MarTREC UTC Project Information Form
USDOT Tier 1 University Transportation Center
Agency ID or Contract Number DTRT13-G-UTC50

Project Title: Corrosion-Tolerant Pre-Stressed CFRP Fatigue Retrofits for Improved Waterway Lock Reliability
Project Abstract (Brief Description): Locks are essential to waterway transport for many river and canal systems, allowing passage of ships through areas of differing water elevation. Over 23M cargo tons passed US Army Corps locks in January of 2015 alone, and 19 locks aid water transport throughout Arkansas, Louisiana, and Mississippi. These waterway locks typically consist of large steel gates that are subject to large alternating forces as water levels are changed, and as lock gates open/close. Repeated loads, corrosive waterway environments, and component geometry can all contribute to fatigue/fracture issues that can limit lock gate service and inhibit the overall reliability of waterway transport. Unfortunately, fatigue issues within steel lock gate components are often only evident once the gates are emptied for routine service, or once serviceability is interrupted by structural failures. Lock service interruptions/repairs are costly (temporary repairs to the Montgomery Lock & Dam =$3.5M) but manageable from a fatigue perspective. Research into cheap, corrosion-tolerant fatigue retrofit solutions is needed. The following project addresses fatigue issues within lock gates, identifying critical components and exploring methods for preventing fatigue cracks for the entire gate component service life. The use of carbon fiber reinforced polymer (CFRP) plates will be explored along with innovative pre-stress and bonding strategies to fine-tune component stresses and achieve infinite component fatigue life.
Describe Implementation of Research Outcomes: This study analytically and experimentally investigated fatigue damage within common lock gate geometries, and developed fatigue mitigation strategies using tuned pre-stress levels to extend gate service-life. In this study, detailed finite element analyses were used to identify critical lock gate fatigue regions and evaluate pre-stress effects on locally extending component fatigue life. Fatigue and fracture mechanics theories related to constant life diagrams were used to develop retrofit strategies for preventing fatigue cracking and fullscale experimental fatigue testing of a critical lock gate component was conducted to provide a baseline for evaluation of retrofit strategies. Retrofit strategies using carbon fiber reinforced polymer (CFRP) plates having optimized pre-stress levels were created and fatigue tested in laboratory conditions. The following conclusions result from the analytical and experimental study:
Impacts/Benefits of Implementation: Fatigue analyses determined gate Section F13 of the Greenup Lock and Dam, as the critical fatigue region. This gate detail geometry is common in much of the US inland waterway lock gate infrastructure. • Considering only the outer flange when determining the required pre-stress level for infinite fatigue using the Goodman Constant Life Diagram results in an inaccurately low estimation of required retrofit pre-stress (the required prestress force of 8.8kips was

determined as too low from finite element and fatigue evaluations). The likely cause is prestress force lag into adjacent component stiffeners. • Considering the stiffened component geometry results in a more accurate estimate of required prestress; however, the required value for the Greenup Lock and Dam is impractically large to apply in a retrofit situation (for infinite life a prestress force of 366.6kips was required). • Pre-stress levels lower than those required for infinite life are still capable of extending gate life by several years. Analytical gate simulations indicate that a pre-stress force of 35.2 kips extends the fatigue life of Section F13 in the Greenup Lock & Dam Gate by 8.6 years. • Application of the pre-stressed retrofit on the notched half-scale specimen increased the fatigue life by more than 1.9 million cycles (a fatigue life increase of nearly 3 times over the un-retrofitted specimen). • Pre-stressing strategies considering friction alone can achieve CFRP pre-stress levels similar to those with epoxy adhesives. The SlipnotTM high friction coating and epoxy bonded CFRP both achieved similar pre-stress levels prior to slip at slightly more than 50ksi of CFRP pre-stress. • Creep and relaxation within the pre-stressing system contributed to minor prestress losses. The full-scale epoxy-bonded CFRP specimen converged to approximately 10% pre-stress loss after 14 days. • The applied CFRP pre-stress is capable of reducing the local stress felt at the notch of both the full-scale and half-scale specimens; however, pre-stress loss did occur due to epoxy adhesive debonding during rapid cyclic loading. Load shedding into the CFRP, even without significant pre-stress applied, contributed to reductions in component notch stresses. Even after debonding, the applied CFRP clamping force was able to provide enough force transfer to the CFRP to reduce the notch local stresses

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