Technologies to Extend the Life of Existing Infrastructure

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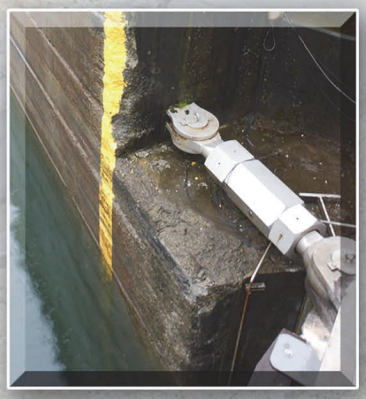
Life Cycle Maintenance Management
Innovative Technologies • Emerging Capabilities



US Army Corps of Engineers®

Innovative Solutions for a Safer, Better World

Technologies to Extend the Life of Existing Infrastructure

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This document available on the web at
http://operations.usace.army.mil/pdfs/TechExtLife1.pdf

Technologies to Extend the Life of Existing Infrastructure

1. Introduction

The purpose of this document is to provide information on new and emerging materials, technologies, methods, and best practices to help extend the service life of existing infrastructure. The Engineer Research and Development Center (ERDC) has a wide range of recent and current research, development and technology (RD&T) from its Civil Works and Military programs producing solutions immediately available for field use. Before a project is started, whether a repair, rehabilitation, or new design, this document along with the ERDC Navigation Technical Director's office should be consulted for the latest information. This document is organized for quick reference by structure type, problem, and material. This document provides the latest to help determine the condition of a structure component using monitoring and nondestructive testing techniques, predict when failure might occur, and provide repair materials and techniques that are better, faster, and less expensive than conventional practices. Included in the appendix of this document are fact sheets on each capability described with contact information to direct you to an ERDC point of contact.

Many USACE locks and dams have exceeded their economic design life and few assets remain in an optimal level of condition. The Infrastructure Strategy OPORD identifies the critical need for an overarching maintenance management strategy that includes prioritization of maintenance resources on critical components and improving the performance and efficiency of maintenance efforts. Technologies developed through ERDC support the need to extend the service life of our nation's infrastructure. This document presents recent RD&T products that

- enhance the Corps' ability to assess condition of assets to better inform maintenance management and prioritization
- reduce repair costs by detecting problems before failures occur and by better predicting remaining service life
- offer new and innovative repair solutions with greater durability, lower costs or reduced down-time
- improve designs for project safety, efficiency and reliability.

Figure 1: A new 110' x 800' lock chamber, completed in 2009 at Marmet Locks and Dam, adds vessel handling capacity to the two original 56' x 360' chambers, constructed circa 1933, to help alleviate traffic delays on the Kanawha River.

Procedures, capabilities, and technologies presented within this document are arranged according to the major component and sub-components of the lock and dam assets. For locks, these include: the miter gates, quoin and miter blocks, and pintle connections; filling and emptying systems; wall recess filler panels; and approach structures. For dams, these include: vertical and tainter spillway gates; trunnion anchorage systems; multi-strand ground anchors; and stilling basins. Products related to general construction and repair materials are also discussed. The appendices contain fact sheets accessible via hyperlinks in the digital document. If viewing a printed copy, refer to the Appendices Tables of Contents to easily find the referenced page.

For information on these capabilities and ever newer ones not included here contact the ERDC Navigation RD&T Technical Director's office (601-634-2471) or the Inland Navigation Design Center (309-794-5226).

2. Products Supporting Navigation Locks

2.1 Miter Gates

Though miter gates are a single component at navigation locks, each has many sub-components that degrade and fail over time. Detecting problems before failures occur, improving maintenance processes and procedures, and using materials and designs less susceptible to deterioration and failure are goals of life cycle maintenance management.

Figure 2: Multiple sensors are installed and wired from the downstream miter gates to a data logger at The Dalles.

Real-time gate monitoring. Monitoring the behavior of structural and electrical-mechanical sub-components, called structural health monitoring, can aid in the prediction and detection of degraded conditions that indicate imminent failure. A real-time navigation lock gate monitoring and warning system detects and reports events like gates dragging debris, barges impacting the gates and degraded quoin-to-wall contact, which are several leading causes of gate failure. The system reports status and warnings to the lock operator through the Lock Operations Management Application (LOMA) interface so actions may be taken when necessary to avoid catastrophic gate failure. The system also automatically emails warnings under specific changes in gate condition. Additionally, USACE personnel may access and analyze logged data via the Internet to better understand and interrogate changes in gate condition. (See: Automated Warning System Fact Sheet) Expanded capabilities leveraging this basic monitoring and warning system framework monitors the gates for other signs of imminent failure of critical sub-components caused by other failure mechanisms. Sensor types, quantities and locations are optimized for affordability and detection of problems in the most probable damage locations. (See: Structure Health Monitoring Fact Sheet) Appropriate USACE guidance for lock gates contains design and implementation documentation for the basic and expanded structural health monitoring system.

Underwater inspection. The condition of submerged gate sub-components is often inspected during lock dewater events, but due to costs the frequency of these events is decreasing. Divers are often used to meet inspection needs, but turbid water frequently exists, reducing their effectiveness and subjecting them to potentially dangerous operational conditions. Additionally, the divers must wait until resurfacing to sketch what was seen or felt with hands while underwater. An acoustic imaging system provides safer conditions for employees engaged in structural inspection activities and enables the user to immediately and permanently log underwater images from inspections. (See: Ultrasonic Underwater Inspection Fact Sheet) Additionally, this tool can facilitate maintenance, construction and placement phases of underwater infrastructure projects.

Corrosion protection. Corrosion protection is a major maintenance need for miter gates. The zinc-rich primers on which the USACE has relied offer heavy pigment loading corrosion protection, but coating adhesion, impact resistance, and flexibility are sacrificed. Epoxy coatings form an excellent barrier to the oxygen and water required for corrosion at the steel surface, but zinc-rich epoxy primers are known to be brittle and have limited durability in areas of abrasion and impact. An innovative primer offers better corrosion control of steel by using carbon nanotubes and reducing the zinc content. This primer

offers the corrosion-inhibiting capability needed and improvements in adhesion, impact resistance, and flexibility. Field demonstrations of this coating are being conducted to determine its effectiveness for navigation structures. A specification for the coating system is added to UFGS 09 07 02 PAINTING: HYDRAULIC STRUCTURES, detailing the requirements for surface preparation, mixing and thinning, coating application and curing so the coating system can be properly selected and specified in painting contracts. (See: Nanotube Epoxy Fact Sheet)

The Corps' Civil Works steel structures are unique in the corrosion industry. Their complicated geometries, the constantly changing environment in which they exist, seasonal fluctuations, dynamic loading, and the high likelihood of damage combine to make it difficult to maintain sufficient corrosion protection. Considering the interdependence of these factors allows for improved engineering design guidance for the field, innovative sensors, modeling expertise on complex steel structures, expanded expertise in cathodic protection (CP) and the design of a monitoring system for CP systems and coatings on HSS. (See: Improved Effectiveness of Corrosion Prevention and Control Systems for HSS Fact Sheet)

2.1.1 Quoin and Miter Blocks

Backing material. Resetting quoin blocks is a critical maintenance item to ensure proper operation of lock gates. Precise alignment of these blocks depends heavily on the choice of backing material and its correct installation and performance. There is no informative guidance on selection of available quoin backing materials other than zinc. Emerging backing, or filler, materials are identified, tested, and evaluated to determine their suitability for use in a submerged environment. Improved guidelines and standard testing protocols enable selection and use of emerging epoxy and grout filler materials that ensure long-term, trouble-free service of miter and quoin blocks in aggressive environments. Updates to UFGS 35 20 16.33, "Miter Gates," include material selection guidance based on key properties of filler materials; minimum performance specification requirements those materials should meet; and realistic predictions of service lifetime for these materials. (See: Emerging Filler Materials Fact Sheet)

Figure 3: Cracks in a miter gate near the pintle resulting from improper contact between the gate's contact blocks and the quoin blocks.

Sealing material. Installation of quoin block backing material is often a challenge due to the failure of sealing materials. This problem can cause significant delay, increasing overall labor costs and keeping the navigational structure out of operation longer than anticipated. A Corps-wide survey revealed a range of sealing materials, which led to a standardized process to test different materials. Guidance updates provide selection of best performing in lab tests and in the field of sealing materials and sealing techniques for use when installing the filler materials. (See: Sealing Techniques for Filler Materials Fact Sheet)

Miter block material. Fabrication and installation of miter blocks constructed using composite materials cost less and offer greater durability than traditionally used materials. The composite material is flexible thus absorbing energy that conventional material may transfer to the gate causing cracking. A field demonstration of miter blocks constructed from fiber reinforced polymer (FRP) composite materials has been performed. Engineer guidance updates reflect lessons learned from the field testing of these miter blocks. (See: Composite Miter Blocks Demo Fact Sheet)

2.1.2 Pintle Connections

Fracture repair. Maintenance and repair of fatigue and fracture failures on hydraulic steel structures, such as cracks near the pintle socket area of the miter gates, represents a major Operations and Maintenance expenditure for the USACE. Current repair methods have often proven to be ineffective. Carbon Fiber Reinforced Polymer (CFRP) strips, properly adhered and installed at optimal locations, extend the fatigue life of steel members. Engineer guidance provides design guidelines and installation methods for bonding steel and CFRP. (See: Innovative Repair of Fatigue and Fracture Problems Fact Sheet)

Pintle design. Gaps develop between the contact blocks and quoin blocks due to wear, corrosion, installation misalignments or minor movement of the miter gate. Redesigned flexible pintle connections allow proper contact between contact blocks and quoin blocks for proper load transfer without damaging the miter gate or connections. The new design may be used for new gates and for retrofitting existing gates. (See: Pintle Redesign Fact Sheet)

2.1.3 Gate Timbers and Guide Walls

Wood is the traditional material used on miter gate bumpers and approach structure fenders and walers. Plastic timbers and hollow steel tubes are now available for miter gate bumpers. Plastic timbers which are inherently resistant to insects and rot without added chemical treatments are now available as options to treated wood. Guidance is being developed through the Inland Navigation Design Center to assist design engineers in making appropriate material choices and design details for a particular application. (See: Bumpers and Fenders Fact Sheet)

2.2 Filling and Emptying Systems

Valve vibration. Lock filling and emptying valves experience complex hydraulic forces with every lockage cycle. Though several valve designs have been tried through the years, design calculations do not consistently produce valves that perform without issue. Common problems include valve vibrations that affect connected operating machinery, and unacceptable uplift and downpull forces that affect valve operations. More realistic simulations generated by improved high-fidelity numeric modeling capabilities enable evaluation of many possible design options for replacement valves, thereby reducing the number of required physical model tests to ensure the valve design will perform properly. (See: Valve Guidance Fact Sheet)

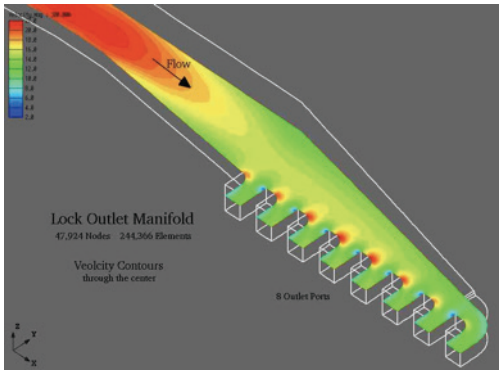


Figure 4: Contours of numerically modeled velocities provide engineers information to evaluate the expected performance of design parameters. Areas of highest velocities are shown in red and lowest in blue.

Hydraulic numerical modeling. Hydraulic design and evaluation of locks and dams often depends on guidance issued 20 to 35 years ago. Innovative designs and construction ideas for lock filling and emptying systems and operation modifications proposed by engineers must be tested prior to implementation. Typical evaluation of these design concepts requires rather large-scale physical models, which are expensive in terms of both time and money. Advancements in numerical modeling capabilities that enable computation of hydrodynamic loads on piers, guard walls, culvert valves, tainter gates, and moored vessels enhance the Corps' ability to provide cost-effective structural, mechanical, and geotechnical designs. Modeling of a lock and dam as an entire system, as well as modeling isolated components such as valves, manifolds, and emergency bulkheads, provides greater certainty that tested designs satisfy the operational and engineering needs of the lock. (See: Lock and Dam Hydraulic Design Guidance Fact Sheet)

2.3 Wall Recess Filler Panels

Recess filler panels are traditionally constructed of steel and are costly, heavy and susceptible to corrosion. Using fiber reinforced polymer (FRP) composite materials to construct these low-risk structural sub-components demonstrates the applicability and suitability of the FRP materials for infrastructure solutions. These FRPs selected meet strength and durability requirements for the target application and provide a non-corrosive material that needs little to no maintenance. (See: Composite Filler Panel Fact Sheet)

2.4 Approach Structures

Flexible walls. Another component of locks benefiting from design innovations are the lock approach walls. New engineering design methodologies and supporting software enable dynamic structural analysis and design of next-generation, pile-founded, flexible, energy-absorbing approach wall systems. A suite of software tools available through the Computer-Aided Structural Engineering (CASE) library facilitates the investigation of various structural configurations of flexible walls during the design process, quantifies the resilience and toughness of these structures, and provides an engineering analysis procedure to determine the shallowest required pile depth. (See: Flexible Approach Walls Fact Sheet) The use of hollow, flexible beams and minimum length piles results in reduced construction cost because structural components weigh less and require less material for construction. Using flexible structural systems also reduces maintenance costs by minimizing damage incurred during barge impacts with the approach walls. Flexible systems make navigation safer by dissipating energy during an impact event, thus preventing the barge train from breaking apart.

Energy absorbing bullnose. Another means of avoiding barges getting into spillway gates is to prevent the barge train from breaking apart. Head-on impacts of barge trains with rigid bullnoses at the ends of lock approach walls can lead to lashing failures. An innovative deformable Bullnose Energy Absorbing System (BEAS) prototype design allows the impact energy to be absorbed by the flexible structure reducing the possibility of lashing failure. The prototype requires site-specific design adaptation for implementation. (See: Energy Absorbing Bullnose Fact Sheet)

2.5 Wicket Gates

Some projects utilize wicket gates to maintain a navigation pool. Traditional wicket gate design utilizes a main body made of wood, typically white oak, which has a normal service life of 10-20 years in the river environment. A commercially available polymer composite manufacturing technique will eliminate the use of wood. This process enables the design and fabrication of a composite wicket gate with mechanical properties equal to or greater than current wooden gates and that allows the use of current hardware for ease of retrofit. (See: Polymer Composite Wicket Gates Fact Sheet)

3. Products Supporting Dam Spillways

3.1 Tainter and Vertical Spillway Gates

Inspection. Many USACE lock and dam components are not inspected very often (or ever) because of accessibility issues, such as spillway tainter gates that are only accessible by personnel rappelling from the top of dams or penstock tubes that require huge scaffolding to access and other confined or inaccessible spaces. Inspecting these components places personnel in higher risk situations and is a time consuming process. Small autonomous aerial and tracked vehicles, microbots, capable of recording required information provide a rapid inspection option without user interaction or placing personnel in dangerous environments. Imagery and lidar data are processed to detect visual defects and appropriate personnel review results to determine if additional inspection is required. (See: Microbotic Infrastructure Assessment Fact Sheet) When such specialized data collection techniques are not needed but there is a need to develop a point clout representation of a structure or an area, the Photogrammetry

Toolbox can be used to transform photographs into a 3D model. The XYZ data can then be analyzed to compute various parameters of the area or for change detection. (See: Photogrammetry Toolbox Fact Sheet)

Abrasion prevention. The downstream side of spillway gates often experience accelerated corrosion. Swirling debris quickly damages conventional vinyl coatings used on the lower portion of these gates resulting in an accelerated exposure to corrosion. Lightweight and strong FRP composites offer a protective coating that is more durable than traditional vinyl coatings to withstand the abrasion. Updates to USACE engineer manuals, the Unified Facilities Criteria and the Unified Facilities Guide Specifications Guidance provide recommendations for these FRP materials. (See: Composite Overlays and Coatings Fact Sheet)

Steel rollers. Vertical lift gates and valves commonly use steel rollers or wheels, which are prone to seizing due to corrosion, making it difficult to impossible to raise or lower gates. Replacing these rollers at a site can cost millions in materials and labor. Ultra-high molecular weight polyethylene (UHMWPE) blocks may be used as slides to replace traditional rollers. This material is not susceptible to corrosion, costs much less (two orders of magnitude), and may be installed easier and faster than traditional rollers. Updates to USACE engineer manuals provide guidance for the design, use and installation of UHMWPE materials as a slide system to replace rollers on gates and valves at navigation projects. (See: Polymeric Slides for Gates Fact Sheet)

Barge impact. Spillway gates are also vulnerable to impacts from breakaway barges. Such impacts often cause a loss of gate control and perhaps loss of a navigable pool. A prototype design of a barge arrest system provides a means of preventing barge impacts to the gates. The designed system can handle large pool variations, will not significantly affect flow when not in use, and is capable of quick, remote deployment. Such a system could save money and lives. (See: Barge Arrest System Fact Sheet)

Figure 5: This trunnion anchor rod cover box indicates multiple rods have failed in the anchorage.

3.2 Trunnion Anchorage Systems

Nondestructive testing. A major sub-component of spillway Tainter gates is the post-tensioned trunnion rod anchorage system. Many project sites utilize these rods in a design where most of the rod is completely embedded in the structure and only a small portion of the rod is exposed. These rods were normally installed in tubes with either grease or grout for corrosion protection. A number of these rods have broken at a variety of sites around USACE, leaving uncertainty regarding the condition and lifespan of remaining rods.

Historically, lift-off tests have been used to determine if the tension in trunnion anchor rods is at or near the design tension. These tests are expensive (up to $2,000/rod) and instances have occurred where rods broke during these tests. A non-destructive test (NDT) method alternative to determine the rod tension uses a dispersive acoustic wave technique. The cost is approximately $250/rod to determine if it has failed and if not, the rod tension. (See: NDT Rod Tension Testing Fact Sheet) However, simply knowing the tension in the rods does not provide indication of possible future failure. Non-linear acoustic testing may be used on rods to detect corrosion and micro-cracks, a flaw that leads to failure in some rods. (See: Trunnion Rod Microcrack Detection Test System Fact Sheet)

Corrosion protection. One suspected cause for corrosion and micro-crack development is the failure or loss of the corrosion protection medium. The life of these rods may be prolonged through techniques for reapplying this corrosion protection. However, in cases where rod damage already exists,

retrofitting techniques for replacement rods may be required to extend the operational life of the tainter gate. (See: Trunnion Anchorage Rod Replacement Fact Sheet)

3.3 Multi-Strand Ground Anchors

Ground anchorage systems comprised of multi-strand tendons are used at many sites for structure stability. These anchors have experienced varying levels of deterioration over the years, even to the point of failure. Engineering procedures and NDT techniques enable the estimation of both the current load-carrying capacity of the ground anchorage and the remaining life of the anchorage. This enables engineers to prolong as safely as possible the replacement of ground anchorage. (See: Multistrand Ground Anchorage Capacity Estimation Fact Sheet)

3.4 Spillway Stilling Basins

Determining the condition of spillway stilling basins and the presence or extent of scour with normal survey vessels can be hazardous due to shallow depths and submerged objects. The multipathing or shadowing of acoustic sensors presents data interpretation problems. An unmanned, remote controlled shallow-draft survey boat equipped with specialized survey equipment collects high-resolution data in shallow water. These data may be analyzed using the Scour Tool Box to help determine the presence or extent of scour or damage around structures. (See: Shallow Water Surveys Fact Sheet)

Scour occurring downstream of stilling basins and along lock walls and guidewalls requires monitoring to ensure dam safety. Survey data should be compared to elevations from construction drawings or post construction surveys to determine scour depths relative to the design elevation. Flow conditions at the time of the survey often impact the scour or fill at a location, so it is useful to compare multiple surveys to a baseline survey. The Scour Analysis Toobox easily compares multiple surveys to a base survey at a given location. The toolbox generates contour plots showing elevation differences and can generate user-designated cross sections. This data can be exported in CAD and GIS formats. The Toolbox provides a means to compare survey results and generate graphics for discussion regarding further analysis. (See: Scour Analysis Toolbox Fact Sheet)

4. Products Supporting General Construction and Repair Materials

Many components and subcomponents at USACE locks and dams utilize carbon steel and concrete materials. These materials experience many different forms of deterioration, so understanding the cause of deterioration is important to extending the life of the infrastructure. Forensic analysis of unusual or unexpected deterioration aids in identifying the problem, which is key to making appropriate retrofits or possibly stopping the deterioration. Identifying sources of problems in concrete and steel provides input to the development of strategies for repair as well as to the development of guidance. (See: Forensic Investigations Fact Sheet)

Figure 6: Severe alkali-aggregate reaction damage at David Terry Lock and Dam, constructed in 1968.

Concrete surfaces of USACE navigation structures are subjected to significant weathering and deterioration that can result in spalling, scaling, and increased surface roughness along with scour and erosion in underwater locations. New materials and application techniques provide repair solutions that have lower risk of debonding, shrinkage cracking, and deteriorating during service. (See: Horizontal Concrete Repair Materials Fact Sheet) Repairs to assets typically submerged, such as spillways, stilling basins, filling/emptying culverts and pilings, present challenges that may be overcome using fiber

reinforced polymer composite epoxies and wraps. These materials may be applied to concrete (See: Polymer Composite Wraps Fact Sheet) or steel (See: H-Pile Repair Fact Sheet). Repairs can be done quickly in the wet or in the dry, and provide lower cost alternatives with increased durability than traditionally used materials and methods that always require lock dewatering to apply. Guidance updates describe appropriate repair materials and application techniques to provide the best repair solution given the anticipated exposure conditions and operational needs. (See: Novel Materials Fact Sheet)

5. Summary

The purpose of this document is to provide information on new and emerging materials, technologies, methods, and best practices to help extend the service life of existing infrastructure. This document presents recent RD&T products that

- enhance the Corps' ability to assess the condition of assets to better inform maintenance management and prioritization
- reduce repair costs by detecting problems before failures occur and by better predicting remaining service life
- offer new and innovative repair solutions with greater durability, lower costs or reduced down-time
- improve designs for project safety, efficiency and reliability.

Products described in this document are the result of research, development and technology problems identified by USACE Field and HQ personnel, prioritized by the Navigation Research Area Review Group (RARG) and approved by HQ Civil Works R&D Steering Committee. New problems and challenges may be added to the ERDC RD&T program by submitting a short Statement of Need through the Navigation Gateway at http://operations.usace.army.mil/ideas/index.cfm?CoP=nav .

Note: *This document has embedded links. Within the body of the document, the name of each fact sheet is also a link that will take the online reader to that fact sheet. A click on the bold title of each fact sheet will take the reader to that fact sheet's mention in the body of the document.*

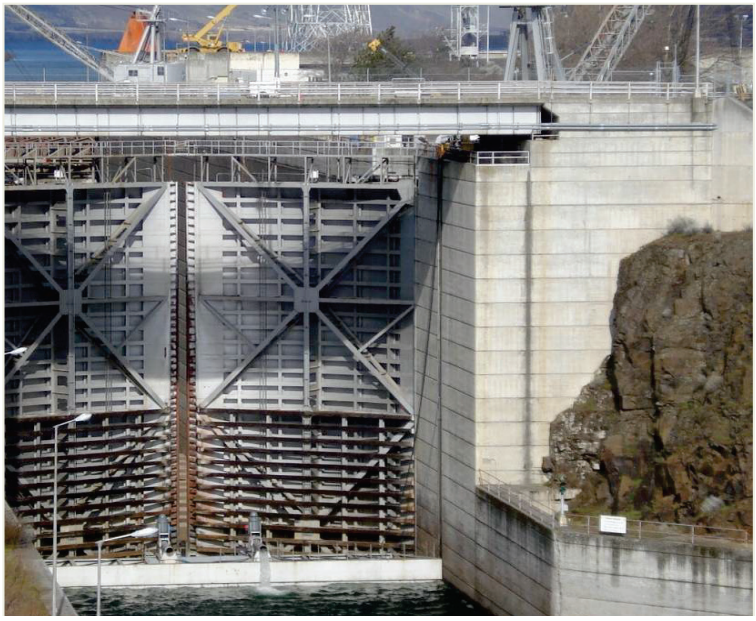
Appendix A: Products Supporting Navigation Locks – Miter Gates

Table of Contents

Automated Early Warning Systems for Lock Gate Condition

Problem

An inexpensive method is needed to monitor structural and electrical-mechanical component behavior for detection and prediction of degraded conditions that indicate imminent catastrophic lock gate failure, as well as to report current status to the lock operator so that actions may be taken to avoid catastrophic gate failure.



The Dalles downstream miter gates; The Dalles, OR

Approach

SMART Gate 2.0 is a fully-automated data-to-decision support system for the condition assessment of miter lock gates. An optimized and affordable sensing system provides data to high-fidelity simulation and surrogate numerical models. Statistical pattern recognition enables the detection of specific events that may eventually result in catastrophic conditions. 'Catastrophic status' is delivered to the lock operator through LOMA. Currently, detection targets are gate impact, dragging of debris, and quoin-to-wall contact degradation. This R&D will expand capabilities for lock monitoring and will be applicable to other types of gates and structures.

Products

A guidance document will be written which describes, in detail, the steps required to design, purchase, and implement an automated early warning system for lock gates and its incorporation into the SMART Gate framework. The system will initially be designed to detect dragging of debris, impacts to the gate, and degraded quoin-to-wall contact. The SMART Gate framework will be augmented to support the new early warning capability. It will provide real-time signals to the lock operator through the Lock Operation Management Application (LOMA) and archived data to other USACE personnel via the internet.

Benefits

Minimizing catastrophic failures will provide a reduction in unscheduled closures, thus providing cost savings and increasing safety for both the Corps and the waterways industry. This research will create an integrated, affordable real-time navigation lock gate monitoring and early warning system to aid the lock operator in identifying adverse lock conditions before they cause a catastrophic failure. USACE lock operators will receive condition signals to alert them of an impending issue with gate operation. USACE District engineers will have access to archived condition data to help in assessing the health of the gate structures. Having a real-time automated early warning system which detects impacts, dragging of debris, and degraded quoin-to-wall contact will help prevent operation of gates during conditions which may lead to an unscheduled lock outage or catastrophic failure.

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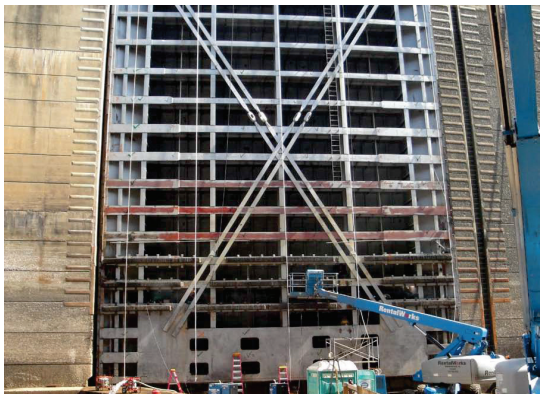
Structural Monitoring System for Lock Structures to Prevent Failure

Problem

USACE owns or operates 236 locks at 191 sites, more than half of which have surpassed their 50-year design life. There are increasing concerns about their continued reliability even though they generally perform quite reliably. As the locks age and their components wear and otherwise deteriorate, there is a greater need for closer monitoring of the infrastructure. Many critical components are submerged, making inspections difficult and expensive. Inspection intervals are often not frequent enough to identify some structural problems before they deteriorate to the point when failure will occur. This all drives a desire for detection of imminent failure in order to minimize unscheduled closure.



Typical horizontal framed miter gate at Holt Lock

Approach

The project will develop new technologies to monitor and sense critical elements and components to detect potential failure of critical lock components. Detailed evaluation and analysis of past lock failures, as well as modeling and analyses, will be used to identify these critical areas. Inspection and sensing technologies will be developed to predict when critical elements and components are subject to failure. Numerical techniques using finite element analysis will be studied and developed to improve the reliability of damage detection algorithms and to provide indications of probable damage locations.

Typical miter gate pintle

Products

Research will develop sensing technologies to detect imminent failure of critical components. A structural monitoring system (SMS) model on an existing lock will be completed – including a user interface, analysis software, system documentation, database, and decision support protocols. Guidance will be written for the overall implementation of a SMS at a lock structure, including modeling for the determination of critical features, sensor locations, damage detection algorithms, and system architecture. This document shall provide the technical information that can provide the basis of an Engineering Manual for a lock SMS.

Benefits

Detection of potential failure of critical components will provide a reduction in unscheduled closures, thus providing cost savings and safety to both the Corps and the waterways industry. This research is targeted for multiple users in the civil works navigation program. Alarms will signal lock operators when conditions indicate a significant problem may have occurred. At the operations level, future repair issues will be identified based on changing conditions. At the engineer level, long term data will be available to study the structural behavior of the lock and perform analyses on the existing condition of the structure.

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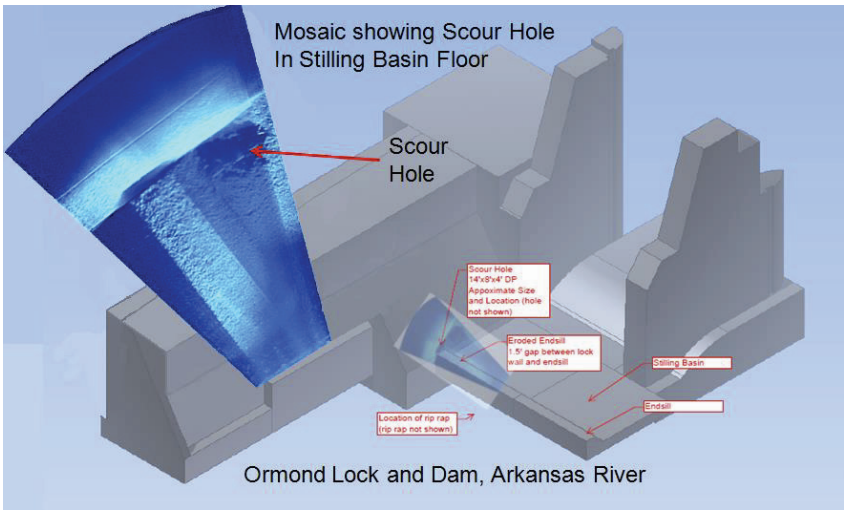
High-Resolution Acoustic Imaging System

Problem

Divers are frequently used in the inspection, maintenance, construction, and placement phases of underwater construction projects. However in turbid water, the lack of visibility severely reduces their effectiveness and subjects them to potentially dangerous operational conditions. In addition, the diver must wait until he returns to the surface before sketching what he saw or felt with his hands while underwater.



Approach

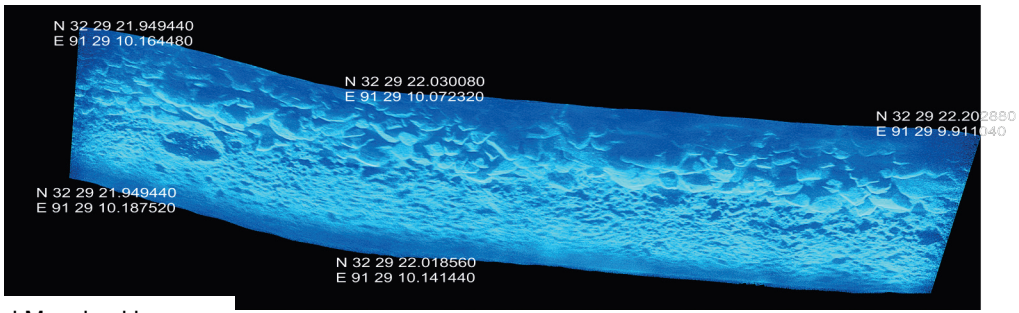
An acoustical imaging camera developed by the private sector has been integrated into a deployable system to be used in turbid water. Also developed are various methods of system operation – a hand mount in which the diver carries the unit underwater; a manual mount in which the user can manipulate the unit from the surface providing *x*, *y* and *z* motion of the camera position; and a pole mounted system that is usually deployed from a surface vessel.

Products

This work has resulted in an operable system with several methods of deployment. Both a Technical Note, ERDC/CHL CHETN-IX-23, and a Technical Report, ERDC/ITL TR-13-3, on inspection and deploying techniques have been issued.

Benefits

The acoustic imaging system improves safety during inspections as well as more efficiently providing more accurate data. More accurate data can be used to expedite construction, repair (including the determination of the volumetric loss of material), and maintenance of underwater structures. The system will provide safer conditions for employees engaged in environmental, wet construction, and structural inspection activities. It also allows users to immediately and permanently log underwater images from inspections.



GIS Referenced Mosaiced images

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Field Demonstration of Nanotube Epoxy Paints

Problem

Coatings are the first line of defense for the corrosion protection of civil works steel structures. These coatings must be durable in a wide range of service environments, from mild atmospheric exposure to immersion in turbulent, debris-laden waters. The Corps relies on zinc-rich primers for inhibiting corrosion at any defect in or inevitable damage to the coating system. Zinc-rich primers are heavily loaded with zinc pigment so that many zinc particles are in contact with each other, forming a network of sacrificial anodic particles that prevent the corrosion of steel. This heavy pigment loading provides corrosion protection, but coating adhesion, impact resistance, and flexibility are sacrificed. Epoxy coatings form an excellent, durable barrier to the oxygen and water required for corrosion at the steel surface, but epoxies, especially zinc-rich epoxy primers, are known to be brittle and have limited durability in areas of abrasion and impact.

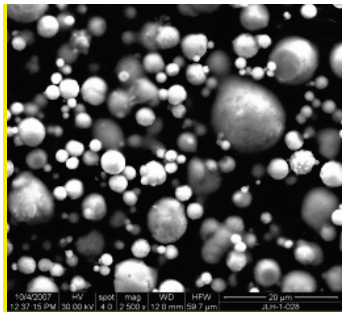
Example of normal breakdown of a coating system on a tainter gate as it ages

Approach

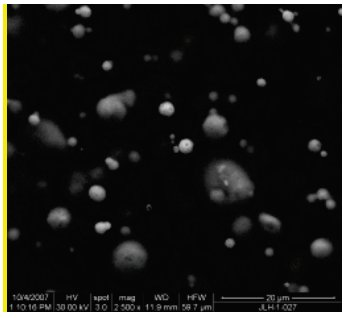
An innovative primer for corrosion control of steel has been successfully demonstrated on the exterior surfaces of a fuel tank at Fort Bragg, CA, and a potable water tank at Ft. Lewis, WA. Carbon nanotubes replace a portion of the zinc in a zinc-rich epoxy primer formulation. Via the electrically conductive nanotubes, the zinc particles remain in electrical contact, and the coating retains its corrosion-inhibiting properties with improvements in adhesion, impact resistance, and flexibility. The improved performance of the coating will extend the service life and provide life-cycle cost savings.

Products

A specification for the coating system will be added to UFGS 09 07 02 PAINTING: HYDRAULIC STRUCTURES to allow the coating system to be specified for use on new and existing steel structures. Requirements for surface preparation, mixing and thinning, coating application and curing will be detailed so the coating system can be properly selected and specified in painting contracts.



Zinc Loading in a Traditional Zinc-Rich Primer



Zinc Loading in Teslan™ Nanotube Epoxy Primer

Benefits

Those responsible for the design and/or maintenance of steel structures will have a new coating system to provide the needed corrosion protection in atmospheric, fresh water, and marine exposures. Compared to traditional epoxy coating systems that employ a zinc-rich epoxy primer, the nanotube epoxy paint system will have greater adhesion and durability, and will provide corrosion protection equal to or surpassing traditional zinc-rich epoxy primers.

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Improved Effectiveness of Corrosion Prevention and Control Systems for HSS

Problem

Years of research has advanced the state-of-the-art for cathodic protection (CP) and protective coatings, but still extensive corrosion is occurring on the Corps' aging hydraulic steel structures (HSS). Every square inch of these steel structures should be protected from corrosion, but often is not. Addressing corrosion occurring at locks is resource intensive, both in labor and money. However, an unscheduled lock closure has a huge impact on commerce, costing the industry up to $3 million per day. The Corps' Civil Works steel structures are unique in the corrosion industry. While the commercial corrosion industry deals moslty with structures of uniform shape, such as tanks and pipelines, in a relatively unchanging environment, the Corps' structures have complicated geometries which can lead to localized under- or overprotection. They are in a constantly changing environment with intermittent wetting, seasonal fluctuations, dynamic loading, and a high likelihood of damage. All these factors contribute to the difficulty in maintaining sufficient corrosion protection.

Corrosion on miter gate at Selden Lock, AL

Approach

This R&D focuses on gaining a better understanding of: 1) the degradation mechanisms of the protection systems; 2) the interaction of the protective coatings and CP with the structure; and 3) the interaction of the monitoring systems with the coating, CP, and structure. This holistic approach that considers the interdependence of the various processes involved in these systems will produce the most effective improvement in the overall corrosion prevention and control system. The work will perform analytical, experimental, and modeling studies to include: electrochemical processes specific to protection system monitoring; a laboratory verified modeling of CP potentials on the complex structures; the effect of coating defects on the CP systems; and how the use of dual CP Systems (sacrificial and impressed) may improve the corrosion protection of complex structures.

Products

This work will provide engineering design guidance for the field, innovative sensors, modeling expertise on complex steel structures, and expanded expertise in CP to include fundamentals of complex structures. The work will also develop a monitoring system for CP systems and coatings on HSS.

Benefits

This research will result in a decrease in the cost of repairs, reduce the risk of unscheduled shutdowns, increase the performance of the corrosion protection systems, optimize maintenance and dewatering scheduling, and improve reporting, all of which will serve to extend the life of the HSS.

Corrosion on miter gate at Claiborne Lock, AL

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Evaluation of Emerging Filler Materials for Miter and Quoin Blocks

Problem

Unified Facility Guide Specifications UFGS 35 20 16.33, “Miter Gates,” contains obsolete guidance for the selection of quoin block backing material. It includes performance specifications for epoxy products that no longer exist. As a result, there is no informative guidance on selection of materials other than zinc. Recently the use of epoxy fillers for miter and quoin block application has been questioned. The amount of water absorption over time is of concern, as long-term water absorption may cause the product to eventually soften. The current ASTM standards for strength and hardness do not account for filler products being submerged. While the current performance standards are clearly inadequate, it is not clear what properties are critical for adequate performance, what the minimum requirements are for these properties, or what would indicate a superior product..

Miter block with epoxy backing material

Approach

The first step was to engage designers and O&M personnel in the Corps Districts and HQUSACE to identify filler materials that are currently being used or have been considered, and identify problems that have been encountered. After identification of candidate epoxy fillers and other grouting materials, material property testing is being conducted relative to in-service performance including material elasticity, water absorption, compressive strength, and degradation due to freeze/thaw cycling and moisture diffusion. Arrhenius-based degradation models are being investigated to predict long-term durability from short-term tests. Fickian or more complex diffusion models will be used for predicting moisture uptake and saturation. Material properties and performance characteristics are being determined to ensure long-term durability, and to allow assessment of alternate materials.

Products

A standard protocol is being developed for long-term testing of filler materials’ compressive strength, water absorption, elastic modulus, shrinkage/expansion, and aging affects. An update of UFGS 35 20 16.33, “Miter Gates,” will include guidance for selection of quoin block filler material. The information will be transferred through technical publications and presentations.

Benefits

Performance specifications for materials such as this filler are important for selection of suitable materials and long term durability. Properly performing filler material allows appropriate load transfer in the miter gate structure and prevents damage due to overload and fatigue cracking in miter gate structures. The savings from avoidance of lock closures for repairs and greatly reduced potential for catastrophic failure are substantial.

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Sealing Techniques for Miter and Quoin Block Backing Materials

Problem

The epoxy backing materials have viscosities that allow them to be poured behind quoin and miter blocks in sections. The gaps are sealed with body filler materials (e.g. Bondo) to contain the epoxy backing material until it is cured. Often, the surface preparation on the quoin block and channel is not ideal for proper adhesion of the currently used sealants. The sealing materials can fail as the pressure head of the epoxy material increases while being poured, causing the epoxy material to leak out. When this happens, the quoin or miter block may have to be removed, cleaned up, and reset, causing significant delay. The backing materials are poured in sections requiring time between fills to allow the epoxy to cure, which increases the overall repair time. This increases overall labor costs and keeps the navigational structure out of operation for longer periods of time.

Sealing lock gate quoin block

Approach

A laboratory mock-up simulating quoin and miter blocks has been constructed in a controlled environment. This mock-up allows control of variables related to surface preparation, gap size, and head pressure. Different sealing materials are being studied to determine their performance. The idea is to seal the quoin block mock-up consistent with current field practice, fill the gap with a suitable liquid, and then incrementally pressurize the system until the sealing material fails. The type and number of failure/leaks and the maximum pressures are recorded, as well as observations related to the use of the material. Adhesion tests will be conducted between the sealing materials and steel substrates for comparison against the mock-up results. The adhesion tests will be conducted at room temperature and at varying temperatures to investigate the sealant suitability in varying environmental conditions.

Products

Recommendations will be made for improved sealing techniques and selection of sealing materials for different temperatures and environmental conditions. An ECB (Engineering Construction Bulletin) and Technical Reports will be produced and the information will be provided in technical presentations to engineering audiences such as the annual Lock Maintenance Workshop.

Benefits

The main benefit of this work is to reduce the overall installation time and delays related to backer sealing material failures. Better sealing techniques will prevent blowouts and leaks that can result long delays. Materials that perform at higher head pressures will allow the backing materials to be poured in higher sections reducing application time and labor costs, and will allow the navigation lock to return to full operation in a shorter time.

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Fiber Reinforced Polymer (FRP) Composite Miter Blocks

Problem

Miter blocks are used on hydraulic gates to create a continuous vertical line of contact between two closed miter gate leaves, forming a watertight seal when closed. Miter blocks are exposed to harsh service conditions including wet-dry cycles, corrosive elements, hydrodynamic forces, mitering forces, and freeze-thaw effects. Traditional steel miter blocks are prone to corrosion degradation which can lead to water leakage and gate misalignment. Load redistribution due to gate misalignment can in turn cause severe damage to the gate and its components.

Corroded steel miter blocks

Approach

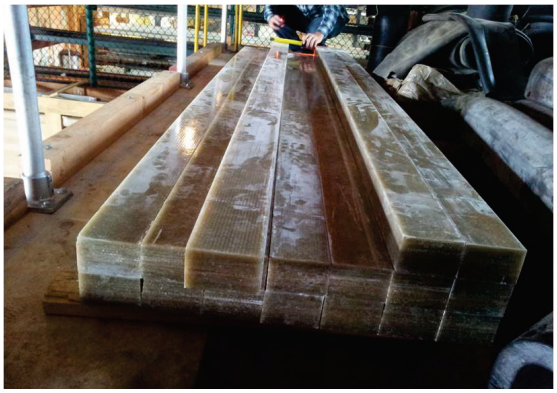
This research effort focuses on the use of fiber reinforced polymer (FRP) composites to replace steel blocks for use as miter blocks on hydraulic gates used in navigation systems. Four different design configurations of FRP were investigated. The blocks are configured to meet or exceed design criteria of 1400 psi compressive stress on the mitering surfaces. A solid block design, manufactured by vacuum-assisted resin transfer molding, provides properties that greatly exceed the minimum design criteria. Laboratory evaluations also studied the effects of long-term immersion on mechanical properties and deformations due to debris caught between the mitering surfaces during gate closure. Successful laboratory results supported progress to a field demonstration. In March 2015, FRP composite miter blocks fabricated using the solid block design were installed in the auxiliary lock at Hiram M. Chittenden Locks in Seattle, WA. These FRP blocks will be monitored for 3 years to assess their performance in actual service conditions.

Products

The primary product of this work will be engineer guidance to design, use, and install FRP composite miter blocks. Initially this guidance will be made available as a Tech Note. The overall investigation and field demonstration will also be described in a series of technical transfer products, including conference proceedings, technical reports, articles in publications such as Navigation e-News, and webinars.

Benefits

Closure of a lock to repair corroded miter blocks and/or other components damaged due to gate misalignment resulting from corroded miters can costs millions of dollars, including loss of revenues to those using the lock to move goods up and down the river. Longer-lasting and more durable FRP composite miter blocks will save maintenance and repair costs and out-of-service time over traditional steel miter blocks.



FRP composite miter blocks awaiting installation

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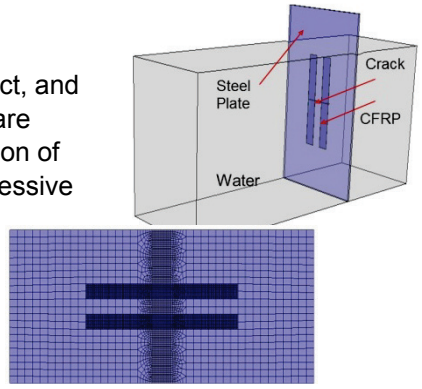
Using Fiber-Reinforced Polymers to Repair Fatigue and Fracture Problems

Problem

The Nation's Hydraulic Steel Structures (HSS) are suffering from significant deterioration due to various effects including corrosion, fatigue cracking, impact, and overloads. Current conventional methods used for the repair of steel bridges are accepted as the state-of-practice for the repair of HSS. However, the application of such methods to HSS has often proven to be ineffective as a result of the excessive deterioration present in the structures. The bridge-based crack repair methods were developed primarily for mitigating cracks under Mode I loading, while HSS often experience mix-mode cracking. Therefore, the need for developing repair methodologies that are pertinent to HSS is not just necessary but essential.



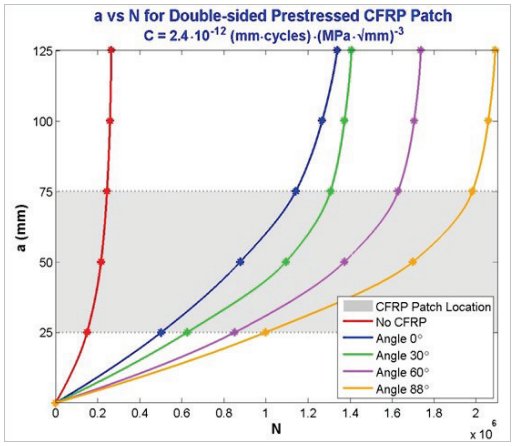
Overview of the finite element model

Approach

New methodologies for fatigue and fracture repairs of HSS will be developed. In the current study, composite materials such as Carbon Fiber Reinforced Polymers (CFRP) that have been used extensively in the aerospace, marine, and ship industries are being investigated. CFRP strips will be bonded over a crack on the inner surface of a fatigued tension flange. This new method of rehabilitation will increase the fatigue life, strength, and time required for a crack to grow to a critical stage. A numerical model constructed using a Coupled Eulerian-Lagrangian (CEL) analysis to calculate the stress intensity factors for different repair configurations has been developed. Results show that CFRP-repaired plates show significant improvement over non-repaired plates, and double-sided prestressed CFRP repairs exhibited the best performance, showing improvements of 5 times or greater the fatigue life compared to unrepaired models, and 2.5 to 3 times better results than single-prestressed and single-sided CFRP repairs. At this time, laboratory experiments are being conducted. Although the unit price of a CFRP strip may be higher than that of steel, the cost of labor and equipment will be greatly reduced, resulting in a decrease in total rehabilitation cost.

Products

The main findings are the number, thickness, width, and position of CFRP strips needed to obtain a pre-defined fatigue life increase. Furthermore, new adhesives capable to be activated sometime after touching water are being tested and are showing signs that these repairs can be implemented without the need for dewatering. These adhesives are also showing significant bonding capacity given the environment and hydrodynamic forces.



Half crack length (a) vs. number of cycles (N) for double-sided prestressed CFRP patch, C = 2.4·10-12 (mm·cycles) (MPa·√mm)

Benefits

Rehabilitation costs for hydraulic steel structures and components should be reduced because of the lower labor and installation costs of CFRP strips. The decreased installation time, over current techniques, will also save the costs of out-of-service time.

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Redesign of Miter Gate Pintle Sockets and Connections

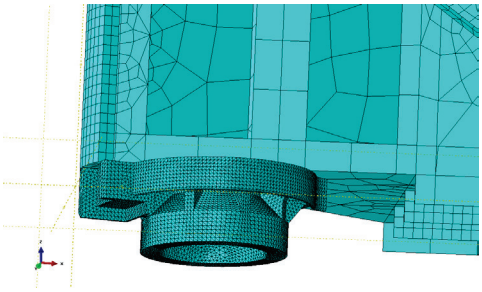
Problem

The current design of miter gate pintle sockets and connections used by the Corps of Engineers is a rigid design which has no allowance for energy dissipation when gaps are present in the contact blocks due to wear, corrosion, poor installation or minor movement of the gate. If gaps between the contact blocks are present, pintle damage or sheared pintle bolts will almost certainly be discovered during dewatering of the locks. The gap between the gate and the contact blocks and quoin blocks can be from wear, corrosion, initial out of tolerance gap, or travel of the gate.

Damaged Pintle Socket, Aberdeen L&D

Approach

This research will result in a new design for miter gate pintle sockets and connections. The new design will be flexible in that it will be able to withstand deterioration of design boundary conditions (gaps between quoin blocks and contact blocks) without resulting in damage to the pintle socket or connections (welds and bolts). An existing Finite Element Model (FEM) will be modified and improved for this project and will be enhanced such that it will be useful on future site-specific projects. The upgraded FEM will be used to model the present (rigid) design to evaluate loading based on (a) new ideal conditions, and (b) degraded contact block/quoin conditions. It will then be used to model multiple alternative (flexible) designs and perform the same evaluations of loading that were performed for the rigid design. The optimum design will then be chosen. Precision adjustments will be made to the chosen design to optimize performance. Physical model tests will be conducted to verify results of the optimum design determined by the FEM numerical modeling, and any required final precision modifications will be implemented.


Finite Element Model of a Pintle Socket

Products

The primary product resulting from this research will be a new design for miter gate pintle sockets and connections that will withstand deterioration of the initial design boundary conditions (gaps between quoin blocks and contact blocks) without damage to the pintle socket or connections (welds and bolts). The new design will be suitable for retrofitting existing projects as well as for installation in new projects. Another product will be an improved Finite Element Model and study method that can be used on other site specific projects. Technical transfer will be accomplished with papers, technical notes, and technical reports.


New Pintle Socket

Benefits

This research will reduce the time and costs associated with damaged pintles by providing a design with a much longer service life. It will also reduce the time and cost associated with unscheduled outages now caused by damaged pintles.

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Material Selection for Bumpers and Fenders for Miter Gates and Guidewalls

Problem

Plastic timbers being mounted on a miter gate

Traditionally wood is used as bumpers on miter gates and for fenders and walers on guidewall structures leading into the lock chamber. Other options are now available, such as plastic timbers made from recycled, post-consumer plastics, from ultra-high molecular weight polyethylene (UHMWPE) and from elastomeric-rubber combinations. Hollow steel members are also used as bumpers. Each material has its advantages and disadvantages. For example, plastic timbers are inherently resistant to rot and insects without any added chemical treatments but are more expensive than wood and may be prone to cracking when notched to fit around braces. In a crushing mode, plastic timbers do not absorb as much energy on impact as wood. In bending, the opposite is true. Steel provides some impact energy absorption capability when the hollow tube is collapsed but must be replaced in order to provide that capability for the next impact. Currently there is no standard guidance available and each District seems to have its preference on which material to use. This effort will develop guidance to assist design engineers in making appropriate material choices for a particular application.

Approach

This research effort is focused on the selection and use of various materials used as bumpers on miter gates and for fenders and walers on guidewall systems. Field demonstrations of various materials as well as laboratory testing will result in data that will inform a guidance update.

Products

The primary product will be engineering guidance to select and install timbers made from wood, polymers, or steel for use on miter gates and guidewall systems. This guidance is expected to be made available through the Inland Navigation Design Center. The overall investigation and field demonstration will also be described in a series of technical transfer products, including conference proceedings, technical reports, articles in publications such as Navigation e-News, and webinars.

Composite timbers installed on a lock guidewall

Benefits

Materials recommended for use will provide increased service life over currently used materials, resulting in reduced maintenance costs and out-of-service times for the associated systems.

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Appendix B: Products Supporting Navigation Locks – Valves, Panels, and Approach Structures

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Repair and Replacement Guidance for Lock Culvert Valves

Problem

Many navigation locks maintained by the Corps have reached or exceeded their design life. Maintenance, rehabilitation, or replacement of lock culvert valves often requires engineering design. Operations personnel have expressed belief that troublesome valves are not stiff enough. Current design guidance for lock culvert valves (EM 1110-2-1610) has not been updated since 1975 while the corporate body of knowledge has dramatically increased since then. Also, current guidance recommends a valve design that has been found to perform poorly and has been a maintenance problem. Field measurements have indicated that current design guidance underpredicts the expected loads a valve must withstand during operation. Valves in service have experienced cracking and excessive uplift forces, while cavitation has been a problem at some projects.

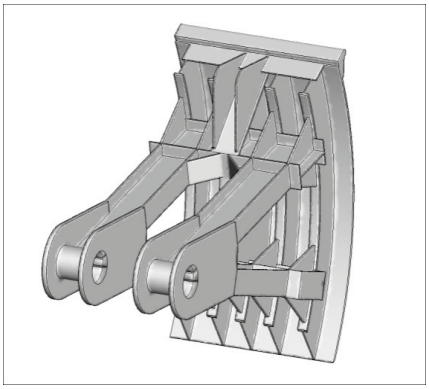
Double-skin plated valve (John Day Lock)

Approach

This research is focused on developing improved design guidance for lock culvert valves. Particular attention is being given to reverse tainter valves because they are the most common valve type found on USACE locks. The guidance will go beyond the current recommendations by pairing valve geometry (radial arms, lateral members, web members, etc.) with culvert size. Visits to navigation projects to observe operations and discuss maintenance history with lock operations and maintenance personnel have helped identify common troubles that particular valve designs have presented. Large-scale physical and computational flow models are being coupled with field and literature reviews to develop an understanding of the fluid/structure interaction within lock culverts. The physical models provide hoist loads and vibration tendencies. Three-dimensional computational models provide detailed understanding of pressure and flow distributions (and the corresponding hydraulic forces) acting on individual valve members.

Products

This research effort will produce Engineering Technical Letters containing information appropriate for an EM 1110-2-1610 update and technical reports. The publications will include items of interest to designers, such as head loss, cavitation potential, and hydraulic loads of common valve configurations. Technical papers and presentations will be given to engineering audiences. Workshops will be held for field engineers who design, operate, and maintain lock culvert valves. These workshops will relay research findings and provide design guidance.



Vertically framed valve (Watts Bar Lock)

Benefits

The research will provide a greater understanding of how to design and improve valves on existing navigation locks. Supplements to the lock valve design manuals will provide the most up-to-date guidance and criteria available for design and evaluation. Well-designed valves will contribute to safer and faster lockages as well as decreased maintenance costs and a reduction in unscheduled outages required for valve repair.

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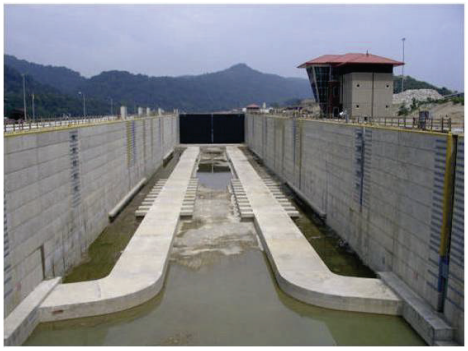
US ARMY CORPS OF ENGINEERS
BUILDING STRONG®

February 2016
Engineer Research and Development Center

Hydraulic Design Guidance for Locks and Dams

Problem



In-chamber longitudinal culvert system; Marmet Lock, Kanawha River

To ensure safety, the design of a lock and dam system requires accurate estimation of the hydraulic performance. Of the different lock components (intakes, valves, gates, culverts, outlets, etc.), none has more impact on providing rapid locking operations and safe navigation conditions than the manifolds that directly fill and empty the lock chamber. Currently, performance evaluation requires large-scale hydraulic models. Construction of physical models is very time consuming and expensive. The use of numerical modeling in place of physical modeling will decrease hydraulic evaluation costs and time. The primary consequence of not conducting this research is that design ideas will be limited to those that have resources to support a physical model study. This could greatly hinder the development of innovative design ideas.

Approach

This research will develop tools for the hydraulic evaluation of locks and dams. Primarily, the effort will be directed toward the extension of the U.S. Army Corps of Engineers' computational modeling capability. Particular consideration will be given to accurately modeling the components of the filling and emptying system, including the intakes, culverts, valves, chamber manifolds, and outlets. Culvert shape and size and port shape, size, and spacing will be investigated in order to develop design guidance for lock manifolds. The result will be a modeling system that can simulate unsteady processes such as valve movement, lock filling and emptying, and hawser forces on tows during lock operations. This modeling method will be applicable to hydraulic structures in general, but particular attention will be paid to the modeling of locks and dams – the entire system as well as isolated components such as valves, manifolds, and emergency bulkheads.

Products

The product resulting from this research will be a comprehensive method that provides accurate solutions to the unsteady flow in lock filling and emptying systems. The models within this method will be capable of reproducing moving valves and hawser forces on tows moored in the chamber. Technical transfer will be accomplished with papers, technical notes, and technical reports. Guidance on determining dimensionless coefficients that are needed to calculate the flow in manifolds will be provided. Workshops will provide field engineers with updated hydraulic design guidance for locks and dams.

Inside Marmet Lock culvert

Benefits

Hydraulic engineers will use these design tools to increase hydraulic efficiency of lock filling and emptying systems, minimizing lockage time and maximizing safety of vessels moored in lock chambers. A comprehensive modeling system will reduce unscheduled outages, and improve environmental stewardship at Corps projects. This research will reduce the time and costs required to thoroughly estimate hydraulic performance of navigation locks and dams. Numerical models capable of computing hydrodynamic loads on piers, guard walls, culvert valves, tainter gates, and moored vessels will advance the Corps' ability to provide cost-effective structural, mechanical, and geotechnical designs.

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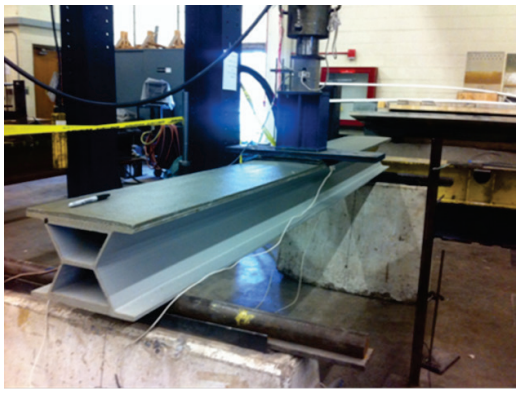
Fiber Reinforced Polymer (FRP) Composite Recess Filler Panels

Problem

Locks with emergency lift gates use panels to fill in the recess area in the lock wall when the emergency gate is in a lowered position. Without these filler panels, vessels passing through the lock could hit the exposed corners of this recess causing serious damage to the lock wall. Recess filler panels are typically made of structural steel and roughly 10-ft-wide by 12-ft-high by 10-in-thick. These panels are very heavy and hard to handle when they need to be moved. Being all steel, they are also susceptible to corrosion. Panels that have been in service show extensive surface damage from mechanical abuse and impact from locking vessels. Corrosion can initiate wherever the protective coating on the panel is damaged.



Laboratory testing of FRP composite section used in the recess filler panel

Approach

This research effort is focused on the design, construction, and use of a fiber reinforced polymer (FRP) composite panel to replace all-steel panels currently used as recess fillers at navigation lock facilities. To assess the feasibility of using FRP composites for the panels, a series of laboratory tests was conducted to evaluate candidate designs and material combinations. Costs dictated that the designs be limited to components available off-the-shelf. A hybrid steel frame and FRP composite insert proved to be the best design to meet the service requirements. Even with the steel frame, the hybrid composite panel is just a fraction of the weight of an all-steel panel. It is also less susceptible to corrosion since the steel frame is not the primary point of contact, minimizing damages to the protective coating on the steel. Three prototype FRP composite filler panels have been fabricated and delivered to Willow Island Locks near Newport, OH, where they will be placed in service in spring 2016. Their performance will be compared to steel panels still in use.

Current Steel Panel

Products

The primary product of this work will be engineer guidance for the design and fabrication of hybrid FRP composite-steel panels to replace all-steel recess panels for lock facilities. A Technical Note will document the guidance recommendations. The overall investigation and field demonstration will also be described in a series of technical transfer products, including journal papers, technical reports, articles in publications such as Navigation *e*News, and webinars.

Final Design

Benefits

The new FRP composite filler panels will be lighter than existing steel panels, making their placement and removal safer and easier. The longer design life and lower susceptibility to corrosion will lower long-term maintenance costs.

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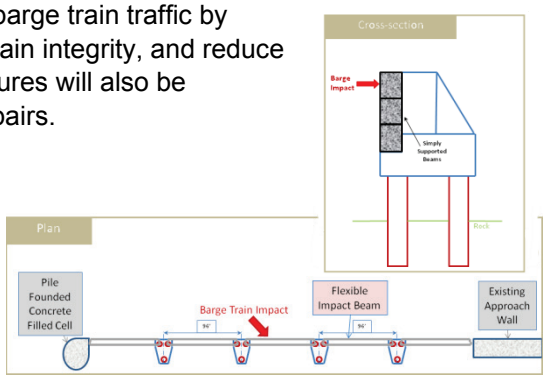
Flexible Approach Walls

Problem

More than 50% of the Corps locks and their approach walls have continued past their economic lifetimes. As these structures wear, they need to be retrofitted, replaced, or upgraded with a lock extension. Energy absorbing flexible approach wall structural systems are being considered. These next generation flexible structures feature reduced replacement costs as well as providing additional protection for barge train traffic and their personnel. Innovative flexible structures would provide cost savings by taking advantage of in-the-wet construction. Flexible structures would help to protect barge train traffic by "flexing" to absorb energy from impacts in order to maintain barge train integrity, and reduce the possibility of broken lashings and runaway barges. These structures will also be *efficiently* resilient under design impact loadings, with less costly repairs.

Approach

The primary objective of this project is to develop simplified engineering methodologies and corresponding PC-based software for use by Corps engineers in the design/analysis of energy absorbing, flexible approach wall structural systems. Specific focus will be applied to approach wall systems containing vertical and batter pile groups for barge impact loading. Pile group response effects define the performance criteria for the design load cases, and proper accounting of these effects is an important part of the engineering methodology development process. A secondary objective is to facilitate energy absorbing, flexible designs and flexible structural components that can make use of in-the-wet construction, thereby affecting a cost savings.



McAlpine Alternative Flexible Approach Wall

Products

Engineering methodology and a suite of supporting software (Impact_Force , Impact_Deck, and Impact_Beam) for the dynamic structural analysis and design of next-generation, pile-founded, flexible, energy-absorbing approach wall systems are being developed. These tools will facilitate the investigation of various structural configurations of flexible walls during the design process and quantify the resilience and toughness of these structures. The engineering software CPGA-R has been developed to support risk and reliability engineering for major rehabilitation studies, and is available in CASE.

Benefits


Barge train impacting a flexible approach wall

Flexible approach walls will provide cost savings by accommodating in-the-wet construction with the use of lighter and smaller structural features. Cost savings will also be realized by avoiding runaway barges in gates. This is done by preserving barge train integrity through the absorption of barge train impact energy by the potential energy of the flexible structure. Flexibility allows the approach wall to absorb the kinetic energy of a fully-ballasted barge train (normal to the wall) with the potential energy through deformation of the deformable piles and superstructure of the approach wall. Key energy absorbing structural system features are flexible impact beams and flexible pile group systems.

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Bullnose Energy Absorbing System (BEAS)

Problem

The forces developed within lashings of barge trains due to head-on collisions of inland barge trains with rigid bull noses at the ends of lock approach walls lead to lashing failures, which in turn, have resulted in individual barges being set free. Barges that are no longer under control can collide with dam and/or navigation lock gates. This scenario at its worst can lead to possible pool loss due to gate failure, total loss of barge and cargo, damages to navigation structures, danger to personnel, etc.

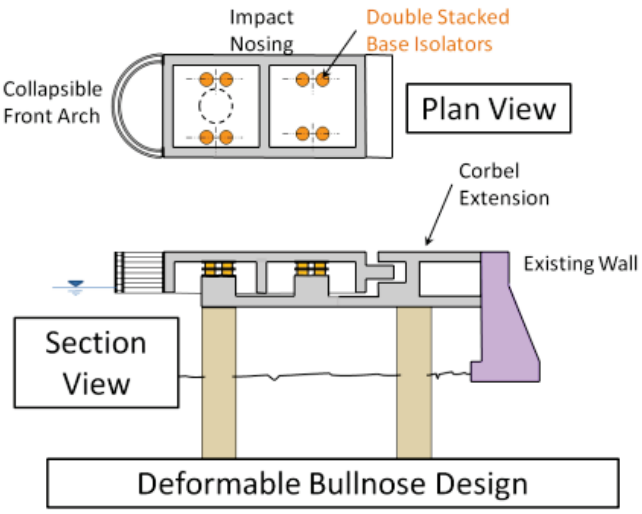
Rigid Bull Nose

Approach

The Corps is developing a new engineering methodology and new structural design concepts for bull noses to mitigate/eliminate the potential for rupture of the lashings and not allow “break-away” barges to occur. This effort is developing innovative bullnose designs and a simplified model of the impact between a barge train and a deformable Bullnose Energy Absorbing System (BEAS) for use as a design tool for the new BEAS structural system.

Products

Several concepts for the deformable bull nose structural system have been developed using base isolators. The initial formulation of an engineering methodology and corresponding PC-based software, dBEAS, for simulation of impact problems has been completed, with the final design capable of withstanding a head-on impact at 6.1 feet/second.



Barge in Gate

Benefits

The benefits from this work unit will be derived from potential cost savings by reducing/eliminating damage to dam and/or lock gates, damage to barges, the potential for the loss of cargo and life, etc., and by reducing the possibility of “break-away” barges. Corps’ District engineers will use this new engineering methodology and software in the design of new deformable bull nose structural systems to retrofit existing rigid bull noses currently in use at numerous Corps navigation structures.

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Fiber Reinforced Polymer Composite Wicket Gates

Problem

Traditional wicket gate design utilizes a main body made of wood, typically white oak. A service life of 10-20 years is typical in the river environment. Gate failure creates difficulties in maintaining upstream pool and the repair or replacement of wicket gates is a costly and dangerous process. A commercially available polymer composite manufacturing technique will allow for the design and creation of a wicket gate that will eliminate the use of wood. This process enables the design and fabrication of a composite wicket gate with equal or greater mechanical properties to a wooden gate and use of current hardware for ease of retrofit.

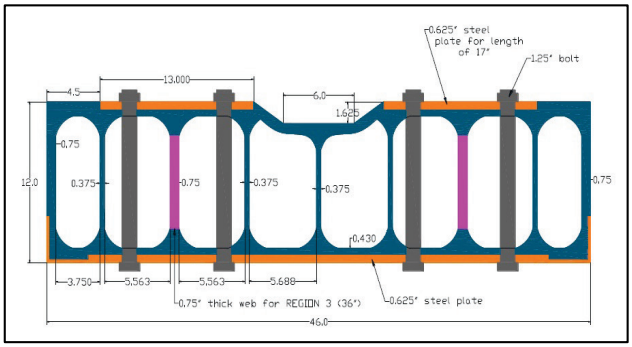
Wooden Wicket Gates

Approach

This research is focused on the use of glass fiber reinforced polymer (GFRP) composite material to replace wood in wicket gates. By utilizing a vacuum assisted resin transfer molding (VARTM) process, it is possible to build a gate made mostly of GFRP material. The composite wicket gate will be of the same general dimensions and equal or greater stiffness as a standard wooden wicket gate. Additionally, the composite design will allow for the use of the original hardware to aid in ease of replacement and operation of the gate. The proposed gate design has inner "channels" that will be filled with various materials with different densities to allow designers to tune the overall weight and center of gravity of the gate. This will ensure that the gate will operate and perform just as a wooden wicket gate, but without the use of wood which degrades in the elements. Engineers at ERDC-CERL, the Inland Navigation Design Center (INDC), Rock Island District, and West Virginia University have contributed to this polymer composite wicket gate design which has a projected installation date of September 2015.

Products

The primary product of this work will be engineering guidance for the design and manufacture of polymer composite wicket gates to maintain navigable pool levels. The overall investigation and field demonstration will also be described in a series of technical transfer products, including conference proceedings, technical reports, articles in publications such as Navigation e-News, and webinars.



Proposed Polymer Composite Wicket gate design showing "channels" that can be filled with varying density materials

Benefits

Polymer composite wicket gates will provide a longer-lasting gate which will result in cost savings from a reduction in maintenance costs and limiting out-of-service times. This will benefit both the Corps and private industry. Successful use of composite wicket gates will be a stepping stone for the design and use of polymer composites for larger, more demanding gates on hydraulic structures.

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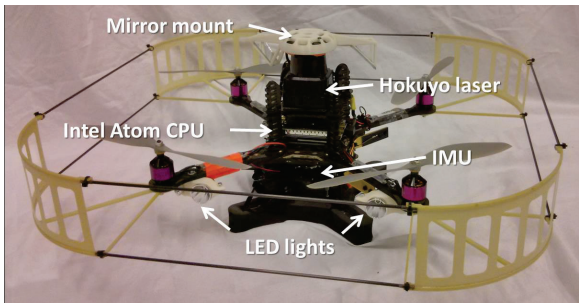
Appendix C: Products Supporting Dam Spillways

Table of Contents

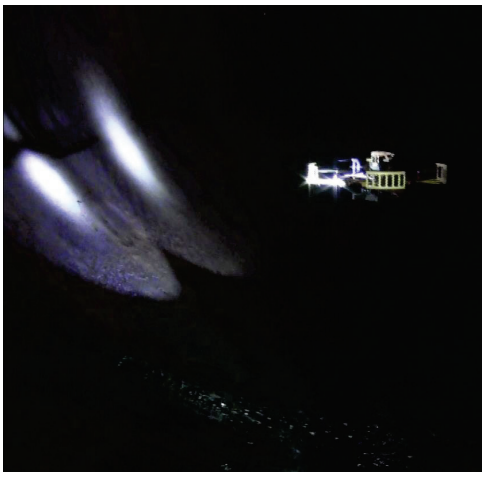
Microbotic Infrastructure Assessment

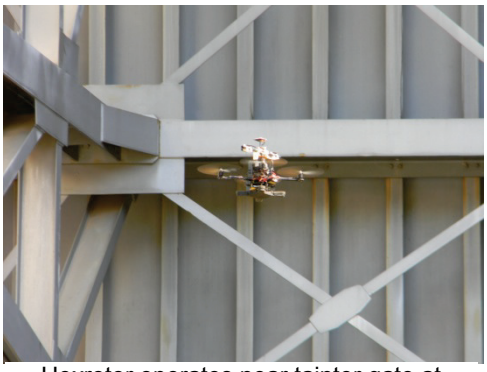
Problem



Quadrotor and on-board equipment

Some components of large USACE lock and dam structures are often difficult, dangerous and/or expensive to access. Assessing the integrity of these components is critical to maintaining operational locks and dams. For example, the coating on penstocks that deliver water to hydroelectric turbines must be inspected by installating of elaborate scaffolding and lighting. Inspectors must work from dark, slippery surfaces in particulate-laden air. Some tainter gates are only accessible by personnel rappelling from the top of dams. Risk to personnel is high, and the size of the components and conditions under which inspectors must work make these assessments very time consuming. Because of the risk and time involved, some penstocks and tainter gates are not inspected as often as they should be.


Quadrotor operates in penstock at Carter's Dam, Georgia


Hexrotor operates near tainter gate at Carter's Dam, Georgia

Approach

Microbotic Infrastructure Assessment research and development focuses on developing a capability to remotely and autonomously assess lock and dam components that are difficult and costly to access, like penstocks and tainter gates. This research is developing remote, autonomous capabilities for the inspection of penstocks and tainter gates specifically, but will be applicable to other difficult-to-access infrastructure components.

Products

A combination of small, autonomous aerial vehicles will be developed which will be able to navigate and collect data, without user interaction, in confined spaces such as penstocks, and along complex vertical structures like tainter gates. Imagery and lidar measurements collected by sensors on the very small vehicles will be processed using custom algorithms designed under this project to automatically detect common defects. The imagery will also be available for manual inspection.

Benefits

Microbotic Infrastructure Assessment will provide a new, cost-effective capability for inspection of penstocks and tainter gates. The microbot inspection will reduce the risk to personnel and the length of outage required to perform manual inspections.

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Photogrammetry Toolbox

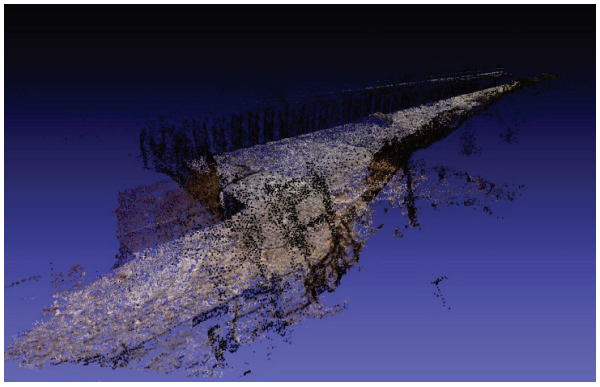
Problem

3D representations of data provide users numerous options, one of which is making data more useful for explaining situations to stakeholders. 3D representations can also be analyzed to compute various parameters. XYZ data of an object or scene can be used to easily calculate measurements such as distance, area and volume. The intent is to develop a low cost and effective way to produce 3D data from pictures.

Pearl River Lock, damaged after hurricane surge caused massive erosion during overtopping

Approach

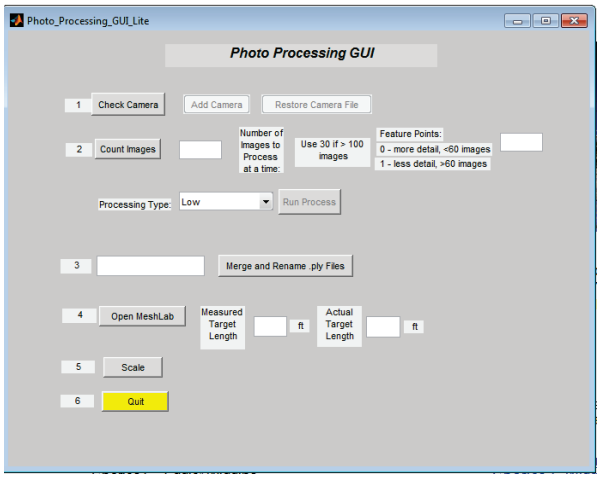
Photogrammetry is a viable low cost method of producing 3D representation of an object or scene through pictures. Using open source software, an easy to use executable program is developed which takes pictures as input and produces XYZ output.



Pearl River Lock – 3D point cloud developed from iPhone photos taken by emergency responder

Products

The Photogrammetry Toolbox is a 5 step process which transforms pictures into a 3D model. This tool integrates various open source codes and provides an easy to use interface. These data can be geo-referenced to a state plane system for comparison to plans and specs. The XYZ data can also be utilized by analysis tools to compute area and volume measurements, and to cut cross-sections through the data for change detection.



The Photogrammetry Toolbox screen

Benefits

The Photogrammetry Toolbox provides methods of producing 3D Data from pictures, which then can be used to compute various measurements.

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Abrasion-Resistant Polymer Composite Overlays and Coatings

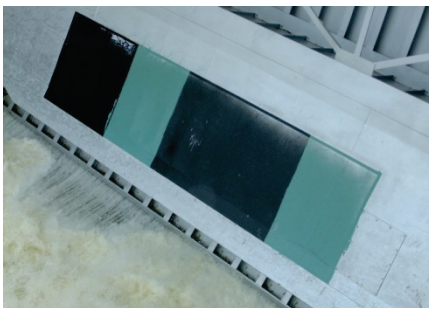
Problem

For over sixty years, vinyl coating systems have been the primary system of choice to protect steel gates on navigation structures from corrosion. A twenty-plus year life expectancy is common before maintenance painting is required. However, locations with high abrasion from debris- and silt-filled flowing water have had normally tough vinyl coatings become significantly damaged in less than five years. The abrasive conditions are the most prevalent on the downstream side of a tainter gate. Polymer composite overlays and coatings provide the possibility of increased service life.

Vinyl coating in poor condition due to abrasive action of debris-filled swirling water

Approach

This research effort focuses on the use of abrasion-resistant polymer composite overlays and coatings to protect the downstream side of tainter gates where swirling debris rapidly deteriorates a conventional vinyl coating system. To evaluate the performance of abrasion-resistant coatings, five different types of polymer composite coatings and an adhesively applied ultra-high molecular weight polyethylene (UHMWPE) thin plate were evaluated in the laboratory. The performance of these new materials was compared to standard Corps of Engineers vinyl coating systems 3-A-Z and 5-E-Z. (3-A-Z is a vinyl zinc-rich primer with an aluminum vinyl topcoat system and 5-E-Z is a vinyl zinc-rich primer with a gray vinyl topcoat system.) Based on laboratory results, two different ceramic-filled composite coatings and the adhesively applied UHMWPE thin plate were selected and applied in September 2014 to a tainter gate at Heflin Dam near Gainesville, Alabama. The ceramic- filled composite coatings were applied directly over bare steel as well as over a standard vinyl system. The UHMWPE sheet was applied to bare steel. The materials performance of these systems will be evaluated over a 3 year time period.



Completed project showing UHMWPE on the far left and the ceramic coatings to the right

Products

The primary product of this work will be engineer guidance on the use and installation of abrasion-resistant polymer composite overlays and coatings to protect the downstream side of tainter gates where the abrasive action of turbulent, debris-filled water prematurely degrades a conventional vinyl coating system. Initially this guidance will be made available as a Tech Note. If the performance is verified by the field installation, the ceramic-filled composites coatings will be submitted for future updates of UFGS-09 97 02, Painting: Hydraulic Structures. The overall investigation and field demonstration will also be described in a series of technical transfer products, including conference proceedings, technical reports, articles in publications such as Navigation *e*-News, and webinars.

Benefits

The abrasion-resistant coatings and overlays will reduce maintenance and out-of-service costs where premature failures of standard vinyl coating systems occur in highly abrasive service conditions. Further cost benefits are possible since the abrasion-resistant coatings and overlays can be applied just to areas of high abrasion, with a standard vinyl coating system protecting areas of low abrasion.

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Polymeric Slides to Replace Rollers on Hydraulic Gates and Valves

Problem

Mechanically Fastened UHMWPE

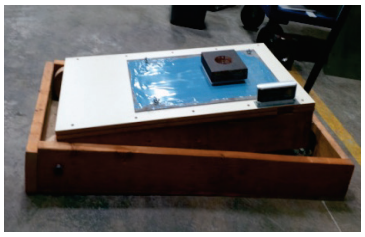
Gates on hydraulic structures are used to regulate the flow of water, be it a gate on a dam or a valve in the locks. In the past, steel rollers or wheels were commonly used on lift gates and valves to assist in the movement of these components. Over time these rollers are prone to seizing up due to corrosion that occurs in the damp environment associated with navigation structures. When this happens, raising and/or lowering the gates or valves becomes difficult and negatively impacts normal operations. Replacement steel rollers can cost millions of dollars, not including installation. Replacing the steel rollers with polymer blocks to act as slides was considered to be a simple and inexpensive fix.

Approach

Embedded, Corroded Steel

This research effort is focused on the use of ultra-high molecular weight polyethylene (UHMWPE) blocks that function as slides on lift gates and valves to replace steel rollers that are prone to seizing up in a typical lock and dam operating environment. As a field test, UHMWPE slides were mechanically fastened on a lift gate at Bankhead Dam in Alabama. Initially the slides functioned as intended, and then the gate started seizing up. Upon removal of the gate, it was determined that the embedded, corroded steel in the reaction wall was damaging the slide and increasing its coefficient of friction. A friction test was designed and multiple materials were tested. Testing results showed that the best combination of materials would be Belzona SuperGlide and either UHMWPE or Teflon (PTFE). The repair method was then modified to smooth out the embedded, corroded steel with a Belzona metal repair compound topcoated with Belzona SuperGlide. A new method to adhesively apply the UHMWPE was used on a second gate. This method proved to be faster and more cost effective than mechanical fasteners. Due to the success of this second method, Mobile District is planning on retrofitting all lift gates at Bankhead Dam with the adhesively applied UHMWPE and imbedded steel repair. Further studies at Portland District are assessing the ability to use these materials on gates with higher hydraulic loadings than those at Bankhead Dam.

Products



Friction Testing of UHMWPE on SuperGlide

The primary product will be engineer guidance to design, use, and install UHMWPE materials as a slide system to replace rollers or wheels on gates and valves used on navigation structures. This guidance is expected to be made available through the Inland Navigation Design Center. The overall investigation and field demonstration will also be described in a series of technical transfer products, including conference proceedings, technical reports, articles in publications such as Navigation e-News, and webinars.

Benefits

Implementing polymeric slides as replacements for rollers or wheels on gates and valves is significant because initial costs for the replacement are about two magnitudes less than currently used replacements. Also, the new materials offer increased service life and reduced future maintenance costs.

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Barge Arrest System

Problem

Recent closures of U.S. Army Corps of Engineers navigation projects attributed to tow/barge accidents have been costly to the towing industry. Closures are also costly to the government due to expensive structural repairs. Cheatham Lock and Dam on the Cumberland River experienced such an accident in March 2002 (picture to right). Designers and operators of locks and dams need a means of arresting break-away barges and avoiding their impact on critical structural and mechanical components. A device to protect spillway gates from breakaway barges would be an asset to the Corps of Engineers.

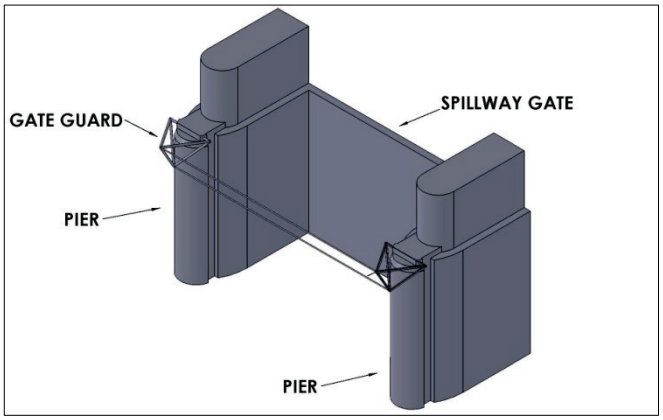
Barges on the Cheatham Dam, TN, after March 2002 Accident

Approach

Computing the impact force during the collision requires knowledge of the barge's mass and velocity. As a break-away barge approaches a structure, it travels with the velocity of flow near the structure. The initial focus of the gate guard design was determining a way to withstand the barge's impact load. Other factors contributed to the final concept: the guard could undergo a controlled deformation as the barge is brought to rest; the avoidance of the accumulation of debris or ice; and the method of deployment if the guard were positioned to allow rapid deployment. Also, navigation projects with large pool variations throughout the year require a structure be positioned for barge impact at lower pools, but not so low that at high water the barge simply floats over it.

Products

The device designed is a set of cables supported by tetrahedra placed on the spillbay piers of a navigation dam. When not deployed the tetrahedra sit on top of the piers and have no effect on the flow approaching the spillway gates or the flow near the structure, nor will they collect debris. During deployment, the tetrahedra rotate forward until they come to rest on the piers. Two cables connect each adjacent tetrahedron. These two cables work in conjunction to catch the vessel as it moves toward the spillway gate. A vessel floating toward a spillway gate will first impact the lower cable, which is designed to absorb the majority of the vessel's longitudinal momentum. The vessel may then start to slide over that cable. If this sliding occurs, the upper cable will limit the vertical movement until the vessel stops. Design details such as overall dimensions and mounting locations will need to be developed on a project-specific basis, and modifications will be required for sites having extremely large pool variations.



Barge Arrest System Schematic

Benefits

This barge arrest system can be adjusted to not interfere with flow or catch debris when not in use, regardless of pool fluctuations. Preventing barges from impacting dam gates will prevent downtime for river traffic, loss of pool, and possible loss of cargo and lives – all of which contributes to cost savings and safer, more efficient waterways.

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Nondestructive Condition Monitoring for Tensioned Steel Members

Problem

West Point Dam, GA

Many Corps of Engineers navigation structures contain embedded and external steel structural members under tension and subject to corrosion and loss of tension. Two examples are tainter gates, held in place by massive steel anchors embedded in the dam, and lock gate diagonal bracing. Lock gates can experience excessive tension on this diagonal bracing. Problems with these components are hidden and difficult to evaluate. A non-destructive testing (NDT) method is needed to determine the tension and the degree of corrosion present. A method to continually monitor the tension while opening and closing gates could prevent abrupt failures of the rods. Present testing methods consist of visual inspection for corrosion, anchor length measurement or hammer testing to determine gross loss of tension, and jacking, which directly measures tension. Problems with present testing methods are accuracy, time, and access.

Approach

This work seeks to develop a high-power acoustic measurement system for nondestructive measurement of the tension in both exposed and buried post-tensioned steel members. The design of this instrument will be based on ERDC-CERL's patent #7,614,303, "Device for Measuring Bulk Stress Via Insonification and Method of Use Therefore." The effectiveness of this new measurement system will be tested in the Engineer Research and Development Center's Anchor Rod Test Bed and on Corps-owned Civil Works structures. Also, system performance will be optimized.

Tension testing of rods at West Point Dam, GA

Products

This work will make use of a commercially available portable acoustic NDT test instrument to conduct quantitative measurements of tension in steel tainter gate anchor rods and lock gate diagonal bracing. It will work in areas with limited access. Post-processing of the data will provide evaluation of fitness for service. It has been successfully demonstrated on 45-ft-long anchor rods. Research results are presented in 2 Coastal and Hydraulics Engineering Technical Notes (CHETNs), CHETN-IX-37 and CHETN-IX-38, *Acoustic Nondestructive Testing and Measurement of Tension for Steel Reinforcing Members – Part 1-Theory* and *Part 2 - Field Testing,* respectively. CHETN-IX-37 is available at http://acwc.sdp.sirsi.net/client/en_US/search/asset/1042074 and CHETN-IX-38 at http://acwc.sdp.sirsi.net/client/en_US/search/asset/1042076

Benefits

This research will create a method that directly interrogates the mechanical and material properties of steel structural members, addresses the corrosion problem, takes little time and human resources to perform, and requires minimal access. The method will provide additional information on anchor tension for economic planning purposes or for maintenance and/or operations.

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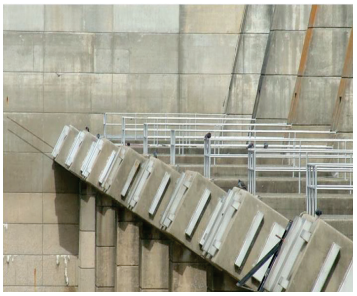
Trunnion Rod Microcrack Detection Test System Verification and Validation

Problem

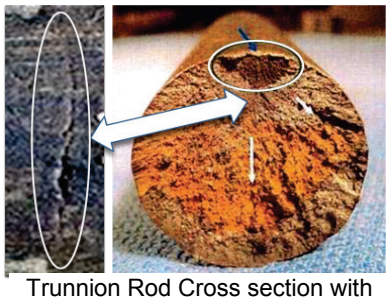
Post Tensioned trunnion rods hold trunnion girders in place at many Corps of Engineers dams. The anchored ends near the gates are typically embedded in concrete, making the removal and replacement of the rods almost impossible. Special types of grease or grouts are injected into the ducts after tensioning to improve the corrosion resistance of the rods. This design has been standard practice since the 1940s. These trunnion anchor rods are now failing in various Corps navigational structures due to orthogonal cracks occurring randomly along their lengths. As these rods fail within a given group, increased demand is placed on the remaining rods. If enough rods within a group fail, the tainter gate will also fail. It is not currently known how many rods are in a cracked pre-failure state or if the current rate of rod failure is likely to increase in the future.



Trunnion rods ejected from pier

Approach

A method was needed to detect, quantify, and track the occurrence of trunnion anchor rod cracking. Presently, only tension can be assessed; this requires a lift off test, which is complex, dangerous, and expensive. In some cases the test itself has caused rods to fail. A non-destructive testing (NDT) method to test for early and late stages of cracks within the trunnion rods was needed. Current research indicates that nonlinear and conventional measurements acquired via ultrasonic guided waves will be effective in detecting microcracking down the length of the rod – distinguishing microcracking from rod contact with the proximal steel sleeve. This ultrasonic method, which has undergone preliminarily field testing, also presents new options for tracking tension changes and developing onsite monitoring. The portable crack detection system is undergoing continued field validation and verification.



Trunnion Rod Cross section with crack shown

Products

This research has resulted in the development of a prototype system for the quick and safe NDT testing or monitoring of trunnion rods for in situ early signs of failure due to rod breakage. Guidelines for application across various diameters, end conditions, and embedment will be provided.

Portable Trunnion Rod Test System

Benefits

This research is developing techniques, procedures and a specialized portable NDT system that will enable USACE personnel to ascertain and monitor the condition of trunnion rods in situ in the presence of grease- or grout-filled trunnion rod conduits. Catastrophic failure of post-tensioned trunnion anchor rods is an ongoing concern caused by propagating orthogonal cracks within trunnion rods which has been described in Technical Notes CHETN-IX-32, CHETN-IX-35, CHETN-IX-36 and Technical Report TR-15-1, *Detection of Microcracks in Trunnion Rods Using Ultrasonic Guided Waves*. In addition, these documents provide background information, initial test bed investigations and field test results of nonlinear and guided wave methods directed at the development of a non-destructive testing capability for long distance microcrack detection in embedded rods.

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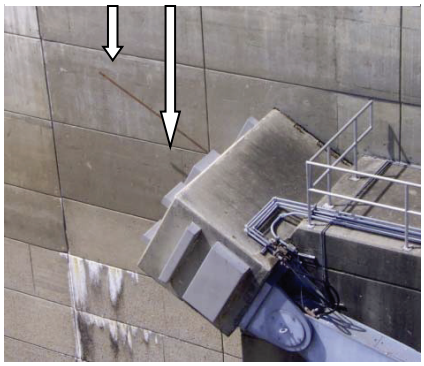
Repair and Replacement of Trunnion Anchor Rods

Problem

A number of Corps dams have experienced failures of individual trunnion anchor prestressed rods. These failures have the potential to compromise the structural integrity of the trunnion anchorage and result in the loss of capability of the spillway gate to maintain and regulate upper pool levels. Failure of multiple rods in an anchorage could result in catastrophic failure of the anchorage and the support spillway gate. These failures demonstrate a need to develop repair and replacement procedures for trunnion anchor prestressed rods. The primary causes of failed rods from metallurgical reports are environmentally assisted cracking or stress corrosion cracks and low fracture toughness.

Broken trunnion rods protruding, R.F. Henry Lock and Dam



Approach

The primary objective of this effort is to develop repair and replacement procedures for anchor rods. Failure of the corrosion protection system is suspected to have contributed to environmentally-assisted cracking. Field replacement of the corrosion protection system is another major objective. A procedure to replace the corrosion protection system and/or rods is being developed. A test bed has been fabricated to test and demonstrate these procedures. Analytical models will be developed to analyze the unloading of prestressing force resulting from rod failures, as well as the detensioning and retensioning of rods during repair and/or replacement. Finally, guidance will be developed for replacement procedures. These procedures could also be applied to rods that have been determined to contain defects. A fracture mechanics analysis will also be conducted to determine the relationship between fracture toughness and tolerable flaw size.

Products

A repair scheme for replacing rods and their corrosion protection system for non-grouted construction is the primary product. Guidance and procedures will be developed for replacement of failed prestressed rods. Being developed are tools to analyze the prestressing force resulting from detensioning and retensioning of rods during repair and/or replacement, as well as to provide a means to analyze trunnion anchorages with failed rods. Documentation of the proposed replacement/repair scheme and the analytical work will be provided in the final report along with the fracture mechanics analysis. The analytical models will be available for District users.

Benefits

The analytical tools and repair and replacement guidance will provide dam operators with tools to assess structural integrity of trunnion anchorages that have failed rods and to develop repair plans based on the scheme and procedure developed. The fracture mechanics analysis will have multiple benefits, including quantifying flaw sizes for researchers developing flaw detection procedures, and establishing minimum fracture toughness requirements for prestressing rods for a given flaw size. It is expected that the proposed repair schemes will be more economical than present proposed schemes. The fracture analysis has the potential to lead to the reduction of future failures by quantifying minimum toughness requirements for anchor prestressed rods.

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Multistrand: Probabilistic Assessment of the Capacity of Multistrand Post-tensioned Ground Anchorage

Problem

The Corps needs methods to determine the remaining life and the current (reduced) capacity of hydraulic structures containing corroded multistrand anchors. Multistrand anchors provide additional capacity for lock walls and other hydraulic structures to handle unexpected or changed load conditions. Some anchors are beginning to fail due to corrosion and other possible failure mechanisms. The details of exactly how and where these defects evolve are poorly understood. Improving on this understanding is important to the development of a non-destructive evaluation (NDE) system for early defect detection and characterization that infers the remaining cross-section area (RCSA) of the anchor tendons.

John Day Lock anchor caps and exposed anchor tendons

Corroded anchor allowing water flow during lockage

Approach

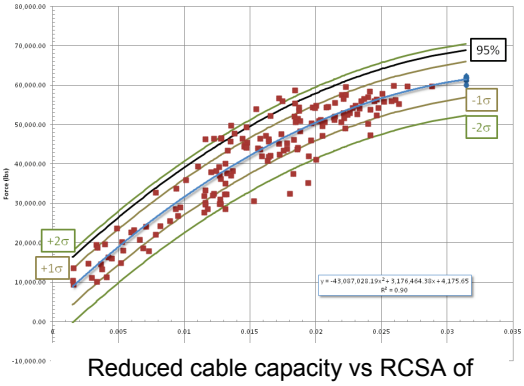
The primary objectives of this R&D project are to develop engineering procedures making use of project data, ERDC laboratory generated data, and/or nondestructive measurement techniques (NDT) to accomplish the following:

- to estimate the current state of load carrying capacity of the ground anchorage
- to estimate remaining life of the tendon, and
- to establish the deterioration of anchorage capacity (with time) so costly replacement of ground anchorage can be delayed until absolutely needed.

Analytical, laboratory, and field testing efforts will all be used in the development of this engineering methodology and resulting analytical model. Probabilistic procedures will be used to formally quantify uncertainties for the primary variables. An analytical model will be developed using these procedures for a probabilistic stability assessment of a hydraulic navigation structure containing corroded post-tensioned anchors. Lastly, procedures to extend the life of deteriorating multistrand tendons are to be investigated.

Products

- Engineering methodology and fundamental research into a NDE procedure for the measurement of corrosion in multistrand post-tensioned anchors.
- Forensic analysis of corroded anchors at John Day Lock.
- Probabilistic measurements of wire strand RCSA, loss rate, and reduced anchor load capacity through full-scale Testbed and other laboratory experiments.
- Probabilistic model for remaining life and reduced capacity assessment based on the RCSA of a multistrand anchor.
- Implementation of the probabilistic anchor model in an engineering stability software.



Reduced cable capacity vs RCSA of individual corroded wire

Benefits

Non-destructive techniques for measuring RCSA and probabilistic models for assessing the status of existing anchors will provide a more accurate and less conservative estimate of remaining life and reduced capacity of multistrand anchors. This will result in significant savings by extending the time until costly anchor replacements are required.

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Unmanned Survey Vessel for Shallow Water

Problem

Accurate, reasonable cost surveys of areas that a regular hydrographic survey boat cannot access are needed to assess those areas.

Approach

Prototype unmanned survey vessel

This research is developing an unmanned survey vessel for use in shallow water and areas normally inaccessible to survey boats. The boat has a catamaran type hull made of roto-molded polyethylene with a foam filled core. It is 10-ft-long, 48-in-wide and drafts 6-8 in of water. A 36-lb-thrust trolling motor is located near amidships in each pontoon for propulsion and steering. A third trolling motor is located at the stern to provide additional propulsion when needed. The boat is driven with a radio control system that directs power independently to each of the three motors. The system allows the boat to turn around in its own length. At this time two deep-cycle batteries provide power to the motors. Two additional batteries provide power for the data acquisition systems. For surveying, the boat is currently equipped with an Odom MB1 Multibeam Echo Sounder which provides a swath width of up to 120 deg. The unit's transducer is mounted below the waterline between the pontoons where it is protected from damage. The Odom is integrated with a sound velocity probe, a TSS motion sensor, and a dual frequency GPS system that provides position, heading, and raw GPS data logging capability. The multibeam unit will work in water less than a meter deep or as deep as 120 m. The transducer mounting bracket is also configured to allow a RDI Workhorse ADCP unit to collect velocity data from the vessel. An i7 CPU on the boat controls the multibeam unit (Odom software) and also logs data from the various sensors using Hypack software. The CPU receives real time video input from a webcam. All settings on this CPU are viewable and remotely controlled by radio link from the ground station. The system has been tested upstream and downstream of Bankhead Lock and Dam on the Black Warrior River. For comparison, data were collected the same week using a survey boat with an interferometric swath system. Additional testing of the survey system will be conducted to help determine operation limits such as operational time and the limits of the radio systems.

Products

This work will result in an unmanned survey vessel capable of collecting multibeam, velocity, GPS, and video data. Having the capability to safely survey all areas around navigation infrastructure will provide worker safety and the data needed to determine scour, obstructions and other conditions that may require engineering actions.

Benefits

Having the ability to determine the extent of scour downstream of dams has the potential to prevent dam failures. Having a reliable survey tool for presently inaccessible areas of waterways will provide more accurate data upon which maintenance decisions can be made.

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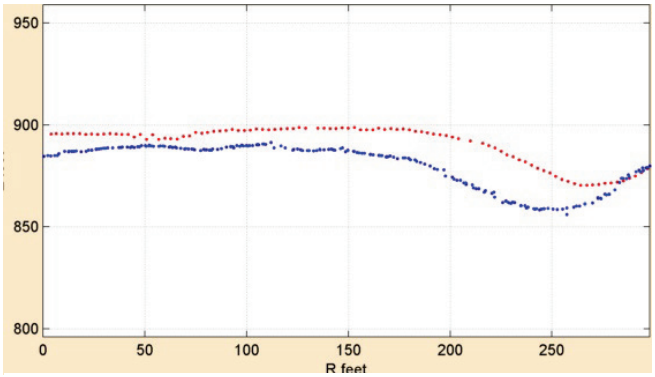
Scour Analysis Toolbox

Problem

Periodic investigation surveys are performed around river locks and dams. Hydrographic survey data are collected around hydraulic structures to monitor for scour and areas of deposition. Scour occurring downstream of stilling basins requires monitoring in order to ensure dam safety. Currents along lock walls and guidewalls can also cause scour that should be closely monitored. Survey data should be compared to elevations from construction drawings or post construction surveys to determine scour depths relative to the design elevation. Flow conditions at the time of the survey often impact the scour or fill at a location, so it is useful to compare multiple surveys to the baseline survey.



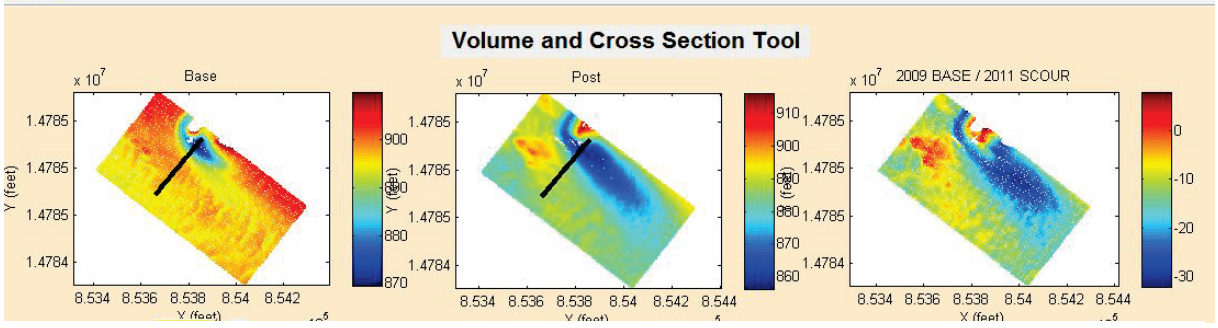
Selected Cross section generated by Volume Tool

Approach

The intent is to develop an executable program that will make comparison of depths and volumes from multiple survey datasets possible without extensive knowledge of CAD or GIS programs. This will facilitate rapid comparisons of surveys and preparation of graphics for presentations. Additional tools and procedures will be developed for use in CAD and/or GIS packages.

Products

The Scour Analysis Toobox was developed to enable the easy comparison of multiple surveys to a base survey at a given location. The toolbox will generate contour plots showing elevation differences of the study area. A pointing tool can be used to select locations to display and to draw cross sections. Cross sections and elevation difference data will be exported in CAD and GIS formats.



Partial Toolbox screen-shot highlighting, left to right, the base survey, the secondary survey, and the differences between the two.

Benefits

The Scour Analysis Toolbox will provide methods of extracting and comparing survey data from multiple surveys. This toolbox provides a means to compare survey results and generate graphics for discussion on further analysis.

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Appendix D: Products Supporting General Construction and Repair Materials

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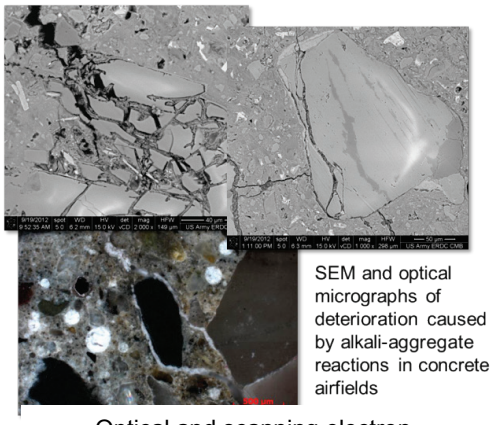
Forensic Investigations of Infrastructure Deterioration and Failure

Problem

Civil works infrastructure is subject to multiple forms of deterioration. Deterioration of concrete can occur by freeze/thaw action, sulfate attack, corrosion, alkali-aggregate reactions, physical abrasion or erosion, and many other types. Steel and other metallic materials may be damaged by corrosion, fatigue, mechanical overloading, stress-assisted corrosion and embrittlement. Polymeric materials may be damaged during service by exposure to harsh conditions such as thermal cycling, moisture, and degradation by ultra-violet radiation. These forms of deterioration have become more and more prevalent as USACE infrastructure surpasses its originally designed service life. New tools and techniques for forensic investigations are needed to identify forms of deterioration and the causes of failures. These forensic investigations provide insights into fundamental deterioration and failure mechanisms that guide the development of repair and retrofit strategies.



SEM and optical micrographs of deterioration caused by alkali-aggregate reactions in concrete airfields

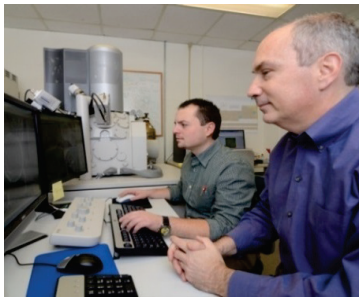
Optical and scanning electron micrographs of deterioration in concrete

Approach

The U.S. Army ERDC employed a tiered approach to forensic investigations of infrastructure deterioration and failure. Initial testing consisted of rapid screening studies to identify mechanisms of interest and define applicable investigation techniques. Based on these rapid studies, more in-depth characterization and testing was performed to provide more definitive answers. For concrete, investigations included various forms of microscopy (e.g., optical and scanning electron microscopy), chemical analysis, mineralogical analysis, durability testing (e.g., chloride ion concentration), and other techniques. For metallic materials such as steel and aluminum, various microscopy and metallographic techniques along with chemical analysis and mechanical testing were used. For polymeric materials (e.g., waterstops, joint sealants, coatings), various types of characterization, durability studies, and mechanical testing can be performed. Non-destructive testing and evaluation is another important component of this capability. The use of robust testing protocols executed by experienced engineers and scientists aids in providing customers with definitive answers to guide mitigation, repair, and retrofit efforts.

Products

Unique capabilities to rapidly perform forensic investigations of infrastructure deterioration in support of USACE Districts have been developed. Reports have been provided to customers in a timely fashion that provide evidence and conclusions from forensic investigations and provide necessary inputs for repair and retrofit.



ERDC researchers examining materials using a scanning electron microscope

Benefits

This in-house capability is being maintained and expanded to aid USACE Districts in investigations of infrastructure. The results provide the necessary inputs in order to effectively mitigate deterioration issues and also repair infrastructure to extend service lives.

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Horizontal Concrete Repair Materials for Inland Navigation Structures

Problem

Typical deterioration of horizontal concrete surfaces

Deterioration of horizontal concrete surfaces (e.g., lockwall surfaces, parking areas, spillways, sidewalks, etc.) is a common problem across USACE, particularly in aging structures with inadequate resistance to cyclic freezing and thawing. Exposure to deicing salts and physical forms of abrasion can also lead to additional concrete deterioration. Other forms of deterioration include erosion, scour, and cavitation in underwater locations such as stilling basins. Deterioration of this type can reduce occupant safety, effect mechanical systems, and possibly alter operations. However, due to their low criticality when compared with catastrophic modes of failure (e.g., damage to a miter gate), this type of concrete deterioration often goes unrepaired, leading to subsequent deterioration of the underlying concrete or other structural components. New material technologies can improve the performance of these systems and the ease of repair. Along with these new materials, robust testing protocols and guidance must be developed to evaluate material properties to ensure they conform to desired mechanical properties (e.g., strength, bond, shrinkage), durability (e.g., thermal cycling, freeze/thaw, salt scaling), and serviceability (e.g., skid resistance) requirements.

Approach

The objective of this research is to investigate materials and methods to cost effectively repair deteriorated horizontal concrete surfaces in inland navigation structures in both in-the-dry and in-the-wet conditions. New materials under investigation for this application include rapid repair materials, shrinkage reducing admixtures, fiber reinforcement, polymer modified repair materials, and other technologies. In-the-dry repairs are being investigated using typical repair techniques consisting of removal of unsound concrete. In-the-wet repair will focus on rapid methods to perform repairs underwater and will evaluate their long-term performance when subjected to relevant flows and exposure conditions. Testing will initially be performed at smaller scales and eventually-scaled up for simulated concrete repairs of relevant structural components and systems (e.g., the top of a lock wall). Another critical component of this research is the development of new testing protocols and guidance that consider the mechanical properties of the material and its long-term durability when subjected to anticipated exposure conditions.

Products

Concrete repair operations at Newt Graham Lock and Dam

Material properties of optimized mixture proportions for making high quality repairs will be developed, including in-house concrete formulations, pre-packaged repair materials, shrinkage reducing admixtures, and fiber reinforcement. New guidance related to these materials and standardized testing protocols to evaluate mechanical properties and durability for various applications will also be developed and vetted for various repair materials.

Benefits

This research will develop a robust set of standardized testing protocols that can be utilized by District engineers to evaluate relevant properties of various repair materials. It will also identify optimal repair materials, admixtures, and fiber reinforcement for various repairs.

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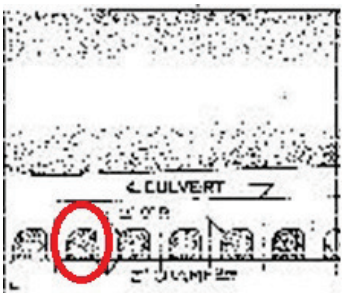
Polymer Composite Wrap for the Repair and Strengthening of Concrete Columns

Problem

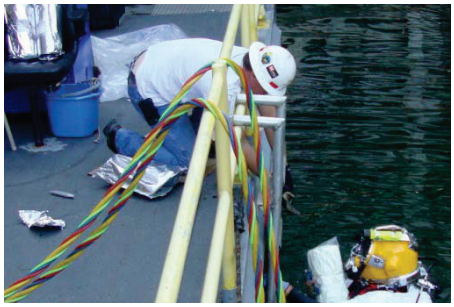
Generally, the repair or retrofit of concrete structures with Fiber Reinforced Polymer (FRP) composite wraps is done in the absence of water. In some locks the discharge concrete ports are close enough that they represent column-like structures. Previously, when these structures showed significant deterioration and section loss due to alkali silica reaction and high velocity flowing water, the repairs were costly and time consuming: a preformed steel shell had to be positioned and welded together by divers and the void was filled with grout. Polymer composite material systems that cure underwater are now available.



Schematic drawing of column-like structure of lock discharge port.

Approach

This research is focused on the use of FRP composite wrapping to be applied underwater for the strengthening of deteriorated concrete columns. A demonstration application has begun on the deteriorating discharge concrete ports at the Chickamauga Lock in Chattanooga, TN, which are close enough that they represent column-like structures. An FRP composite system was developed and tested in the laboratory to determine the feasibility of using an FRP composite repair system that would be easier, quicker, and with equal performance compared to the steel shell-and-grout design. In July 2013, one column was wrapped using an FRP composite system. Placement was monitored via cameras mounted on the divers' helmets. At forty days and 1 year after installation, divers reported that the material and installation looked the same as it did the day it was applied. Future assessments will be made during periodic dive inspections. In the summer of 2015, additional discharge ports will be repaired and strengthened with FRP composite wrapping.



Worker handing diver a roll of composite wrap

Products

The primary product of this work will be engineering guidance to design, use, and install FRP composite wrapping for the underwater repair and rehabilitation of deteriorated concrete columns. The overall investigation and field demonstration will also be described in a series of technical transfer products, including conference proceedings, technical reports, articles in publications such as Navigation e-News, and webinars. Link to article about this demonstration in the Nashville District Digest: http://www.lrn.usace.army.mil/Media/NewsStories/tabid/6957/Article/17796/nashville-district-works-with-partners-on-engineering-solutions-at-chickamauga.aspx

Benefits

FRP composite wrapping applied underwater on concrete columns in lock structures will provide quicker, longer-lasting repairs, providing cost savings from shorter out-of-service times, benefiting both the Corps and industry. Composite wrap repairs will also provide longer service life than a traditional repair and be virtually maintenance free for the remaining life of the asset.

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Polymer Composite Wrap and Shell Repair of Corroded Steel H-Piles

Problem

Severely corroded steel H-Piles for load bearing structures such as bridges are costly to repair and require a significant downtime of the structure. Traditional repairs consist of cleaning the corroded steel, welding new steel in place, and then painting the repaired areas. If funding is unavailable, the load rating of the structure is reduced, causing a significant reduction or total inability to use the structure for its intended purposes. Currently, there are polymer composite materials that can be used as a system to repair corroded load bearing steel H-Piles and bring them back up to or surpass their original load bearing capacity.

Corroded Steel H-Pile on East Fork Bridge

Approach

This research is focused on the use of Fiber Reinforced Polymer (FRP) composite wrapping and shells to strengthen and repair corroded steel H-Piles. A demonstration application has been completed on the deteriorated steel H-Piles on the East Fork Bridge at East Lynn Lake outside Huntington, WV. An FRP composite system was developed utilizing an FRP shell that performs as a concrete form which is then wrapped with an FRP wrap to provide additional compressive strength and confinement to the column. In March 2014, the corroded steel was hand tool cleaned, shear studs were installed 12 inches below the corroded area, an FRP shell was installed around the H-Pile, epoxy grout was poured into the base, the shell was wrapped with an FRP wrap, the system was filled with a self consolidating concrete from the top, and finally the whole system was painted for extra weathering protection. The bridge was load tested 1 month after repair and the repaired piles load capacity is now greater than the original load capacity when the bridge was first built.

Bottom shell around good steel with shear studs and filled with epoxy grout

Products

The primary product of this work will be engineering guidance to design, use, and install FRP composite wrapping and shells for the repair and rehabilitation of corroded load bearing steel H-Piles. The overall investigation and field demonstration will also be described in a series of technical transfer products,including conference proceedings, technical reports, articles in publications such as Navigation e-News, and webinars. Link to article about this demonstration in the *Army News*:
http://www.army.mil/article/123030/Small_R_D_project_in_West_Virginia_has_big_implications_for_civil_works_projects_worldwide/?from=RSS

Benefits

FRP composite wrapping and shell materials used together in a system will provide a quicker, longer-lasting repair which will result in cost savings from shorter out-of-service times, benefiting both the Corps and industry. A composite wrap and shell system repair will be virtually maintenance free for the remaining life of the asset.

Repair near completion

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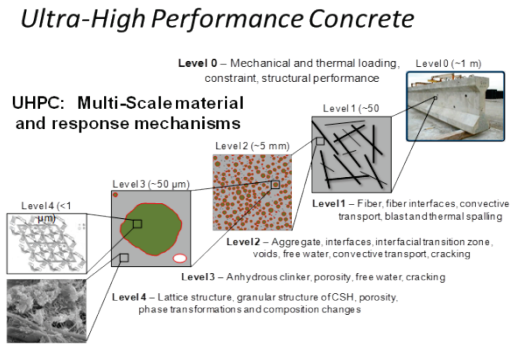
Applications of Novel Materials for Civil Works Infrastructure

Problem

As the age of USACE civil works infrastructure extends beyond its originally designed service life, deterioration of construction materials such as concrete and steel becomes a prevalent problem for many Districts. As infrastructure deteriorates, maintenance and repair is necessary to maintain acceptable performance. Many materials currently provided by manufacturers or recommended in guidance do not meet the structural, serviceability, and durability requirements necessary to extend the life of our existing infrastructure. Novel materials represent a new paradigm for materials selection with the potential to greatly improve the performance of our civil works infrastructure at a reduced cost and also to impart new capabilities such as self-sensing for integral structural health monitoring.



Example novel material technologies

Approach

This research leverages previous R&D investments by working to transition novel materials developed for military engineering and civil works applications to answer the operational needs of aging civil works infrastructure. Materials considered include advanced cement-based materials such as ultra-high performance concrete and rapid repair cements; metallic materials with improved strength and corrosion resistance; advanced polymeric materials with improved mechanical properties and durability; and potentially self-sensing materials. Stakeholder-identified operational needs and materials issues are correlated with potential novel materials solutions. Many of these novel materials were originally developed for military engineering applications and are now being transitioned to answer the needs of our civil works infrastructure. Laboratory-based studies optimize material properties and investigate the feasibility for repair and retrofit. Collaborations with USACE Districts are leveraged to investigate novel material feasibility in field demonstration projects and to develop guidance on using novel materials for various applications.

Products

This research will produce publications and presentations related to novel materials and their applications in laboratory and field demonstration projects. Guidance will be developed that leverages novel material developments and identifies relevant repair and retrofit applications.

Applications of novel materials for civil works infrastructure

Benefits

Novel materials have the potential to increase the performance and durability of aging USACE civil works infrastructure, reducing maintenance needs and possible structure closures.

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Infrastructure Technologies

Increased Reliability • Reduced Cost
Engineering Guidance • Performance Optimization • Cost-effective
Nondestructive Testing • Forensic Analysis