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DEPARTMENT OF TRANSPORTATION

OFFICE OF RESEARCH & INNOVATION

Estimating Corrosion of Embedded Steel Rebars in Bridge Structures

TECHNICAL SUMMARY

Questions?
Contact research.dot@state.mn.us.

Technical Liaison:
Paul Pilarski, MnDOT
paul.pilarski@state.mn.us

Investigator:
Behrouz Shafei, Iowa State University

PROJECT COST:
$100,966

Cracks in concrete indicate potential corrosion in internal reinforcing rebars.

Corrosion of steel reinforcement in bridge structures creates uncertainty in the structural capacity. A new prediction tool will help estimate rebar section loss to accurately plan for appropriate bridge maintenance repairs.

What Was the Need?

While bridges are generally designed for at least a 75-year life span, damage from corrosion can manifest after a few years of exposure. Fluctuations in temperature and moisture and exposure to deicing salts may cause material deterioration such as corrosion of steel rebars embedded in concrete bridge structures.

Corrosion of rebar creates rust and rebar cross-section loss—a weakening of and decrease in steel content. Because rust has a higher volume than the steel rebar, the rusting process also causes expansion that results in concrete cracking and potentially spalling. Whether the rebar is still providing structural reinforcement at design capacity depends on how much of the steel bar's cross-sectional area remains intact.

Conventionally, bridge inspectors visually assess bridge structures to look for cracks and use hammers to find delaminated concrete and visible rebar. There is, however, no industry standard to measure the section loss of the reinforcing steel rebar. While the inspector may use visual judgment or a caliper to measure the remaining diameter if the rebar is exposed, there is little guidance to assess section loss if the steel reinforcement is still within the concrete. Furthermore, visual judgment and spot measurement can be inaccurate because of the irregular nature of corrosion pitting and general corrosion. Even the highest quality observation, thus, may be inadequate given the difficulty in accurately measuring a corroded steel bar and estimating the lost steel.

Understanding the level of reinforcement deterioration is critical to determining structural capacity. Without guidance, bridge inspectors may be gathering less accurate data that is then used for engineering evaluation. MnDOT needed guidance on accurately estimating rebar cross-section loss to inform repair strategies and efficiently plan preventive and corrective bridge maintenance. Better tailoring repair strategies will reduce material and labor costs and minimize bridge closures and traffic disruptions.

What Was Our Goal?

The goal of this project was to develop guidance and aids to enhance visual and other nondestructive methods of estimating reinforcement section loss. The guidance and aids would be developed specifically for standardized 2-inch concrete cover over reinforcement with 4,000 psi strength concrete.

What Did We Do?

Researchers reviewed available literature on steel reinforcement corrosion and identified mathematical equations that would best correlate the progression of reinforcement corrosion to concrete cracking. They examined destructive and nondestructive methods to evaluate deterioration. From the literature reviews, they identified two formulations that could best envelope rebar corrosion: In situation 1, reinforcement could not be directly observed; in situation 2, reinforcement was exposed. For situation 1, concrete crack measurement was the means to estimate the rebar section loss because increased rust volume is a causal factor of concrete cracking. In situation 2, where direct visual examination may be possible, the high variability of rebar section loss led the researchers to choose a mathematical formula based on exposure time.

For both situations, field data collection was necessary to correlate with the predictive methods. Many piers of a bridge near Minneapolis were scheduled for concrete repair due to reinforcement

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Accurate estimates of the extent of reinforcement section damage, particularly when not visible, reduce the risk of unforeseen revisions during repair work. When reinforcement corrosion progresses to generate enough rust to push off concrete cover, spalling can occur.

corrosion, providing an opportunity to document observed conditions before the concrete repair and discover actual rebar section loss during the concrete repair. Before performing concrete repairs, researchers conducted extensive photo documentation and mapping of delaminated concrete, which is almost always due to rust formation and corrosion of internal steel reinforcement.

During the concrete repair project, researchers collected data that included photo documentation and visual assessments of rebar section loss. In addition, they extracted select steel reinforcement samples that were taken to the laboratory for more exact measurements and testing. In the laboratory, researchers removed the rust and measured the remaining steel. They used 3D scanning to plot the cross-sectional areas of the bars for calculating section loss and also performed mechanical tests to determine strength and failure point of the corroded rebars.

Then they recalibrated predictive models for two types of rebar section loss: concrete that has maintained its overall integrity but has visible cracks in its surface (situation 1) and concrete that has partially or completely delaminated to expose embedded steel rebars (situation 2).

"The upper bound of section loss estimated by the model for cracked concrete will be helpful to avoid being overly conservative by closing a bridge when we don't have to. We will, however, need more bridge rebar samples to refine the model for delaminated concrete."

—Paul Pilarski,
Bridge Construction and Scoping Engineer, MnDOT Bridge Office

What Did We Learn?

Based on empirical and theoretical research validated by field data, researchers developed a guidance tool to predict rebar reinforcement section loss to help MnDOT better manage its bridge inventory and inform bridge maintenance and replacement decisions.

Field investigation showed that the range of locations and magnitudes of corrosion-induced concrete damage are very large once the reinforcement has spalled concrete. Visual assessment was not sufficiently accurate, particularly when the bar was rust-covered or partially embedded. The 3D scanning method, however, accurately estimated section loss. The results from 3D scanning were comparable to visual assessments when the section loss was relatively large (above 75%) but not for smaller losses. Mass measurements were consistent with 3D scanning.

Combining these results with the tensile tests, researchers concluded that the visual-only assessment of section loss can be conservative for very low actual losses in steel reinforcement but unconservative for larger section losses. A conservative estimate would result in underestimating the structural capacity and may cause an engineer to program unnecessary and costly strengthening. On the other hand, an unconservative assessment would result in overpredicting structural capacity and reducing the factor of safety.

Using the field data test results, researchers developed section loss guidance tables. In the cracked concrete model, section loss (including upper and lower bounds) is based on the crack width from a photograph or field measurement. In the delaminated concrete model (situation 2), where the bridge support suffers from advanced corrosion-induced damage, the section loss is based on the age of the steel reinforcement. The generality of rebar age was due to lack of correlation with any other factors.

"We've developed and calibrated a set of models with Minnesota-specific conditions for more accurate estimates of reinforcement section loss. Such estimates are instrumental in ensuring the safety and performance of bridge structures in service."

—Behrouz Shafei,
Associate Professor, Iowa State University

What's Next?

The models and guidance tables developed have large ranges, and the accuracy can be improved with data from additional bridges, which would not only improve the number of samples in the data set, but represent a greater diversity of ages, locations and exposure conditions. MnDOT plans to collect additional samples during major bridge repairs.

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Office of Research & Innovation
MS 330, First Floor
395 John Ireland Blvd.
St. Paul, MN 55155-1899
651-366-3780
www.mndot.gov/research

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