelf Life</b>	1 year in original, unopened bag	
<b>Storage Conditions</b>	Store dry at 40°-95°F (4°-35°C). <b>For best results, condition material to 65°-75°F before using.</b>	
<b>Color</b>	Concrete gray.	
<b>Mixing Ratio</b>	Approximately 5 - 5.5 pints of liquid per 50 lb. bag.	
<b>Application Life</b>	Approximately 15 minutes after adding powder to the water.	
<b>Compressive Strength, psi</b>	<b>Mortar - ASTM C-109</b>	<b>*Concrete - ASTM C-39</b>
1 hour	**2,500 psi (17.2 MPa)	2,000 psi (10.3 MPa)
2 hours	**4,000 psi (27.6 MPa)	3,000 psi (13.8 MPa)
1 day	**6,500 psi (44.8 MPa)	4,500 psi (24.1 MPa)
7 days	7,500 psi (51.7 MPa)	5,000 psi (31.0 MPa)
28 days	**8,500 psi (58.6 MPa)	5,500 psi (37.9 MPa)
<b>Flexural Strength, psi (ASTM C-78)</b>		
1 day	850 psi (5.9 MPa)	600 psi (4.1 MPa)
7 days	1,000 psi (6.9 MPa)	900 psi (6.2 MPa)
28 days	**1,100 psi (7.6 MPa)	1,000 psi (6.9 MPa)
<b>Splitting Tensile Strength, psi (ASTM C-496)</b>		
1 day	850 psi (5.9 MPa)	
7 days	1,000 psi (6.9 MPa)	
28 days	1,100 psi (7.6 MPa)	
<b>Bond Strength, psi (ASTM C-882) modified</b>		
1 day	**2,000 psi (13.8 MPa)	1,500 psi (10.3 MPa)
7 days	2,900 psi (20.0 MPa)	2,500 psi (17.2 MPa)
28 days	**3,100 psi (21.4 MPa)	2,700 psi (18.6 MPa)
<b>Direct Tensile Bond, psi (ACI 503)</b>	<b>28 days</b>	300 psi (substrate failure)
<b>Drying shrinkage, % (ASTM C-596)</b>	<b>28 days</b>	**0.06
<b>Modulus of Elasticity, psi (ASTM C-469)</b>	<b>28 days</b>	4.6 x 10 <sup>6</sup>
<b>Chloride Permeability, Coulombs (ASTM C-1202)</b>	<b>28 days</b>	< 500
<b>Freeze/Thaw Resistance, % (ASTM C-666)</b>	<b>28 days</b>	**98%
<b>Scaling Resistance, lb./ft<sup>2</sup> (ASTM C-672)</b>	<b>50 cycles</b>	0.080
<b>Initial Set, Minutes (ASTM C-266)</b>	14-21	
<b>Final Set, Minutes (ASTM C-266)</b>	20-36	
<b>Abrasion Resistance, Inches of Wear at 1 hr. (ASTM C-779)</b>	<b>28 days</b>	0.026

\*Material was tested with an addition rate of 25 lbs. of clean, well-graded, saturated surface dry, low-absorption and high-density coarse aggregate. Water was added (approximately 5.5 pints per bag) to achieve a 5 to 7 in. slump.  
\*\*Independent certificates available upon request.



## How to Use

<b>Surface Preparation</b>	Surface must be clean and sound. Remove all deteriorated concrete, dirt, oil, grease, and other bond-inhibiting materials from the area to be repaired. Be sure repair area is not less than 1/4 in. deep. Preparation work should be done by appropriate means. Obtain an exposed aggregate surface with a minimum surface profile of $\pm$ 1/8 in. (CSP-6) on clean, sound concrete. To ensure optimum repair results, the effectiveness of decontamination and preparation should be assessed by a pull-off test. Saw cutting of edges is recommended. Saturate surface to be repaired with clean water. Substrate should be saturated surface dry (SSD) prior to application.
<b>Priming</b>	For priming of reinforcing steel use Sika Armatec 110 EpoCem (consult Technical Data Sheet). <b>Concrete Substrate:</b> Prime the prepared substrate with a scrub coat of SikaQuick 2500 prior to placement of the mortar. The repair mortar has to be applied into the wet scrub coat before it dries.
<b>Mixing</b>	Mechanically mix in an appropriately sized mortar mixer. Wet down all tools and mixer to be used. <b>With water:</b> Start with 5 pints of water added to the mixing vessel. Add 1 bag of SikaQuick 2500 while continuing to mix. Add up to another 1/2 pint of water to achieve desired consistency. Do not overwater. <b>With Latex R:</b> Pour 5 pints of Sika Latex R into the mixing container. Slowly add powder, mix and adjust as above. <b>With diluted Latex R:</b> Sika Latex R may be diluted up to 5:1 (water: Sika Latex R) for projects requiring minimal polymer-modification. Pour 5 pints of the mixture into the mixing container. Slowly add powder, mix and adjust as above. For applications greater than 1 in. in depth, add 3/8 in. coarse aggregate. The aggregate must be non-reactive (reference ASTM C-1260, C-227 and C-289), clean, well graded, saturated surface dry, have low absorption and high density, and comply with ASTM C-33 size number 8 per Table 2. <b>Note:</b> Variances in aggregate may result in different strengths. The addition rate is 25-30 lbs. of aggregate per bag of SikaQuick 2500. (25-30 lbs. of 3/8 in. aggregate is approximately 2.0 - 2.4 gallons by loose volume of aggregate). Do not exceed a slump of 7 in. This may cause excessive bleeding and retardation and will reduce the strength and performance of the material.
<b>Application</b>	The prepared mortar must be scrubbed into substrate. Be sure to fill all pores and voids. Force material against edge of repair, working toward center. After filling repair, screed off excess. Allow concrete to set to desired stiffness, then finish. If a smoother finish is desired, a magnesium float should be used. Mixing, placing, and finishing should not exceed 15 minutes maximum. To control setting times, cold water should be used in hot weather and hot water used in cold weather.
<b>Curing</b>	As per ACI recommendations for portland cement concrete, curing is required. Moist cure with wet burlap and polyethylene, a fine mist of water or a curing compound meeting ASTM C-309. Moist cure should commence immediately after finishing. If necessary, protect newly applied material from rain. To prevent from freezing, cover with insulating material.
<b>Limitations</b>	<ul style="list-style-type: none"> <li>■ Minimum ambient and surface temperatures 45°F and rising.</li> <li>■ Minimum application thickness 1/4 in. as a mortar and 1 in. extended with aggregate.</li> <li>■ Do not feather edge.</li> <li>■ Do not exceed 7 in. slump when extended.</li> <li>■ Use only potable water.</li> <li>■ Variations in aggregates may produce differences in strengths from the typical values stated in Sika's Technical Data.</li> <li>■ As with all cement based materials, avoid contact with aluminum to prevent adverse chemical reaction and possible product failure. Insulate potential areas of contact by coating aluminum bars, rails, posts etc. with an appropriate epoxy such as Sikadur HI-Mod 32.</li> <li>■ Do not use Sika Armatec 110 EpoCem as a bonding agent with SikaQuick 2500.</li> </ul>
<b>Caution Irritant</b>	<b>Skin/Eye/Respiratory Irritant.</b> Avoid breathing dust. Dust may cause respiratory tract irritation. May cause delayed lung injury (silicosis). <b>Warning:</b> This product contains crystalline silica, which in the state of California, is known to cause cancer.
<b>First Aid</b>	<b>Eyes</b> -rinse thoroughly with water a minimum of 15 minutes. Consult a physician. <b>Skin</b> -wash thoroughly with soap and water. Remove contaminated clothing. <b>Inhalation</b> -Remove person to fresh air. Consult a physician. <b>Ingestion</b> -Dilute with water. Consult a physician. In all cases, if symptoms persist contact a physician.
<b>Handling and Storage</b>	Avoid contact. Wear suitable personal protective equipment (chemical resistant goggles/gloves/clothing). Remove contaminated clothing and laundry before reuse. Use in the presence of adequate ventilation. In the absence of adequate ventilation, wear a properly fitted NIOSH respirator. Uncured material can be removed with water. Cured material can only be removed mechanically. Store in a cool, dry area. Keep bag tightly closed.
<b>Clean Up</b>	In case of spill, wear protective equipment (chemical resistant gloves/goggles/clothing). Ventilate area. In the absence of adequate ventilation, use a properly fitted NIOSH respirator. Confine spill. Vacuum or scoop into an appropriate container. Dispose of in accordance with current applicable local, state and federal regulations. In case of emergency, call CHEMTREC at 1-800-424-9300. 703-527-3887 (outside USA & Canada).

KEEP CONTAINER TIGHTLY CLOSED  
NOT FOR INTERNAL CONSUMPTION  
CONSULT MATERIAL SAFETY DATA SHEET FOR MORE INFORMATION

KEEP OUT OF REACH OF CHILDREN  
FOR INDUSTRIAL USE ONLY

Sika warrants this product for one year from date of installation to be free from manufacturing defects and to meet the technical properties on the current technical data sheet if used as directed within shelf life. User determines suitability of product for intended use and assumes all risks. Buyer's sole remedy shall be limited to the purchase price or replacement of product exclusive of labor or cost of labor.

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1-800-933-SIKA NATIONWIDE

**Regional Information and Sales Centers.** For the location of your nearest Sika sales office, contact your regional center.

**Sika Corporation**  
201 Polito Avenue  
Lyndhurst, NJ 07071  
Phone: 800-933-7452  
Fax: 201-933-6225

**Sika Canada Inc.**  
601 Delmar Avenue  
Pointe Claire  
Quebec H9R 4A9  
Phone: 514-697-2610  
Fax: 514-694-2792

**Sika Mexicana S.A. de C.V.**  
Carretera Libre Celaya Km. 8.5  
Corregidora, Queretaro  
C.P. 76920 A.P. 136  
Phone: 52 42 25 0122  
Fax: 52 42 25 0537



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## FIVE STAR® HIGHWAY PATCH

Fast Traffic Area Repair

### PRODUCT DESCRIPTION

Five Star Highway Patch is a one component, fast setting hydraulic cement material ideal for horizontal repairs of concrete in traffic areas. Five Star Highway Patch provides resistance to oil, grease, gasoline, salts and other chemicals found in the transportation environment.

### ADVANTAGES

- High early strength
- One component/ease of use
- Open to traffic in two hours
- Freeze/thaw resistance
- Adjustable working time
- Resistant to salts
- Cold weather installation
- Coarse aggregate extension

### USES

- Highways and bridges
- Parking decks and ramps
- Airport runways and taxiways
- Expansion joint rebuild
- Dowel bar retrofit
- Cold weather repairs

### TECHNICAL SUPPORT

Five Star Products maintains the industry's foremost Engineering and Technical Support Group:

- Over 30 years of experience in concrete repair
- Technical Center staffed with experienced engineers available for consultation
- Design-A-Spec™ for engineering specification assistance
- Experienced representatives for field service
- Corporate research laboratory available to customize products for unique applications

### PACKAGING AND YIELD

Five Star Highway Patch is packaged in heavy-duty polyethylene lined bags each weighing 50 lb (22.7 kg) yielding approximately 0.40 cubic feet (11.3 liters) and approximately 0.66 cubic feet (16.9 liters) with an 80% coarse aggregate extension. Also available in 3000 lb bulk bags.

### SHELF LIFE

One year in original unopened packaging when stored in dry conditions. Higher humidity will reduce shelf life.

### TYPICAL PROPERTIES AT 73°F (23°C)

Compressive Strength, ASTM C 109	
2 Hours	2000 psi (13.8 MPa)
3 Hours	3500 psi (24.1 MPa)
1 Day	5100 psi (35.2 MPa)
7 Days	7000 psi (48.3 MPa)
Bond Strength, ASTM C 882	
1 Day	1500 psi (10.4 MPa)
7 Days	2000 psi (13.8 MPa)
Length Change, ASTM C 157	
28 Days Wet	+0.05%
28 Days Dry	-0.05%
Time of Set, ASTM C 266	
Initial	15 minutes
Final	30 minutes
Freeze/Thaw Resistance, ASTM C 666A	
Relative Durability Factor	90%
Flexural Strength, ASTM C 78	
3 Hours	400 psi

The data shown above reflect typical results based on laboratory testing under controlled conditions. Reasonable variations from the data shown above may result. Test methods are modified where applicable.



## PLACEMENT GUIDELINES

1. **SURFACE PREPARATION:** All surfaces in contact with Five Star Highway Patch shall be free of oil, grease, laitance, and other contaminants. Concrete must be clean, sound and rough to ensure a good bond. Remove all oxidation from exposed reinforcing steel and for additional protection coat reinforcing steel with Five Star® AC Coat. A perimeter edge and minimum depth of one inch (25 mm) should be provided for a durable repair. Featheredging is not desirable. Soak concrete surfaces prior to application with liberal quantities of potable water, leaving the concrete saturated and free of standing water or use Five Star® Bonding Adhesive. Surfaces shall be conditioned to between 35°F and 90°F (2°C and 32°C) at the time of placement.
2. **MIXING:** Mix Five Star Highway Patch thoroughly for approximately three to five minutes with a mortar mixer or drill and paddle mixer. Adjust consistency if necessary, but do not exceed maximum water content stated on the package or an amount that will cause segregation. Do not mix more material than can be placed in 10 minutes. Addition of coarse aggregate, meeting ASTM C 33, should be used for pours greater than two inches (50 mm) in depth.
3. **PLACEMENT PROCEDURES:** When bonding adhesive is not used, firmly work Five Star Highway Patch into substrate and place full depth from one side of the repair to the other. Where this is not practical, placement must be continuous to prevent cold joints between pours. Finish as necessary.  
**SPECIAL CONDITIONS:** For use in cold temperatures, Five Star Highway Patch must be maintained at a temperature of at least 35°F (2°C). Protect from freezing until a compressive strength of at least 1000 psi (6.9 MPa) is obtained. Faster strength gain will occur when the Five Star Highway Patch and mixing water have been conditioned to a higher temperature prior to placement.  
In hot temperatures, Five Star Highway Patch should be kept as cool as possible, but not exceeding 90°F (32°C). Chilled water should be used for mixing to help maintain sufficient working time.
4. **POST-PLACEMENT PROCEDURES:** Five Star Highway Patch shall be protected until initial set, then immediately coat with an approved curing compound meeting water retention properties of ASTM C 309 or wet cure for a minimum of three days. In-service operation may begin immediately after the required strength has been reached.  
**NOTE:** PRIOR TO APPLICATION, READ ALL PRODUCT PACKAGING THOROUGHLY. For more detailed placement procedures, call the Five Star Products Engineering and Technical Center at 203-336-7900.

## LIMITATIONS

- Never exceed the maximum water content stated on the package or an amount that will cause segregation.
- Temperature of surfaces must be between 35°F and 90°F (2°C and 32°C) at time of placement. For cold and hot weather placement, call the Five Star Products Engineering and Technical Center.
- Substrate shall be free of frost and ice.
- Repair material shall be protected from freezing until it reaches 1000 psi (6.9 MPa).
- Placement shall be continuous to avoid cold joints.

## CAUTION

Contains cementitious material and crystalline free silica. International Agency for Research on Cancer has evaluated that there is sufficient evidence for the carcinogenicity of inhaled crystalline silica to humans. Take appropriate measures to avoid breathing dust. Avoid contact with eyes and contact with skin. In case of contact with eyes, immediately flush with plenty of water for at least 15 minutes. Immediately call a physician. Wash skin thoroughly after handling. Keep product out of reach of children. PRIOR TO USE, REFER TO MATERIAL SAFETY DATA SHEET.

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For worldwide availability, additional product information and technical support, contact your local Five Star distributor, local sales representative, or you may call Five Star's Engineering and Technical Center at 203-336-7900.

### Corporate Offices

Five Star Products, Inc.  
425 Stillson Road  
Fairfield, CT 06430  
Tel: 203-336-7900  
Fax: 203-336-7930  
[www.fivestarprouducts.com](http://www.fivestarprouducts.com)



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# SET® 45 AND SET® 45 HW

Chemical-action repair mortar

PRODUCT DATA

3 03930

Concrete Rehabilitation

**Description**

Set® 45 is a one-component magnesium phosphate-based patching and repair mortar. This concrete repair and anchoring material sets in approximately 15 minutes and takes rubber-tire traffic in 45 minutes. It comes in two formulations: Set® 45 Regular for ambient temperatures below 85° F (29° C) and Set® 45 Hot Weather for ambient temperatures ranging from 85 to 100° F (29 to 38° C).

**Yield**

A 50 lb (22.7 kg) bag of mixed with the required amount of water produces a volume of approximately 0.39 ft³ (0.011 m³); 60% extension using 1/2" (13 mm) rounded, sound aggregate produces approximately 0.58 ft³ (0.016 m³).

**Packaging**

50 lb (22.7 kg) multi-wall bags

**Color**

Dries to a natural gray color

**Shelf Life**

1 year when properly stored

**Storage**

Store in unopened containers in a clean, dry area between 45 and 90° F (7 and 32° C).

**Features**

- Single component
- Reaches 2,000 psi compressive strength in 1 hour
- Wide temperature use range
- Superior bonding
- Very low drying shrinkage
- Resistant to freeze/thaw cycles and deicing chemicals
- Only air curing required
- Thermal expansion and contraction similar to Portland cement concrete
- Sulfate resistant

**Benefits**

- Just add water and mix
- Rapidly returns repairs to service
- From below freezing to hot weather exposures
- Bonds to concrete and masonry without a bonding agent
- Improved bond to surrounding concrete
- Usable in most environments
- Fast, simple curing process
- More permanent repairs
- Stable where conventional mortars degrade

**Where to Use**

APPLICATION

- Heavy industrial repairs
- Dowel bar replacement
- Concrete pavement joint repairs
- Full-depth structural repairs
- Setting of expansion device nosings
- Bridge deck and highway overlays
- Anchoring iron or steel bridge and balcony railings
- Commercial freezer rooms
- Truck docks
- Parking decks and ramps
- Airport runway-light installations

LOCATION

- Horizontal and formed vertical or overhead surfaces
- Indoor and outdoor applications

**How to Apply**

**Surface Preparation**

1. A sound substrate is essential for good repairs. Flush the area with clean water to remove all dust.
2. Any surface carbonation in the repair area will inhibit chemical bonding. Apply a pH indicator to the prepared surface to test for carbonation.
3. Air blast with oil-free compressed air to remove all water before placing Set® 45.

**Mixing**

1. Set® 45 must be mixed, placed, and finished within 10 minutes in normal temperatures (72° F [22° C]). Only mix quantities that can be placed in 10 minutes or less.
2. Do not deviate from the following sequence; it is important for reducing mixing time and producing a consistent mix. Use a minimum 1/2" slow-speed drill and mixing paddle or an appropriately sized mortar mixer. Do not mix by hand.
3. Pour clean (potable) water into mixer. Water content is critical. Use a maximum of 4 pts (1.9 L) of water per 50 lb (22.7 kg) bag of Set® 45. Do not deviate from the recommended water content.



## Technical Data

### Composition

Set® 45 is a magnesium-phosphate patching and repair mortar.

### Test Data

PROPERTY	RESULTS				TEST METHODS
<b>Typical Compressive Strengths*</b> , psi (MPa)					ASTM C 109, modified
	<b>Plain Concrete</b> 72° F (22° C)	<b>Set® 45 Regular</b> 72° F (22° C)	<b>Set® 45 Regular</b> 36° F (2° C)	<b>Set® 45 HW</b> 95° F (35° C)	
1 hour	—	2,000 (13.8)	—	—	
3 hour	—	5,000 (34.5)	—	3,000 (20.7)	
6 hour	—	5,000 (34.5)	1,200 (8.3)	5,000 (34.5)	
1 day	500 (3.5)	6,000 (41.4)	5,000 (34.5)	6,000 (41.4)	
3 day	1,900 (13.1)	7,000 (48.3)	7,000 (48.3)	7,000 (48.3)	
28 day	4,000 (27.6)	8,500 (58.6)	8,500 (58.6)	8,500 (58.6)	

NOTE: Only Set® 45 Regular formula, tested at 72° F (22° C), obtains 2,000 psi (13.8 MPa) compressive strength in 1 hour.

Modulus of Elasticity, psi (MPa)	RESULTS		TEST METHODS
	<b>7 days</b>	<b>28 days</b>	ASTM C 469
Set® 45 Regular	4.18 x 10 <sup>6</sup> (2.88 x 10 <sup>6</sup> )	4.55 x 10 <sup>6</sup> (3.14 x 10 <sup>6</sup> )	
Set® 45 Hot Weather	4.90 x 10 <sup>6</sup> (3.38 x 10 <sup>6</sup> )	5.25 x 10 <sup>6</sup> (3.62 x 10 <sup>6</sup> )	

Freeze/thaw durability test, % RDM, 300 cycles, for Set® 45 and Set 45® HW	RESULTS	TEST METHODS
	80	ASTM C 666, Procedure A (modified**)

Scaling resistance to deicing chemicals, Set® 45 and Set 45® HW	RESULTS	TEST METHODS
5 cycles	0	ASTM C 672
25 cycles	0	
50 cycles	1.5 (slight scaling)	

Sulfate resistance	RESULTS	TEST METHODS
Set® 45 length change after 52 weeks, %	0.09	ASTM C 1012
Type V cement mortar after 52 weeks, %	0.20	

Typical setting times, min, for Set® 45 at 72° F (22° C), and Set® 45 Hot Weather at 95° F (35° C)	RESULTS	TEST METHODS
Initial set	9 – 15	Gilmore ASTM C 266, modified
Final set	10 – 20	

Coefficient of thermal expansion,*** both Set® 45 Regular and Set® 45 Hot Weather coefficients	RESULTS	TEST METHODS
	7.15 x 10 <sup>-6</sup> /° F (12.8 x 10 <sup>-6</sup> /° C)	CRD-C 39

Flexural Strength, psi (MPa), 3 by 4 by 16" (75 by 100 by 406 mm) prisms, 1 day strength,	RESULTS	TEST METHODS
Set® 45 mortar	550 (3.8)	ASTM C 78, modified
Set® 45 mortar with 3/8" (9 mm) pea gravel	600 (4.2)	
Set® 45 mortar with 3/8" (9 mm) crushed angular noncalcareous hard aggregate	650 (4.5)	

\* All tests were performed with neat material (no aggregate)

\*\*Method discontinues test when 300 cycles or an RDM of 60% is reached.

\*\*\*Determined using 1 by 1 by 11" (25 mm by 25 mm by 279 mm) bars. Test was run with neat mixes (no aggregate).  
 Extended mixes (with aggregate) produce lower coefficients of thermal expansion.

Test results are averages obtained under laboratory conditions. Expect reasonable variations.

4. Add the powder to the water and mix for approximately 1 – 1-1/2 minutes.
5. Use neat material for patches from 1/2 – 2" (6 – 51 mm) in depth or width. For deeper patches, extend a 50 lb (22.7 kg) bag of Set® 45 HW by adding up to 30 lbs (13.6 kg) of properly graded, dust-free, hard, rounded aggregate or noncalcareous crushed angular aggregate, not exceeding 1/2" (6 mm) in accordance with ASTM C 33, #8. If aggregate is damp, reduce water content accordingly. Special procedures must be followed when angular aggregate is used. Contact your local Degussa representative for more information. (Do not use calcareous aggregate made from soft limestone. Test aggregate for fizzing with 10% HCL).

#### Application

1. Immediately place the mixture onto the properly prepared substrate. Work the material firmly into the bottom and sides of the patch to ensure good bond.
2. Level the Set® 45 and screed to the elevation of the existing concrete. Minimal finishing is required. Match the existing concrete texture.

#### Curing

No curing is required, but protect from rain immediately after placing. Liquid-membrane curing compounds or plastic sheeting may be used to protect the early surface from precipitation, but never wet cure Set® 45.

#### For Best Performance

- Color variations are not indicators of abnormal product performance.
- Regular Set® 45 will not freeze at temperatures above -20° F (-29° C) when appropriate precautions are taken.
- Do not add sand, fine aggregate, or Portland cement to Set® 45.
- Do not use Set® 45 for patches less than 1/2" (13 mm) deep. For deep patches, use Set® 45 Hot Weather formula extended with aggregate, regardless of the temperature. Consult your Degussa representative for further instructions.
- Do not use limestone aggregate.
- Water content is critical. Do not deviate from the recommended water content printed on the bag.
- Precondition these materials to approximately 70° F (21° C) for 24 hours before using.
- Protect repairs from direct sunlight, wind, and other conditions that could cause rapid drying of material.
- When mixing or placing Set® 45 in a closed area, provide adequate ventilation.
- Do not use Set® 45 as a precision nonshrink grout.
- Never featheredge Set® 45; for best results, always sawcut the edges of a patch.
- Prevent any moisture loss during the first 3 hours after placement. Protect Set® 45 with plastic sheeting or a curing compound in rapid-evaporation conditions.
- Do not wet cure.
- Do not place Set® 45 on a hot (90° F [32° C]), dry substrate.
- When using Set® 45 in contact with galvanized steel or aluminum, consult your local Degussa sales representative.
- Make certain the most current versions of product data sheet and MSDS are being used; call Customer Service (1-800-433-9517) to verify the most current versions.
- Proper application is the responsibility of the user. Field visits by Degussa personnel are for the purpose of making technical recommendations only and not for supervising or providing quality control on the jobsite.

#### Health and Safety

SET® 45

#### Cautions

#### Risks

Eye irritant. Skin irritant. Lung irritant. May cause delayed lung injury.

#### Precautions

KEEP OUT OF THE REACH OF CHILDREN. Avoid contact with eyes. Wear suitable protective eyewear. Avoid prolonged or repeated contact with skin. Wear suitable gloves. Wear suitable protective clothing. Do not breathe dust. In case of insufficient ventilation, wear suitable respiratory equipment. Wash soiled clothing before reuse.

#### First Aid

Wash exposed skin with soap and water. Flush eyes with large quantities of water. If breathing is difficult, move person to fresh air.

#### Waste Disposal Method

This product when discarded or disposed of is not listed as a hazardous waste in federal regulations. Dispose of in a landfill in accordance with local regulations.

For additional information on personal protective equipment, first aid, and emergency procedures, refer to the product Material Safety Data Sheet (MSDS) on the job site or contact the company at the address or phone numbers given below.

#### Proposition 65

This product contains materials listed by the state of California as known to cause cancer, birth defects, or reproductive harm.

#### VOC Content

0 lbs/gal or 0 g/L.

**For medical emergencies only,  
call ChemTrec (1-800-424-9300).**

#### Degussa Building Systems

899 Valley Park Drive  
Shakopee, MN, 55379

www.degussabuildingsystems.com

Customer Service 800-433-9517

Technical Service 800-243-6739

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## VITA

Donald Patane Scholz was born near Philadelphia, Pennsylvania on September 1, 1981 to Donald R. and Joanna P. Scholz. He has two wonderful sisters, Mary and Hilary. Don grew up in Havertown, Pennsylvania, and graduated from Archbishop John Carroll High School in 1999.

Don enrolled at the University of Delaware in the fall of 1999 and graduated with a Bachelor of Civil Engineering in May 2003. He then pursued his interest in structural engineering by attending graduate school at the Virginia Polytechnic Institute and State University. Upon completion of his Master of Science in Civil Engineering in December 2004, Don plans to return to the Philadelphia area to pursue a career in structural design and rehabilitation.