DEPARTMENT OF TRANSPORTATION

Dowel — Concrete Interface Material Categorization & Performance in Isolated Test Slabs

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16. Abstract

The Minnesota Department of Transportation (MnDOT) investigated the use of dowel bars with various anchoring methods. This report examines the characteristics of various epoxy and grout anchorage systems at the interface between new construction and existing concrete. Twelve different anchoring materials as well as various anchoring methods were studied and compared to a control using no grout. This study did not examine the effects of the number of dowels used but instead was limited to the methods and materials used to anchor the dowels. This experiment was performed on concrete panels in-house. The tube grout method exhibited the best visual and magnetic imaging results. The evaluation methods did not clearly categorize the materials in order of performance but showed advantages of cleaning the drill-hole prior to dowel placement as well as the merits and demerits of using a retaining collar. The results generally suggested the need for an actual deployment research project on actual pavement in real-world service conditions. The field experiment was reported in a separate document.

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Dowel–Concrete Interface Material Categorization & Performance in Isolated Test Slabs

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EXECUTIVE SUMMARY

In regular full-depth concrete rehabilitation projects, repair limits are tied to sawcut ends by grout or epoxy anchored dowels. Adequate anchorage of the dowels to the existing concrete ensures compatibly and consequently should forestall subsidence and other premature distresses.

However, numerus occurrences of subsidence at some of these concrete repair locations in some concrete rehabilitation projects posed a challenge to reexamine the suitable number of dowels across each 12-ft wide panel and the various anchorage materials and mechanisms used. This research paper examined the characteristics of various epoxy and grout anchorage systems at the interface between new construction and existing concrete.

This indoor experiment examined 12 different materials and installation procedures, as well as a control experiment. The experiments identified the tube grout method as the best anchorage material based on visual and MIRA (ultrasonic tomography) results.

Chapter 1 consists of an introduction to the experiment and background information for better understanding of the concepts covered in this report. The method of dowel insertion may not be familiar to many and as such, is included in detail here. Chapter 2 discusses the research set up including diagrams necessary to understand the varying treatments, both in how the retrofits were performed and where the dowels were placed and anchored. The chapter provides the detailed set up of the varying treatments and how they compared with one another. The two methods of analysis, MIRA and visual, are also explained in Chapter 2.

In Chapter 3, the MIRA and visual results are given via ranking and separated based on treatment to best compare how each treatment may affect those it works in tandem with. These results are discussed in depth to conclude that the bag injected grout and the capsule grout, along with both types of epoxies, provided the most optimal MIRA and visual results, while the grout dip method provided the worst results.

Chapter 4 examines the various types of bonding materials and methods and attempts to compare their performances based on the MIRA as well as with scored visual methods. The discussion compares epoxies to grouts in general and carefully examines the coherence of MIRA to visual observation particularly when there is correspondence in a group and non-correspondence in another or when the coherence spreads through the entire sample space.

The discussion also looks at special effects such as the ring collar that is designed to retail the grout or epoxy in the drilled hole and whether the collar/ring is counterproductive.
Finally, the preparation methods ranging from zero preparation through air blowing and brushing are also examined and compared.

Chapter 1: Introduction

1.1 Background

In sustainable development it is not always prudent to reconstruct a concrete pavement unless the concrete surfacing and support structure are in such poor condition that a rehabilitation will not be cost-effective. Sustainable approaches therefore consist of concrete overlays, including unbonded overlays and even Whitetopping of flexible pavements, as well as concrete rehabilitation. Rehabilitation of concrete is organized into two categories: minor rehabilitation and major rehabilitation. In minor rehabilitation, a limited number of partial-depth repairs and full-depth repairs are performed per lane-mile of project and the distance between repairs is significant. Some minor rehabilitations are post construction mop-ups. In major rehabilitation, there are typically full-depth repairs, dowel-bar-retrofits and a few partial-depth repairs, which occur at shorter intervals within the control section or project area.

Regardless of the type of full-depth repair, it is always indispensable to tie the new concrete material to the existing concrete. In practice, this is achieved by gang-drilling into the existing concrete and anchoring dowel bars into the holes at specified spaces with acceptable anchorage materials. Two aspects to the challenge of dowel bar anchorage have been the sufficiency of the number of dowels used at the end of a full-depth concrete repair and what interface bonding material and installation process maximizes performance of these repairs. The traditional method of rehabilitation entailed gang-drilling and insertion of dowels with epoxy or grout and the use of dowels at one foot center to center. Previously, in the typical rehabilitation, 12 dowels were placed in the lane. In 2002, there was a shift to 11 dowels to avoid clipping of the exterior dowels during paving. This shift automatically transferred to the number of dowels at repair cross-sections. This was later reduced to 7 and then to 6 dowels with 3 on each wheel path, not institutionally, but in a trial mode. There was no consensus as to the sufficiency of the 6 dowels, particularly as a finite element and similar analysis was not conducted. A project using 6 dowels resulted in widespread subsidence along the repair limits. It was also suggested that the methods of anchorage used for compatibility between the existing concrete and the repaired portion may have been defective. It became necessary to ascertain the evenness and uniformity of application around the annular space between the gang-drilled hole and the dowel and determine, using acoustic impedance, which materials and processes were defective and which were suitable. Ipso facto, the question remained whether the problem was exclusive to the use of the gang-drill and epoxy, as well as the use of grout.

According to the Minnesota Department of Transportation's (MnDOT) *Concrete Rehabilitation Manual* [1], the 1/8- to 1/4-inch drilled hole oversizing allows the non-shrink grout adhesive or epoxy adhesive injected in the gang-drilled hole to freely flow around the dowel bar/reinforcing steel, displacing any air voids with adhesive. While pull-out tests were not performed and uniaxial fatigue testing was not conducted on the axis of encastre during this study, the ultrasonic tomography MIRA device [2] [3] was successfully used to show degrees of uniformity of application and material around the dowel bars. This led to the categorization of materials and processes into good, marginal, and less than marginal.

Insufficiently sized drilled holes jeopardize the integrity of the dowel-concrete interface. This is likely due to the inadequate space between the dowel bar and the drilled-hole walls, making it very hard, if not impossible, to force the grout or epoxy adhesive from the back of the drilled hole out and around the dowel bar when the bar is installed into the drilled hole. The challenges were intensified when some full-depth repairs were done on interstate Highway 90 in 2012, for instance. There were numerous occasions in which panels that were placed post-rehabilitation subsided after the first year, leading to uneven surfaces that could potentially initiate rapid degradation. These subsidence scenarios were similar to typical dowel action failure experienced in structural reinforcement failures or rebar anchorage failures. In addressing this problem, a testing scheme was designed and executed by a joint effort of Industry and MnDOT.

The study entailed the replication of dowel anchorage in panels that were pre-gang-drilled and brought into the MnROAD Pole Barn. Each epoxy supplier or grout supplier anchored a set of dowels with their products. Although pull-out tests were not conducted, a device known as the MIRA scanned the annular space to detect uniformity of anchorage material and absence of void. The MIRA data along with visual observation by researchers was used to analyze the dowel anchoring methods.

1.2 Synthesis

Gang-drilling is used during “full-depth” repairs of distressed panels or joints. During these repairs, dowel bars must be replaced and/or added to the transverse joints. It is essential to properly clean the dowel holes prior to installing new dowels. The dowel holes are cleaned by inserting a compressed air nozzle into the back of the hole. The air compressor ensures the removal of debris present from the drilling process. If the debris is not significantly removed, it prevents the adhesive material from properly bonding to the concrete. When using the air compressor, it is important to occasionally check the air for oil and moisture contamination. If contaminated, correct bonding will be inhibited.

Some anchoring techniques involve injection of material starting at the back of the hole using a long nozzle. This assures that the anchoring material will flow forward along the entire dowel embedment length during insertion, decreasing the likelihood of leaving voids between the dowel and the concrete. Some methods use prefabricated epoxy cartridges that supply enough material for one to two holes. A more cost-effective method for large projects is a pressurized injection system from bulk epoxy containers. The injection wand on the installation unit should contain an auger-type mixing spindle to mix a two-part epoxy. A caulk-gun type tool is preferable when using non-shrink cementitious grouts.

The anchoring material that has been injected can occasionally flow out while inserting the dowels. A plastic grout-retention disk is thus occasionally used to provide a barrier that prevents the escape of the anchoring epoxy or grout. When there has been a sufficient amount of material injected, some anchoring material should be visible from the sides of the disk after installation. If no anchoring material is seen, there may not be enough in the hole. If retention disks are not available, some extra grout should be placed around the dowel. This is not an ideal installation but is preferable to leaving a void. Ideally, anchoring materials will remain in the hole without a retention disk, but if it is difficult to control the loss of material, it may be necessary to adjust the mix. Due to the propensity to stiffen after mixing, non-shrink cementitious materials are typically mixed in small batches, changing their installation properties.

1.2.1 Possible Dowel Distribution Scenarios

Aside from the traditional dowel spacing, there are three other analysis methods of dowel spacing discussed. These three methods include: alternate corner dowel spacing, removal of centerline dowels, and alternative dowel designs.

The alternate corner dowel spacing method entails varying the distance between the center of the dowel closest to the slab corner and the edge of the slab. This method investigates the potential impacts these various distances have on pavement response.

The removal of the centerline dowels investigates the effect on pavement response when a number of dowels are removed from the center of the lane, along the transverse joint. Since the majority of the wheel loading straddles the center of the lane, the traditional methods with equal dowel spacings leads to an overly conservative design.

The alternative dowel design method analyzes the effect on pavement response with alternative dowel spacings along the transverse joint. Since wheel loading is typically channelized in the lane, the traditional method leads to inherent inefficiencies. The alternative design removes some dowels, while redistributing other dowels along the joint.

This discussion intends to present results that illustrate the influence dowel spacing has on various pavement responses. If dowels of appropriate size are used, dowels can be removed from the lane and/or redistributed without significantly affecting the pavement response.

1.3 Objective

To minimize redundancy, a new strategy placed three dowels on each wheel path in a few projects between 2011 and 2012. Following these installations, widespread subsidence was observed. It was also suggested that the methods of anchorage critical to the compatibility between the existing concrete and the repaired portion of those sections may have been defective.

This experiment sought to ascertain the evenness and uniformity of application around the annular space between the drilled hole and the dowel and to determine using acoustic impedance, which materials and processes were defective, and which were suitable. Although pull-out tests were not performed and uniaxial fatigue testing was not conducted on the axis of encastre, the MIRA ultrasonic tomography device showed the degree of uniformity of application and material and led to the categorization of materials and processes into good, marginal, and less than marginal. An added goal was to evaluate the discrepancies between current field adhesive products and methods utilizing knowledge from agency observation, and work with the installation process as dictated by the pavement industry and adhesive product suppliers to minimize gaps.

The experiment was also aimed at comparing performance trends of the various grout and epoxy materials and processes but was limited in scope to exclude the determination of optimum dowel intervals or even the examination of the suitability of a lesser number of dowels per wheel path. This experiment assumed that the prudent configuration was insufficient and proceeded to examine the adequacy of the various grouting and epoxying techniques with 11 dowels arranged at 1 ft center-to-center.

Chapter 2: Research Design & Process

2.1 Experimental Design & PROCESS Summary

This experiment was performed in a controlled setting. Representatives from material suppliers installed dowel bars into pre-drill concrete panels that had been cut out of some roadways and brought into the MnROAD heated Pole Barn at the MnROAD site on February 12th, 2013.

This study tested different combinations of various adhesive materials and application methods used for dowel bar installation, with the different combinations found in Table 1. These different combinations were tested using visual analysis to determine if there was a trend in regard to which anchoring material and application method provided the least number of internal voids between the bars and the concrete The lack of consolidation of the anchoring material can inhibit the proper performance of dowel bars. MIRA ultrasonic tomography testing was also conducted on the anchorages. [4]. MIRA provides qualitative results as to which anchoring material and application method keeps the dowel bar situated in the middle of the dowel hole. Maintaining uniform thickness of the adhesive material surrounding the dowel bar is essential for optimal dowel bar performance. If the anchoring material seeps to the bottom of the hole, it leaves the potential for voids to occur on top of the dowel. Various anchoring materials allow the dowel to sink to the bottom of the hole, simultaneously pushing the majority of the bonding material on top of the dowel bar. This viscosity issue may be counterproductive as it forestalls consistent support or bonding all around the dowel. Figure 1 shows a schematic of the dowel behavior and figures 2 and 3 show the experimental set up of the concrete panels and assignment of serial numbers to the proposed experiments.

Two concrete panels that were gang drilled for full-depth dowel repairs, The drilled coordinating numbered layout for each dowel hole on the concrete panels is shown in Figure 2. Figure 3 shows an image of the two panels after drilling the holes. It is essential to properly clean the drilled dowel holes removing debris to achieve correct bonding of the anchoring material upon inserting the dowel. Each hole location investigated different combinations of various cleaning methods along with various bonding materials and application methods, shown in Table 1. Three days after inserting the dowels, the edges of the panels were cut at the 4.5" plane line to expose hidden features of the annular space or uniformity or eccentricity of grout or epoxy around the dowels. This process is shown in Figures 4, 5, and 6. These cuts allow for internal visual examination, providing the most accurate evaluation of void presence and comparison with MIRA results.

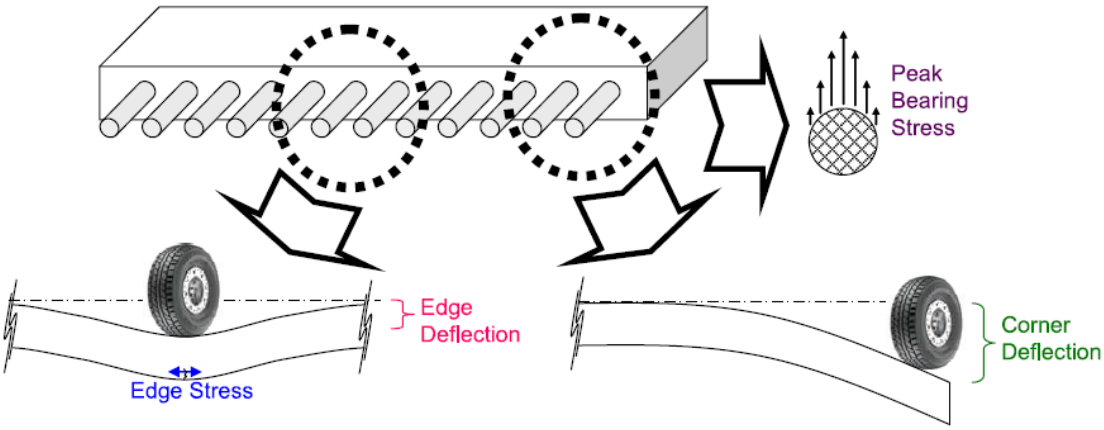

Figure 1. Diagram of the dowelled panel and the various stresses and deflections can induce bearing stresses

	Panel A	Panel B
Front		
Back		

Figure 2. Drilling Lay-out for the Concrete Panels

Figure 3. Concrete Panels after gang drilling Process

Figure 4. Cutting the first Concrete Panel to allow for cross sectional view of grout distribution

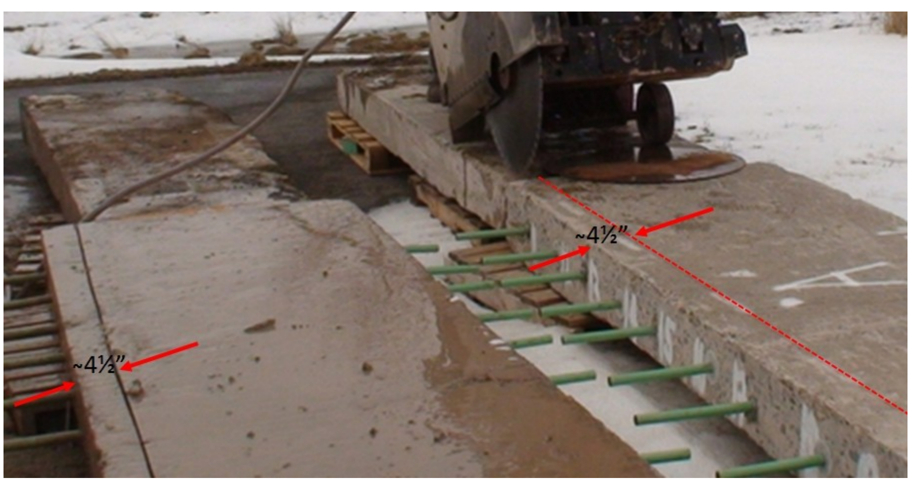

Figure 5. Preparing to cut the second Concrete Panel at 4.5" from panel face

Figure 6. Making the final forensic cut on the first concrete panel (both sides of the second panel had been completed)

The adhesive materials investigated in this report are described and can be accessed in the MnDOT approved/qualified concrete product list. The products most relevant to this experiment are listed under epoxies and non-shrink grouts. The MIRA reflective category and visual inspection category for each dowel hole have been tabulated across the bottom two rows in Table 1. In the abbreviation “NS” represents “Non-Shrink”, “PG” represents “Poly-Grout.”. This allows for direct comparisons to be made in regard to the combinations of different materials and methods that fall within each MIRA reflection and visual ranking categories.

	Adhesive	PANEL A = 140' X 41' X 9'																				PANEL B = 146' X 41' X 9'																				
		PANEL A - FRONT										PANEL A - BACK										PANEL B - FRONT										PANEL B - BACK										
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
Bonding Material Type	Two-Part Epoxy; Hand Mixed			X	X	X	X																																		X	
	Two-Part Epoxy; Mechanically Mixed									X	X	X	X	X	X	X	X	X	X	X	X																					
	Poly Grip "Caulk Gun" 25 handle "pumps"																					X																				
	Poly Grip "Caulk Gun" 20 handle "pumps"																						X	X	X																	
	Non-Shrink Grout																															X	X	X	X	X	X	X	X	X	X	X
	Non-Shrink 'OLD' Grout							X	X																																	
	Non-Shrink Pre-Packaged Capsulated Grout Tube																										X	X	X	X												
	Non-Shrink Pre-Packaged Capsulated Grout soaked longer																									X					X											
Cleaning Method	Blown Only	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X									X																	
	Brushed & Blown																X	X	X	X	X	X	X	X		X	X	X	X	X	X								X	X	X	
	NO Cleaning																															X	X	X	X	X	X	X				X
Application Method	Dowel Bar Rotating Together Mixing Process	X	X																																							
	Single Dip			X	X																											X	X								X	
	Double Dip					X	X																																			
	Drilled Hole and Applied Bead of Epoxy to Dowel as Being Inserted											X	X	X	X	X	X	X	X	X	X																					
	Epoxy in Hole Only									X	X																															
	Grout Box																																	X	X	X	X	X	X	X		X
	Poly Retaining Ring		X		X		X		X		X		X		X		X		X		X		X		X		X		X				X		X	X		X		X		
	Gordy Special	X	X					X	X																																	

Table 1. Combination of Bonding Material and Application Methods at each Hole

The images shown in Figures 7 through 12 display some of the methods that are listed in Table 1. Figure 7 shows the grout-bag injection method, by which grout is placed into a bag with a hole at the end that acts as a vehicle for the grout. Figure 8 depicts the grout-dip method, in which the dowel itself is dipped into the grout and inserted into the hole. Figures 9 and 10 depict different points during the grout capsule method, where Figure 9 is an image of the grout capsules when dry and Figure 10 is an image of the capsules being inserted into the dowel hoes after being saturated with water first. Figure 11 shows the dowels being hammered into the dowels using a rubber mallet, this can be done to all methods, however it is most important to the capsule method because the capsule method relies on the dowel breaking through the cloth shell to release the grout to the outside as well as leave the cloth as a reinforcement within the dowel hole. Figure 12 is a diagram of the way epoxy is used to install the dowels. Since epoxy hardens quickly and becomes unusable, the epoxy is only mixed in small batches. There are two parts to most epoxies, often kept in their own containers. There are two systems of batching. First, as epoxy is used it is blended when researchers hand mixes small batches or dip a dowel each into a part and mix the epoxy left on the dowels together. The alternative system for batching is a special system where tubing or an epoxy gun injects the two parts into the hole separately and then when the dowel is inserted, it is rotated to help blend the epoxy together.

Figure 7. Grout - Bag Injection Method

Figure 8. Grout - Dip Method Insertion

Figure 9. Pre-Saturated Grout Capsules

Figure 10. Insertion of Saturated Grout Capsule into Pre-Drilled Hole

Figure 11. Insertion of Dowel Bar into Pre-Drilled Hole

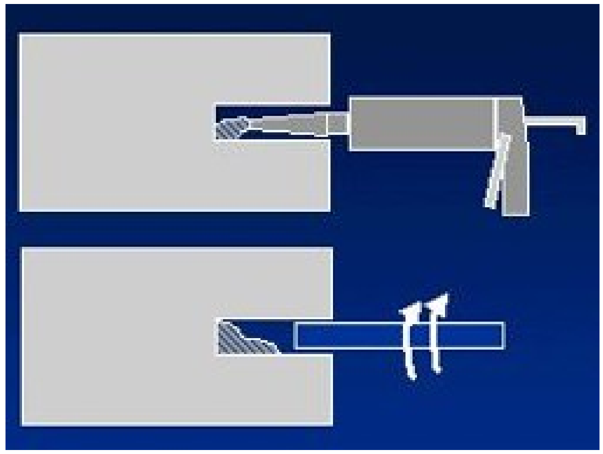

Figure 12. Dowel Bar Installation Process when Utilizing Epoxy

2.2 MIRA Data Analysis

The experiment was originally planned to be evaluated with an accelerated loading device. Logistics and timing of the experiment frustrated that initial plan. However, since fixity of the dowels and integrity of the filler were critical items, the experiment used a magnetic imaging response of the filler and the filler-concrete interface as well as the filler –grout / epoxy interface. To facilitate a proper forensic evaluation, a sawcut was made on the pavement, 4 ½ inches into the concrete. This full-depth sawcut exposed the integrity of the interfaces and provided sufficient surface for MIRA in Figure 13. The MIRA ultrasonic linear array device used for analysis is composed of transmitting and receiving transducers. It transmits ultrasonic waves and detects their reflections at the surface with the transducers. By changing the acoustic impedance, the waves reflected are those traveling between two different mediums. These reflections are processed and analyzed to understand the structure within the pavement and can detect flaws within it. The MIRA reflectiveness therefore accentuates the condition of the space around the dowel, whether it contains air pockets or grout/epoxy.

MIRA Ranking ranged from A to C, with an A indicating significant reflection and C indicating little or no reflection at the dowel-grout to grout-concrete interface. In general, the less reflection at the dowel location, the better the damage ranking. Presence of a “MIRA Type C - Little or No Reflection at Dowel Location” is a good indicator that the grout/epoxy surrounding the dowel is in good or great condition. A MIRA ranking of Type B – indicates slight reflection at a dowel location (often due to edge effects).

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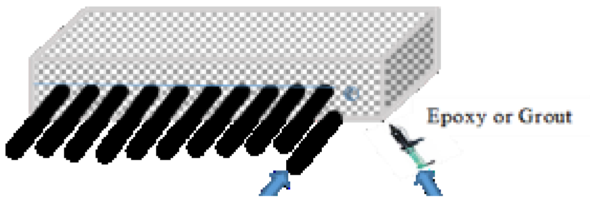
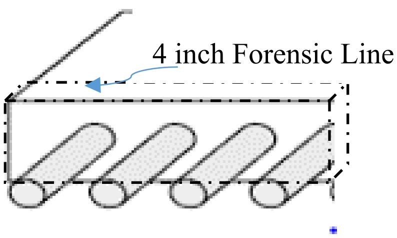
<tr><td>
</td><td colspan="2"></td></tr>
<tr><td>Dowels Anchored with Various Epoxies or Grout</td><td colspan="2">Forensic Saw Cuts across the Dowels</td></tr>
<tr><td rowspan="2">
</td><td></td><td></td></tr>
<tr><td>Forensics on #17 Slot</td><td>Forensics on #6 slot</td></tr>
</table>

Figure 13. In – house installation and forensic processes

2.3 Visual Data Analysis

To facilitate a proper forensic evaluation, a sawcut was made on the pavement, 4 ½ inches into the concrete. The exposed faces were thus visually inspected as indicative of the inside of the anchorage system to augment observations made at the surface of a joint. This full-depth sawcut exposed the integrity of the interfaces and provided sufficient exposure for visual observation in Figure 13. The various grout/epoxy- installation factorials were visually inspected for interfacial compatibility and for the presence of discontinuities or bug drilled holes. They were also examined for poor fixity or any other defects. A visual imaging scoring was designed to evaluate the interface.

Visual evaluation of the forensic faces of the dowel grout interface was quantified numerically as an index ranking from rank 1 to rank 4. A visual of 1 represents unacceptable condition, with bug drilled holes of ¼ inch interfacing, a condition ranking of 2 is a marginal condition typified by discontinuities in the filler, while rank of 3 indicates that the visual condition is good with hardly any non-uniformity and 4 represents very good condition.

Chapter 3: Results

3.1 MIRA Results

Evaluation in this experiment was mainly visual, with MIRA results supplementing the results from visual observation. Conclusions are based on the consolidation and the uniformity of the adhesive coating within the drilled hole, as described previously. Table 2 shows the summary of the overall results from this experiment. The MIRA reflective results at the 4.5" plane line have been separated into three categories: Type A, Type B, and Type C. Descriptions of these MIRA reflective categories are also shown in Table 2. This table shows the total amount of dowels that fall under each visual inspection category, and the average visual ranking result that corresponds with each MIRA reflective result category. An example of various hole locations experiencing splitting is shown in Figure 14. Descriptions of the visual inspection categories include:

- Rank 4 – Great: full bonds with no voids
- Rank 3 – Good: mostly bonded with little to no voids
- Rank 2 – OK: some level of debonding or voids present
- Rank 1 – Bad: significant level of debonding and voids present

Table 2. Number of Dowel Holes that fell within each MIRA Category and their corresponding Visual Inspection Category (Average Rank is Weighted)

		Visual Result (# Holes)				
MIRA Type	**MIRA Type Description**	**Rank 1 (Bad)**	**Rank 2 (OK)**	**Rank 3 (Good)**	**Rank 4 (Great)**	**Average Rank**
A	Significant Reflection at Dowel Location – Poor	3	6	2	1	2.08
B	Slight Reflection at Dowel Location (often due to edge effects) - Questionable	9	2	2	6	2.26
C	Little or No Reflection at Dowel Location - Good	0	0	2	8	3.80

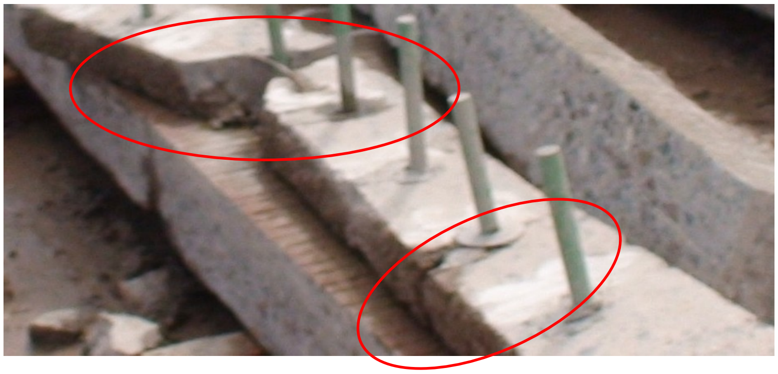


Figure 14. Splitting at Various Dowel Locations

The MIRA reflective type and visual ranking results provided insight to the uniformity and consolidation of the adhesive material surrounding the dowel bar. For evaluation of consolidation, a visual rank of 3 or 4 is preferred. When analyzing the uniformity, MIRA Type A is preferred. However, from Table 2, Type A, in general, provided low quality visual ranking results. There was a total of 12-hole locations that fell under the Type A category, and 75% of these dowel holes produced visual ranking results of 1 or 2. From Table 2, in general, the MIRA showed little or no reflection at the dowel location thus providing a better visual inspection result. This suggests that the presence of a MIRA Type C reflective result is a good indicator that the adhesive surrounding the dowel is properly consolidated.

3.2 Visual Results

There were 2 two-part epoxies analyzed in this study: one was hand mixed and the other was mechanically mixed. Twelve-hole locations utilized the mechanically mixed two-part epoxy, and five-hole locations used the hand mixed two-part epoxy. From the bottom rows in Table 1, ten of the 17 two-part epoxy locations fell under the MIRA Type A category, and six of the 17 locations fell under the MIRA Type B category. Only two of these locations provided a visual ranking results better than a 1 or 2; dowel holes 6 and 17. Locations 6 and 17 provided MIRA types and visual rankings of A – 3 and B – 4, respectively. Images of the cuts at these hole locations are shown in Figures 15 and 16.

Figure 15. Dowel Hole Location 6 - Significant Reflection with Little to No Voids Present

Figure 16. Dowel Hole Location 17 - Slight Reflection with No Voids Present

A summary of the results for the hole locations using two-part epoxies is shown in Table 3. From this table, in general, the use of two-part epoxies provided quality uniformity, but poor consolidation. The majority of the epoxies showed results similar to drill-hole location 5, shown in Figure 17.

Table 3. Number of Hole Locations using Two-Part Epoxies that fell within each MIRA Category and Visual Ranking Category

Two-Part Epoxies Hand Mixed and Mechanically Mixed						
Mira Results		**Visual Results**				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	3	6	1	0	1.8
B	Slight (typically edge) Reflection at Dowel Location	4	1	0	1	1.67
C	Little or no reflection at Dowel Location	0	0	1	0	3.00

Figure 17. Dowel Hole Location 5 - Significant Reflection with Some Voids Present

From Table 1, there were four non-shrink grout types analyzed in this study: normal non-shrink grout, non-shrink ‘old’ grout, non-shrink pre-packaged capsulated grout tube, and non-shrink pre-packaged capsulated grout soaked longer. Examining MIRA results and visual results of these non-shrink grouts from Table 1, 13 of the 19 dowel hole locations provided a MIRA Type B ranking, and five of the 19 locations provided a MIRA Type C. This indicates that the utilization of non-shrink grouts may generally provide mediocre to low quality uniformity between the dowel bar and the concrete.

Visual rankings of the non-shrink grouts from Table 1, 13 of the 19 dowel hole locations provided a visual ranking result of three or four. This indicates that generally, utilizing non-shrink grout provides good consolidation between the dowel bar and the concrete. A summary of the results from the dowel-hole locations utilizing non-shrink grouts is shown in Table 4. That shows that in general, non-shrink grout may exhibit optimal consolidation with mediocre uniformity. From Table 4, there were five locations that provided MIRA results and visual rankings of B – 4, and one location that provided A – 4. The dowel hole location utilizing non-shrink grout that provided a MIRA result and visual ranking of A – 4 was 41. An image of the cut at dowel hole location 41 is shown in Figure 18.

Table 4. Number of Hole Locations using Non-Shrink Grouts that fell within each MIRA Category and Visual Ranking Category

Non-Shrink Grout (All types)						
Mira Results		Visual Results				
Mira Type	Description	Rank 1	Rank 2	Rank 3	Rank 4	Average Rank
A	Significant Reflection at Dowel Location	0	0	0	1	4.00
B	Slight (typically edge) Reflection at Dowel Location	5	1	2	5	2.54
C	Little or no reflection at Dowel Location	0	0	0	5	4.00

Figure 18. Dowel Hole Location 41 - Significant Reflection with No Voids Present

The last general category of adhesive material utilized in this study was the poly grip applied using a caulk gun. There were only four dowel drill-hole locations that utilized the poly grip caulk gun method. From Table 1, all four of these locations provided a MIRA Type C, and three of the four locations provided a visual ranking result of four. From Table 1, location 22 where poly-grip was used provided a MIRA result and visual ranking of C – 4. An image of the cut at this location is shown in Figure 19.

Figure 19. Dowel Hole Location 22 - Little to No Reflection with No Voids Present

Figure 19 also shows a great example of how severely the dowel in this location lacks uniformity. The thickness of the poly grip surrounding the top half of the dowel bar is much larger than the thickness of the poly grip surrounding the bottom half of the dowel bar, resulting in a MIRA Type C reflective result.

The effectiveness of a poly retaining ring can be observed from Table 5. In order to determine how the retaining ring would affect the consolidation and uniformity of the adhesives analyzed in this experiment, external factors had to be eliminated. This was achieved by testing two different drill-hole locations with the same anchoring and application methods; however, one location utilized a retaining ring while the other did not. Using the results in Table 1, Tables 5 and 6 were constructed. These tables show the summary of the MIRA reflective results and visual ranking results for the drill-hole locations with and without a retaining ring, respectively.

Table 5. Number of Hole Locations using a Retaining Ring that fell within each MIRA Category and Visual Ranking Category

No Ring						
Mira Results		Visual Results				
Mira Type	Description	Rank 1	Rank 2	Rank 3	Rank 4	Average Rank
A	Significant Reflection at Dowel Location	2	1	1	0	1.75
B	Slight (typically edge) Reflection at Dowel Location	6	2	0	2	1.80
C	Little or no reflection at Dowel Location	0	0	1	4	3.80

Table 6. Number of Hole Locations not using a Retaining Ring that fell within each MIRA Category and Visual Ranking Category

No Ring						
Mira Results		Visual Results				
Mira Type	Description	Rank 1	Rank 2	Rank 3	Rank 4	Average Rank
A	Significant Reflection at Dowel Location	1	5	1	1	2.25
B	Slight (typically edge) Reflection at Dowel Location	3	0	2	4	2.78
C	Little or no reflection at Dowel Location	0	0	1	4	3.80

Overall, MIRA reflective results and visual ranking results for the drill-hole locations are shown in Table 7.

Table 7: MIRA reflective results and visual ranking results for the drill-hole locations

Adhesive	PANEL A 140” X 40” X 9”																				PANEL B 146” X 41” X 9”																				
	PANEL A FRONT										PANEL A BACK										PANEL B FRONT										PANEL B BACK										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
MIRA Category	A	B	A	A	A	A	B	B	A	B	B	A	A	A	A	C	B	B	A	B	C	C	C	C	C	B	B	C	C	C	B	B	B	B	B	B	B	B	C	B	A
Visual Rank	3	1	2	1	2	3	4	1	2	1	1	2	2	1	1	3	4	1	2	2	4	4	3	4	4	4	4	4	4	4	1	1	3	2	1	3	4	4	4	1	4

3.3 Discussion

There were only four dowel hole locations that utilized the poly grip caulk gun method. From Table 1 these were identified as locations 21-24, all four of these locations provided a MIRA Type C, and three of the four locations provided a visual ranking result of four. These results indicate that while the utilization of poly grip provides optimal consolidation based on MIRA results, it does not achieve ideal uniformity between the dowel bar and the concrete when visual results are also considered. This shows that the utilization of a two-part epoxy material can potentially provide optimal uniformity and consolidation, however, since the majority of the locations using two-part epoxies exhibited poor consolidation these locations can be considered anomalies.

MIRA categorization was not always consistent with visual results because of the visual limitation to the drilled In order to determine the most effective adhesive material and application method, drill-hole locations producing optimal uniformity and consolidation must be highlighted. Combinations of MIRA reflective types and visual rankings that would be considered optimal include A – 4, A – 3, and B – 4. The results of Table 4 indicated a higher average visual ranking in all MIRA categories when compared to Table 3. This may indicate that the grout produces more uniformity than the epoxy. As optimal results include A -4, A -3, and B -4, this may indicate the grout, with a significant number of group B and lower visual rankings, produces more optimal results than the epoxy.

From Tables 5 and 6, the utilization of a poly retaining ring does not appear to be advantageous. These tables show that it is more likely to achieve a MIRA Type A and a visual ranking of four when using no retaining ring. This indicates that there is more potential to achieve optimal consolidation and uniformity without a retaining ring. This can potentially be attributed to the retaining ring not allowing for excess air to be released, subsequently creating more potential for voids. From these results, the adhesive material and method allowing for the most potential to achieve optimal consolidation and uniformity between the dowel bar and concrete is the non-shrink grout without the use of a poly retaining ring.

Two Part Epoxy: The hand mixed 2-part epoxy system were located in holes 3, 4, 5, and 9 to 20 and 40. Based on the MIRA scoring criteria, the hand mixed and the mechanically mixed exhibited approximately the same reflectance. Both mixing types were associated preponderantly with slight reflectance. In each case the average visual rank corresponding to the hand mixed 2-part epoxy were 0 and 3 respectively.

Non-Shrink Grout: Apart from the prepackaged Non-shrink grout, all others showed high average ranks and little or no reflectance. At holes 7, 8, 25-30 and 31 to 40 the NS grout appeared to perform better than the epoxies, visually and based on the MIRA criteria in this experiment. MIRA and visual results of NS grouts from Table 1 indicate that 13 of the 19-dowel drilled-hole locations provided a MIRA Condition B, and five of the 19 locations provided a MIRA Condition C. This indicates that the NS grouts generally provided mediocre to low quality uniformity between the dowel bar and the concrete.

The results from Table 4 show that NS grouts exhibiting optimal consolidation with mediocre uniformity. There were five locations that provided MIRA results and visual rankings of "B – 4", and one location that provided "A – 4". The dowel drilled-hole location utilizing NS grout that provided a MIRA result and visual ranking of A – 4 was #41. An image of the cut at dowel drilled-hole location #41 is shown in Figure 18.

Retaining Ring Vs, No retaining Ring: The examination was facilitated by a pair of drilled-hole locations with the same adhesive and application methods, one with the ring and the other without. Barring experimental error implicit in a small sample space, results showed that it is more likely to achieve a MIRA Condition A and a visual ranking of four when using no retaining ring. It is suggested that there is more potential to achieve optimal consolidation and uniformity without a retaining ring, all things equal. This can potentially be attributed to the retaining ring not allowing for excess air to be released, subsequently creating more potential for voids. The adhesive material and method allowing for the most potential to achieve optimal consolidation and uniformity between the dowel bar and concrete is the NS grout without the use of a poly retaining ring. Examining the performance of grout applied ordinarily to that applied ahead of a retaining ring, Tables 5 and 6 show the polyglot seemed to perform better with the ring application than with the ordinary application alone when the MIRA reflectance was in the C category. Similarly with the non-shrink grout, the ring did not seem to improve the ordinary application. However, in each case the high score of 4 corresponded to MIRA reflectance in the C category. It was suggested that the retaining ring may not be best when consolidation is required. However, when the grouting material is lean and mobile the retaining rimming may be beneficial.

Cleaning (Cleaned vs Non-Cleaned Drill Holes): Holes 8, 16 and 17 compared cleaning methods that included air blown or blasted only, and the no-cleaning alternative. MIRA and visual scoring indicated that the brushed and blown preparation method showed better scores than the non-cleaning alternative in the MIRA B and C categories only. Ironically in the category C the no cleaning scored 4 in visual evaluation in parity with the brush and blown alternative.

Chapter 4: Further Visual & MIRA Analysis

4.1 Basis

This chapter examines the various types of bonding materials and methods and attempts to compare their performances based on the MIRA as well as with scored visual methods. The discussion compares epoxies to grouts in general and carefully examines the coherence of MIRA to visual observation particularly if there is correspondence in a group and non-correspondence in another or if the coherence spreads through the entire sample space. The discussion also looks at special effects such as the ring collar that is designed to retail the grout or epoxy in the drilled hole and if the collar / ring may be counterproductive.

Finally, the preparation methods ranging from zero preparation through air blowing and brushing are also examined and compared.

4.2 DISCUSSION

Epoxy Summaries

Table 8 shows the MIRA reflective results and visual ranking results for both hand mixed and mechanically mixed epoxies.

Table 8 Two-Part Epoxies (Hand Mixed and Mechanically Mixed)

		Visual Result				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	3	6	1	0	1.80
B	Slight (typically edge) Reflection at Dowel Location	4	1	0	1	1.67
C	Little or No Reflection at Dowel Location	0	0	1	0	3.00

In Table 7 there is a preponderance of the lower visual ranks resulting in generally low averages, but the MIRA type c corresponds to an average rank of 3. Here there is some degree of coherence between the visual and the MIRA. Tables 9 and 10 show the MIRA reflective results and visual ranking results for mechanically and hand-mixed, respectively.

Table 9 Two-Part Epoxy Mechanically Mixed

		Visual Result				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	2	4	0	0	1.67
B	Slight (typically edge) Reflection at Dowel Location	3	1	0	1	1.80
C	Little or No Reflection at Dowel Location	0	0	1	0	3.00

In Table 9 there is also a preponderance of the lower visual ranks resulting in generally low averages, but the MIRA type c corresponds to an average rank of 3 . Here there is some degree of coherence between the visual and the MIRA.

Table 10 Two-Part Epoxy Hand Mixed

Two-Part Epoxy Hand Mixed						
		Visual Result				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	1	2	1	0	2.00
B	Slight (typically edge) Reflection at Dowel Location	1	0	0	0	1.00
C	Little or No Reflection at Dowel Location	0	0	0	0	0.00

In Table 10 there is also a distribution of the lower visual ranks resulting in generally low averages. Comparatively, the 2-part epoxy mechanically mixed seems to perform slightly better than the hand mixed. One another advantage of mechanical mixing here may be sole ergonomic. Here the is some degree of incoherence between the visual and the MIRA.

Table 11 (a, b and c) shows the MIRA reflective results and visual ranking results for Non-Shrink Grout Summaries.

Table 11 Non-Shrink Grout Summaries

Non-Shrink Grout (All Types) (a)						
		Visual Result				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	0	0	0	1	4.00
B	Slight (typically edge) Reflection at Dowel Location	5	1	2	5	2.54
C	Little or No Reflection at Dowel Location	0	0	0	5	4.00
Non-Shrink Old Grout (b)						
		Visual Result				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	0	0	0	0	0.00
B	Slight (typically edge) Reflection at Dowel Location	1	0	0	1	2.50
C	Little or No Reflection at Dowel Location	0	0	0	0	0.00
Non-Shrink Pre-Packaged Capsulated Grout Tube (c)						
		Visual Result				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	0	0	0	0	0.00
B	Slight (typically edge) Reflection at Dowel Location	0	0	0	2	4.00
C	Little or No Reflection at Dowel Location	0	0	0	2	4.00

In Table 11a there is also a preponderance of the higher visual ranks and overall population resulting in generally high average ranks, but the MIRA type c corresponds to a average rank of 4. Here there is some degree of incoherence between the visual and the MIRA. Comparatively, the non-shrink grout seems to perform at a high level.

In Table 11b there is also the absence of lower visual ranks resulting in generally low averages, but the MIRA type c corresponds to an average rank of 0. Here the is some degree of coherence between the visual and the MIRA. Comparatively, old non-shrink grout seems to perform at an average level .

In Table 11c there is some degree of coherence between the visual and the MIRA. Comparatively, the non-shrink prepackaged grout seems to perform at a high level if the sample space is not a confounding factor. The grouts seem to be generally better than the epoxies based on this method of evaluation. Table 12 shows the MIRA reflective results and visual ranking results for Non-Shrink Pre-Packaged Capsulated Grout Soaked Longer.

Table 12 Non-Shrink Pre-Packaged Capsulated Grout Soaked Longer

		Visual Result				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	0	0	0	0	0.00
B	Slight (typically edge) Reflection at Dowel Location	0	0	0	0	0.00
C	Little or No Reflection at Dowel Location	0	0	0	2	4.00

In Table 12 there is also an absence of the lower visual ranks and overall population resulting in generally low averages, but the MIRA type c corresponds to an average rank of 4. Here there is some degree of coherence between the visual and the MIRA. Comparatively, Non-Shrink Pre-Packaged Capsulated Grout Soaked Longer performed at a high level if the sample space is not a confounding factor. Table 13 shows the MIRA reflective results and visual ranking results for poly grip.

Table 13 POLY GRIP Summaries

Poly Grip Caulk Gun (20 and 25 handle pumps)						
		Visual Result				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	0	0	0	0	0.00
B	Slight (typically edge) Reflection at Dowel Location	0	0	0	0	0.00
C	Little or No Reflection at Dowel Location	0	0	1	3	3.75

In Table 13 there is also an absence of the lower visual ranks and overall population resulting in generally high averages, but the MIRA type c corresponds to an average rank of 3.75 barring the effect of a sample space. Here the is some degree of coherence between the visual and the MIRA. Comparatively, polygrip seemed to perform at a high level if the sample space is not a confounding factor.

Evaluating the Effect of a Ring or Collar.

Table 14 (a and b) shows the MIRA reflective results and visual ranking results for retaining ring for no ring and poly retaining ring, respectively.

Table 14 Retaining Ring Summary No Ring

No Ring (a)						
		Visual Result				
Mira Type	Description	Rank 1	Rank 2	Rank 3	Rank 4	Average Rank
A	Significant Reflection at Dowel Location	1	5	1	1	2.25
B	Slight (typically edge) Reflection at Dowel Location	3	0	2	4	2.78
C	Little or No Reflection at Dowel Location	0	0	1	4	3.80
Poly Retaining Ring (b)						
		Visual Result				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	2	1	1	0	1.75
B	Slight (typically edge) Reflection at Dowel Location	6	2	0	2	1.80
C	Little or No Reflection at Dowel Location	0	0	1	4	3.80

In Table 14 there is also equitable distribution of visual ranks and overall population resulting in generally higher overall ranking in spite of MIRA categorizations. MIRA type c corresponds to an average rank of 3.80 for both no ring and poly retaining ring . Here the is some degree of coherence between the visual and the MIRA. Comparatively,   the no-ring and the poly retaining ring seemed to perform at the same level. All things considered; the grouts appear to perform better than the epoxies.

Table 15 shows the MIRA reflective results and visual ranking results for Non-Shrink Grout with no Ring

Table 15 Non-Shrink Grout with no Ring

		Visual Result				
Mira Type	Description	Rank 1	Rank 2	Rank 3	Rank 4	Average Rank
A	Significant Reflection at Dowel Location	0	0	0	0	0.00
B	Slight (typically edge) Reflection at Dowel Location	2	0	2	3	2.86
C	Little or No Reflection at Dowel Location	0	0	0	3	4.00

In Table 15 there is also an equitable distribution of visual ranks and overall population resulting in generally higher overall ranking in spite of MIRA categorizations. MIRA type c corresponds to an average rank of 4. Here the is some degree of coherence between the visual and the MIRA.

Table 16 shows the MIRA reflective results and visual ranking results for Non-Shrink Grout with ring.

Table 16 Non-Shrink Grout with Ring

		Visual Result				
Mira Type	Description	Rank 1	Rank 2	Rank 3	Rank 4	Average Rank
A	Significant Reflection at Dowel Location	0	0	0	1	0.00
B	Slight (typically edge) Reflection at Dowel Location	3	1	0	2	2.17
C	Little or No Reflection at Dowel Location	0	0	0	2	4.00

In Table 16 there is also an equitable distribution of visual ranks is haphazard and overall population resulting in generally low overall ranking in spite of MIRA categorizations. MIRA type c corresponds to an average rank of 4 . Here the is some degree of coherence between the visual and the MIRA. Comparatively, the no-ring of the epoxies seem very similar sand seemed to perform at the same level. All things considered; the grouts appear to perform better than the epoxies, but the ring made no observable difference to the grouting process.

Cleaning Factorials

Preparation of the drilled hole prior to installation is an important step. Tables 17, 18 and 19 show the MIRA reflective results and visual ranking results for air blowing only, air blowing and brushing, and no cleaning, respectively.

Table 17 Air Blowing Only

		Visual Result				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	3	5	2	0	1.90
B	Slight (typically edge) Reflection at Dowel Location	4	0	0	1	1.60
C	Little or No Reflection at Dowel Location	0	0	0	1	4.00

Table 18 Air blowing and Brushing

		Visual Result				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	0	1	0	0	2.00
B	Slight (typically edge) Reflection at Dowel Location	2	1	0	4	2.86
C	Little or No Reflection at Dowel Location	0	0	2	7	3.78

Table 19 No Cleaning

		Visual Result				
Mira Type	**Description**	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Average Rank**
A	Significant Reflection at Dowel Location	0	0	0	1	4.00
B	Slight (typically edge) Reflection at Dowel Location	3	1	2	1	2.14
C	Little or No Reflection at Dowel Location	0	0	0	0	0.00

Generally, there is also a distribution of visual ranks is haphazard and overall population resulting in generally low overall ranking in spite of MIRA categorizations. MIRA type c corresponds to high visual rank for air blowing only and air blowing with brushing. MIRA type A corresponded to the high visual rank in the no cleaning (unbrushed and unblown) scenarios. There is some degree of coherence between the visual and the MIRA in the treated sections but they were diametrically opposite in the untreated section. Comparatively, the preparation of the epoxies seemed to improve the integrity of the filler. All things considered, it seems prudent to do the basic preparation of air blowing and or brushing the drilled hole before application of epoxy or grout.

4.3 General Notes

It seems the grouts perform better than the epoxies in general. The application of a ring or collar may be usable if it does not obliterate the grout application process. So far it did not seem advantageous in ensuring a uniform annular ring around the dowels and based on the qualitative / quantitative evaluations performed. For all intents and purposes, the grouts and epoxies used in the network represented in this study all seem to meet some minimum expectations.

Chapter 5: Conclusions and recommendations

5.1 Conclusion

The shearing stresses implicit in the mechanism of traffic load application and load transfer were not simulated in this in-door experiment. Instead, 12 different anchoring materials as well as various anchoring methods were studied and compared to a control experiment using no grout. This study did not examine the effects of the number of dowels used but instead was limited to the methods and materials used to anchor the dowels. This experiment was performed on concrete panels in-house. The tube grout method exhibited the best visual and magnetic imaging results. However, field validation will be necessary because actual load transfer over time and ride measurements over time will provide a real-life evaluation of the suitability of the anchorage systems. The two adhesive methods with comparatively lower performance included the method using no grout for repairs and the grout-dip method. The grout-dip method proved to underperform. From Table 1, the three locations that used the non-shrink grout with the dip application method, numbers 31, 32, and 40, all exhibited low uniformity and poor consolidation. It seems grouts perform better than epoxies in general. The application of a ring or collar may be used if it does not obliterate the grout application process. So far, it did not seem advantageous in ensuring a uniform annular ring around the dowels based on the qualitative/quantitative evaluations performed. For all intents and purposes, the grouts and epoxies used in the network represented in this study all seemed to meet some minimum expectations.

While it was challenging for the evaluation methods used to clearly categorize the materials in order of performance, it showed advantages of cleaning the drill hole prior to dowel placement as well as the merits and demerits of using a retaining collar. Results generally suggested the need for an actual deployment research project on an actual pavement in real time.

5.2 Recommendations

Without field evaluations, this study is not sufficient to be used for any major decision making regarding anchorage materials categorization. A validation experiment in real time will better represent the actual relative performance of the anchorage materials and systems. The deployment experiment was conducted, and the results are detailed in a separate report.

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APPENDIX A COLLAGE OF EXPOSED FACES WITH DOWEL

APPENDIX 1 Pictured Results of all 41 Adhesive Sample Test Holes

Adhesive Sample Test Hole **#1** - Epoxy Dowel Bar Rotating Together Mixing Process

Adhesive Sample Test Hole **#2** - Epoxy Dowel Bar Rotating Together Mixing Process

Adhesive Sample Test Hole **#3** - Single Dip Two Part Epoxy / Hand Mixed

Adhesive Sample Test Hole **#4** - Single Dip Two Part Epoxy / Hand Mixed

Adhesive Sample Test Hole **#5** - Double Dip Two Part Epoxy / Hand Mixed

Adhesive Sample Test Hole **#6** - Double Dip Two Part Epoxy / Hand Mixed

Adhesive Sample Test Hole **#7** – Non-Shrink Grout, used past recommended application time

Adhesive Sample Test Hole **#8** - Non-Shrink Grout, used past recommended application time

Adhesive Sample Test Hole **#9** - Epoxy filled hole

Adhesive Sample Test Hole **#10** - Epoxy filled hole

Adhesive Sample Test Hole **#11** - Epoxy filled hole and applied bead of epoxy to dowel

Adhesive Sample Test Hole **#12** - Epoxy filled hole and applied bead of epoxy to dowel

Adhesive Sample Test Hole **#13** - Epoxy filled hole and applied bead of epoxy to dowel

Adhesive Sample Test Hole **#14** - Epoxy filled hole and applied bead of epoxy to dowel

Adhesive Sample Test Hole **#15** - Epoxy filled hole and applied bead of epoxy to dowel

Adhesive Sample Test Hole **#16** - Epoxy filled hole and applied bead of epoxy to dowel

Adhesive Sample Test Hole **#17** - Epoxy filled hole and applied bead of epoxy to dowel

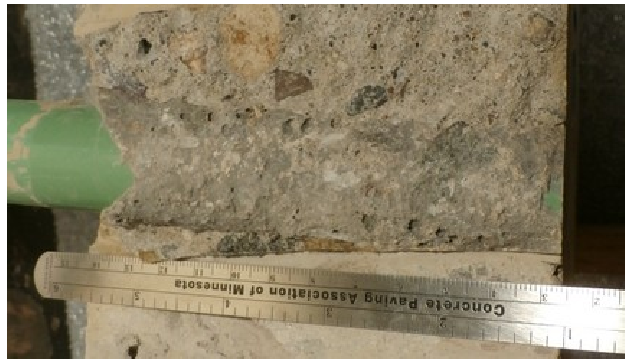
Adhesive Sample Test Hole **#18** - Epoxy filled hole and applied bead of epoxy to dowel


Adhesive Sample Test Hole **#19** - Epoxy filled hole and applied bead of epoxy to dowel




Adhesive Sample Test Hole **#20** - Epoxy filled hole and applied bead of epoxy to dowel





Adhesive Sample Test Hole **#21** - Poly-Grip is a two-component epoxy – 25 ‘Pumps’ of adhesive


Adhesive Sample Test Hole **#22** - Poly-Grip is a two-component epoxy – 20 ‘Pumps’ of adhesive


Adhesive Sample Test Hole **#23** - Poly-Grip is a two-component epoxy – 20 ‘Pumps’ of adhesive

Adhesive Sample Test Hole **#24** - Poly-Grip is a two-component epoxy – 20 ‘Pumps’ of adhesive

Adhesive Sample Test Hole **#25** - Cementitious Anchoring Capsule Grout

Adhesive Sample Test Hole **#26** - Cementitious Anchoring Capsule Grout

Adhesive Sample Test Hole **#27** - Cementitious Anchoring Capsule Grout

Adhesive Sample Test Hole **#28** - Cementitious Anchoring Capsule Grout

Adhesive Sample Test Hole **#29** - Cementitious Anchoring Capsule Grout

Adhesive Sample Test Hole **#30** - Cementitious Anchoring Capsule Grout

Adhesive Sample Test Hole **#31** – Non-Shrink Grout

Adhesive Sample Test Hole **#32** – Non-Shrink Grout

Adhesive Sample Test Hole **#33** – Non-Shrink Grout

Adhesive Sample Test Hole **#34** – Non-Shrink Grout

Adhesive Sample Test Hole #35 – Non-Shrink Grout

Adhesive Sample Test Hole #36 – Non-Shrink Grout

Adhesive Sample Test Hole **#37** – Non-Shrink Grout

Adhesive Sample Test Hole **#38** – Non-Shrink Grout

Adhesive Sample Test Hole **#39** – Non-Shrink Grout

Adhesive Sample Test Hole **#40** – Non-Shrink Grout in combination

with Single Dip Two Part Epoxy, Hand Mixed

Adhesive Sample Test Hole **#41** – Non-Shrink Grout