Investigation of Negative Moment Reinforcing in Bridge Decks

tech transfer summary

Multi-span pre-tensioned pre-stressed concrete beam (PPCB) bridges made continuous, for live loads, usually may experience a negative total moment over the intermediate supports, which this research investigated as part of an investigation into current Iowa DOT design practices.

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RESEARCH PROJECT TITLE
Investigation of Negative Moment Reinforcing in Bridge Decks

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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Background

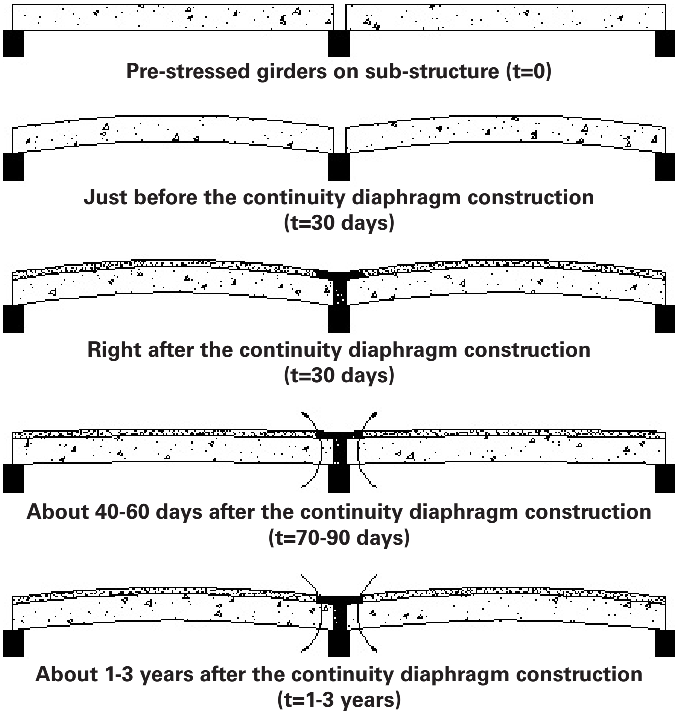
For design, multi-span pre-tensioned pre-stressed concrete beam (PPCB) bridges are usually assumed to experience two different stages of behavior. During the first stage, the PPCB girders are placed on supports and are assumed to behave as a simply-supported span to resist the self-weight of the structure.

After the concrete deck is placed and fully cured, the bridge moves to the second stage, during which it behaves like a fully continuous structure over the intermediate support to resist live loads and superimposed dead loads that occur after the deck has cured. During the second stage, the structure will experience negative moments over the intermediate supports due to the passage of live loads.

Conventional thinking dictates that sufficient reinforcement must be provided in this region to satisfy the strength and serviceability requirements associated with the tensile stresses in the deck. The American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications recommend that the negative moment reinforcement be extended beyond the inflection point (into a zone of deck compression).

However, based upon satisfactory previous performance and judgment, the Iowa Department of Transportation (DOT) Office of Bridges and Structures (OBS) currently terminates the so-called b2 reinforcement at 1/8 of the span length. Although this policy results in approximately 50% shorter b2 reinforcement than the AASHTO LRFD specifications indicate, the Iowa DOT has not experienced any significant deck cracking over the intermediate supports.

One of five bridges that had strain gauges installed on the decks and girders at several transverse sections for field tests and inspections



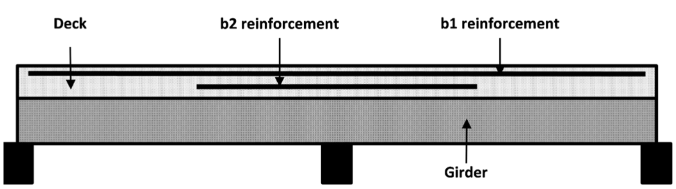
Construction sequence and development of secondary moments in a two-span continuous bridge

Problem Statement

This research was undertaken to provide evidence as to the appropriateness of current OBS policy so it could be modified if needed.

Objectives

- Investigate the Iowa DOT OBS policy regarding the required amount of b2 reinforcement to provide negative moment continuity
- Investigate the OBS policy regarding the termination length of b2 reinforcement
- Investigate the impact of the b2 reinforcement termination pattern
- Investigate the effect of secondary moments on the performance of PPCB bridges



Sufficient reinforcement (longitudinal continuous deck reinforcement (b1) plus additional longitudinal reinforcement over the intermediate supports (b2)) is needed to satisfy the strength and serviceability requirements within the negative moment region

Research Methodology

Each project task was developed based on lessons learned from the previous task.

Task 1 – Information Gathering

A literature search was conducted to collect information on the design of negative moment reinforcement for PPCB bridges. The current domestic state of the practice with regard to continuity and the associated design of b2 reinforcement and termination were also collected through a web-based survey.

Task 2 – Field Tests and Inspections

Field tests and inspections were conducted on five bridges with diverse geometric properties (width, span length, skew angle, girder type, number of spans, and number of girders) to study the actual behavior of typical PPCB bridges. Strain gauges were installed on the decks and girders at several transverse sections.

A known snooper truck then crossed the bridges along several longitudinal paths, generating longitudinal strain profiles. Strain profiles were used to study general bridge performance and to calibrate analytical models.

Task 3 – Analytical Modeling

A significant focus of the research was to investigate the effects of b2 reinforcement on both skewed and non-skewed bridges with bulb-tee girders. From the five field-tested bridges, Bridge A (on Meredith Drive over I-35/I-80) with a smaller skew angle and Bridge B (on I-80 over US 65) with a larger skew angle were selected for further study with calibrated three-dimensional finite element models.

The finite element models were highly discretized in such a way that the behavior of an individual b2 reinforcement could be evaluated. These models were then used to conduct parametric studies.

Three different types of models for Bridge A were used in the parametric studies: Model 1 - Uncracked Deck, Model 2 - Cracked Deck, and Model 3 - Cracked Deck with Cracked Pier Diaphragm. The length, area, and distribution pattern of the b2 reinforcement were the primary parameters of the study. Linear static analysis was used to conduct the parametric studies with live load (equivalent UDL) and 56-day shrinkage load.

The parametric studies of Bridge B were conducted similar to that for Bridge A to demonstrate the effect of skew angle coupled with changes in the b2 reinforcing details. In addition, one bridge was selected to study the significance of secondary moment at the intermediate supports.

Task 4 – Reporting the Recommendations

A final report was developed to present all the observations, conclusions, and recommendations on the design of negative bending moment b2 reinforcement of multi-span continuous PPCB bridges.

Key Findings

Literature Review

In PPCB bridges, the predominant mode of deck cracking is transverse cracking, which usually occurs over the transverse reinforcement. The effects of numerous contributing factors and mitigation procedures are not yet fully understood.

Most research work has focused on the construction materials, mix designs, construction practices, and environmental conditions during construction to determine why transverse cracks occur on bridge decks. Very little research has been carried out on the effects of structural design factors such as girder type, shear stud configuration, deck thickness, reinforcement size and type, and the effect of vibrations on deck cracking.

Secondary moments due to creep of the girders as well as differential shrinkage between the deck and the girders are known to play an important role in the design of the reinforcement at the bottom of the continuity connection.

Several research projects developed and improved methods to calculate the secondary moments and some of them developed more efficient positive moment connections to mitigate the cracks at the bottom of the continuity connection due to these secondary moments.

Researchers have also concluded that the positive reinforcing steel at the support has no significant effect on the resulting negative moment.

State-of-the-Practice Survey

The web-based survey was used to identify the state of the practice on continuity considerations and negative moment reinforcement (b2 reinforcement) with an emphasis on the design policies and practices associated with designing multi-span PPCB bridges.

About 45% of the respondents assumed that adjacent spans act as simple spans for dead loads (girder and deck self-weight) and as continuous for superimposed dead (wearing surface, parapets) and live loads on the composite structure. Simple span for all dead loads and continuous for all live loads was assumed by 30% of the respondents. Furthermore, 20% of the respondents assumed simple spans for all loads.

Extension of the bottom pre-stressing strands with the girder end embedded into the diaphragm plus additional negative moment reinforcement in the deck were the most commonly used continuity connection details. Different DOTs use various practices to terminate the b2 reinforcement.

For example, in addition to the embedment length, the North Carolina DOT uses 1/3 of the span for termination of the b2 reinforcement, whereas the Kansas DOT uses 1/4 of the span, both near the point of inflection. The Delaware DOT, Nevada DOT, and several other DOTs follow the AASHTO LRFD guidelines to terminate the b2 reinforcement. The New Mexico DOT uses the lengths as per the CONSPAN bridge design software. The Michigan DOT and Pennsylvania DOT use a staggered b2 reinforcement pattern to minimize any transverse cracking.

Field Testing

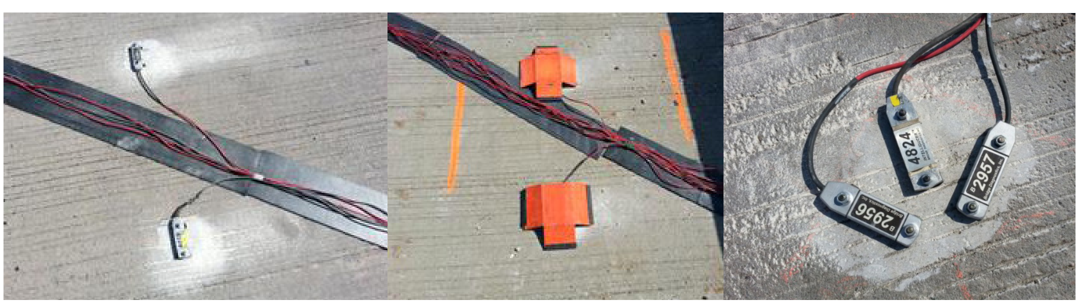
Even though the field tests involved five bridges with different properties, the strain profiles from the deck and girder gauges look similar in terms of pattern and magnitudes. For example, the strain gauges 1 ft beyond the b2 reinforcement showed slightly higher strains than the strain gauges within the b2 reinforcement.

When the truck axles were in the vicinity of the strain gauge rosettes that were used, an expected compression and tension behavior of the bridge was observed in the two-span bridges. Major and minor principal strains of approximately the same magnitudes with opposite signs were observed when the truck axles were away from the rosettes.

In the three-span bridges, principal strains of the same magnitudes with opposite signs were always observed.

Calibration

A finite element model of Bridge A was calibrated with the field test results in the vicinity of the negative moment region. The field test results from the deck gauges agreed with the finite element results. The modulus of elasticity of the girders was increased and the support conditions were modified to minimize the difference between the finite element model and the field test.



Deck strain gauges at the end of the b2 bar (left) with cover plates to prevent damage (center), and 45°rectangular strain gauge rosettes near b2 reinforcement (right)

The finite element model was then compared with the cracking strain of the concrete to simulate the transverse field cracks. It was found that a uniform distributed load (UDL) approximately equivalent to eight large truck (AASHTO HS20) loads was not sufficient to produce cracking strains.

Furthermore, an 80-degree temperature drop was also found to not be sufficient to develop cracks. A deck shrinkage load of 56 days was applied to the model and it was found that this amount of deck shrinkage could induce strain that exceeded cracking levels.

The live load calibration results of Bridge A were used as the initial conditions for calibrating Bridge B, followed by a refined calibration with Bridge B field test results. The finite element results of Bridge B generally agreed with the field test results.

Parametric Studies

The parametric study results showed that Model 1 Uncracked Deck had no significant difference in the strain distribution for different b2 parameters under either the live load or the 56-day shrinkage load. Both Model 2 - Cracked Deck and Model 3 - Cracked Deck with Cracked Pier Diaphragm show similar strain distributions.

An increase of b2 reinforcement area slightly reduces the strain magnitudes over the pier. Increased length of b2 reinforcement slightly reduces the strains of the deck at the 1/8 of the span length location. A staggered b2 reinforcement pattern also slightly reduces the strains of the deck at the 1/8 of the span length location.

Results of the parametric study of Bridge B are similar to Bridge A, except Bridge B shows smaller strains over the pier due to the live load and slightly larger strains over the pier due to the shrinkage load.

Secondary Moment

While the Iowa DOT uses b2 reinforcement that is approximately one half that specified by the AASHTO guidelines, no significant effect of the b2 reinforcement was observed in the parametric studies nor had any anecdotal evidence been identified to suggest that the b2 reinforcement was not performing adequately.

Secondary moments may be positively impacting the negative moment performance. The RMCalc program was used to compare the magnitude of the secondary moments with live load negative moment. It was found that the secondary moments may actually be large enough to counteract any negative moments resulting from live loads.

General Conclusions

- The parametric study results show that an increased area of the b2 reinforcement only slightly reduces the strain over the pier. Similarly, an increased length and staggered reinforcement pattern only slightly reduce the strains of the deck at 1/8 of the span length.
- Finite element modeling results suggest that the transverse field cracks over the pier and at 1/8 of the span length are mainly due to deck shrinkage.
- Bridges with larger skew angles have lower strains over the intermediate supports.
- Secondary moments affect the behavior in the negative moment region. The impact may be significant enough such that no tensile stresses in the deck may be experienced.

Implementation Readiness and Benefits

- Based on the finite element results, termination of b2 reinforcement at 1/8 of the span length is acceptable.
- Secondary moments may reduce the amount and length of the b2 reinforcement required.

Due to uncertainties associated with these secondary moments, further field tests and laboratory tests are recommended to gain more confidence in considering the secondary moments. This additional research should include a broad experimental program coupled with a detailed analytical evaluation and should result in the development and recommendation of design tools for considering secondary moments in PPCB design and detailing.