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PROJECT SUMMARY REPORT

Project Summary Report 0-1857-S

Explore New Uses for T-Headed Bars in Structural Concrete Reinforcement Applications

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How Safe Are TxDOT Bridges with Premature Concrete Deterioration?

In late 1995 the Texas Department of Transportation (TxDOT) noticed premature concrete deterioration in a significant number of in-service bridge structures around the state. Most affected structures are prestressed beams, though substructures (abutments, columns and bents) at some bridge sites are also damaged. Typical damage to prestressed beams consists of horizontal cracking on the bottom flanges, longitudinal cracks underneath, and distributed "map cracking," concentrated at but not limited to the ends. An example of this kind of field damage is shown in Figure 1.

This premature concrete deterioration is caused by two expansive damage mechanisms: Alkali-Silica Reaction (ASR) and Delayed Ettringite Formation (DEF). Other TxDOT studies have shown how these mechanisms work and what causes them to occur in specific cases. Basically, each damage mechanism takes place within the concrete itself, and is more severe in the presence of water.

What We Did...

Faced with these deteriorated structures, TxDOT needed to decide whether to replace them immediately (at considerable inconvenience and expense), continue to monitor them, or some combination of these. The overall objective of Project 0-1857 was to provide TxDOT with specific tools for deciding what to do with in-service structures experiencing premature concrete deterioration. That objective was accomplished using the following work plan:

1) Over a four-year period, field investigations were carried out on five TxDOT structures in different parts of Texas. In some structures, crack widths increased very slowly over time, indicating a very slow deterioration (Figure 2). In other structures, crack widths increased more quickly over time, indicating more rapid deterioration (Figure 3). For a range of affected structures, those field investigations documented the increase in deterioration over time, and they gave the investigators information about the factors that would make the deterioration proceed more slowly or more rapidly.
2) Using a group of prestressed girders that had previously been rejected by TxDOT, laboratory tests were conducted to determine the bending and shear strength of full-sized girders compared with those of otherwise identical but undamaged girders, and compared with the capacities assumed in design.

Figure 1: Example of field damage from Premature Concrete Degradation (PCD)

Fatigue loads as well as static loads were studied.

3) Using cores extracted from those damaged specimens, decreases in strength and stiffness due to PCD were investigated, and were related to observed and computed decreases in the capacity of structural elements.

4) A simple numerical index of damage, referred to as a Damage Index (DI), was developed to quantify visual observations of damage. That Damage Index is computed as $\sum \ell\, w^2$ for a 12-in. square defined area, where ℓ is the crack length and w is the crack width. Because the Damage Index is relative, the units are arbitrary. The Damage Indices obtained in this study were calculated using crack widths in thousandths of an inch, and crack lengths in inches.

5) Nondestructive evaluation (NDE) techniques, principally acoustic emission, were related to visual observations of damage to observed strengths.

What We Found...

1) Premature concrete damage, as measured by decreases in the compressive strength of the damaged concrete, is very strongly related to the Damage Index (Figure 4).

2) The Damage Index can be estimated quickly for a particular structure in terms of the maximum crack width in that structure (Figure 5).

3) Reductions in concrete compressive strength due to premature concrete degradation can be related to reductions in the capacity of damaged members, using current design models or strut-and-tie models, and substituting the reduced compressive strength of the damaged concrete for its original strength.

4) Because premature concrete deterioration is more severe in concrete that is kept wet, field structures show more damage at the ends of girders, under

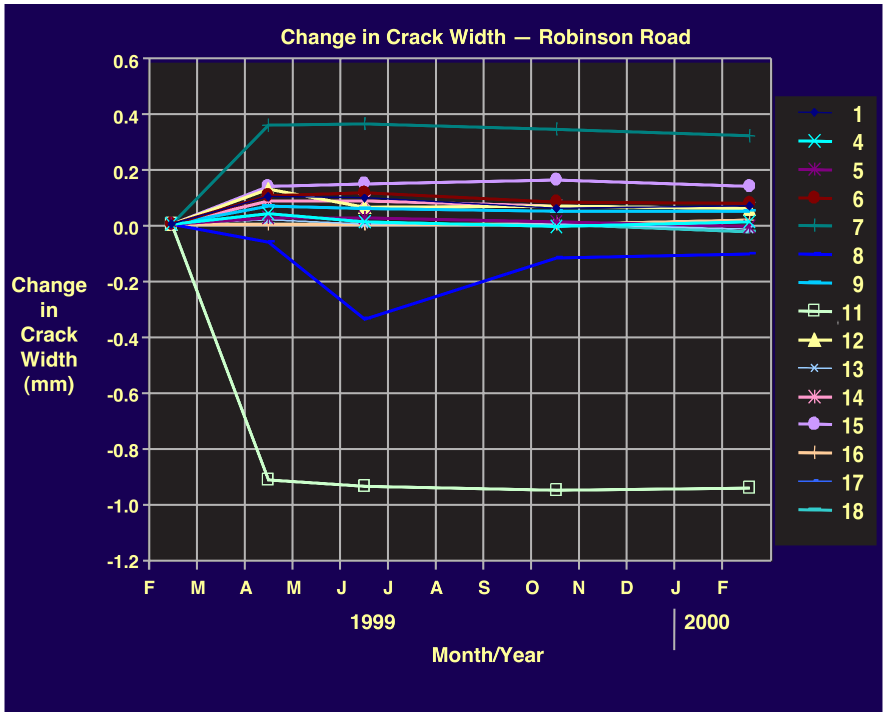

Figure 2 Example plot of crack widths over time, showing a field structure with slow deterioration

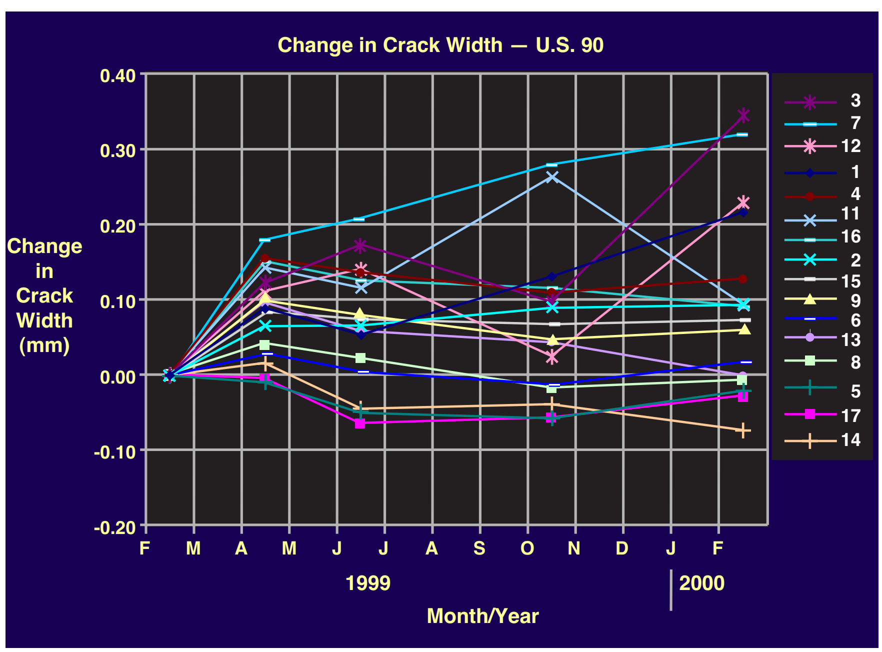

Figure 3 Example plot of crack widths over time, showing a field structure with faster deterioration

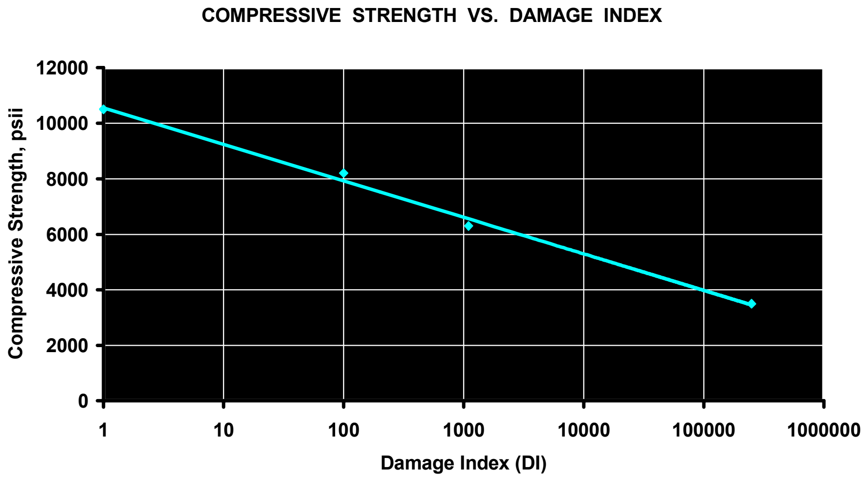

Figure 4 Core compressive strength versus Damage Index

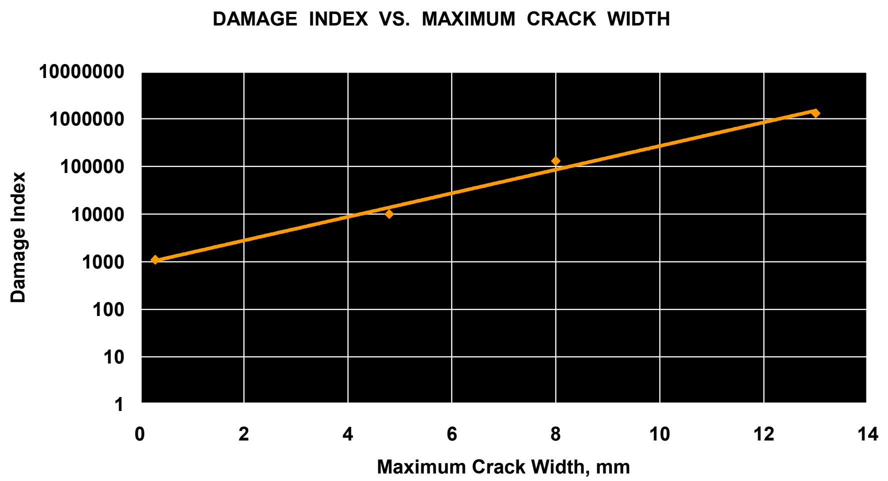

Figure 5 Damage Index (DI) in terms of maximum crack width

joints in bridge decks. Because those end regions are normally also subjected to the highest shear, premature concrete damage can be critical for the shear capacity of damaged girders, which showed a reduction in shear capacity of about 14% over that of otherwise identical but undamaged girders.

5) Because the midspan regions of beams are normally not subjected to as much wetting as the end regions, midspan damage due to premature concrete degradation is generally small, and the moment capacity of damaged beams is not significantly reduced.

The Researchers Recommend...

1) TxDOT should monitor crack widths in field structures, estimate the corresponding damage indices using structure-specific curves like that of Figure 5, estimate the loss in compressive strength using structure-specific curves like that of Figure 4, and estimate the corresponding loss in flexural and shear strength using conventional design equations.

For example, the latest maximum crack width measured on a particular structure is 0.13 in. (3.4 mm). Using Figure 5, this corresponds to a damage index of 13,097 (US customary units). Using Figure 4, the compressive strength is estimated as 5170 lb/in^2. If this is below the specified compressive strength, TxDOT should use shear design equations to estimate the reduced shear capacity of end regions of affected girders. If the shear capacity estimated in this way fell significantly below that used for design, compressive strengths could be verified by core tests.

Benefits

1) The primary benefit is confidence in structural integrity of in-service structures.
2) Determination of the Damage Index for a particular girder is relatively quick and simple. As girders exhibiting PCD are monitored over time, the Damage Index is determined and flexural and shear capacity are computed, assuring TxDOT engineers of the structural capacity of a given bridge.
3) This tool has the potential to save TxDOT hundreds of thousands of dollars in girder replacement costs and costly load tests for in-service bridges exhibiting premature concrete deterioration.
4) Motorist delay associated with girder replacement or live load testing is also eliminated through use of this innovative analysis tool.

For More Details...

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The research is documented in the following reports:

Research Report 0-1857-1, "*Bridges with Premature Concrete Deterioration: Field Observations and Large Scale Testing*," October 2001.

Research Report 0-1857-2, "*Nondestructive Testing of Prestressed Bridge Girderswith Distributed Damage*," August 2002.

Research Report 0-1857-3, "*Bridges with Premature Concrete Deterioration: Fatigue Testing of Full-Scale, Prestressed Concrete Box Girders Failing in Shear*," October 2001.

TxDOT Implementation Status January 2004

Results from this project were immediately useful in that they allayed concerns regarding the structural capacity of in-service, pretensioned concrete girders exhibiting premature concrete deterioration (PCD). As a result of the testing performed, immediate or near-term replacement of girders with PCD is not considered necessary. The Bridge Division is considering how best to implement the Damage Index concept developed under this project for long term monitoring of in-service structures exhibiting PCD. Additional work relating to the Damage Index to percent capacity reduction of girders should be pursued to facilitate easier implementation of the Damage Index concept.

For more information please contact Tom Yarbrough, P.E., RTI Research Engineer, at (512) 465-7403 or email at tyarbro@dot.state.tx.us.

Your Involvement Is Welcome!

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