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## *Tech Brief*

### Improvement of Continuity Connections over Fixed Piers

FHWA-NJ-2004-017

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#### **SUMMARY**

Bridges composed of simple-span, precast, prestressed concrete girders made continuous via cast-in-place decks and diaphragms are commonly used in the U.S. These bridges are continuous only for live loads and superimposed dead loads. Diaphragms often crack due to time dependent effects in the prestressed girders. These cracks not only impair bridge esthetic and durability, but also reduce "degree of continuity" of the joint. A related issue is that the existing joint detail is time consuming and expensive to build due to reinforcement congestion. This research presents a series of field tests, analytical studies, and laboratory experiments concerning the design and performance of this type of bridge. Improvements to the current practice are recommended and a new continuity connection is developed and validated in laboratory tests.

#### **BACKGROUND**

Due to the creep of concrete, prestressed concrete girders often tend to camber upward even after continuity is established in this type of construction. The established continuity tends to keep the girder ends from rotating, which results in a positive restraint moment in the girders over the piers. Because of this positive moment, cracks usually develop at the bottom of the diaphragms.



Diaphragm Cracking

A number of studies have been performed on this subject. In the 1960's, the Research and Development Laboratories of the Portland Cement Association carried out a series of experimental and analytical studies of this type of bridge. Two types of positive moment connection were investigated: hooked bar connection and welded bar connection. It was concluded that the welded bar connection was more reliable both from strength and serviceability points of view. Estimates of restraint moments due to creep and differential shrinkage based on the rate of creep and the effective modulus methods were presented.

In the late 1980's, the Construction Technology Laboratories investigated the time dependent effects of this type of bridge. Based on a parametric study, it was concluded that the presence of positive moment connection in the diaphragms has a negligible effect on the reduction of resultant mid-span service moments and no positive moment reinforcement should be used in the connection.

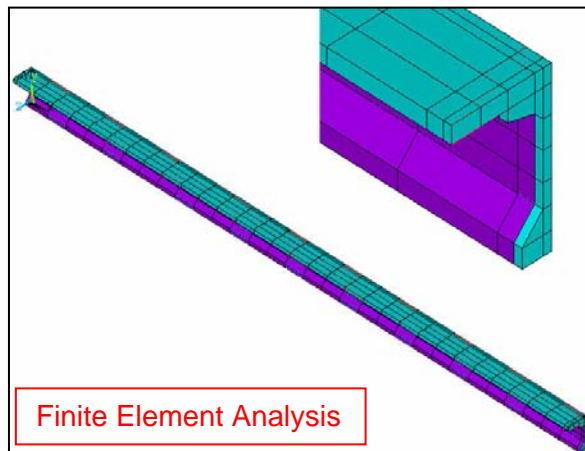
The latest research on this subject was conducted in 2003 by R. A. Miller (et al.) under NCHRP (National Cooperative Highway Research Program) Project 12-53. Eight full-scale specimens were tested: six 32' long with AASHTO Type II girders and two 100' long with AASHTO Type III girders. It was concluded that the connections maintained continuity even when cracked. Based on the study, changes to the AASHTO LRFD Specifications were proposed. The major change was to provide an amount of positive moment reinforcement equivalent to 1.2 times the cracking moment in the girder.

## RESEARCH APPROACH

Based on a survey of the state departments of transportation in the U.S. and a literature review, the current practice concerning this type of bridge is evaluated. Three bridges in New Jersey were instrumented and tested for continuity.

A computer program called "CONTINUITY" was developed to analyze the restraint moments and the degree of continuity of bridges up to four continuous spans with unequal span lengths. The program takes into account concrete creep and shrinkage and strand relaxation. For concrete creep and shrinkage, users can choose from three different models: ACI-209 (American Concrete Institute), CEB-FIP (European) and HPC (High Performance Concrete). Support details and cracking of the composite girder and diaphragm sections are also considered in the program. Three-dimensional finite element analyses (FEA) have been

Field Test



carried out to further study two important factors affecting restraint moments, namely; the girder age at continuity and the amount of positive moment reinforcement at the support.

As a part of this research a new continuity connection is developed using Carbon Fiber Reinforced Polymer (CFRP) composites. By making the girders continuous for slab self-weight, the additional negative moment developed in this new connection counteract the positive restraint moment and keep it below the cracking moment of the diaphragm. Thus, cracks will not



form and positive moment reinforcement is not needed in the continuity diaphragm. A total of 20 laboratory tests were carried out to assess the viability of the concept. Results show that CFRP, when bonded properly, is effective as external reinforcement and can be employed to provide continuity in this type of bridges. Recommendations for the use of CFRP reinforcement and a design example are presented.

## CONCLUSIONS AND RECOMMENDATIONS

- The degree of continuity under service live load varies significantly for bridges composed of simple-span precast prestressed concrete girders made continuous. For the three bridges tested, it ranged from 0% to 90%.
- Embedding the girders in the diaphragm combined with the use of thin elastomeric pads that have little lateral and rotational deformations capacity and presence of bonded anchor bolts at each girder line make the supports more like a “fixed” connection than one that allows rotation. The fixity restrains the girders from sliding and rotating and causes cracking in the diaphragm and even in the top flange of the girders.
- Possible improvements for the existing design include: a) debond the girder ends or do not embed them at all; b) avoid using anchor bolts, or if needed put them in the diaphragm between stringers and sheath them to allow for free rotation of the girders to prevent damage to the diaphragm due to anchor bolt pull-out; c) it is preferable to design only one “pin” support (fixed both vertically and horizontally) for continuous spans to allow for longitudinal deformation.
- U-shaped positive moment connections don’t perform as well as expected, at least in the sense of serviceability, especially when the development length is inadequate.

Per PCA test results, it is recommended that welded connections be used for the positive moment reinforcement. Another approach would be to make the girders continuous for slab dead load, as proposed, and avoid providing the positive moment reinforcement in the diaphragm.

- Finite element analyses confirm that the amount of positive moment reinforcement over the pier has negligible effect on the resultant mid-span moments.
- Finite element analyses show that the girder age at continuity has a significant influence on restraint moment induced by time dependent effects. To balance the effects of creep and differential shrinkage, a girder age of 45-90 days is recommended before casting the deck and diaphragm.
- The computer program CONTINUITY developed under this study is an effective tool for engineers to check the restraint moments caused by time dependent effects and to examine the degree of continuity of simple span girders made continuous.
- For the external flexural strengthening of plain concrete members, the bond between the concrete and the reinforcement is the most critical element. The CFRP fabric sheet is effective as tensile reinforcement when properly bonded through lateral wrapping and surface preparation.
- The load carrying capacity increases with an increase in the number of CFRP layers used. However the efficiency of the CFRP reinforcement diminishes with the use of additional layers. The load carrying capacity also increases with the CFRP bonding length until it reaches the effective bonding length, beyond which no more increase in capacity can be realized.
- By making the girders continuous for slab dead load as well, the additional negative moment over the support can counteract the positive restraint moment and keep it below the positive cracking moment of the section therefore eliminating diaphragm cracking. Although more field tests are needed before its widespread application, the laboratory tests support the concept of making the girders continuous for slab dead load in addition to live load through the use of CFRP composites.
- The new continuity connection makes for an excellent project to be pursued under the FHWA Innovative Bridge Research and Construction (IBRC) Program.

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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](mailto:Research.Division@dot.state.nj.us) and ask for:

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