Technical Brief
Southern Utah Engineering
Test Evaluation of the 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](image_url)  
*Machining dimensions for the test specimens showing the initial notch.*

![Figure 2](image_url)  
*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.

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**Figure 3:** Test specimens with the repair hole location.

**Figure 4:** CAH repaired crack

**Figure 5:** StopCrackEX repaired crack

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**POST REPAIR SPECIMEN PARAMETERS**

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Thickness (inch)</th>
<th>Width (inch)</th>
<th>Crack length (inch)</th>
<th>Max Net Stress (ksi)</th>
<th>R</th>
<th>Max Load (lbs)</th>
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<tr>
<td>1</td>
<td>0.249</td>
<td>3.007</td>
<td>0.29</td>
<td>20.5</td>
<td>0.05</td>
<td>10,995</td>
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<td>0.248</td>
<td>3.009</td>
<td>0.285</td>
<td>20.5</td>
<td>0.05</td>
<td>10,961</td>
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<tr>
<td>3</td>
<td>0.246</td>
<td>3.005</td>
<td>0.298</td>
<td>20.5</td>
<td>0.05</td>
<td>10,853</td>
</tr>
<tr>
<td>4</td>
<td>0.248</td>
<td>3.005</td>
<td>0.264</td>
<td>20.5</td>
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<td>10,941</td>
</tr>
<tr>
<td>5</td>
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<td>0.265</td>
<td>20.5</td>
<td>0.05</td>
<td>10,793</td>
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<td>3.002</td>
<td>0.265</td>
<td>20.5</td>
<td>0.05</td>
<td>11,058</td>
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<tr>
<td>7</td>
<td>0.247</td>
<td>3.005</td>
<td>0.262</td>
<td>20.5</td>
<td>0.05</td>
<td>10,897</td>
</tr>
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</table>

**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

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

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.
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


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