Field Applications of In-Situ Tensile Pull-Off Tests

By Bruce A. Collins

The International Concrete Repair Institute (ICRI) has recently published Technical Guideline No. 03739, "Guide to Using In-Situ Tensile Pull-Off Tests to Evaluate Bond of Concrete Surface Materials." Like most ICRI documents, this one went through numerous iterations prior to consensus ICRI approval. These iterations were mainly due to the large number of variables that affect concrete-to-concrete bond strength and our ability to control and measure these variables. The industry currently does not have a means for predicting bond strength. We have been relegated to measuring the tensile strength of the concrete substrate prior to application and curing of the repair material. Subsequent bond tests are compared with the substrate strength. The guideline identifies important testing variables and conditions.

The Army Corps of Engineers has also published information of bond strength equipment and methods in *REMR Bulletin* REMR-CS-61, "An Evaluation of Equipment and Procedures for Tensile Bond Testing of Concrete Repairs." The ICRI guideline, some ACI standards, and the *REMR Bulletin* are all good sources of information about this test procedure. And while the ICRI document represents the best consensus among our members, the industry is still gathering data about how to measure bond strength and how to interpret this data. ICRI understands that our published guidelines may need to evolve as the repair industry learns and grows (this is why we have a standard policy for review and potential revision of our published documents).

Having more data on field applications of this test will enable a stronger review by the committee responsible for the guideline. To this end, Restruction Corporation, a longtime member of ICRI that understands the importance of the tensile bond test and has used it successfully in several concrete repair projects, has collected the following data.

Concrete Repair of Wastewater Plant Chlorine Contact Basin

A 109 x 20 ft (33 x 6 m) reinforced concrete chlorine contact basin with 9 ft (3 m) high concrete baffle wall was deteriorating due to freezing-and-thawing cycles. The baffle walls were spaced at 7.33 ft (2.23 m) intervals and staggered left to right down the north-south length of the basin. The baffle walls were used to impede the water flow, mixing the water and interjected chlorine. Due to fluctuating water depths, the baffle and basin walls were deteriorated over approximately 67% of their surface. A total quantity of 445 ft^3 (12.6 m^3) of concrete removal and replacement was bid. The basin floor was not affected. Repair specifications and drawings were produced by an independent engineering firm and included the use of tensile bond strength testing. Three mock-up repair locations were prepared in August 2002. Concrete removal to a depth of 1.5 in. (3.8 cm) was completed using a 15 lb chipping hammer. Surface preparation by dry sandblasting and 3000 psi (20.7 MPa) water wash was also completed. Tensile pull-off testing was completed on the prepared concrete substrate. A

Table 1: Repair mock-up tensile bond tests for concrete contact basin

Date	Location no.	Prepared substrate pull-off value	Prepared surface failure mode	Repaired surface bond strength	Repaired surface failure mode
8/19/02	1	404 psi (2.78 MPa)	50% at disk/epoxy 50% at epoxy/concrete	291 psi (2.01 MPa)	ICRI Mode 2
8/19/02	2	155 psi (1.07 MPa)	100% concrete substrate	197 psi (1.36 MPa)	85% ICRI Mode 2 15% ICRI Mode 6
8/19/02	3	163 psi (1.12 MPa)	100% at epoxy/concrete	137 psi (0.94 MPa)	100% ICRI Mode 6

prepackaged dry-mix shotcrete material was applied using a Ridley C-9 shotcrete gun. The shotcrete was air cured for 7 calendar days. The same testing company, using the same equipment, took three tensile bond tests directly next to the substrate tests. The specification required a tensile bond value of 250 psi (1.72 MPa). The results are shown in Table 1.

The average bond strength of the trials was 208 psi (1.43 MPa). The mock-up test results were accepted for several reasons. One bond value was measured at 291 psi (2.01 MPa), which is greater than the specified value. The second bond value of 197 psi (1.36 MPa) was below specifications but was higher than the tensile capacity of the prepared surface and predominantly failed in the repair material (85% Mode 2). The third bond test measured at 137 psi (0.94 MPa) and was below the prepared surface tensile value of 163 psi (1.12 MPa). The failure, however, was 100% located in the prepared surface concrete (ICRI Failure Mode 6). While a matter of concern, this test was also accepted due to the failure mode. The project was allowed to continue without changing the specification value. The project team, however, determined that additional tests taken in the full production repair areas would be required. The results for these additional tests are shown in Table 2.

Test Location 4, measured at 196 psi (1.35 MPa) bond strength, was below specification but significantly above the concrete substrate tensile strength of 111 psi (0.76 MPa). The failure mode, described by the testing agency, indicates that this was an excellent test of bond strength. Photographs were not taken to document these results. Test Location 5 had a similar outcome to Test Location 4. Test Location 5 failed 100% within the concrete substrate (ICRI Failure Mode 6). Both test Locations 4 and 5 were accepted. Test Location 6 bond strength was measured at 211 psi (1.45 MPa), only slightly above the 206 psi (1.42 MPa) prepared surface tensile strength. Test Location 6 bond strength was accepted and finalized the emerging pattern of project bond strength. Test Locations 7, 8, and 9 bond strengths were not only below specifications but also below their partner prepared concrete substrate tensile value. Each bond strength, however, was described at 100% in the prepared concrete substrate. (ICRI Failure Mode 6). The bond strength values for each test were at or above the project average. All tests were accepted and the project was deemed a success.

Folded Roof Plate Concrete Repair

A warehouse building with a reinforced concrete, folded roof plate was burned in an industrial fire. The fire affected 7140 ft^2 (660 m^2) of the 48,640 ft^2 (4518 m^2) roof. The roof plate slab was measured as 3.5 in. (8.9 cm) thick. No original construction drawings were found. Pachometer readings and some minor concrete excavations were used to find and map the roof reinforcing steel. It was determined that the reinforcing steel bond to the concrete had been affected by the fire. The project structural engineer needed to reestablish this bond to restore the structural integrity. Hydrodemolition of 1.5 in. (3.8 cm) of concrete followed by wet-mix shotcrete repair material was proposed. Mock-ups of the proposed repair system, including tensile bond strength testing, were required prior to acceptance. Six tensile pull values of unburned roof concrete were taken in two separate locations. The results are shown in Table 3.

The average tensile strength of the unburned concrete is 180 psi (1.24 MPa) if the 78 psi (0.54 MPa) test is removed from the sample. Two surface preparation areas were selected and a 20,000 psi (138 MPa) low volume hydrodemolition wand was used to remove 1.5 in. of burned concrete. One tensile strength pull test of the prepared concrete substrate was taken in each hydrodemolition test area. The results are shown in Table 4.

Table 2: Full production tensile bond tests for concrete contact basin

Date	Location no.	Prepared substrate pull-off value	Prepared surface failure mode	Repaired surface bond strength	Repaired surface failure mode
10/1/02	4	111 psi (0.76 MPa)	70% at epoxy/concrete 30% at concrete substrate	196 psi (1.35 MPa)	60% ICRI Mode 6
10/1/02	5	135 psi (0.93 MPa)	95% at epoxy/concrete 5% at concrete substrate	173 psi (1.19 MPa)	100% ICRI Mode 6
10/1/02	6	206 psi (1.42 MPa)	95% at epoxy/concrete 5% at concrete substrate	211 psi (1.45 MPa)	90% ICRI Mode 6 10% ICRI Mode 3
10/10/02	7	217 psi (1.50 MPa)	100% concrete substrate	184 psi (1.27 MPa)	100% ICRI Mode 6
10/10/02	8	232 psi (1.60 MPa)	75% epoxy/concrete 25% concrete substrate	171 psi (1.18 MPa)	100% ICRI Mode 6
10/10/02	9	249 psi (1.72 MPa)	60% epoxy/concrete 40% concrete substrate	244 psi (1.68 MPa)	100% ICRI Mode 6

The results indicate that the hydrodemolition surface preparation did not lower (microfracture) the tensile strength of the concrete substrate. Shotcrete was applied to the mock-up locations and allowed to cure for 7 calendar days. Longer cure times were contemplated. Due to owner requirements, however, 7 days were used for the testing. Nine total bond strength tests were taken, three tests in each of three mock-up locations. The results are shown in Table 5.

The average bond strength is 234.6 psi (1.62 MPa). The bond strength was accepted and full-scale repairs were completed.

Conclusions

I will not try to provide conclusions the project teams deduced from these individual projects. Instead, I choose to allow you, the reader, to study the information provided and draw your own conclusions, as if these projects were your own. It is the intention of the ICRI committee that produced Technical Guideline No. 03739, "Guide to Using In-Situ Tensile Pull-Off Tests to Evaluate Bond of Concrete Surface Materials," that project teams and individuals draw conclusions based upon their project data, using the guide.

Currently, the industry does not have a standard method to predict values for direct tensile strength of concrete. I believe our industry will evolve until a value can be predicted. The guideline recommends use of prepared concrete substrate tests prior to bond tests. I would also like to recommend, where possible, tensile testing of the original concrete prior to concrete removal or surface preparation. This may allow you to determine the effect on bond the removal tool creates. Additionally, some projects require higher bond strengths. For instance, should the bond strength of the folded roof plate slab be higher than repairs made to walls of the contact basin? Chapter 3 of the ICRI guideline discusses equipment and material requirements.

Some commercially available testers cannot measure vertical repairs. Some projects may not allow for core drilling to the recommended depths. What effect does this have on measured bond strength? The *REMR Bulletin* tested and reported on this condition, and the ICRI guideline addresses some of these concerns as well. To facilitate a meaningful review of this guideline, ICRI asks you to implement Technical Guideline No. 03739, record, and send the results of your field trials to Kelly Page at the ICRI Headquarters. She will then pass them on to the Evaluation Committee for discussion and use in review. The industry will benefit from this sharing of data.

Table 3: Tensile pull-off values of unburned original concrete

Location	Test no.	Tensile failure strength of unburned concrete
1	1	185 psi (1.28 MPa)
1	2	263 psi (1.81 MPa)
1	3	148 psi (1.02 MPa)
Average		**199 psi (1.37 MPa)**
2	1	78 psi (0.54 MPa)
2	2	171 psi (1.18 MPa)
2	3	132 psi (0.91 MPa)
Average		**127 psi (0.88 MPa)**

Table 4: Tensile pull-off value of hydrodemolition prepared burned concrete area

Test no.	Tensile strength of prepared concrete substrate
1	212 psi (1.46 MPa)
2	172 psi (1.19 MPa)
Average	**192 psi (1.32 MPa)**

Table 5: Tensile pull-off values for repaired mock-up locations

Location	Test no.	Bond strength	Failure
1	1	239 psi (1.65 MPa)	ICRI Mode 2
1	2	363 psi (2.50 MPa)	ICRI Mode 2
1	3	115 psi (0.79 MPa)	ICRI Mode 6
2	1	237 psi (1.63 MPa)	ICRI Mode 2
2	2	130 psi (0.90 MPa)	ICRI Mode 3
2	3	364 psi (2.51 MPa)	ICRI Mode 2
3	1	197 psi (1.36 MPa)	ICRI Mode 2
3	2	Not reported	ICRI Mode 2
3	3	236 psi (1.63 MPa)	ICRI Mode 6

This Viewpoint article has been selected by the editors as an offering to the interest of our readers. However, the opinions given are not necessarily those of the International Concrete Repair Institute or of the editors of this magazine. Reader comment is invited.

***Bruce A. Collins**, a Fellow of ICRI, is Vice President of Business Development at Restruction Corporation, Sedalia, Colorado. Collins has been active in ICRI for many years. He has served on the Board of Directors and is currently a member of the Technical Activities Committee. Collins is also a member of ACI and a speaker for their Concrete Repair Basics and Concrete Repair Workshop Seminars.*