Technical Brief

Southern Utah Engineering

Test Evalution of the StopCrackEX™ Process

FATIGUE TECHNOLOGY

DM #542282 August 2011 v3.0

TECH BRIEF: *Standard Bridge Crack Arrest Holes VS. FTI'S StopCrackEX™ Process*

INTRODUCTION

As of 2007, there were 599,766 bridges in the National Bridge Inventory (NBI). Approximately 32% of those bridges are either steel or continuous steel superstructures [1-4]. Steel bridges are composed of numerous individual steel members that are connected by some combination of bolts, rivets, and welds; the most common problems at these connections are corrosion and cracking or a combination of both.

Cracking at steel bridge connections are primarily caused by local material fatigue failure. Fatigue is the formation and propagation of a crack resulting from variable and cyclic loads. Fatigue cracks typically occur and grow over a period of time and are functions of the effective stress range, frequency of load events, and structural details. If a fatigue crack is allowed to grow and reach a critical crack length, fracture may occur resulting in structural failure of the member or collapse of the entire structure [5]. Retarding or arresting further fatigue crack growth will result in significant cost savings on supplemental inspection requirements, significant reduced repair costs for owners, and will avoid bridge shut down to complete more permanent/temporary repairs. Structural fatigue failures on bridges cost lives, add significant cost to infrastructure, and create major disruption to travel and commerce.

A commonly used practice used in the bridge maintenance and repair field is to use drill stops, also known as a crack arrest hole (CAH), to retard the growth of fatigue cracks. This method is often ineffective in the short term, particularly if the primary cause of cracking is left unaddressed. This issue is not unique to the bridge industry. The aerospace industry experiences the same metal fatigue issues and consequences. The purpose of the testing described herein is to evaluate a method of dramatically increasing the effectiveness of these CAH's using proven methods from the aerospace industry.

BACKGROUND / TEST SUMMARY

Southern Utah Engineering was retained by Miceli Consulting, LLC (MIC) to conduct a series of independent fatigue tests investigating the effectiveness of Fatigue Technology's (FTI) StopCrackEX™ process in stopping fatigue cracks in bridge steel. The StopCrackEX process is a derivative of FTI's StopCrack® process that has been used in the aerospace industry for decades to retard or arrest the growth of aircraft structural fatigue cracks. StopCrackEX incorporates FTI's high interference fit ForceMate® cold expanded bushing into the CAH. A test plan was designed in conjunction with MIC and FTI to compare typical crack arrest holes with FTI's StopCrackEX process.

TEST DETAILS

- Seven specimens
- 22 kip MTS test frame
- Three samples were repaired using a conventional ½ inch crack arrest hole
- Four were repaired using the StopCrackEX process within the ½ inch hole
- Specimens cycled at 10Hz until a new crack was initiated and propagated to .15 inch on the other side the given repair or until 4,000,000 cycles, except in one test which went to 20,000,000 cycles
- Gross Stress = 25ksi
- Stress ratio = 0.05

TEST SPECIMEN

The test specimens were machined as illustrated in Figure 1. The specimens were then cyclically loaded in a test frame to initiate and grow a crack to 0.25 inch. Details are shown in Figure 2.

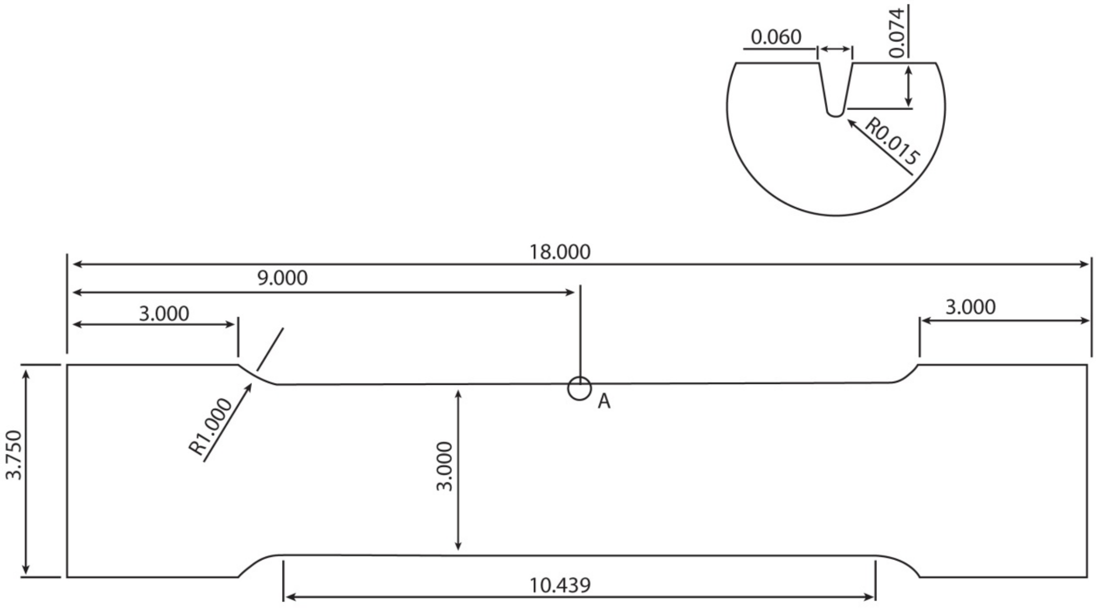

Figure 1: Machining dimensions for the test specimens showing the initial notch.

Specimen	Thickness (inch)	Width (inch)	Max Gross Stress (ksi)	Max Load (lbs)	R	Cycles to initiate crack	Cycles for 0.25 inch crack
1	0.249	3.007	25	18,719	0.05	38,750	119,712
2	0.248	3.009	25	18,656	0.05	36,552	151,195
3	0.246	3.005	25	18,481	0.05	108,300	202,320
4	0.248	3.005	25	18,631	0.05	45,000	127,957
5	0.245	3.002	25	18,387	0.05	42,358	122,647
6	0.251	3.002	25	18,838	0.05	60,000	123,000
7	0.247	3.005	25	18,556	0.05	38,000	146,000

Figure 2: Specimen dimensions and precracking data.
(All specimens were machined from the same A36 Steel with a yield point of 46.6 ksi and an ultimate strength of 70.1 ksi)

CRACK ARREST REPAIR

CAH holes were sited and drilled ahead of the crack tip, leaving a 0.060-inch ligament ahead of the crack tip as shown in Figure 3. Figure 4 shows the location of the baseline CAH and Figure 5 shows the StopCrackEX bushing installed in the same CAH of a separate specimen. A table showing the actual specimen repair details is shown in Figure 6.

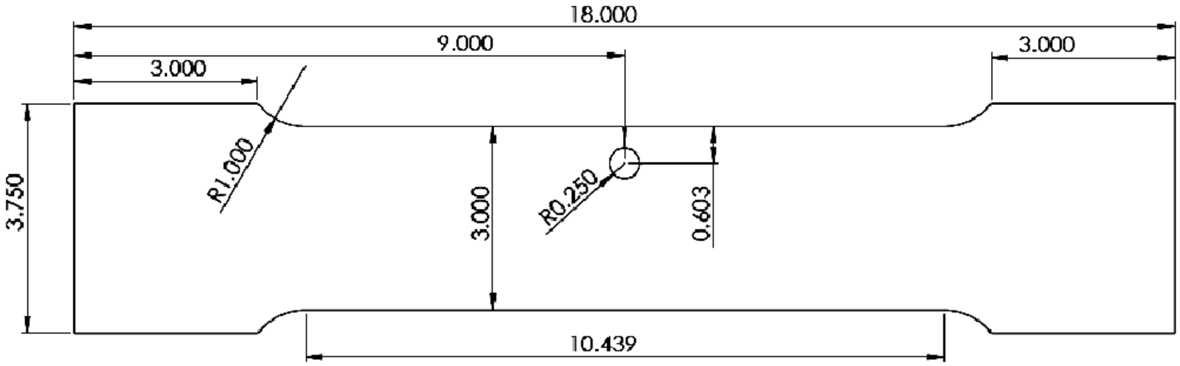

Figure 3: Test specimens with the repair hole location.

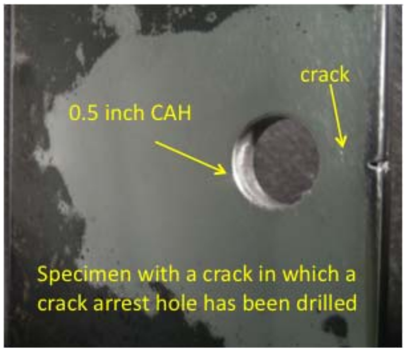

Figure 4: CAH repaired crack

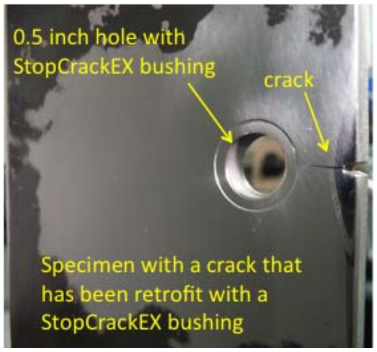

Figure 5: StopCrackEX repaired crack

POST REPAIR SPECIMEN PARAMETERS

Specimen	Thickness (inch)	Width (inch)	Crack length (inch)	Max Net Stress (ksi)	R	Max Load (lbs)
1	0.249	3.007	0.29	20.5	0.05	10,995
2	0.248	3.009	0.285	20.5	0.05	10,961
3	0.246	3.005	0.298	20.5	0.05	10,853
4	0.248	3.005	0.264	20.5	0.05	10,941
5	0.245	3.002	0.265	20.5	0.05	10,793
6	0.251	3.002	0.265	20.5	0.05	11,058
7	0.247	3.005	0.262	20.5	0.05	10,897

Figure 6: Testing parameters of post repair testing.

POST REPAIR TESTING

The specimens were monitored and crack growth measured periodically by stopping the test and visually evaluating the repair area for the initiation and/or propagation of a crack with an optical microscope while the test specimens were loaded to 80% of maximum load. Tests were terminated when the crack on the other side of the drill stop hole reached 0.150 inch or 4 million cycles. Figure 8 shows the terminating crack of 0.150 inches on the other side of the baseline CAH.

POST REPAIR TEST RESULTS

SPECIMEN	RETROFIT METHOD	CRACK LENGTH (inches)	MAX NET STRESS (ksi)	R	CYCLES TO BREAK HOLE	CYCLES TO BECOME A THROUGH CRACK	CYCLES TO REINITIATE	CRACK LENGTH (inches)
1	StopCrackEX™	0.29	20.5	0.05	580,000	1,700,000	**4,000,000**	**No Crack**
2	StopCrackEX™	0.285	20.5	0.05	250,200	300,000	**4,000,000**	**No Crack**
3	CAH	0.298	20.5	0.05	15,600	17,500	230,000	0.145
4	CAH	0.264	20.5	0.05	5,868	7,000	440,000	0.149
5	StopCrackEX™	0.265	20.5	0.05	700,000	4,000,000	**4,000,000**	**No Crack**
6	CAH	0.265	20.5	0.05	4,165	6,000	250,000	0.14
7	StopCrackEX™	0.262	20.5	0.05	210,000	3,700,000	**20,000,000**	**No Crack**

Figure 7: Post repair testing results.

Figure 8: Image of new crack that initiated after being drilled with a crack arrest hole.

Note: Specimen #7 was continued to be cycled after the completion of the test to see how many cycles it would take to initiate a 0.15-inch crack on the other side of the bushed hole. Testing was terminated at 20 million cycles with no evidence of a crack. This equates to greater than 60 times life improvement over the CAH configuration.

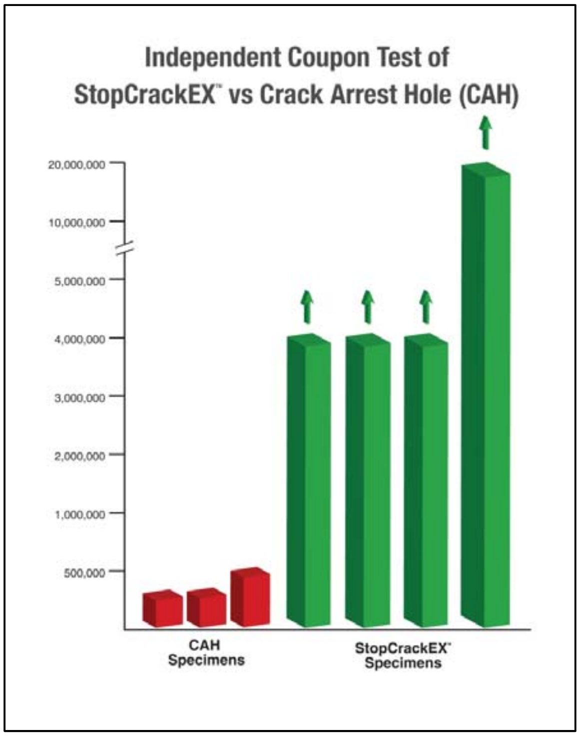

Figure 9: Summary of coupon test results

SUMMARY

The conventional CAH, in theory, provides a method for postponing a more expensive retrofit. Ideally, a CAH lowers the stress concentration sufficiently to arrest further crack growth [6] but this is often not the case.

It has long been known that compressive residual stresses induced around a hole provide a beneficial result in extending the fatigue life of metal components [7-11]. The compressive stress shields the hole from the effect of the cyclic tensile loads and reduces the stress intensity factor associated with crack growth, thereby minimizing the potential for crack reinitiation and retards or arrests fatigue crack propagation. In the aircraft and railroad industry, cold working of holes has been successfully used for over forty years as a method for improving the fatigue life of holes. FTI's StopCrackEX system is an extension of this technology.

When StopCrackEX is used as a replacement for the CAH in bridges, it provides a region of high compressive stresses around the hole. The high interference fit of the bushing combined with the induced compressive residual stress provides the necessary stress field modification needed to impede future crack propagation and initiation.

The StopCrackEX process has shown over a 60 times improvement in crack growth life when compared with the CAH. The life extension of the specimens demonstrates that the StopCrackEX process significantly improves the life of the crack locations and will provide significant cost savings to bridge owners and reduce the need for costly repeat inspection of repairs when used as a replacement for the conventional CAH method.

CONCLUSIONS

- The StopCrackEX system retarded propagation of the precrack and significantly extended the crack growth life compared to the traditional CAH method.
- The StopCrackEX process showed over a 60 times improvement for crack reinitiation and specimen life when compared with the CAH. Reinitiation was not observed in any of the StopCrackEX specimen and tests were stopped at the predetermined cycle count of 4,000,000.
- The StopCrackEX process not only induced the beneficial residual compressive stresses around the hole, it also propped the hole and provided a visual indication of process incorporation.
- The StopCrackEX process proved to be easy and quick to install.
- One specimen with the StopCrackEX was run out to 20,000,000 cycles without crack initiation evident.

REFERENCES

1. U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics; based on data from Federal Highway Administration, Office of Bridge Technology, National Bridge Inventory Database, special tabulation. Data as of Aug. 14, 2007.
2. "Reliability of Visual Inspection for Highway Bridges, Volume I: Final Report," Moore, M., Phares, B.M, Graybeal, B.A., Rolander, D.D., Washer, G.A. Federal Highway Administration, Publication No. FHWA-RD-01-020, June 2001.
3. Investigation of Delayed Cracking in Pivot Steel Girders, M.G. Lozev, G.A. Washer, W.J. Wright, Virginia Transportation Research Council, Report Number VTRC 97-R18, June 1997.
4. A Better Look Inside Steel bridges, V. Speed, Bridges, April 2006.
5. "Summary Report on Steel Bridge Testing Program (SBTP) Crack Detection in Steel Bridges," Draft V. 3, Jalinoos, F., Haldipur, P., Jin, S., Lui, R., Satyanarayana, R., May 20, 2011.
6. Welsch, W.H. "A Concept for Preventing Repeated Weld Repairs of Bridge Structures," *Extending the Life of Bridges*, ASTM STP 1100, G.W. Maupin, Jr., B.C. Brown, and A.G. Lichtenstein, Eds., American Society for Testing Materials, Philadelphia, 1990, pp. 44-52.
7. Frost, N.E., Marsh, K.J., Pook, L.P., *Metal Fatigue*, Oxford University Press, 1974.
8. Fuchs, H.O. and Stephens, R.I., *Metal Fatigue in Engineering*, John Wiley & Sons, 1980.
9. Berns, H. and Weber, L., "Influence of Residual Stresses on Crack Growth," *Impact Surface Treatment*, edited by S.A.Meguid, Elsevier, 33-44, 1984.
10. Ferreira, J.A.M., Boorrego, L.F.P., and Costa, J.D.M., "Effects of Surface Treatments on the Fatigue of Notched Bend Specimens," Fatigue, Fract. Engng. Mater., Struct., Vol. 19 No.1, pp 111-117, 1996.
11. Crain, J.S., Simmons, G.G., Bennett, C.R., Gonzalez, R.B., Matamoros, A.B., and Rolfe, S.T., "Development of a Technique to Improve Fatigue Lives of Crack-Stop Holes in Steel Bridges," *Transportation Research Record,* Journal of the Transportation Research Board No. 2200, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 69–77.

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Key Words: Fatigue cracking, bridges, drill stop, crack arrest hole (CAH), repair, bushing.