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Evaluation of Tie-Bar Anchoring Methods: Non-Shrink Grout vs. Epoxy

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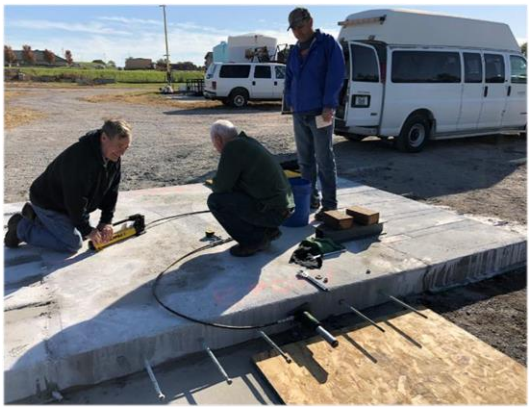

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Background

Tie bars are epoxy coated steel bars that connect the longitudinal joints in concrete pavement. Tie bars prevent faulting and joint separation between lanes Tie bars can be placed into the plastic concrete or inserted after curing by drilling and anchoring with epoxy or non-shrink grout. The specification for the tie bars requires the use of a No. 5 bar, 18 inches long and shall meet ASTM A775 / A775M [1], Section 1020.The Nebraska Department of Transportation "Standard Specifications for Highway Construction," (Section 603.03) requires contractors to mechanically insert tie bars into the face of pavements during construction. Tie bars are also used during the construction of pavement repairs.

In 2015, Nebraska Department of Transportation Materials & Research Divisions (M&R) conducted research to determine the best method for inserting tie-bars. In the study, M&R conducted a survey to evaluate placement and testing requirements of other agencies, and compared different methods and materials for installing tie-bars. The materials for anchoring tie-bars were not investigated.

Purpose of the Investigation

NDOT materials engineers observed during pavement repairs (PR) that tie-bars placed with non-shrink grout exhibited poor strength when pulled M&R engineers launched an investigation into the strength of non-shrink grout and epoxy anchored tie-bars in PR projects. The purpose of this investigation was to verify whether or not non-shrink grout provides suitable strength in repairs and provide a recommendation for construction specification.

Field Investigation (Test Methodology)

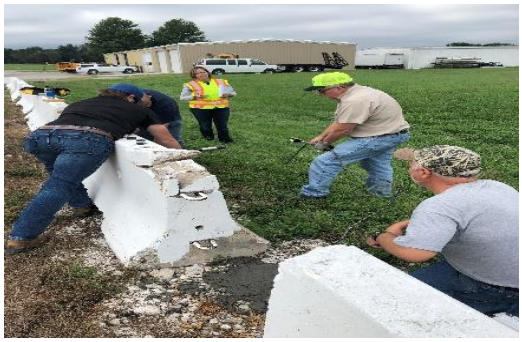

Figure 2 - Physical Tests technicians perform the pull-out test. Tie-bars were inserted into concrete barriers to determine the strength of non-shrink grout.

NDOT researchers designed two tests to meet the research objective. The first test involved drilling holes in Jersey barrier, anchoring tie-bars with non-shrink grout, then testing at 4 and 8 hours, shown in Figure 1. Technicians cleaned the drilled holes differently to determine if the preparation would impact the strength of the grout. The three ways of cleaning were no cleaning, cleaning with compressed air, and cleaning with a wire brush and compressed air. During this phase of the testing, researchers discovered that regardless of drilled-hole preparation, required strength of 12,000 lbs. was not achieved. Figure 2 shows the tie bar pulling from the barrier before achieving required strength. All the pull-out testing will be evaluated in accordance of the strength of anchors in concrete Elements ASTM E 488 [2].

Figure 1 - A tie-bar pulled from the barrier. Grout can be seen on the bar after pulling from the barrier.

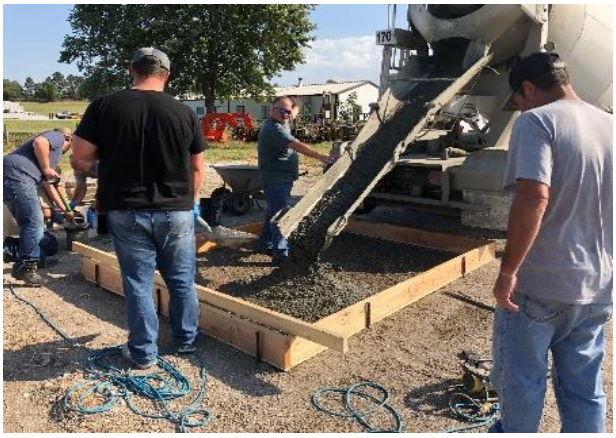

Figure 3 - Casting the 6' x 6' slab with 47BD concrete Salt Valley's maintenance yard

Following the barrier drilled-hole test, researchers started another field test to assess the epoxy and non-shrink grout strength on an in-house designed pavement repair test slab. First, a 6 x 6 foot concrete slab was cast using State of Nebraska 47BD mix design, shown in Figure 3. The concrete was finished by NDOT technicians and cured with white-pigment. The slab was cured in the field for 28 days, then was prepared for tie-bar placement by drilling six 8.5-inch deep holes on all four sides of the slab with a total of 24 drilled holes.

Two lengths (18-inch and 6-foot) of #5 tie-bars were anchored in the 24 drilled holes of the slab. Six 18-inch and six 6-foot bars were secured using non-shrink grout. The remaining twelve bars, six of each length, were secured using Simpson StrongTie ET-HP epoxy.

All bars were left exposed on the ends. The 6-foot bars were secured in a form with a smooth plastic liner on the bottom. Engineers designed foam blocks to serve as a buffer between the saw blade and the 47BD slab. Then PR concrete was cast around the bars and cured with white pigment. Figure 4. shows the 47BD slab with tie-bars anchored and secured forms before placing PR concrete.

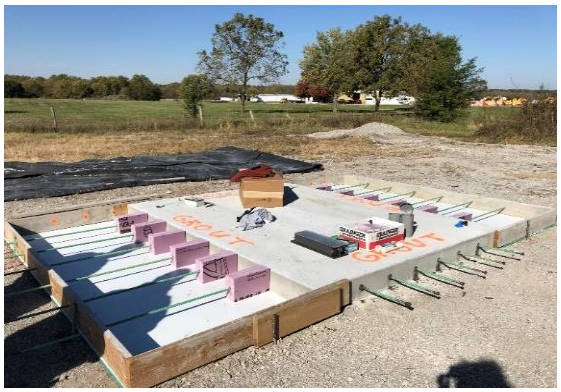

Figure 4 - The research slab awaiting placement of PR concrete. 18-inch bars were left exposed, while the 6-foot bars were embedded in the PR concrete. The pink foam inserts serve as a buffer to prevent sawing into the 47BD slab.

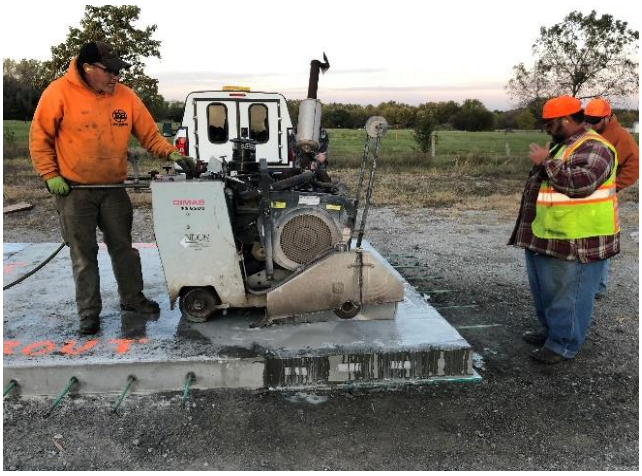

Figure 4 - The Salt Valley maintenance crew sawed through the thickness of the PR slab. Foam inserts prevented cutting into the 47BD slab.

Approximately 18 hours after placement, NDOT Salt Valley Maintenance crew sawed through the thickness of the PR pavement, shown in Figure5. The foam blocks served as a buffer between the saw blade and the 47BD slab because cutting into the 47BD slab would weaken the concrete around the tie-bar.

The original test planned for sawing through the PR concrete on both sides of each 6-ft. bar; however, one bar fixed with epoxy and one bar fixed with grout could not be sawn because the saw would not fit on the slab to make those cuts.

After sawing, the NDOT Physical Tests Lab conducted pull-out testing on the 18-in. bars anchored in the 47BD concrete. Physical Tests pulled three 18-in. bars fixed with epoxy at 24-hrs and three 18-in. bars fixed with non-shrink grout at both 24-hrs and 96-hrs, as shown in Figure 6.
All of the epoxy bars tested at 24-hrs exceeded the required strength of 12,000 pounds. Therefore, the epoxy was not tested at 96-hrs.

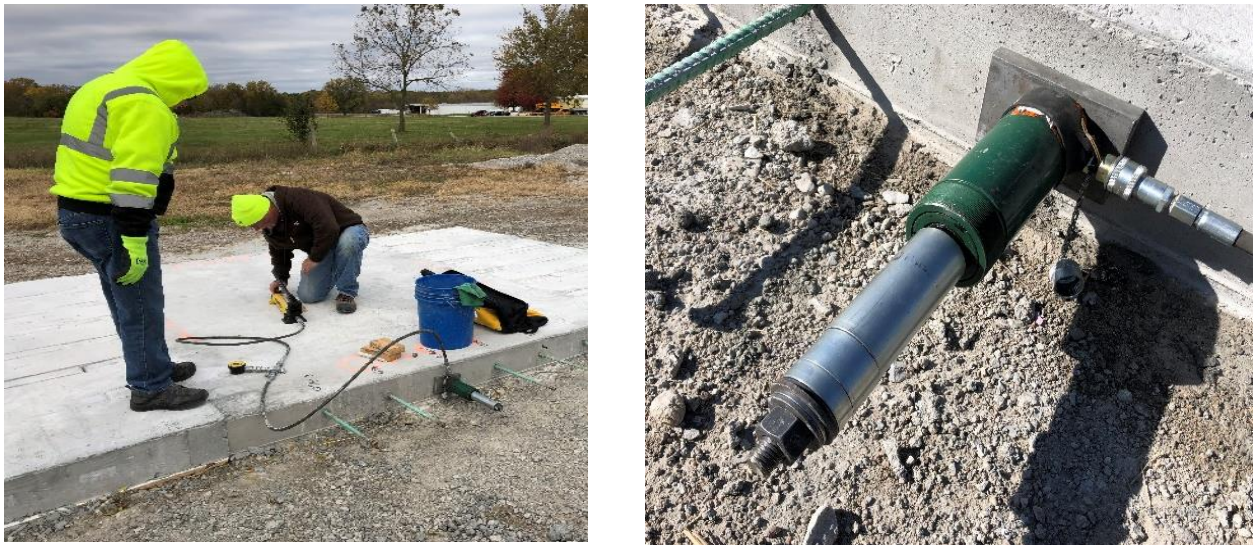

Figure 5 - Physical tests technicians operate the 12-ton hole-ram (left). The tie-bars are threaded so the ram can be fastened to the rebar. The ram is ready for testing (right).

The 6-ft. bars embedded in PR concrete were tested at 24-hrs and 96-hrs after anchoring the tie bars. Technicians pulled three of the 6-ft. bars anchored with epoxy at 24-hrs. The 6-ft. bars exceeded the required strength of 12,000 pounds, therefore the testing at 96-hrs did not occur. During the epoxy pulls, researchers observed cracking in the PR concrete. These cracks developed roughly between 3,000 and 4,000 psi as shown in Figure 7. This was caused by the elongation of the bar as it was loaded. The researchers observed no failure in the bond.

Three of the 6-ft. bars secured with grout were pulled at 24-hrs and two were pulled at 96-hrs. The three bars pulled at 24-hrs all failed at the grout bond with relatively low strengths. A slight increase in strength was observed over the 18-in. bar results. The strength gain was most likely caused by the ram pulling additional mass and overcoming the friction between the PR concrete and the smooth plastic the concrete was placed over.

Results

The testing performed at Jersey barrier using non-shrink grout failed to achieve the required 12,000 lbs. of strength. The results of the 2-tests and 6-hour tests are shown in Table 1.

Table 1 - Jersey Barrier Testing – Non-shrink Grout.

Jersey Barrier Testing – Non-shrink Grout			
Cleaning Method	**Time**	**Load (psi)**	**Strength (lbs.)**
None	10:00 am	7.0	16.5
	2:00 pm	8.0	18.9
Compressed Air	10:10 am	8.0	18.9
	2:05 pm	12.0	28.3
Brushed/Compressed Air	10:15 am	8.0	18.9
	2:10 pm	20.0	47.2

The pull-out tests on the 18-in. bars fixed with epoxy showed that epoxy adequately achieved the required strength at 24-hours. The pulls on the PR-embedded bars also achieved the required strength by 24-hours. In these specimens, the concrete failed before the epoxy bond shown in Figure 7. The epoxy was not tested at 96-hours as the epoxy specimens maxed out the testing equipment. Strengths are shown in Table 2.

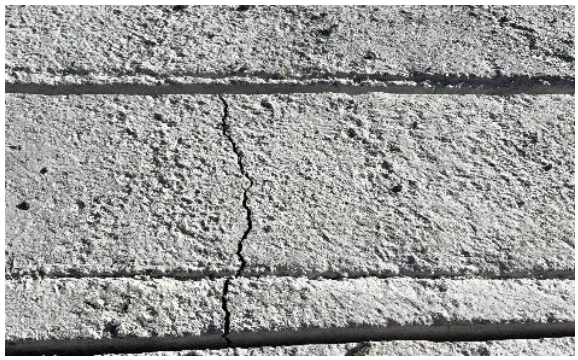

Figure 6 - PR concrete with embedded cracked during the pull testing.

Table 2 - Epoxy strength results at 24 hours.

EPOXY - Simpson Strong-Tie ET-HP - 24 hr. pulls					
	Bar #	**Load (psi)**	**Strength (lbs.)**	**Observations**	
18" Rebar	1	9,558	22,557	No signs of bond breakage. Thread stripped, nut popped off.	
	2	9,045	21,346	No signs of bond breakage. Stopped due to equipment max. hose pressure of 10,000 psi	
	3	9,065	21,393	No signs of bond breakage. Stopped due to equipment max. hose pressure of 10,000 psi	
6' Rebar	1	6,483	15,300	No signs of bond breakage. Nut popped off.	Concrete cracked at 3,980 psi.
	2	9,033	21,318	No signs of bond breakage. Stopped	Concrete cracked at 3,360 psi.
	3	9,082	21,434	No signs of bond breakage. Stopped	Concrete cracked at 4,000 psi.

The non-shrink grout pull-out tests were conducted at 24-hours and 96-hours. The results for the tests are shown in Tables 3 and 4. All of the grout samples de-bonded at strengths below the required 12,000 lbs.

Table 3 - Non-shrink grout strengths at 24 hours.

Non-Shrink Grout - 24 hr. pulls				
	Bar #	**Load (psi)**	**Strength (lbs.)**	**Observations**
18" Rebar	1	270	637	-
	2	328	774	-
	3	403	951	-
6' Rebar	1	1,540	3,634	Higher strengths likely due to pulling mass of concrete and overcoming friction.
	2	1,070	2,525	Higher strengths likely due to pulling mass of concrete and overcoming friction.
	3	818	1,930	Higher strengths likely due to pulling mass of concrete and overcoming friction.

Table 4 - Non-shrink grout strengths at 96 hours.

Non-Shrink Grout - 96 hr. pulls				
	Bar #	**Load (psi)**	**Strength (lbs.)**	**Observations**
18" Rebar	1	424	1,001	
	2	1,215	2,867	
	3	1,070	2,525	
6' Rebar	1*	8,340	19,682	Concrete cracked, (bar elongation). Pulled concrete from the main slab.
	2	1,964	4,635	Bond failed. No cracking.
	3	-	-	-

**the strength for the 1st test at 96 hrs is unlikely high. Rather, the saw cuts for this bar likely did not go through the thickness of the slab.*

Conclusions and Recommendations

Based on the results of the pull-out testing, NDOT will require epoxy to be used when inserting tie-bars in drilled-holes for both new construction and pavement repairs.

Acknowledgements

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References

[1] ASTM A775 / A775M, “Standard Specification for Epoxy-Coated Steel Reinforcing Bars” ASTM International, www.astm.org
[2] ASTM E 488, “Standard Test Methods for Strength of Anchors in Concrete Elements” ASTM International, www.astm.org