Accelerated Freshwater Harbor Corrosion Study
In The Duluth-Superior Harbor

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Abstract

The steel sheet piling in the Duluth-Superior Harbor is corroding at an accelerated rate compared to other Great Lakes fresh water harbors and ports. Based on observations of both older and new sheet pile installations, the accelerated corrosion appears to have begun in the late 1970s. Underwater inspections have revealed that the corrosion is widespread throughout the harbor on all types of steel piling buttressing the docks. Some of the steel beams supporting the dock structures have holes the size of footballs (15-30 cm) which have already been or are in the process of being repaired.

To provide a systematic focus for the needed research and mitigation recommendations, a steering committee was formed and recommended the corrosion problem be reviewed by an independent group of experts, each specializing in a different area of corrosion. In September 2004, a panel of five experts in corrosion, microbiology, metallurgy and chemistry examined the corrosion problem. The experts narrowed down the initial list of 12 possible causes to a few likely causes and made both long- and short-term recommendations.

This paper will 1) describe the accelerated fresh water corrosion observed in the Duluth-Superior harbor, 2) describe the project steering committees and expert panels role with the project, 3) discuss how project funding is being pursued, and 4) discuss the ongoing studies and preliminary results to determine the cause or causes of the accelerated freshwater harbor corrosion.

Introduction to Harbor and Accelerated Corrosion Problem

The Duluth-Superior harbor is located at the extreme western tip of Lake Superior. The harbor is a naturally protected harbor at the mouth of two rivers, the St Louis River in Minnesota and the Nemadji River in Wisconsin. The harbor is sheltered from Lake Superior by a 14.5 kilometer long sand spit and has two navigational entries (the Duluth entrance and the Superior entrance). The harbor has over 79 kilometers of waterfront, approximately 27 kilometers of dredged channels and 49 square kilometers of land and water area (see Figure 1).

The port ranks number one in Great Lakes total cargo volume and number 18 in national total cargo volume. The harbor has 15 major cargo terminals including 6 multi-purpose bulk terminals, two ore docks, six grain elevators, one coal dock and one general cargo distribution center. The principal cargo loadings in 2005 were coal (18.8 million metric tons, 45% of total port tonnage), iron ore (16.6 million metric tons, 40%) and grain (2.8 million metric tons, 7%) (Duluth Seaway Port Authority 2006).

The port has over 20 kilometers of steel sheet pile and wooden dock structures with steel fasteners, many with severe fresh water corrosion which appears to be corroding at an accelerated rate. The corrosion is evident on most structures within the working harbor area. Based on observations of both older and new sheet pile installations, the increased rate of corrosion appears to have begun in the late 1970s. Steel structures older than the mid 1970s exhibit the similar nature and extent of corrosion, regardless of age. Steel structures installed since the 1970s exhibit corrosion proportional to age.

Underwater inspections have revealed that the corrosion is widespread throughout the harbor on all types of steel piling buttressing the docks, regardless of steel metallurgy or age. Most of the steel is riddled with small pits, scooped out in diameters of 6 to 25 mm, primarily in the first one to two meters below the waterline and tapering off around 3 to 3.5 meters. For most structures there is only minor or insignificant corrosion loss deeper than 3.5 meters, all the way down to the mud line. There is light marine growth evident within the pits. Zebra mussels (recent infestation since 1998) tend to cover the steel below 3.5 meters, but the maturity of the corrosion indicates that its initiation predates the zebra mussel infestation. Some of the steel beams supporting the dock structures have holes the size of footballs (15-30 cm), many of these have already been or are in the process of being repaired (see Photos 1 through 3). This extent of corrosion is similar to that commonly observed in saltwater ports but not seen in freshwater environments. In addition, corrosion to this extent has not been documented in other Great Lakes ports and harbors.

Given the estimated rate of corrosion observed, the structural integrity of docks and loading facilities could be significantly compromised within the next 10 years and the failing steel would have to be replaced at a cost of $1,500 to $2,000 (2006 dollars) per lineal foot. The Duluth Seaway Port Authority estimates there could be 120 million dollars of possible repairs in the harbor to steel that is being weakened by corrosion. As noted above, several of the port facilities have already begun replacement and/or repair of the more severely corroded steel structures.

Experts Investigate

To provide a systematic focus for research and mitigation, a steering committee was formed to examine the problem. The committee was composed of members from the Wisconsin and Minnesota Sea Grant programs, the Duluth Seaway Port Authority, the U.S. Army Corps of Engineers, the University of Minnesota-Duluth and its Natural Resources Research Institute and the local engineering consultant firms Krech Ojard & Associates; now AMI Consulting Engineers PA) whose diver first recognized the problem. After reviewing what was known and what was not known about the corrosion, the committee recommended that the problem be reviewed by an independent group of experts, each specializing in a different area of corrosion.

In September 2004, a panel of five experts was selected with expertise in freshwater corrosion processes, corrosion mitigation techniques, electrolysis, microbiology (microbiologically influenced corrosion), and chemistry. The experts were given background information collected by the steering committee and then visited the harbor to examine the corrosion. They spent one day visiting areas of the port where accelerated corrosion was particularly apparent, and met to discuss their observations and review information gathered by the steering committee. On the second day of their meetings, they presented findings and recommendations at a public meeting/news conference. A formal report was published in March, 2005 (Marsh, el al). The steering committee asked the expert panel to specifically address the following six questions:

1) Is there accelerated corrosion and is it different than seen in other fresh water ports?
2) What is the spatial extent of the corrosion?
3) What are the likely causes of the corrosion?
4) What research/monitoring is needed?
5) How should the research/monitoring needs be prioritized?
6) What can be done to mitigate the problem?

The expert panel noted that due to the limited information available and short time frame spent visiting the harbor, definitive conclusions about the causes and appropriate actions to mitigate the corrosion would require additional data to be gathered through formal measurement, testing, and engineering analysis.

However, the experts reviewed and then narrowed down the initial list of 12 possible causes (see table 1) to a few of the more likely causes based upon the preliminary data and their visual observations (Marsh, et al, 2005).

The expert panel then focused attention on the following possible causes which should be investigated further as well as recommending the following short and long term studies to be initiated:

***Possible Causes to be Investigated Further*:**

- The harbor's water chemistry might have changed in ways that promoted corrosion. Highway de-icing salts may have added significant amounts of chloride to the harbor. Also, as reduced pollution improved water quality, higher amounts of dissolved oxygen in the harbor could have boosted corrosion rates.

- Microorganisms like bacteria or fungi could be eating away at the steel, a phenomenon known as "microbiologically influenced corrosion" (MIC). One type of MIC, accelerated low water corrosion, is reported to be a growing problem in European ports.

- Prior to the expert panel meeting, it was thought that stray current from a high-voltage direct-current line could be speeding up corrosion. The high voltage DC power line actually terminates several miles north of the harbor and the observed corrosion sites. Based upon preliminary testing, the experts considered stray currents to be an unlikely cause of the accelerated corrosion, but one that needs to be formally ruled out.

- The harbor has experienced many changes during the past 35 years, such as the rate of ship traffic, types of cargo ships and various harbor modifications. The panel noted that without more detailed studies, it is difficult to know which changes in harbor use may have affected steel corrosion.

Expert Panel Short-term Recommendations:

- The panel recommended corrosion rates at a number of sites in the harbor be measured to establish a baseline for future reference.

- Water chemistry analyses should be made for at least two years at a number of representative sites and depths.

- Corroded steel should be tested for the presence of MIC activity.

- Tests to determine the presence and source of any stray currents should be performed.

- In areas where safety issues or economic losses are of high concern, structure conditions should be assessed.

Expert Panel Long-term Recommendations:

- A coordinated maintenance management strategy should be developed to provide a systematic, proactive means of tracking current and projected conditions.
- An ongoing monitoring program should be established for water chemistry and corrosion rate measurements.
- A standard replacement design should be developed using both coatings and cathodic protection.
- The panel of experts strongly recommended that other Great Lakes ports and harbors be studied and their managers made aware of this issue. Because this type of rapid corrosion isn't common in freshwater harbors, harbor managers may not be looking for the problem.

Funding Secured and Studies Initiated

Multiple sources of study funding continue to be pursued by the steering committee. To date, the State of Minnesota has appropriated $100,000 and in November 2005 the U.S. Army Corps of Engineers were approved $300,000 (FY 06 budget) for the initiation of studies to determine the causes of the corrosion. Additionally, the University of Minnesota Center for Urban and Regional Affairs (CURA) and Minnesota Sea Grant will be supporting research into specific biological influences that may be contributing to the corrosion process.

Prior to the actual allocation of project funding described above, two short-term investigations were initiated. The first investigation was a coating test to observe several commercial products available for protecting steel sheet pile structures from corrosion. The coatings, which have been in place for almost five years were removed in the summer of 2006 and will be analyzed later this year (fall 2006). The second investigation involved the visual inspection of the chains and harbor channel marker buoy anchors placed and removed by the US Coast Guard each year throughout the harbor. These were visually inspected for evidences of pitting and corrosion as they were removed by the U.S. Coast Guard in early winter 2005 (see photo #4). Preliminary observations of the anchor chains indicate a gradual lessening of observed corrosion as one moves upstream from the lower harbor basin. This trend is consistent with the general observations of more severe corrosion seen in the lower harbor than further upstream.

With the appropriation of the initial project study funding from the State of Minnesota and the U.S. Army Corps of Engineers, the project steering team began the following additional studies in the summer of 2006:

Water Quality Database: Existing historical water quality data from a wide variety of sources continues to be collected and cataloged into a project database. Specific water quality parameters pertinent to the study are being included and the database structure set up to receive future data as it is collected. The data collection locations will also be GIS referenced for harbor location identification and future analysis.

Existing Structure, Water Quality & Initial MIC Evaluations: Existing harbor structures are being catalogued by type, age, owner, depth, condition, etc. In addition, divers (see photo #5) have completed the underwater inspection of many facilities throughout the harbor. Additional parameters measured by the divers included thickness loss due to corrosion, analysis of water samples (PH, DO, conductivity, turbidity & temperature) at several water depths at each inspection station, light intensity near the structures, and water clarity. Corrosion product characterization was also completed noting pitting details, marine growth present, extent of corrosion, etc. The initial MIC study is also currently underway consisting of collecting corrosion product samples and analyzing them for the presence or absence of either iron-oxidizing or sulfate-reducing bacteria by DNA testing of the samples (see photo #6). The divers also conducted instantaneous corrosion rate (ICR) measurements at several locations. The ICR study consisted of structure in the corrosion zone, letting it equalize for a week and then taking the measurement of material loss.

Coupon Study: Coupons (small steel plates) were placed in the corrosion zone at several of the existing dock walls throughout the harbor and will be periodically sampled for rates of corrosion and evidence of MIC.

Additional Coating Tests: In addition to the specific studies currently being conducted, the steering committee plans to initiate a series of coating tests to evaluate the use of various types of protective coatings to protect the steel from corrosion. These tests are scheduled for 2007 and will focus on both the application of coating materials to existing structures as well as further testing of coatings applied to new steel before it is placed into the harbor structures.

High Voltage DC Current Test: While not considered a significant factor in the harbor corrosion, there is a high voltage DC power line which terminates in the region. A relatively simple test is planned to verify that this is not a factor.

Project Public Outreach: The steering committee periodically prepares updated project fact sheets to keep interested citizens and other Great Lakes ports and harbors managers updated on our project studies and preliminary results. In addition, a project web site has been prepared and is periodically updated. (http://seagrant.wisc.edu/coastalhazards/Default.aspx?tabid=1535)

Potential Future Funding and Additional Project Studies

The steering committee is seeking similar levels of federal funding for FY07, and is approaching the State of Wisconsin for a grant similar to the Minnesota appropriation. Additional funding is expected for extensive microbiological research and also for the development of repair and maintenance procedures that dock owners can reference as a standard for protecting their steel dock structures.

Conclusions

The detailed investigations into the accelerated fresh water corrosion problem observed in the Duluth-Superior harbor have been initiated after a well coordinated and methodological process of forming a steering committee, collecting existing data, engaging an independent corrosion expert panel to review the data and existing conditions and then obtaining state and federal funds to conduct the studies. Projects studies began in summer of 2006 and are expected to continue through the fall of 2007. Preliminary study results are currently being peer reviewed but were not yet available. This paper described the general approach taken by the project team to accomplish these tasks.

References

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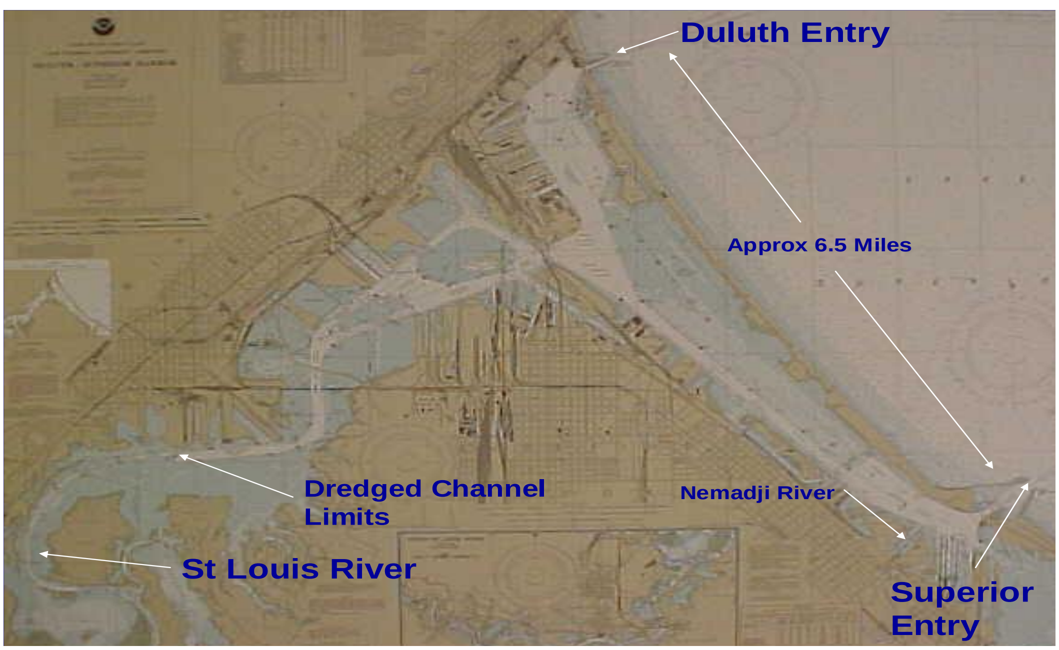

Figure 1. Duluth-Superior Harbor Plan View.

Possible Causes of Harbor Corrosion	Assessment of Significance
Water chemistry	Significant
Temperature	Not Significant
Dissolved oxygen content	Significant
Dissolved chlorides from de-icing salts	Significant
Microbiologically influenced corrosion	Not clear (further analysis)
Stray current corrosion	Not significant (but check)
Storm water runoff / sewage discharge (related to water chemistry)	Not significant (of itself)
Ballast discharge	Not significant
Zebra mussels	Not significant
Metallurgy of steel	Not significant
Water electrolysis from power distribution	Not significant
Functional changes within the harbor	Not clear (bear in mind)

Table 1. Expert Panel Estimated Importance of Possible Causes of Harbor Corrosion.

Photo 1. Bulkhead Pitting at Superior Entry

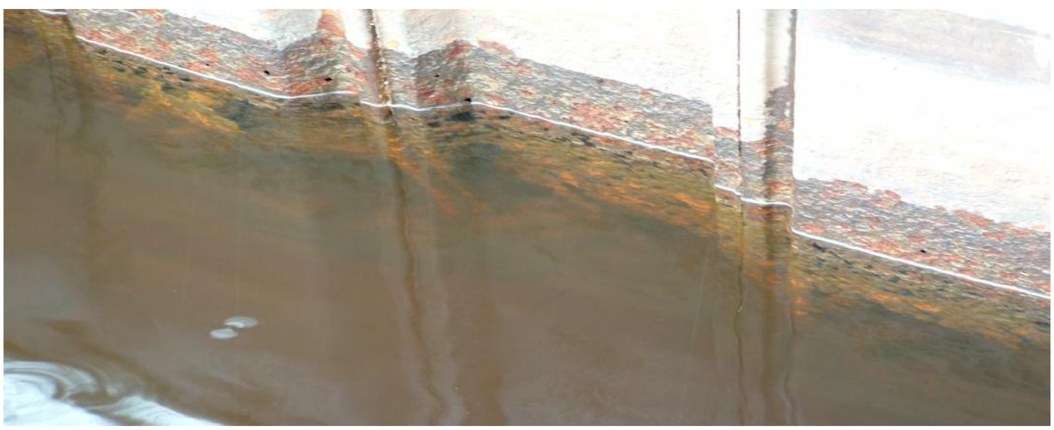

Photo 2. Sheet Pile Pitting and Large Perforations at Local Marina

Photo 3. H-Pile Jacketing Repair

Photo 4. U.S. Coast Guard Channel Marker Buoy & Anchor Chain Bridle

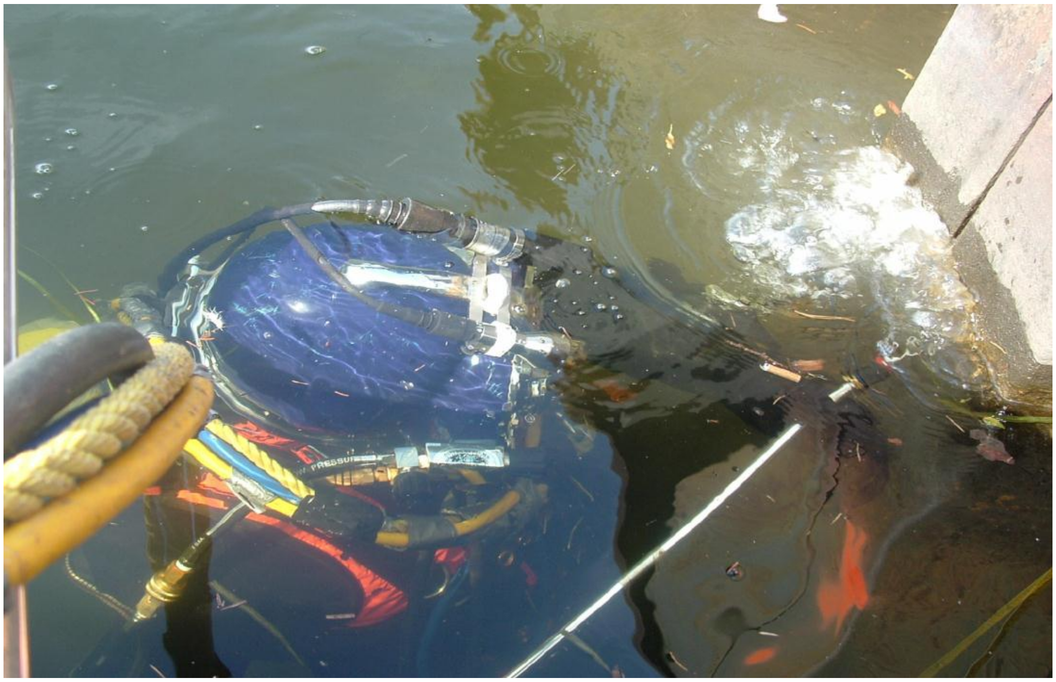

Photo 5. Diver Preparing Sheet Pile Prior to Pit Inspection

Photo 6. Corrosion Product Samples Collected for MIC Analysis