

**MICHIGAN DEPARTMENT OF TRANSPORTATION  
M•DOT**

Performance Evaluation of Isotropic Bridge Decks  
(Ontario Design)

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## Introduction

To improve the nation's highway system, designers strive to find alternative details that will decrease cost while maintaining a high level of safety. In the past, the AASHTO Bridge Code<sup>1</sup> required bridge designers to design bridge decks with *flexure* being the principal mode of failure. Although this design philosophy worked well in the past, other designs may serve as acceptable alternatives.

Research has shown that *punching shear* is often the failure mode for concrete slabs<sup>2,3</sup>. This was determined through laboratory testing<sup>4</sup>. The Ontario Highway Bridge Design Code<sup>5</sup> (OHBDC) follows this theory by specifying the principal mode of failure is *punching shear* not *flexure* and designing accordingly. The OHBDC design is often referred to as an *isotropic bridge deck* because it is composed of an arrangement of reinforcement in which the bars are orthogonal with equal ratios of the reinforcement in both directions. With this design method, the Ontario Code uses roughly 40 percent less steel than the AASHTO design with smaller bars spaced further apart.

Some researchers believe there is a better representation of the stress distribution through a typical isotropic slab as shown in Figure 1. Once the bridge deck cracks, compressive membrane forces create *arching action*<sup>6</sup>. For arching action to develop, the beams must have the lateral support supplied by the transverse reinforcing bars and intermediate diaphragms. Since compressive membrane forces cannot occur when the deck overhangs the fascia beam, the deck must be designed for flexure.

Due to the lack of long term performance and the anticipated longitudinal cracking required for *arching action*, the durability of the isotropic deck is difficult to determine. Therefore, agencies experimenting with this bridge deck closely monitor its performance. Since 1982, New York state has constructed 29 experimental isotropic bridge decks. In a 1992 report<sup>7</sup>, they found that their isotropic bridge decks were performing satisfactorily, even though the longitudinal crack density was slightly higher than the AASHTO decks. In their ten-year study, the isotropic decks showed no major signs of distress and were behaving comparable with the AASHTO decks. Although New York state is not the only agency constructing isotropic decks, they do appear to be the only agency reporting the performance of the isotropic decks. As previously stated, Ontario has adopted the isotropic deck as their standard and to date they have not reported any problems associated with them.

## Scope

This study was initiated to compare the performance of isotropic bridge decks with that of the conventional AASHTO design method given Michigan's environment and vehicle loads.

Two structures that had their decks replaced with isotropic and conventional decks were studied: Franklin Street over US-131, (R03 of 41131), and US-127 over the Grand River, (B04 of 38111). Spans 13 and 14 on the Franklin Street bridge were replaced with an isotropic deck and spans 8 and 9 with the conventional AASHTO deck. The US-131 bridge over the Grand River had the northbound spans replaced with an AASHTO deck and the southbound spans with an isotropic deck.

## **Comparison**

### **Franklin Street over US-131 (R03 of 41131)**

The Franklin Street Bridge, located in the City of Grand Rapids, consists of 25 spans. During the deck replacement two spans were replaced with a simply supported isotropic deck, spans 13 and 14. The isotropic decks were to be compared with spans 8 and 9, both simply supported AASHTO decks. The isotropic decks have a length of 9,800 mm (32') for spans 13 and 14. The studied AASHTO decks have a length of 14,400 mm (47') and 10,500 mm (35') for spans 8 and 9, respectively. Both decks have an out to out width of 17,800 mm (58') and have a deck slab thickness of 230 mm (9"). According to 1995 traffic counts, the ADT for the structure was 7,400 with 19% commercial traffic.

### **Construction**

Two different I-beams were used during the replacement of the four spans. Type I prestressed concrete I-beams, 711 mm (28"), were used for spans 13 and 14 (isotropic deck) and Type II prestressed concrete I-beams, 914 mm (36"), were used for span 8 and 9 (AASHTO deck).

Reinforcement for the AASHTO decks was epoxy coated Grade 420 MPa (60 ksi) bars. Number 10 (Number 3) bars were placed longitudinally and Number 19 (Number 6) bars were placed transversely for the top layer of reinforcement. Number 16 (Number 5) bars were placed longitudinally and Number 19 (Number 6) bars were placed transversely for the bottom layer of reinforcement. Refer to Figure 2 for placement and spacing. Reinforcement used for the isotropic deck were epoxy coated Grade 420 MPa (60 ksi) Number 13 (Number 4) bars for both top and bottom layers. Refer to Figure 3 for placement and spacing of the bars. Figure 4 displays the typical deck section for both AASHTO and isotropic decks.

With traffic rerouted over existing local roads, AASHTO spans (8 and 9) were poured on April 12, 1991 using a total of 114 m<sup>3</sup> (152 cyds) of Grade D (45D) concrete. The high temperature for the cloudy, windy day was 6 °C (42 °F) and the low was 0 °C (32 °F). Concrete temperature ranged between 12 °C (54 °F) and 17 °C (62 °F). The slump was measured between 57 mm (2 1/4") and 70 mm (2 3/4") and the entrained air between 5.3% and 6.5%. Aggregate was supplied from two different sources. The fine aggregate, 2NS, was from Wilson Pit (3-88) and the coarse aggregate, 6AA, from Michigan Lime and Chemical (71-3). The deck slab

was cured with the aid of 201 liters (53 gallons) of white curing compound. Concrete cylinders were tested at 7 day, 14 day, and 28 day intervals. The compression tests results were: 29.0 MPa (4,209 psi) and 34.8 MPa (5,040 psi) for 7 day, 33.8 MPa (4,898 psi) for 14 day, and 39.6 MPa (5,747 psi) for 28 day.

On April 17, 1991, the isotropic spans (13 and 14) were poured using 80 m<sup>3</sup> (107 cyds) of concrete with traffic rerouted over existing roads. The weather ranged from a clear windy 14 °C (57 °F) to a cloudy 0 °C (32 °F). The concrete type was Grade D (45D) with a temperature between 16 °C (60 °F) and 24 °C (76 °F) and a slump of 70 mm (2 3/4") to 76 mm (3"). Entrained air was 5.6% to 7.6%. Aggregate for the isotropic slabs was from the same two sources as the AASHTO slabs. The curing methods were the same. White curing compound was sprayed over the deck slab, 110 liters (29 gallons) for the isotropic deck. Twenty-eight days after the pour, four cylinders were tested for compressive strength. The strength ranged from 29.8 MPa (4,315 psi) to 41.0 MPa (5,942 psi).

## Results

The Franklin Street bridge was monitored monthly for the first three months, then quarterly for two years, and finally annually for the remainder of the study. Overall, the bridge has been monitored for five years. The monitoring was extensive at first to observe the initial cracking resulting from shrinkage and live loads.

In the summer of 1996, we decided to perform a crack map survey of each deck. We wanted to look at the deck as a whole picture due to many small cracks developing. Figure 5 displays the cracks found on the AASHTO deck and Figure 6 displays the cracks found on the isotropic deck. Comparing the crack densities, the AASHTO deck had a higher density of 192 mm/m<sup>2</sup> (525 in/ft<sup>2</sup>) than the isotropic deck's 111 mm/m<sup>2</sup> (303 in/ft<sup>2</sup>).

Observing the underside of each deck revealed mostly typical shrinkage cracks less than 0.10 mm (0.004 in) wide. On October 2, 1996, a random sampling of crack widths was performed on the underside of each deck. The sample revealed typical crack widths ranging from 0.05 mm (0.002 in) to 0.08 mm (0.003 in) on the AASHTO deck and from 0.05 mm (0.002 in) to 0.10 mm (0.004 in) on the isotropic deck. The isotropic deck also contained center longitudinal cracks about 0.20 mm (0.008 in) wide.

Four large cracks were present on the isotropic deck. Three of the four appeared at the midpoints of bay 6, bay 8, and bay 19 and had widths of 0.30 mm (0.012 in). Efflorescence was only present in bay 19. The fourth crack occurred at the third point of bay 16. This crack width was roughly 0.40 mm (0.016 in) with no efflorescence present.

We could not monitor the underside of the AASHTO deck very closely because railroad tracks and a power line in the area make an unsafe work environment.

Therefore, only limited data are available for the AASHTO deck's underside. We did, however, determine that shrinkage cracks less than 0.10 mm (0.004 in) existed throughout the underside. This is comparable to the isotropic deck.

### **US-27 over the Grand River (B04 of 38111)**

This structure, located south of Jackson, consists of northbound and southbound structures. Both structures have three simply supported spans of 11,140 mm (37'), 13,700 mm (45'), and 11,130 mm (37'), which have a total length of 35,980 mm (118'). The total out to out deck surface width was 13,840 mm (45'). The 230-mm (9") deck slab was placed on the existing W760X161 (W30X108) steel beams using the existing shear spiral connectors on span 2 and shear stud connectors on spans 1 and 3. Refer to Figures 7 and 8 for the placement and spacing of the reinforcement bars in the AASHTO and isotropic decks. The typical cross-section for both decks is displayed in Figure 9. According to 1994 traffic counts, the ADT for the structure was 23,000 with 9 percent commercial traffic.

The deck replacement (Summer 1996) was performed in 4 stages; 1) traffic reduced to one lane both directions and maintained on the passing lanes while the shoulder lanes were removed, 2) form and pour the shoulder lanes, 3) shift traffic to the newly constructed shoulder lanes and remove the existing passing lanes, 4) form and pour the passing lanes and open to traffic.

During our initial survey (Fall 1996) we discovered both the isotropic decks and the AASHTO decks were virtually crack free. There were only five full depth cracks in the shoulder lane and two in the passing lane on the AASHTO deck, Figure 10, and only two full depth cracks in the shoulder lanes and zero in the passing lanes on the isotropic deck, Figure 11. All full depth cracks that could be measured were 0.08 mm (0.003 in) in width and were outlined with a white powder residue, possibly calcium carbonate. A typical full depth crack is displayed in Figure 12.

## **Conclusion**

For the Franklin Street Bridge, the isotropic deck used roughly 50 percent less steel than the AASHTO deck. The isotropic deck used 19 kg/m<sup>2</sup> (3.9 lb/ft<sup>2</sup>) of reinforcing steel compared with 38 kg/m<sup>2</sup> (7.8 lb/ft<sup>2</sup>) for the AASHTO deck. Assuming the cost for epoxy coated reinforcement is \$1.75/kg (\$0.79/lb.), the isotropic deck saves roughly \$33/m<sup>2</sup> (\$3/ft<sup>2</sup>). The total area for the bridge is 5,619 m<sup>2</sup> (60,480 ft<sup>2</sup>). If we designed the entire bridge deck as isotropic, there would be a total savings of roughly \$186,000 over the AASHTO design.

After five years, the Franklin Street isotropic deck is performing satisfactorily when compared with the AASHTO deck. Both decks have only minor cracks. More cracks are found in the AASHTO deck but this could be the result of construction errors. We found nothing to make us believe the isotropic deck will not continue to perform satisfactorily.

As for US-127 over Grand River, we have only completed the initial crack survey and can only state that both decks are virtually free of cracks with the isotropic deck having fewer full depth cracks than the AASHTO deck.

The Structural Research Unit will continue to monitor both bridge decks for the next five years.

### **Recommendations**

Criteria need to be developed for isotropic bridge deck design, analysis, and use as follows:

1. The maximum beam spacing that can be used with an isotropic deck.
2. How an isotropic deck responds to an acute angle of crossing (less than 65 degrees or more than 115 degrees).
3. How an isotropic deck responds to a bituminous overlay placed over a waterproofing membrane.
4. Isotropic deck performance differences if placed on steel beams compared with concrete beams.
5. How an isotropic bridge deck load is rated.

In effort to develop our understanding of isotropic bridge decks further, five bridges have been selected to receive isotropic decks in conjunction with AASHTO decks for replacements. They are as follows:

Bridge Number	Type of Beams	Beam Spacing	Approx. Angle of Crossing	Job #	Unit leader	Const. Plan Completion Date
B04 of 38111	W760X161 (W30X108) Steel Beam	1,676 mm (5'-6")	85°	32475	Occhiuto	Built 1996
S01 of 83033	1,524 mm (60") Plate Girder	2,667 mm (8'-9")	43°	33006	Mahdavi	7/98
R01 of 83033	1,778 mm (70") PCI	2,591 mm (8'-6")	102°	33006	Mahdavi	7/98
S06 of 83033	1800 PCI girder	1,829 mm (6'-0")	78°	33007	Jildeh	7/98
S03 of 83033	1,676 mm (66") Plate Girder	2,616 mm (8'-7")	76°	33006	Mahdavi	7/98

The Structural Research Unit should continue to be involved in answering the remaining questions and help develop department policy. Due to the fact that the isotropic decks cost significantly less than and are performing comparably with our current AASHTO decks, the department should increase the use of this detail. Designers should follow AASHTO LRFD when designing for isotropic bridge decks.



## References

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