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Ultrasonic Impact Treatment of Vertical Stiffener Welds at FAST Bridge

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Summary

Transportation Technology Center, Inc. (TTCI), in collaboration with Applied Ultrasonics, carried out Ultrasonic Impact Treatment (UIT) testing on vertical stiffener welds of a bridge girder exposed to heavy axle loads. The purpose of this investigation, conducted on the bridge at the Facility for Accelerated Service Testing (FAST) in March, 2002, was to verify the effectiveness of UIT as an alternative to traditional peening methods for relieving residual tensile stress in welds and improving fatigue performance of weld details. The following inferences were drawn:

- UIT relieved residual stress at weld toes. The decrease in stress in this case was as much as 8.2 ksi.
- The UIT technique penetrates the entire depth of steel.
- UIT can be used effectively on welded railroad bridges to reduce residual stress of weld toes, thereby improving fatigue life of various welded details.
- UIT is physically less demanding than traditional techniques in that very little force is required during treatment and vibrations from the instrument are minimal.
- Stiffener toe treatment was completed within a few minutes.
- Treated areas develop a thin (10-micron), white layer that provides resistance to corrosion and abrasion.

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Suggested Distribution:

- ☐ Maintenance of Way
- ☐ Planning & Analysis
- ☐ Bridges & Structures
- ☐ Safety

Work performed by TTCI Transportation Technology Center, Inc.
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BACKGROUND

With steel railroad bridges aging and the number of heavier axle loads increasing, fatigue damage to bridge components has become a major concern for railroads. Fatigue cracks may appear at any point within a bridge structure, but weld details are a common starting point. The welding process causes local tensile residual stresses to develop on the surface near weldments and in the adjacent base metal. These stresses, combined with stresses due to applied loads, may reach the yield stress of the material; irrespective of its type (e.g., 36 ksi for A36 structural steel).[1] Cyclic stresses superimposed on the residual stresses create areas of high tendency for fatigue crack initiation. Several techniques may be used to alleviate this problem. These include: grinding, shot peening, air hammer peening, gas-tungsten arc (TIG) re-melting, and re-welding with improved characteristics.[2] A newer method is Ultrasonic Impact Treatment (UIT), which differs from traditional peening methods that operate at a frequency below 100 Hz and require considerable effort from the operator. UIT equipment operates at a frequency of 27 kHz and requires little effort to operate. It offers additional benefits such as the formation of a thin (10-micron), white layer that provides resistance to corrosion and a reduction of stress concentration by improving the weld toe profile.[1]

UIT uses ultrasonic transducers to convert electrical harmonic oscillations into physical impulses at the same frequency. These impulses transfer energy to the weld surface through moving steel pins. This causes a transformation of the material characteristics of the weld.

In the FAST bridge, several fatigue cracks have started at the lower ends of stiffener welds. The web areas surrounding these weld toes are tension zones. The primary aim of UIT is to introduce compressive stresses in these areas. This decreases the overall residual tensile stress and lowers the propensity for initiation of fatigue cracks.

TEST PROCEDURE

A stiffener weld location was selected based on its accessibility and an ultrasonic inspection was done prior to UIT testing to ensure no cracks existed at the location. Identical vertical stiffeners with welded toes exist on both sides of the web. Strain gages were attached to the backside of the bridge web about 3/8 inch from the weld (Exhibit 1). This is the opposite side of the location UIT was to be applied. The reason for using the opposite side was to determine whether the UIT technique would affect the entire depth of the weld, not just the surface. Strain data was collected during UIT application.

Exhibit 1. Strain Gages Attached to Backside of Girder Web

The UIT equipment (Exhibit 2) may be separated into three primary components:. the ultrasonic generator, the cooling system, and the treatment tool. The ultrasonic generator provides energy to the treatment tool bringing the tool to its acoustic resonant frequency (in this case, 27 kHz), which is then converted to mechanical displacement of the impacting elements. The cooling system prevents the tool from overheating when energized but not treating. Prior tests have shown UIT to be effective to a depth of 0.47 inch (12 mm), while the web thickness for this test was 0.5 inch (12.7 mm).[1]

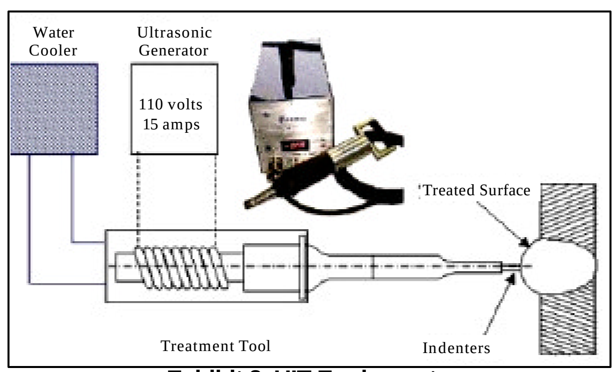

Exhibit 2. UIT Equipment

UIT was performed on the lower section of a stiffener weld (Exhibit 3). The operator applied light pressure of about 10 pounds to the treatment tool in a smooth, vertical motion. The treatment was applied in 1-inch (2.54-cm) segments and the total length of the treated area was about 4 inches (10.16 cm) per side.

Exhibit 3. UIT in Progress at Stiffener Weld Toe

About two minutes were required for each side of the stiffener including the weld toe (Exhibit 4). The ambient temperature was about 65°F. During this treatment four 0.12-inch (3-mm) spherical indenters, of 0.79 inch (20 mm) in length, were used for transmitting the energy to the treatment zone.

Exhibit 4. Stiffener Weld Toe after Treatment

Various indenter configurations are available and interchangeable based on the properties and configuration of the surface to be treated. The amplitude of the treatment indenters when energized during treatment is between 25 and 40 microns. This is dependent on the desired effect of treatment and the level of energy transmitted to the tool. An amplitude of 35 microns was used during the treatment of the stiffeners.

RESULTS

Both strain gages on the bridge were initially set to be at or near zero strain before UIT application. The left side of the stiffener underwent treatment first. The strain gage on the left side was compressed about 240 microstrain in a two-minute period (Exhibit 5). Similar results were obtained for the treatment of the right side of the stiffener with a compression of approximately 270 microstrain (Exhibit 6). These figures show that strain relief occurs immediately after the start of UIT application. For the left-side gage, there is a fairly constant slope resulting from the gradual application of the peening treatment by the operator. The slope then tapers off at the end of treatment. The right-side gage had a slope similar to that of the left gage, except a little steeper. The strain relief also tapered off near the end of treatment. It can be observed that the right-side strain gage had already undergone a 50-microstrain compression due to the prior left-side treatment.

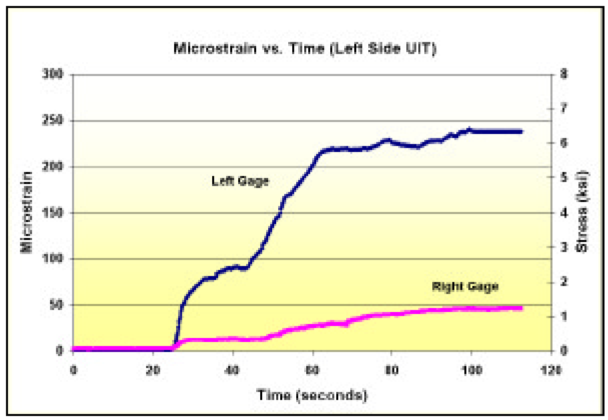

Exhibit 5. Treatment on Left Side of Stiffener Weld

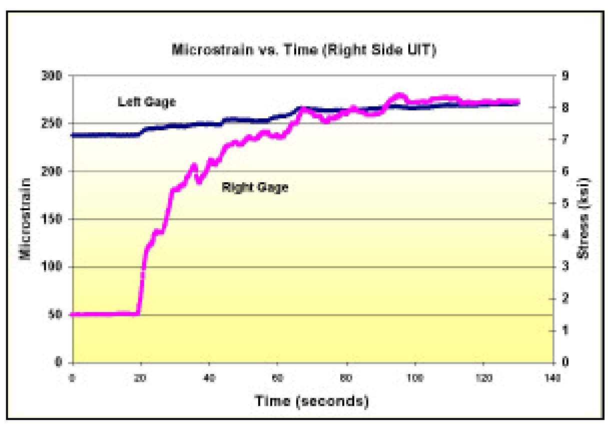

Exhibit 6. Treatment on Right Side of Stiffener Weld

A total compression of 271 microstrain was realized on the left-side web. This approximates to a stress relief of 8.1 ksi. Similarly, a 273-microstrain compression on the right-side gage corresponds to a stress relief of 8.2 ksi. It should be noted that the stress relaxation for each gage was experienced by the web surface on the backside of the UIT treatment. This shows the UIT technique can penetrate the entire depth of a 0.5-inch (12.7-mm) steel plate.

Previous UIT experiments have shown that the effects of UIT treatment at the surface layer differ significantly from the effects through the thickness of the member.[2] The experiments also reveal that UIT is anisotropic at the surface layer, with stress relief greater in the direction parallel to the weld than perpendicular to it. The test showed a surface stress relief of about 58 ksi in the parallel direction and 22 ksi in the perpendicular direction. Another laboratory test has shown UIT to improve the fatigue strength of the welded detail by 80 to 120 percent of the original.[3]

CONCLUSIONS

UIT on a stiffener weld toe is capable of penetrating the entire depth of a 0.5-inch steel plate and reducing residual tensile stress by introducing compressive stresses. This reduction of stress results in an increase in the fatigue life of the weld detail Along with improvement of fatigue life, UIT provides an additional benefit over traditional methods in the creation of a corrosion-resistant protective layer in treated areas. UIT application takes about three to five minutes for each weld detail depending on the weld configuration. It is simple to apply, lightweight, and user-friendly. The tool is designed for ease of treatment in field applications.

UIT can be used effectively on welded railroad bridges to reduce residual stress at weld toes, thereby improving fatigue life of various welded details.

RECOMMENDATIONS FOR FUTURE WORK

In this investigation strain gages were placed on the back side of the treated area. In future tests, strain gages should be attached to both sides and the results compared. Also, strain gages should be positioned vertically to test the anistropic nature of UIT strain relief.

Long-term testing may be necessary to determine the validly of the UIT treatment. Laboratory tests have been conducted to this effect, but long-term field testing is rare. An example of a long-term test would be to treat the entire south side of the FAST bridge with UIT while leaving the north side untreated. Results after specific MGT could then be compared.

References

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2. Sougata, R. Fisher, J.W. and Yen, B. T., "Fatigue Resistance of Welded Details Enhanced by Ultrasonic Impact Treatment (UIT)," Proceedings, ISOPE 2001, Stavanger, Norway, June 2001.
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