United States Department of the Interior

BUREAU OF RECLAMATION
P.O. Box 25007
Denver, Colorado 80225-0007

IN REPLY REFER TO:

86-68180
PRJ-8.10

Sept 30, 2009

MEMORANDUM

To: Lisa Krosley, Program Manager, 84-44000

From: Kurt F. von Fay, Civil Engineer

Subject: Report of Findings, Laboratory Evaluation of Concrete Thin Repair Materials – Yellowtail Dam Spillway Tunnel Repairs - Yellowtail Unit, Lower Bighorn Division, Pick-Sloan Missouri Basin Program, Montana

Materials Engineering and Research Laboratory Report No. MERL-2009-36

Introduction

The Materials Engineering and Research Laboratory (MERL) selected 8 concrete repair materials, out of a group of over 20, to evaluate for use to make concrete repairs to the flow surfaces of the Yellowtail Dam Spillway Tunnel.

During an inspection of the tunnel conducted in July of 2006, damage to the concrete tunnel lining was noted. A follow up exam was performed in March of 2007 to specifically look at the damaged concrete to see if further investigations were needed to confirm cause and extent of damage. The damage appeared to be mostly surficial and isolated, and not related to any active concrete deterioration mechanism. Overall concrete quality appeared to be good.

However, because some of the concrete surface defects were in areas of potential high velocity flows, there was concern that the defects might be a cause for cavitation damage in the event of a spill. Based on the concern about cavitation, the decision was made to perform repairs in April, 2007. The decision included provisions to limit the amount of sound concrete removal prior to repairs, as would be the standard recommendation based on Reclamation's M-47, "Standard Specification for the Repair of Concrete". In addition, the placement conditions were difficult, with cold temperatures (about 40 to 50 deg. F), wet surfaces, flowing water, and steep slopes.

Based on results from an initial study, a more thorough program was proposed to the Dam Safety Technology Development Program and was approved. Further testing was designed to more fully evaluate a wider range of thin repair products.

Work started in December, 2007. The bulk of the testing was completed in July of 2008. Based on results from that work, one material was recommended for use at Yellowtail.

Conclusions

1. Conpro Set, manufactured by Conproco, Inc. was recommended for use to repair shallow spalls on the spillway flow surfaces at Yellowtail Dam.

2. Over thirty vendors of concrete thin repair products were contacted, in addition to Reclamation O&M staff, and staff at other water management agencies. They were given a short write-up on the needs for the project and a description of the service conditions.

3. That work resulted in 29 product recommendations. Based on product data supplied by repair material vendors, not all of the products were evaluated. Eight products were selected for evaluation.

4. Products were evaluated using ASTM and other tests. The Bond Strength test was modified by placing repair materials on wet, cold surfaces to match field conditions. In addition, a special test was used that modeled placement conditions – wet surfaces and flowing water.

5. Due to the difficult placement conditions, and the overall success rate of thin repair materials experienced at Reclamation facilities (estimated to be about 50% failure rate within 5 years), the performance of the repairs needs to be monitored.

Discussion

The Yellowtail Dam Spillway Tunnel is located in the left abutment of the dam and consists of an approach channel, an intake and control section including gates and hoists, a bridge, a concrete lined tunnel through the rock of the left abutment, and a combined stilling basin and flip-bucket structure. Discharge through the spillway is controlled by two 25-foot-wide by 64.4-foot-high radial gates with a total capacity of 92,000 cfs at reservoir elevation 3,660.0 feet. Downstream of the crest structure, the spillway transitions from a concrete lined sloping tunnel 40.5 feet in diameter into a 32-foot-diameter horizontal concrete lined tunnel and then into a stilling basin. The spillway crest elevation is 3,593.0 feet.

Because of the characteristics of the tunnel, certain portions are susceptible to cavitation damage when water is spilling. To ensure that the tunnel lining is in satisfactory condition in susceptible areas, the tunnel is inspected. Examinations have been routinely conducted to inspect the tunnel.

Based on recent inspections, concerns were raised about concrete quality in areas that might be subjected to high velocity flows. A follow-up inspection was performed which included a concrete specialists from the TSC. The purpose of the inspection was to examine the concrete damage, and to possibly select concrete core locations for further analysis if that was determined to be necessary.

Areas of concrete damage were observed that needed repairs, but the overall quality of the concrete was determined to be satisfactory, and no core sampling was necessary. Many of the observed areas of concern were determined to be related to the thin epoxy mortars that were applied during previous repair activities.

During a series of meetings concerning the spall repairs, the decision was made to only remove loose material, and not to excavate to a minimum of 1 ½ inches depth, which would typically be required for thin repairs. There was concern that because of the difficult working and repair material placement conditions (steep slopes, cold temperatures, wet concrete, and flowing water), there was a reasonable chance that deeper repairs might become unbonded, and leave holes that were much deeper than the allowable tolerances.

Since it became apparent that there were not any readily available repair materials for use in applications like those at Yellowtail, and because of Reclamation's needs for a repair material that would work well in those conditions, a more thorough testing program was proposed. The key elements of that proposal were to:

1. Conduct a literature search to see if others had used repair materials in similar circumstances.
2. Conduct an extensive review of available repair materials
3. Contact vendors of repair materials to get their suggestions for possible materials
4. Contact Reclamation O&M staff to get information from them on materials they may have used and had success
5. Review the data sheets for suggested repair materials
6. Select candidate materials for a laboratory evaluation program
7. Recommend one or more repair material for use at Yellowtail for the next round of repairs that were performed in September, 2008.

When vendors, other agencies, and O&M personnel were contacted to suggest a repair material for BOR to evaluate, they were provided with a description of the placement and exposure conditions expected at Yellowtail. An example of the description is included below.

> *"The Bureau of Reclamation is seeking a concrete repair material to evaluate in a testing program. The repair material should be capable of bonding to a damp, steep, cold surface, and cure relatively quickly. The defects being repaired are small spalls (about 1-ft square) and aggregate popouts about 1-inch deep. As far as we know, the damage is not the result of an active deterioration mechanism, but just damage resulting from some poor quality areas and damage from falling debris, etc. These repairs are to flow surfaces that can see very high velocity water flows, so are subject to cavitation, and will see freezing and thawing weather.*
>
> *If you have any suggestions for concrete repair materials that we should evaluate for this purpose, please let me know."*

The program was conducted in 2 phases – a material selection phase and a material testing phase.

Material Selection

This part of the program was comprised of the first 6 steps of the proposal. Results from the literature search indicated that concrete thin repair materials were occasionally tested by various municipalities and government agencies and results reported. However, many of the reports were several years old, and none were for materials that were used in circumstances similar to those at Yellowtail.

While conducting the literature search, an extensive search was conducted to find candidate repair materials. An internet search was performed, Reclamation O&M personnel were contacted, other water management agencies were contacted, and 2 industry trade groups were contacted. As a result if these efforts, over thirty vendors were contacted. The full list is shown in Appendix A.

The various venders ended up recommending a total of 29 products to consider. A complete list of all the product recommendations is shown in Appendix A. From that list, 22 products were selected for more thorough consideration (Appendix B). After reviewing material data on those 22 repair materials, eight materials were selected for testing. Five of the materials were cementitious materials and 3 were epoxy mortar repair materials.

Testing Program

It was not clear from any of the supplied data from the repair material manufacturers how well the repair materials might perform in the application at Yellowtail. Because of this, a testing program was started. Appendix C describes the tests that were performed.

The test program was constructed to help select a thin repair material that would have a high likelihood of success under the placement and exposure conditions at Yellowtail. The performance of thin repair materials has been hard to predict. Informal surveys of Operations and Maintenance personnel have indicated that many times the repairs occur relatively quickly, although some seem to last for many years. About half of thin concrete repairs have been estimated to fail within 5 years of application.

Many factors went into selecting repair materials to evaluate, including data from the suppliers, apparent ease of use, and expected performance. It was apparent that some recommended materials were not suitable for evaluation. For example, even though we told vendors that the repair material would be placed on a wet substrate, several vendors supplied information for materials that required application on dry substrates.

A summary was prepared listing all of the salient characteristics reported by the manufacturer of the suggested repair materials as they related to this program. Characteristics considered included substrate surface moisture requirement, minimum cure temperature, cure time, freeze/thaw performance, minimum/maximum thickness, horizontal/ vertical application, coefficient of thermal expansion, and compressive strength. Occasionally, follow-up information was requested from some manufacturers to clarify information.

After that review process was completed, 8 repair materials were selected to evaluate using the testing program we developed. A complete list of proposed tests to be performed is included in Appendix C.

Some of the standard ASTM tests were modified to more closely match placement conditions. For the bonding tests, a ½-inch thick patch was placed on a wet, cold substrate, and the repair material was cured in a 50 deg F cold room. Due to test equipment availability issues, the freezing and thawing tests and the coefficient of thermal expansion tests were not performed.

Table 1 summarizes the test results. Most results were within expected parameters. However, the Ico-Gel FC material was apparently formulated for much colder conditions, and it became quick hot and expanded in the test molds, so was evaluated using all the tests.

Table 1. – Test Results for Joint Sealant Studies

MATERIAL	CHEMISTRY	COMPRESSIVE STRENGTH, PSI, 7 /14/28 DAYS	SPLITTING TENSILE STRENGHT, PSI	BOND STRENGTH, PSI	ASTM C 884 CRACKING TEST
BASF 1060	Cementitious	7300/			
EcoCrete 451	Epoxy	9385/			None
Dayton Superior Perma Patch V/O	Cementitious	5960/			
Five Star Structural Concrete V/O	Cementitious	5450/			
International Coatings Ico-Gel FC	Epoxy	Not Tested	Not Tested	Not Tested	None
SikaRepair 224	Cementitious	9450/			
Belzona 4114	Epoxy	9390			None
Conproco Conpro Set	Cementitious	4230/			

Using results from this phase of the material testing, 4 materials were selected for a special screening test. Only cementitious materials were selected for this part of the testing program, since these materials were judged to be the easiest to mix and place under field conditions.

This test was developed to model placing the repair material on a wet, sloped concrete surface. The test used a platform that had cutouts designed such that the repair material would be placed in a cavity where the top edge was 1-inch deep, the bottom edge was ¼-inch deep and was 12-inches square. The platform was angled 55 degrees and a small stream of water running down over the repair areas. A picture of the test setup is shown below.

Figure 1. The testing apparatus shortly after all the materials were cast on the concrete substrates.

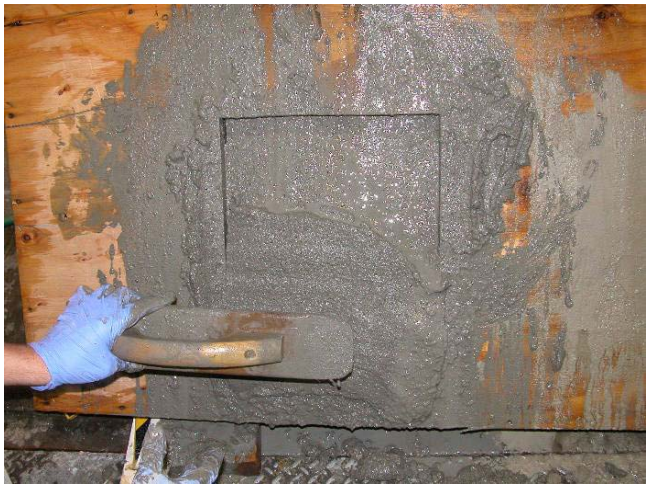
The repair materials were placed on a damp substrate and after smoothing with a float, water was allowed to slowly run over the repair material.

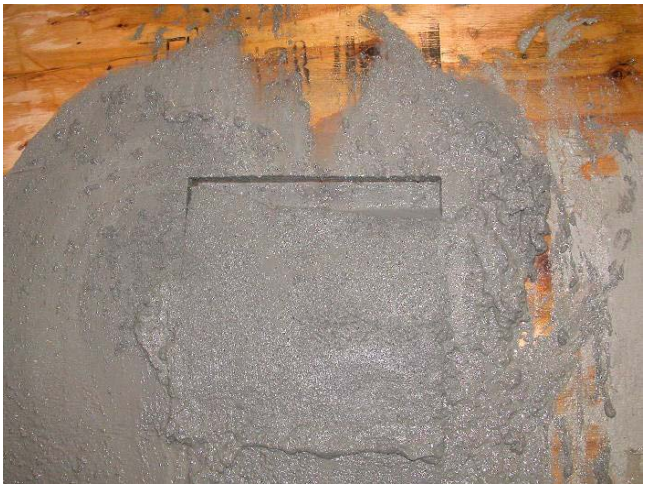
The four materials tested, applied in the order from left to right were:

Product Name	**Company**
Sika Repair 224	Sika Corporation
ConProSet	Conproco Corporation
10-60 Rapid Mortar	BASF Chemical Company
Five Star Structural Concrete	Five Star Products Inc.

Sika Repair 224

This material initially sagged after placement. When held in place with a wooden float, the material was able to bond and setup. After it was held in place the top edge still sagged down over an inch.

a) 

b) 

c) 

Figure 2. The Sika material a) sagging away after initial application, b) after being held in place for a short time, and c) after about 2 hours.

Conproco ConPro Set
This material setup and performed the best in this test. The top edge sagged down very little, but it never had to be held in place. There was a small amount of initial washout on the surface.

a) 

b) 

Figure 3. The ConproSet material a) after initial application and b) after about 2 hours.

BASF 1060
This material didn't bond or hold its structure. It sagged and ran down the slab as soon as it was applied and water came in contact with it. Trying to hold it in place with the float was not effective.

a) 

b) 

c) 

Figure 4. The BASF material a) when applied to the substrate, b) immediately sagging after the application, and c) completely sagged off a short time later.

Five Star Structural Concrete
This material sagged and didn't bond to the substrate. When held in place it still sagged after slightly setting up. When water ran down it after the structure setup, the slow stream of water eroded a path in the surface.

a) 

b) 

c) 

d) 

Figure 5. The Five-star material a) during application, b) sagging away after approximately one minute, c) the starting of erosion, and d) setting up.

Appendix A
Repair Material Vendors Contacted and Products Recommended

Vendor Name	Products Recommended
Woodbury Cement	No response
Edison Coatings	No response
Belzona	4111, 4131
Sak Crete	No response
McKinnon Materials	No response
CSS Corp	EcoCrete 451
CTS Cement	CementAll
True Bond	No response
Dayton Superior	Perma Patch VO
Concrete Mender	No response
BonStone	Last Patch Limestone, Fast Set Extreme
Sto Corp	No response
Five Star Products	Five Star Structural Concrete V/O
Kwik Bond	Kwik Bond, Kwik Flex
Enecon	DuraQuartz
Sider-Oxydor, Inc	Sider-Screed, Sider-Resin M50
CGM Building Products	No response
Lone Star Epoxies	CR-60
Epoxy.com	No response
MAPAEI	No response
BASF	10-60 Rapid Mortar, Emaco S88, Masterstop 1182
Unitex	Pro-Poxy 2500, heat to 130, add sand, 1 gal, send report
Euclid Chemical (also now TAMMS)	No response
WR Meadows	No response
Conproco	ConPro Set, Gun Shot LPS
Sika	SikaRepair 224, SikaRepair SHA, SikaSet Mortar, SikaLatex R
Quikcrete	Fast Set Repair Mortar
Garon Products	Arctic Freezite
Road Doctor	Flexset Rapid Concrete
FlexKrete	FlexKrete Texas
De Neef	None
USG	None
Henkel (Loctite)	Magna-Crete

Appendix A
Results of Preliminary Screening of Material Vendors and Products

BASF	10-60 Rapid Mortar
Bonstone	Fast-Set Extreme
Bonstone	Last Patch Limestone
Construction systems Supply	EcoCrete451fc
Dayton Superior	Civil / Structural VO
Encrete	Encrete Duraquartz
Five Star	Five Star Structural Concrete V/O
Garon	Artic Freezite
International Coationgs	Ico-Guard Liner FC
International Coationgs	Ico-Gell FC
Capital Industries	Kwik Flex
Lone Star Epoxies	CR-60
PTI	FlexCrete Rapid Concrete
FlexKrete	FlexCrete 102
Quikrete	Commercial Grade Fast Set
ThoRock	Sewer Guide TG Epoxy Liner
Sider Oxydro Inc.	Sider Screed
Sika	SikaLatexR
Sika	SikaRepair224
Unitex	Pro-Proxy 2500
Belzona	4111
Conproco	Conspro Set

Appendix C
Testing Program

Test Specimens for Bond Strength tests

1. Make 12 in. by 12 in. by 3-in. thick concrete base slabs (USBR 4031 – "Making and Curing Test Specimens in the Field")
2. Cure for 28 days in the fog room, then condition to 45 deg F
3. Sand blast surface and clean
4. Moisten slab surface just prior to repair material placement.
5. Place repair material on conditioned base slab — 3/4 to 1-inch thick.
6. Cure for 7 days
7. Perform Bond Strength tests (see below).

Test Specimens for Thermal Compatibility — ASTM C884 - "Standard Test Method for Thermal Compatibility between Concrete and an Epoxy Resin Overlay"

1. Make 12 in. by 12 in. by 3-in. thick concrete base slabs (USBR 4031 – "Making and Curing Test Specimens in the Field")
2. Cure for 28 days in the fog room, then condition to 45 deg F
3. Sand blast surface and clean
4. Moisten slab surface just prior to repair material placement.
5. Place repair material on conditioned base slab — 3/4 to 1-inch thick.
6. Cure for 7 days
7. Perform compatibility testing.

Test Specimens for Slopped/Wet Application

1. Place 12 in. by 12 in. by 3-in. thick concrete base slabs in wood frame angled to match spillway surface.
2. Adjust slab in frame such that the top of the slab is recessed about one inch from the wood surface and the bottom of the slab is recessed about1/4-inch deep.
3. Moisten slab surface just prior to repair material placement.
4. Adjust drip hose so there is slight water flow down the wood frames surface and onto the concrete slab.
5. Place repair material on conditioned base slab. Finish flush to wood frame surface.
6. Document placement performance.

Compressive strength

- Extended mortar and concrete—ASTM C 39: 3 x 6-in. (76 x 152-mm) cylinders.
- Cure specimens as stated above.

Modulus of elasticity—ASTM C 469

- Extended mortar and concrete—3 x 6-in. (76 x 152-mm) specimen.
- Cure specimens as stated above.

Bond Strength - ASTM C1583 – "Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)

- Use a concrete substrate of 4000 to 5000 psi (27.6-34.7 MPa) compressive strength and CSP #3 as defined by ICRI Guideline No. 03732, “Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays” for the substrate of the repair material application. Apply the repair material to the manufacturer’s recommended thickness (if a range of thicknesses, use the midpoint of the range) using the manufacturer’s recommendations for material mixing, placement, and curing.
- Report the failure mode for each specimen (i.e., cohesive or adhesive through material, at the bond line, or within the substrate). If mixed failure modes are found, report the percent adherence to each interface.

WBR: KvonFay:09/30/2009:303-445-2399

(H:\D8180\MERL Reports\2009\MERL-09-36\ThinRepairStudy.DOC)