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WISCONSIN DEPARTMENT OF TRANSPORTATION

PUTTING RESEARCH TO WORK

BRIEF

Computer models identify methods to reduce bridge cracks during production processes

While most motorists see only the bridge deck, strong bridge girders are the basis for a stable system to support the traffic-handling surface. Concrete bridge girders often have two major components: the web, which is an I-shaped cross section and vertical element for resisting shear forces; and flanges, which are horizontal elements that resist bending.

Wisconsin has developed a special series of flanged girders, called "W" girders. To increase performance, these girders are precast and prestressed in a production facility. The prestressing process casts concrete around tensioned steel strands that run the horizontal length of the girder. The strands may be straight or draped, with the latter being angled through the web plan to balance internal stresses. After the concrete hardens, strands are detensioned by cutting the link between the girder and stretching mechanism and relieving the tensile forces. After detensioning, the strands contract and the internal forces strengthen the concrete load. Girders may also be strengthened with vertical steel reinforcement bars.

What's the problem?

While prestressing strengthens concrete girders, the process also causes cracking at the girder ends due to the large forces applied during pre-stressing. These cracks have negative impacts on performance as they can allow water and deicing chemicals to reach and corrode the steel strands and reinforcement bars. This, in turn, weakens structural capacity and may increase life-cycle maintenance costs. Cracks can be especially severe in heavily prestressed W girders used in Wisconsin, especially for the deep narrow web variety (54 to 82 inches).

Common methods used to mitigate cracking include adding regular steel reinforcing bars, performing sequential cutting of strands during detensioning, and using lower draping. Another method to mitigate cracks reduces interactions between the steel and concrete through a technique called debonding. This occurs when a percentage of strands are insulated near the girder ends to prevent bonding to the concrete.

Research objectives

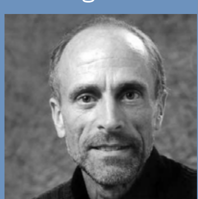
The objectives of this study were to use finite element computer modeling to investigate the behavior of Wisconsin W wide-flanged prestressed girder ends during and immediately following the strand detensioning process, and to identify solutions for controlling girder end cracking by reducing concrete tension strain or introducing sufficient reinforcement to keep concrete tension strains low and crack width limited.

Methodology

Researchers created finite element computer models of deep, wide-flanged W girders that account for cracking and nonlinear behavior of concrete. They used the models to identify principal strain directions and magnitudes in girder ends that matched typical cracking patterns. The analysis identified the steel-to-concrete stress transfer mechanism and defined the material properties of concrete needed to represent this transfer.

The accuracy of finite element models was verified through comparison to measured strains observed in two prestressed girders during detensioning at manufacturing facilities in Wisconsin and using strains on girder ends published by other studies. Results showed good agreement between observed strains and those predicted by finite element modeling.

Investigator



"This project provides WisDOT with a variety of potential solutions for preventing girder end cracking and improving the performance of its structures."

–Michael Oliva
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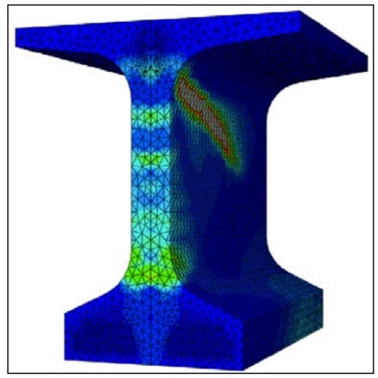

Researchers compared cracks and tensions on a girder instrumented with strain gages (left) to tension strains predicted by finite element computer modeling (right).

The validated finite element models were applied to examine potential changes in the design or manufacturing process to control end cracking. Alternatives that the models were used to simulate include: modifications to the size of steel reinforcement bars, the percentage of strands debonded near girder ends (debonding ratios), the strand cutting sequence and the use of draped strand patterns. Researchers compared the results from different analyses to quantify the likely success of each method in reducing the strains causing girder end cracks.

Results

Finite element analysis results showed that concrete tension strains in the girder web, leading to horizontal web cracking, could be reduced up to 50 percent by increasing the size of the vertical end zone reinforcement bars closest to the girder end. Strain reduction is subject to practical limitations of selecting bar sizes that can be accommodated by the girder cross section.

Inclined cracking, or diagonal cracking near the top of the web, can be addressed by optimizing the number and spacing of draped strands. Removal and wider spacing both reduce cracking. These changes require modifications to the prestressing strands located in the bottom of the cross section that have the effect of reducing the structural capacity of the girder. Scientifically controlling these variables in the production facility is impractical and uneconomical. The modeling tool developed in this research simulates the impacts of the changes in the quantity and placement of reinforcing steel on cracking to select the most appropriate designs.

Y-shaped cracks on the bottom flange can only be prevented in heavily prestressed girders by methodically debonding bottom strands. This method is most effective for debonding exterior strands, while keeping the draped strands bonded and distributing remaining bonded strands evenly across the bottom flange. Researchers found that debonding some bottom flange strands also helped mitigate other types of cracking.

Benefits and Implementation

A combination of solutions involving debonding, extra reinforcement in the web and a controlled sequence of strand detensioning can be used to reduce or eliminate girder end cracking. This will reduce the costs of bridge maintenance, which requires sealing cracks to prevent moisture and deicing chemicals from infiltrating girders and corroding steel strands and reinforcement bars, seriously compromising the strength of the structure. WisDOT will review the recommendations from this research and focus primarily on the use of strand debonding and cutting sequence to control girder end cracking.

Project Manager

"By reducing cracking on our girders, we'll reduce both maintenance costs and construction claims for our bridges."

–Dave Kiekbusch
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This brief summarizes Project 0092-10-12, "Finite Element Analysis of Deep Wide-Flanged Prestressed Girders," produced through the Wisconsin Highway Research Program for the Wisconsin Department of Transportation Research Program, 4802 Sheboygan Ave., Madison, WI 53707.

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