Investigating underwater steel corrosion

Duluth-Superior harbor structures experience accelerated corrosion

Duluth-Superior harbor is under attack, and it appears to be an inside job. Steel structures within the harbor are corroding at a much greater rate than normal in a freshwater environment. In fact, in some locations, corrosion has accelerated to rates resembling those of saltwater environments.

Steel in the harbor is corroding at a rate from two to ten times greater than normal. "An as yet unexplained aggressive water chemistry specific to the lower St. Louis and Superior Bays may be pitting the steel," said expert Rudy Buchheit, professor of materials science and engineering at Ohio State University, "but we haven't ruled out other factors or a combinations of factors."

Corrosion has pitted steel surfaces throughout the harbor. The pits, or pock marks, are largest and deepest in the four feet just below the water surface. From four to ten feet down, the pits gradually become smaller until they end at around the ten-foot mark. Eight miles up the St. Louis River, corrosion appears normal.

The corroding pock marks are covered by an orange coating that tends to cover the pit. It's not the individual pits that are of concern, but rather their proliferation. In some cases, the pits intersect, so that the overall strength of structures is being lost.

A panel of experts documented the abnormality in a study conducted last year. The panel released its report in March 2005, concluding that further detective work is absolutely necessary to uncover the corrosion cause and determine the best solution.

The Duluth Seaway Port Authority first raised harbor corrosion concerns in 2003. The Duluth-based engineering firm, Krech Ojard & Associates, was the first to document and study the underwater damage.

Nearly 13 miles of steel sheet pile and numerous wooden docks held together by steel fasteners are located within Duluth-Superior harbor. Steel columns support highway bridges, and taconite is shipped through docks built of steel. With sheet pile currently costing about $1,500 per lineal foot, replacement cost for the steel piling alone is estimated at $100 million.

Duluth Seaway Port Authority, U.S. Army Corps of Engineers, Minnesota and Wisconsin Sea Grant Programs and the Natural Resource Research Institute of the University of Minnesota-Duluth sponsored the Duluth-Superior Harbor Accelerated Corrosion Expert Panel Meeting in September, 2004. Five experts in the fields of corrosion, microbiology and chemistry met for two days, answered questions from an invited audience (representing facilities operating in the Duluth-Superior harbor area, government agencies, the port authority and educational institutions) and concluded with a news conference.

Many possible causes. According to the panel's March report, "Freshwater Corrosion in the Duluth-Superior Harbor," published by the U.S. Army Corps of Engineers' Construction Engineering Research Laboratory, the increased rate of corrosion appears to have begun in the late 1970s. The panel reported that most harbor steel more than 30 years old shows similar levels of damage, but more recent installations exhibit the effects of accelerated corrosion.

"Corrosion rate estimates, made from dissolved oxygen measurements near the Burlington Northern bridge, suggest an increase in corrosion rates from about 12 mils [0.3048 mm] per year during the 1970s to 22 mils [0.5588 mm] per year during the 1980s. Total thickness losses estimated from this analysis at least appear to generally coincide with actual observation of corrosion thickness losses of sheet pile across the harbor," said the report.

Based on their experience, the expert panel compiled a list of possible causes, noting that "without direct quantitative measurements of corrosion from the site of the problem, it is not possible to definitively state a cause." Of the 12 causes discussed, water chemistry, dissolved oxygen (DO) content and dissolved chlorides from deicing salts seem to be the most likely agents of accelerated corrosion. It is unclear whether microbiological factors or functional harbor changes are influencing the corrosion.

> The panel's short-term and long-term recommendations included corrosion rate monitoring, water chemistry analysis, corrosion product and MIC analysis, stray current testing and condition assessment.

Corrosion is an electrochemical process, so an analysis of water chemistry is important. Water chemistry itself can be affected by a variety of chemical, biological and electrical processes in the marine environment. "Given the multiple and potentially widespread effects that are possible from either global or localized changes in water chemistry, this factor is significant and requires quantitative testing," the report says. It also pointed out that the "presence of dissolved tannins related to biological decomposition

General solutions to harbor corrosion

Until further study of Duluth-Superior harbor corrosion is completed, solutions cannot be identified. However, the expert panel's report did present the following general types of possible solutions:

Cathodic protection. Using either an electric power source or the natural electrical potential between a steel structure and another metallic anode, this solution would be expensive and only useful for high, localized applications.

Corrosion-resistant alloys. Structural alloys are expensive, and if used in harbor structures, must not be connected with existing sheet pile, "otherwise destructive galvanic effects would occur. The same also would be true of in-kind replacement, because new steel, when connected to old steel, will quickly corrode" to match the old steel, the report stated.

Non-metallic advanced materials. There are currently no affordable, performance-tested non-metallic sheet pile alternatives on the market.

SOURCE: AL BEITELMAN, DIRECTOR, PAINT TECHNOLOGY CENTER, U.S. ARMY CORPS OF ENGINEERS CONSTRUCTION ENGINEERING RESEARCH LAB

in connected rivers is also a factor that could affect pH, dissolved oxygen content, microbiology and other aspects of water chemistry."

Dissolved oxygen content is a critical component in the electrochemical corrosion process. The apparent increase in the corrosion rate through the 1980s suggests that a change in the DO content in the harbor may be a contributing, or perhaps dominant, factor in accelerated sheet pile corrosion. Runoff into the Duluth-Superior harbor suggests that dissolved chlorides from roadway de-icing salts may be a significant source of corrosion-enhancing chloride ions.

Storm runoff and sewage discharge also affect water chemistry and DO, but "no observations suggested that runoff or sewage discharge constitute a corrosion problem for Duluth-Superior harbor."

Sheet piles at waterline. The orange corrosion just below the waterline is the item of concern. It is accelerated corrosion, but its specific cause has yet to be determined.

POSSIBLE CAUSES OF DULUTH-SUPERIOR HARBOR CORROSION

Possible Cause	Assessment of Importance
Water Chemistry	Significant
Dissolved Oxygen Content	Significant
Dissolved Chlorides from De-Icing Salts	Significant
Microbiologically Influenced Corrosion	Not clear; Further analysis
Functional Changes within the Harbor	Not clear; Bear in mind
Storm Water Runoff, Sewage Discharge (Related to water chemistry)	Not significant of itself
Stray Current Corrosion	Not significant, but check
Temperature	Not significant
Ballast Discharge	Not significant
Zebra Mussels	Not significant
Metallurgy of Steel	Not significant
Water Electrolysis from Power Distribution	Not significant

Harbor corrosion panel recommendations

The panel of experts made short-term recommendations relative to the Duluth-Superior harbor corrosion:

Corrosion rate monitoring. The rate of corrosion should be immediately measured at a number of sites in order to quantify the problem and to establish a baseline for future reference.

Water chemistry analysis. Analyses focused on corrosion-related parameters should be made at a number of sites and depths. Given the probability of seasonal variations, these analyses should be performed for at least two years.

Microbiologically influenced corrosion (MIC) from the activity of microorganisms appears to be a growing problem in European ports. It is not clear if MIC is significant in Duluth-Superior harbor, but the experts recommended further analysis.

The study team noted that, "Although a high-voltage DC power line terminates in the region of some Duluth-Superior harbor corrosion sites, observations do not suggest that it has had a significant effect on harbor corrosion." However, the panel recommended conclusive testing.

More research is needed. Since the cause for the corrosion cannot be positively identified without further study, the panel could not present definite solutions. It is also uncertain if a one-time solution is possible or if appropriate management will be necessary instead. The experts did identify general possible solutions, including cathodic protection, use of corrosion-resistant alloys, use of non-metallic advanced materials, protective coating systems and condition-based maintenance and management.

The panel's short-term and long-term recommendations included corrosion rate monitoring, water chemistry analysis, corrosion product and MIC analysis, stray current testing and condition assessment.

"It is too early to tell if this problem is one that can be easily corrected or not," said Gene R. Clark, Wisconsin Sea Grant coastal engineering specialist and member of the steering team that sponsored the expert panel. "Until we know what is causing the problems, we really can't predict the solutions, costs or results. We are continuing to seek funding for follow-up studies, and that is the current emphasis of our efforts. At this point in time, no specific studies are underway."

Defining the specific causes of Duluth-Superior harbor corrosion and identifying fixes must wait for further investigation, and further investigation must be funded.

In May 2005, Congressmen James Oberstar (D-MN) and Dave Obey (D-WI) asked the Corps of Engineers to conduct an in-depth investigation. "Congressman Oberstar and I agree that the Corps should move forward with that [study] as soon as possible, and we are working together to make sure that they can proceed," said Obey. He secured $300,000 in a measure approved by the Appropriations Committee on May 18 to allow the Corps to begin its study.

"The Corps must document and study the spreading underwater damage so that it can be contained and eradicated," Oberstar said. As a member of the Transportation and Infrastructure Committee, he is

You can protect "H" piles by putting a jacket around them and filling with concrete, but this is not very practical for sheet piles.

working to secure long-term authorization for the harbor corrosion investigation.

The $300,000 House appropriation must still be approved by the Senate. When the funding comes through, it will likely be granted to the Corps of Engineers, who will lead the investigation. In addition, the Duluth Seaway Port Authority expects an additional $100,000 from the State of Minnesota. Regional institutions (Sea Grant, universities) will, or course, also be involved in the study effort.

"Further study is expected to follow the recommendations of the workshop report," said Charles Marsh, U.S. Army Corps of Engineers Materials Research Engineer, and lead member of the expert panel. "The primary focus of the study will be the Duluth-Superior harbor, but other ports will also be examined with the intent of either confirming or ruling out the presence of accelerated corrosion. We fully intend to coordinate the education and outreach of this study to other Great Lakes ports and harbors."

"We really need to determine whether this problem is more widespread. Many times, corrosion issues don't arise until people start looking," Buchheit said

Over 1,000 port calls are made at Duluth-Superior annually by Great Lakes and ocean-going ships. A handful of lake vessels overwinter in the port each year. Could accelerated corrosion affect them?

"There has been a report of an entirely unpainted barge that has exhibited a similar corrosion effect," said Marsh, but the consensus is that ships are protected from corrosion by virtue of their hull paint. "In winter, very little corrosive degradation is expected. As a ship's paint degrades and 'holidays' appear, corrosion should be considered a concern, as always."

Jim Sharrow, Duluth Seaway Port Authority facilities manager, and Wisconsin Sea Grant's Clark will be presenting a harbor corrosion project update at the fall 2005 meeting of the Wisconsin Commercial Ports Association in Washburn, Wisconsin.

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