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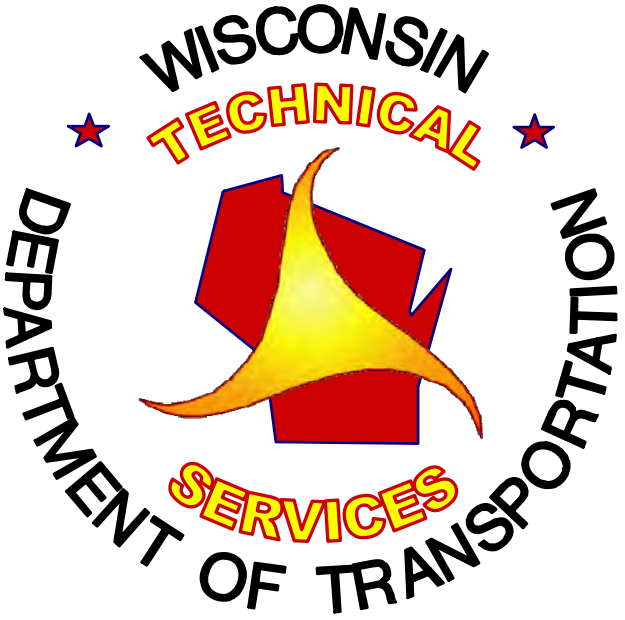
Evaluation of the Ontario Empirical Method for Design of Composite Bridge Deck Slab Reinforcement

FINAL REPORT



June 2012

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Research Study # WI-83-01

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16. Abstract

In 1979, the *Ontario Highway Bridge Design Code* was released, containing an empirical method for the design of concrete bridge decks. The Wisconsin DOT initiated a research study in 1983 to evaluate the empirical design method for bridge deck reinforcement. Bridge deck reinforcement at three locations in the state was designed and constructed using the Ontario empirical method. Comparison decks were constructed at each location using the conventional AASHTO reinforcement design.

The surface and underside of the bridge decks were monitored for cracking and other distress after five years in service. Their current condition (after 23 to 27 years in service) was also evaluated. The Ontario and AASHTO design methods resulted in similar performance, although slightly more cracking was noted when the Ontario method was used. One bridge deck designed with the Ontario method had more full-depth transverse cracking than its comparison structure with the AASHTO design. Other bridge decks designed with the Ontario method (not specifically monitored in this research study) have had more longitudinal cracking than AASHTO designed bridge decks. The total structure cost using the Ontario method for reinforcement design was three to six percent lower than when the AASHTO method was used. This is a result of the lower reinforcement requirement using the empirical method. The cost benefit was small, however, and the increased cracking risk was a disadvantage of the empirical design.

Current Wisconsin bridge design practice is in accordance with AASHTO *LRFD Bridge Design Specifications*. An AASHTO empirical bridge deck design procedure is an option for specific design situations. However, the Ontario design method is not an approved Wisconsin bridge deck design method.

17. Key Words Concrete bridge deck reinforcement, empirical design method, Ontario Highway Bridge Design Code		**18. Distribution Statement** Distribution unlimited, approved for public release	
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Commonly Used Abbreviations

Initializations

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
BAD	Base aggregate dense
CABC	Crushed aggregate base course
CRCP	Continuously reinforced concrete pavement
CTH	County trunk highway
DOT	Department of Transportation
EBS	Excavation below subgrade
FDM	Facilities Development Manual
FWD	Falling weight deflectometer
HMA	Hot mix asphalt
IRI	International roughness index
JPCP	Jointed plain concrete pavement
JRCP	Jointed reinforced concrete pavement
M-E	Mechanistic-empirical
MEPDG	Mechanistic-empirical pavement design guide
NB	Northbound
PCC	Portland cement concrete
PCI	Pavement condition index
PDI	Pavement distress index
PDR	Pavement design report
SB	Southbound
SMA	Stone matrix asphalt
SN	Structural number
STH	State trunk highway
STN	State trunk network
TSR	Transportation Synthesis Report
USH	United States highway
WisDOT	Wisconsin Department of Transportation

Units

ksi	kips per square inch
in	inch/inches
psi	pounds per square inch
m/km	meters per kilometer
ft	foot/feet
ft^2	square feet
CY	cubic yards

1. Introduction and Background

Twentieth century bridge design in the United States was typically based on the American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges*. In the late 1970s, research by the Province of Ontario and the State of New York indicated that the failure mode of reinforced concrete bridge decks was not via simple flexure stress, as assumed in the design methods used at that time. It was hypothesized that the actual load capacity of reinforced concrete bridge decks was much greater than predicted, and that the conventional design methods resulted in over-reinforcement.

In 1979, the Ontario Ministry of Transportation published the first edition of the *Ontario Highway Bridge Design Code*. These specifications contained an empirical design method for concrete bridge deck slabs. The reinforcing steel requirement was typically lower using this empirical design compared to standard AASHTO reinforcement design.

The Wisconsin Department of Transportation (WisDOT) initiated a research study in 1983 to evaluate the Ontario method for concrete bridge deck reinforcement design. The objective of the study was to design and construct bridge deck reinforcement using the Ontario method and evaluate the impact on cost and performance. Concrete decks with the conventional AASHTO design were constructed simultaneously for comparison.

Nearly thirty years have passed since the original research structures were constructed. In that time, Wisconsin has revised its bridge design practices to follow the AASHTO *Load and Resistance Factor Design (LRFD) Bridge Design Specifications*, the standard adopted nationwide in the early 2000s.

The intent of this report is to finalize the original evaluation of three bridge decks designed using the Ontario method. The results of performance evaluations are reported, and current WisDOT practices are outlined.

2. Bridge Deck Evaluations

Three locations were initially selected for bridge deck reinforcement design trials using the Ontario method. These locations are listed in Table 1. Sections 2.1 through 2.3 provide bridge deck design information for the structures listed in Table 1, along with cost information and performance summaries.

Table 1. Trial Bridge Deck Locations

Structure ID	County	Feature On	Feature Under
B-70-7 & B-70-8	Winnebago	USH 41 NB	Lake Butte des Mortes
B-32-56	La Crosse	USH 53 NB/STH 157 WB	I-90
B-39-30 & B-39-31	Marquette	I-39/USH 51	CTH J

2.1 Structures B-70-7 and B-70-8, Winnebago County

These structures are located on USH 41 northbound in Winnebago County, spanning Lake Butte des Mortes. The structures were constructed in 1954 and had bridge deck replacements in 1985. For the 1985 replacement project, the deck reinforcement for structure B-70-7 was designed using the Ontario method, and the AASHTO method was used for structure B-70-8. The reinforcement design parameters are shown in Table 2. Additional design and construction information is available in the Appendix. The reduced steel specified in the Ontario method design resulted in a 6.1 percent construction cost savings for the entire structure.

Table 2. Reinforcement Design, B-70-7 and B-70-8

Parameter	B-70-7 (Ontario)	B-70-8 (AASHTO)
Deck thickness	7 in	7 in
Reinforcing steel (size @ spacing)		
Top - Transverse	#4 @ 10 in	#5 @ 6.5 in
Top - Longitudinal	↓	#4 @ 12 in
Bottom - Transverse	↓	#5 @ 6.5 in
Bottom - Longitudinal	↓	#4 @ 6 in

A performance inspection was conducted on both structures in 1991, after the decks had been in service for six years. Surface spalling was not present on either deck. Cracking was noted on the underside of both decks. All cracks were perpendicular to the centerline of the structures (in the direction of the transverse reinforcing steel). The extent of the cracking was similar for both bridge decks.

Another crack inspection was performed in 2011, after the decks had been in service for 26 years. The surfaces of both bridge decks had very few cracks, most of which had been sealed. Cracking on the underside of the decks matched that of the 1991 review. The only visually discernible performance

difference between the decks was the presence of several asphalt patches on the center span of B-70-8 (AASHTO design). Cracks on the deck surface radiated from these patches to the parapet walls.

Both structures were scheduled for replacement in 2011 as part of the USH 41 expansion project.

2.2 Structure B-32-56, La Crosse County

This bridge is located on USH 53 northbound (STH 157 westbound) over I-90, in La Crosse County. It is a two-span structure constructed in 1984. The deck reinforcement in the first span was designed with the AASHTO method, and the second span was designed with the Ontario method. The reinforcement design parameters are shown in Table 3. Additional design and construction information is available in the Appendix. The reduced steel specified in the Ontario method design resulted in a 3.2 percent construction cost savings for the entire structure.

Table 3. Reinforcement Design, B-32-56

Parameter	**Span 1 (AASHTO)**	**Span 2 (Ontario)**
Deck thickness	8 in	8 in
Reinforcing steel (size @ spacing)		
Top - Transverse	#6 @ 8 in	#4 @ 10 in
Top - Longitudinal	#4 @ 12 in	↓
Bottom - Transverse	#6 @ 8 in	
Bottom - Longitudinal	#4 @ 6 in	

A five-year deck inspection was performed in 1989. The deck surfaces did not have any spalling or delamination. Cracking on the surface of the decks was approximately equal for both spans. These cracks were perpendicular to the centerline of the bridge (in the direction of the transverse reinforcement). Six transverse cracks were visible on the underside of span 2 (Ontario design), while no cracks were visible on the underside of span 1 (AASHTO design).

The routine bridge inspection report was reviewed from August 2011, at which point the deck had been in service for 27 years. No major distresses were noted on either span. Infrared and ground penetrating radar (GPR) scans indicated less than one percent distressed surface area on the deck. There was no comment on the underside of the spans. [*1*]

2.3 Structures B-39-30 and B-39-31, Marquette County

These structures are located on I-39/USH 51 and span CTH J in Marquette County. Both were constructed in 1986 and opened to traffic in 1987. The Ontario method was used for the deck reinforcement design on the northbound structure, B-39-30. The AASHTO design method was used for the southbound structure, B-39-31. The reinforcement design parameters are shown in Table 4. Additional design and construction information is available in the Appendix. The reduced steel specified in the Ontario method design resulted in a 5.2 percent construction cost savings for the entire structure.

Table 4. Reinforcement Design, B-39-30 and B-39-31

Parameter	B-39-30 (Ontario)	B-39-31 (AASHTO)
Deck thickness	7.5 in	7.5 in
Reinforcing steel (size @ spacing)		
Top - Transverse	#4 @ 12 in	#6 @ 7.5 in
Top - Longitudinal	↓	#4 @ 12 in
Bottom - Transverse		#6 @ 7.5 in
Bottom - Longitudinal		#4 @ 6 in

There is no record of a five-year performance evaluation of the B-39-30 and B-39-31 bridge decks. Recent routine bridge inspection reports were reviewed to compare long-term performance of the deck slabs. The structures were inspected in May 2010, after 23 years in service. A summary of the condition of each deck is reported in Table 5. Both bridge decks experienced moderate cracking. [*1*]

Table 5. Inspection Report Summary, 2010, B-39-30 and B-39-31

	B-39-30 (Ontario)	B-39-31 (AASHTO)
Deck surface	Moderate longitudinal and transverse cracks*	Moderate cracks*
Deck underside	Several cracks at ends with light efflorescence	Moderate transverse cracks with efflorescence in pier area and both ends

* Deck surface cracks were not sealed in 2010 but had been sealed in the past.

3. Current Department Practices (2012)

Wisconsin highway bridge design is performed using the AASHTO *LRFD Bridge Design Specifications*, as mandated in 2007 by AASHTO and the Federal Highway Administration (FHWA). The LRFD specification replaced the AASHTO *Standard Specifications for Highway Bridges*, in which design methodologies were based upon allowable stress design (ASD) and load factor design (LFD). The LRFD method takes into account known variability of applied loads and material properties. Calibrated factors for loads and resistance are used in design equations, resulting in more uniform performance and enhanced serviceability. [*2*]

Concrete bridge deck design in Wisconsin is typically performed using AASHTO LRFD 4.6.2.1, the "Approximate Method of Analysis," commonly called the "equivalent strip method." [*3, 4*] Chapter 17 of the WisDOT Bridge Manual provides additional guidance and history related to bridge deck design.

Section 9.7.2 of the AASHTO *LRFD Bridge Design Specifications* contains procedures for the empirical design of concrete deck slabs. Chapter 17 of the WisDOT Bridge Manual states that the AASHTO empirical method may only be used for certain design conditions, and that this method should not be

used for bridge decks where heavy truck traffic is anticipated. WisDOT approval is required if this method is selected for design. [*3*]

The 2005 version of the WisDOT Bridge Manual referenced the performance of bridge decks that were designed using empirical methods, including the Ontario design method decks monitored as part of this research study. The 2005 Bridge Manual stated: [*5*]

> "WisDOT has tried several empirical deck designs beginning in the 1980s. When the performance of these decks is based on deck cracking, they have underperformed the decks designed by the conventional method. In addition to the normal transverse deck cracks, about a third of these decks have also developed longitudinal cracks between girders. The only advantage to using the empirical design method is the savings in cost due to a slight reduction in the pounds of transverse deck steel required."

4. Summary and Conclusions

This research study tracked the performance of three sets of bridge decks with two deck reinforcement design methods: (1) the empirical method outlined in the 1979 *Ontario Highway Bridge Design Code* and (2) the conventional design method found in the AASHTO *Standard Specifications for Highway Bridges*. The bridge decks were constructed between 1984 and 1986.

The surface and underside of the bridge decks were monitored for cracking and other distresses. The bridge decks had similar performance under both the Ontario and AASHTO design methods, although slightly more cracking occurred when the Ontario method was used. One experimental bridge deck designed with the Ontario method had more full-depth transverse cracking than its comparison structure with the AASHTO design.

A beneficial feature of the Ontario design method is a reduction in the amount of reinforcing steel required. For the structures with deck reinforcement designed using the Ontario method, the reduced steel requirement resulted in a total structure cost that was three to six percent lower than the comparison structures with AASHTO deck reinforcement design.

In the time since this research study began, the Department has adopted the AASHTO *LRFD Bridge Design Specifications*. The LRFD specifications contain an empirical method for bridge deck reinforcement design; however, it is only used for Wisconsin structures in limited design applications.

The Ontario method of bridge deck reinforcement design had a lower steel requirement and thus a lower construction cost. However, the trial Ontario decks did not exhibit better performance than the conventionally designed decks and in one case had slightly more cracking than the comparison deck with AASHTO design. Furthermore, increased longitudinal cracking was noted in other empirically-designed bridge decks not monitored in this study. Therefore, the empirical method for bridge deck reinforcement design is not recommended for regular use in Wisconsin.

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3. Wisconsin Department of Transportation Bridge Manual. Chapter 17, "Superstructure - General;" Section 17.5, "Design of Slab on Girders." January 2012.

4. AASHTO *LRFD Bridge Design Specifications*, 6th edition. American Association of State Highway and Transportation Officials, Washington, D.C. 2012.

5. Wisconsin Department of Transportation Bridge Manual. Chapter 17, "Superstructure - General;" Section 17.3, "Design of Slab on Girders." November 2005.

Appendix - Structure Details

Design Information	**B-70-7 & B-70-8**		**B-32-56**	**B-39-30 & B-39-31**
Average daily traffic	17,015 (1988)		7900 (1988)	N/A
Truck percentage	17% (1988)		10% (1988)	N/A
Skew	0°		28°	4°
Number of spans & lengths	3; 66'-3", 83'-0", 66'-3"		2; 110', 110'	2; 81', 81'
Girder type	Rolled girder (33WF130)		Steel plate girder	45" Prestressed girder
Girder spacing	6'-2.5"		9'-6"	8'-11"
Effective deck span	5'-8.75"		9'-0"	8'-3"
Reinforcing steel layout	Perpendicular to roadway CL		Perpendicular to roadway CL	Perpendicular to roadway CL
Diaphragm spacing	14'-0"		25'-0"	27'-3"
Deck poured	July 1985		October 1984	November 1986
Open to traffic	August 1985		November 1984	May 1987
Field measurements	B-70-7	B-70-8		
Concrete air content	5.9%	6.7 %	5.7%	N/A
Concrete slump	2.8"	3.0"	2.875"	N/A
Cylinder strength (28-day)	5750 psi	5560 psi	5530/5340 psi (AASHTO/Ontario)	N/A
Average steel cover	2.75"	2.5"	2.5"	N/A
Average deck thickness	7.375"	7.375"	8"	N/A

N/A - data not available