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Cause and Control of Transverse Cracking in Concrete Bridge Decks

FHWA-NJ-2002-019 December 2002

SUMMARY

A significant number of concrete bridge decks develop transverse cracking, often at early age, some right after construction, and others after the bridge has been opened to traffic for a period of time. It is estimated that more than 100,000 bridges in the United States develop early transverse cracks. These cracks reduce the service life of the structure and increase maintenance costs. This study investigated the causes of transverse deck cracking in order to develop design recommendations to minimize and/or eliminate cracking. To achieve this goal a comprehensive literature review was conducted and 24 bridges in the state of New Jersey were surveyed. Furthermore, 2-D and 3-D finite element analyses were performed to evaluate structural factors. Based on these results design recommendations were developed.

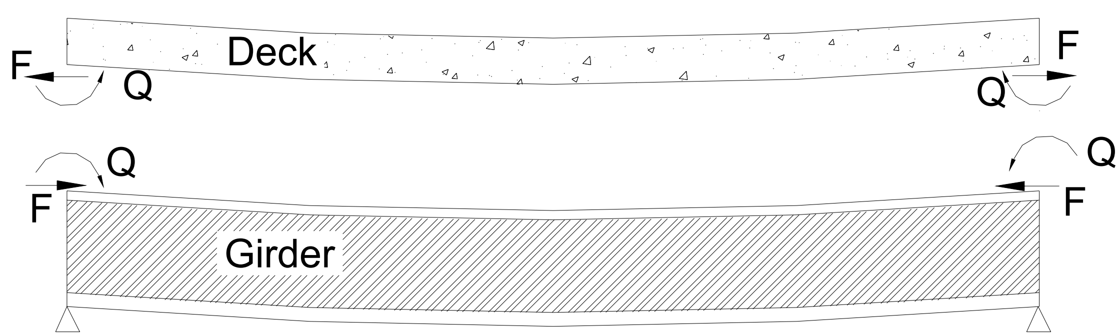
Rt. 133 EB over NJ Turnpike

WHY CONCRETE BRIDGE DECKS CRACK?

Cracks in concrete occur when a *restraint* mass of concrete tends to *change volume*. These cracks are typically full depth located 1-3 m (4-12 ft) apart along the length of the span and are usually observed over transverse reinforcement. It has been reported that predominant form of deck cracking is transverse cracking.

Volume change in concrete depends on the properties of its components and their proportions as well as environmental conditions such as ambient temperature changes and humidity. Restraint, which is basically due to composite action of deck and girder, depends on design characteristics of the bridge (i.e., structural design factors). Construction techniques also contribute to volume change and/or to degree of restraint of concrete mass.

As concrete shrinks (changes volume) the girder resists shortening of the deck by applying a tensile force (force F in the figure shown) and a moment (Q) to the deck. Magnitude of F and Q, and direction of Q depend on relative stiffness of the deck to girder stiffness. However, F is always tensile on the deck and compressive on the girder. As a result the deck may crack. Interestingly, despite the fact that the deck is in tension the girder (and consequently the bridge) deflect downward under this state of stresses.



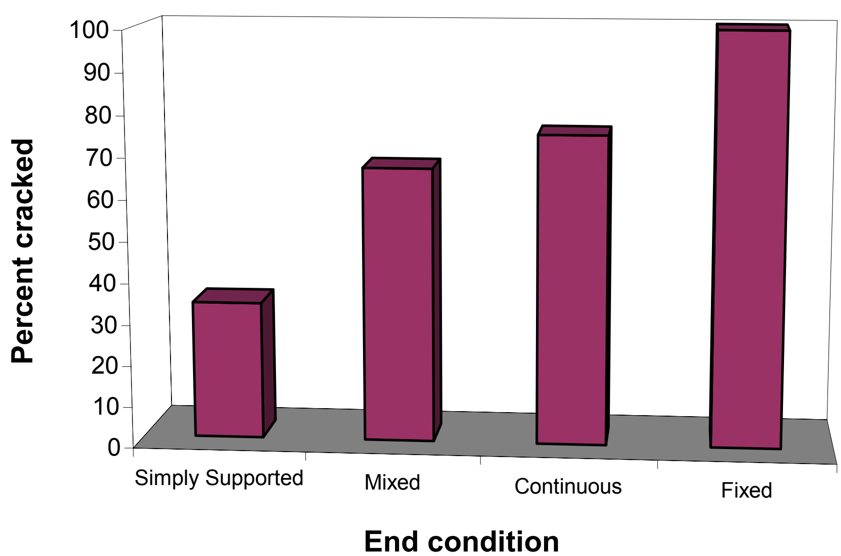
HAVE OTHERS LOOKED INTO THIS PROBLEM?

Amount of volume change in concrete depends on mix design and construction procedures. As it was briefly discussed, restraining effect arises from the composite action between the deck and girder, which is mostly controlled by structural design factors although partly dependent on construction practices too. Thus, causes of transverse deck cracking are generally classified under three categories of: 1) material and mix design, 2) construction practice and ambient condition factors, and 3) structural design. Factors associated with the first two classes (namely mix design/material and construction procedures) have been the subject of a significant number of research studies over the past several decades. Among many literatures available on these subjects is NCHRP Report 380. This report documents the results of a study conducted in 1996 P.D. Krauss, and E.A. Rogalla, E. entitled *"Transverse Cracking in Newly Constructed Bridge Decks."*

Structural design factors have not been the subject of much research in the past and they were the main thrust of this research study. Under this study efforts were also made to quantify the results of prior research work in order to develop design recommendations for possible implementation.

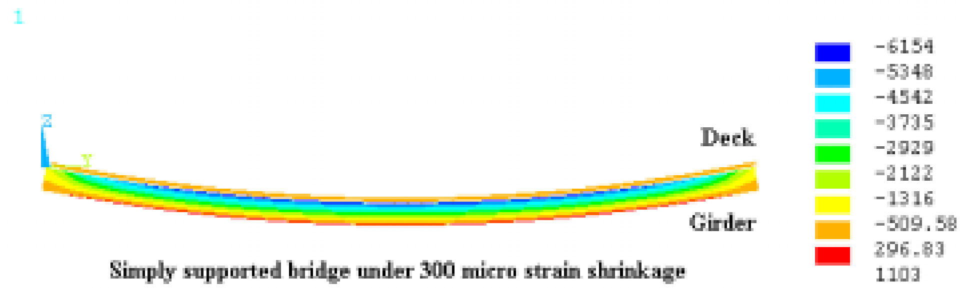
RESEARCH APPROACH

In addition to a comprehensive literature review and evaluation, we surveyed many bridges in New Jersey. Design and construction data for these bridges were also collected. Analyses of the data collected along with field surveys helped us identify factors that might affect cracking, and to evaluate current deck concrete mix design and construction practices in the state of New Jersey. Based on these evaluations and literature review, recommendations with regard to material and mix design as well as construction practices were developed in order to improve bridge deck performance. Another important objective of the field study was to help to focus the analytical phase of the study by narrowing down the list of important factors that need to be investigated in more details. These were factors that either have not

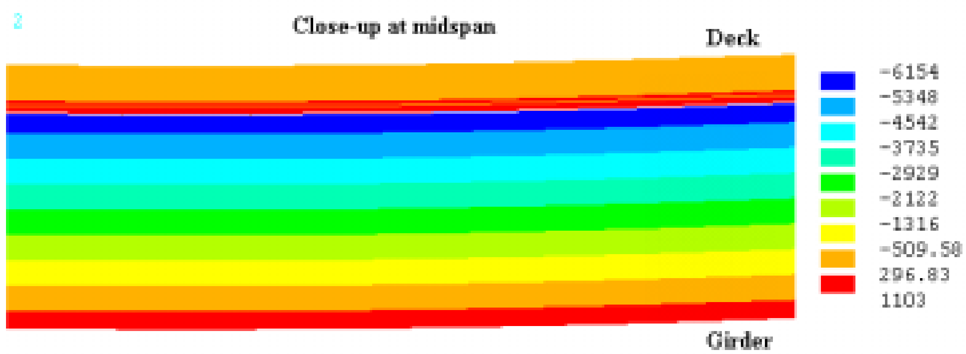


received proper attention during past research or because these factors are related to particular design and/or construction practice unique to the state of New Jersey.

Analytical part included both 2-D and 3-D finite element analyses of typical bridges. Among parameters considered were girder stiffness, deck thickness, girder spacing, relative stiffness of deck to girder, and amount of reinforcements. The following figure shows stress contours in a simply supported beam due to 300με shrinkage. Note that high tensile stresses develop in the deck while the entire system deflects downward.



Simply supported bridge under 300 micro strain shrinkage



Close-up at midspan

A window based application tool is also developed for various boundary conditions and different number of spans. This provides a simple mean for designers to perform AASHTO (3.12) checks on shrinkage and temperature loading. The program, called **StrEstimate,** is available online for free download.

RECOMMENDATIONS

Structural Design Factors

- Specify an upper limit on actual concrete strength vs. the design value.
- Minimize the ratio of girder to deck stiffness.
- Boundary restraints should be consistent with design.
- Time-dependent loadings must be considered in design of bridges with integral abutments.
- Employ more flexible superstructures.
- Use uniform reinforcement meshes.
- Design should consider AASHTO Article 3.12. (A simple design tool has been developed under this study to facilitate this.)

Mix Design (Material)

- Reduce cement content to 650-660 lb/yd^3, and consider using fly ash.
- Limit water cement (w/c) ratio to 0.4-0.45.
- Use AASHTO specification Type II cement.
- Adopt a restraint shrinkage test.
- Consider using type K shrinkage compensating concrete when available.
- Use aggregate size and shape as discussed in the report.

Construction Practices

- As specified in NJDOT Specs, ensure that curing starts immediately after finishing and wet cure for at least 7 consecutive days.
- If “early-open” is not an issue consider 14-day wet curing.
- Make use of evaporation rate chart proposed by ACI and cast the deck in mild temperatures.
- Record wind speed and humidity during construction for future reference.
- Give consideration to pouring sequence as outlined in the report.

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A final report is available online at http://www.state.nj.us/transportation/research/research.html

If you would like a copy of the full report, please FAX the NJDOT, Division of Research and Technology, Technology Transfer Group at (609) 530-3722 or send an e-mail to Research.Division@dot.state.nj.us and ask for:

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