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<b>16. Abstract</b> <p>This report compares the performance of the isotropic bridge deck design method, also known as the empirical design method, with that of the conventional AASHTO design method given Michigan's environment and vehicle loads. An isotropic bridge deck is composed of an arrangement of reinforcement in which the bars are the same size and spaced equally in both the transverse and longitudinal directions. This design is based on the failure method for bridge decks being punching shear instead of flexure, which has been shown through research and testing. Designed accordingly, the amount of reinforcement necessary may be less for an isotropic deck. This study looked at ten isotropic decks and several conventional decks on parallel structures. Crack widths and crack densities were found to be comparable between the two designs, with isotropic decks exhibiting less transverse cracking and more longitudinal cracking than conventional decks. Cracking was found to be proportional with beam spacing and volume of truck traffic for both deck design methods, and the effects of skew were inconclusive. The cost savings for the isotropic design were found to be proportional to beam spacing, with smaller beam spacing providing little or no cost savings over the conventional design. Since the performance of the isotropic design was found to be satisfactory and comparable to the conventional design, it is recommended that the department continue use of the isotropic design method where cost savings are realized.</p>			
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**MICHIGAN DEPARTMENT OF TRANSPORTATION  
MDOT**

**Performance Evaluation of  
Isotropic Bridge Decks**

**Peter O. Jansson, P.E.**

**Structural Section  
Construction and Technology Division  
Report 91-F-0170  
Research Report R-1515**

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June 2008**

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# 1. INTRODUCTION

## 1.1 BACKGROUND

The empirical deck design method, often referred to as the isotropic deck design method because of equal amounts of reinforcing steel spaced in orthogonal directions, was incorporated into the Association of American State Highway and Transportation Officials' (AASHTO) first edition of the Load and Resistance Factor Design (LRFD) Bridge Design Specifications in 1994. Research leading to this inclusion was investigated previously<sup>1,7</sup>, and concluded that bridge deck slabs resist wheel loads primarily through compressive membrane stresses and internal arching action, and the primary failure method is punching shear, not flexure as previously believed. Accordingly, the deck steel reinforcement can be arranged to resist punching shear, which can require less steel reinforcement than the traditional design based upon flexure.

The Michigan Department of Transportation (MDOT) constructed its first isotropic deck in 1991. MDOT currently specifies two standard types of bridge deck design<sup>5</sup>, one based upon flexure with steel reinforcement selected as specified in MDOT Bridge Design Guide 6.41.01, *Standard Bridge Slabs (Load Factor Design)*, and the empirical design with steel reinforcement selected as specified in MDOT Bridge Design Guide 6.41.02, *Standard Bridge Slab (Empirical Design)*. The design guides can be seen in Appendix A.

When referring to the type of deck design, the terms isotropic and empirical are equivalent, but isotropic will be used in this report.

## 1.2 PAST RESEARCH

MDOT published an interim report on the performance of the isotropic deck design in 1997<sup>7</sup>. Two bridges with the isotropic design were monitored and found to be performing satisfactorily when compared with the conventional design. It was recommended that the department continue to monitor these structures and consider increasing the use of the isotropic deck detail. It was also recommended that the effects of beam spacing, beam type, skew, and load rating be investigated for isotropic decks. This evaluation continues the monitoring from the interim report, expands the monitoring to several more structures, and investigates the effects of different structural parameters.

The New York State Department of Transportation (NYSDOT) compared the performance of 39 bridge decks, 28 isotropic decks and 13 conventional decks, in 1991<sup>10</sup>. The isotropic decks were found to be performing satisfactorily, with no spalling or delamination and cracking judged to be minor with regards to serviceability. Longitudinal cracking was a larger percentage of the total crack density for the isotropic decks and transverse cracking was a larger percentage of the total crack density for the conventional decks. Quantitatively, when deck age was considered, the transverse cracking was found to be equivalent for the isotropic and conventional designs, while the isotropic design exhibited slightly higher longitudinal cracking. The isotropic decks inspected had two mats of #5 reinforcing bars spaced at 12 inches in both directions. No follow up research reports were published by the NYSDOT, though the isotropic deck design is currently the NYSDOT preferred method<sup>3,9</sup> for bridges that have four or more beams spaced

between 5 and 11 feet, a minimum deck thickness of 9.5 inches, skew angles up to 45 degrees, and meet other select criteria. It should be noted that the current NYSDOT standard detail for isotropic decks uses two mats of #4 reinforcing bars spaced at 8 inches in both directions.

MDOT sponsored a research project to investigate the analysis procedures and load rating for isotropic decks in 2003<sup>8</sup>. Field testing and Finite Element Analysis (FEA) were used to investigate isotropic decks supported by steel and prestressed concrete girders. It was found that dead load and live load stresses were less than the required stress to initiate cracking in the deck, but tensile stresses due to restrained shrinkage could exceed the modulus of rupture of the deck concrete depending on the composite section geometry, stiffness, and spacing of the girders. It was recommended that the steel reinforcement be increased for isotropic decks on deeper steel girders and AASHTO Type IV prestressed concrete beams.

AASHTO<sup>1</sup> states that the available test data indicates that there is a factor of safety of at least 10.0 for decks designed according to the flexure design method contained in the 16<sup>th</sup> edition of the Standard Specifications for Highway Bridges, and the comparable factor of safety for the isotropic deck design is about 8.0. Therefore, when evaluating the two design methods, serviceability and durability are the critical factors.

### **1.3 REPORT SCOPE**

This investigation evaluated the performance of isotropic decks, compared to the performance of similar structures with conventionally designed decks where possible, analyzing the effects of beam spacing, beam type, and skew. The costs of the two deck designs were also compared.

A total of ten bridges with the isotropic deck design, constructed between 1991 and 2001, were inspected for this evaluation. For three of the bridges, a parallel structure with the conventional design was also inspected, and for a fourth case, one bridge with both isotropic and conventional decks for different spans was inspected. Table 1-1 lists the structures with isotropic decks that were inspected; the shaded cells indicate parallel structures or similar spans with the conventional design were also inspected for comparison. In Table 1-1 ADT denotes Average Daily Traffic and ADTT denotes Average Daily Truck Traffic.

When inspecting the bridges, cracking was noted on the deck surface and on the underside of the deck where possible, though many structures had stay in place (SIP) metal forms. Cracking was mapped to identify cracking patterns and quantified to calculate crack densities. When conducting deck surface inspections, cracks visible while bending at the waist were marked and measured. The crack density was calculated by dividing the total length of all cracks in the bridge deck by the roadway area bounded by the barrier faces and transverse reference lines, and reported in inches per square foot. When reporting the crack density of the underside of decks, the deck obscured from view by the beam flanges was not subtracted from the deck area.

**Table 1-1 Isotropic decks inspected**

Structure Location	Bridge ID	Beam Type	Beam Spacing, c-c (ft)	Structure Length (ft)	No. of Spans	Skew (deg)	ADT	ADTT (%)	Construction Date
US-131 under Franklin St, Grand Rapids	R03 of 41131	PCI Type I	8.73	64 (spans 13-14)	2	0	10,204	14	1991
		PCI Type II	8.73	82 (spans 8-9)	2	13			
US-27 over the Grand River, Jackson	B04-2 of 38111	30" Steel	5.50	118	3	2	12,304	10	1996
US-131 over State Rd 43, Cadillac	S01 of 83033	1800mm PCI	6.25	255	3	47	4,314	8	1999
US-131 over TSB Railroad, Cadillac	R01 of 83033	70" PCI	8.50	117	1	13	4,314	8	1998
M-66 over North Branch Chippewa River, Barryton	B01 of 54032	24" Steel	4.67	50	1	0	4,325	6	1999
M-66 over North Branch Chippewa River, Barryton	B02 of 54032	24" Steel	4.67	80	2	15	2,959	8	1999
M-66 over North Branch Chippewa River, Barryton	B03 of 54032	24" Steel	4.67	80	2	45	2,978	9	1999
I-75 over Central Michigan Railroad, Bay City	R01-1 of 09035	30" Steel	6.0 (avg)	139	3	1	38,776	9	2001
US-131 under Whaley Rd, Cadillac	S03 of 83033	70" PCI	8.58	244	2	14	1,200	5	1998
US-131 under No. 36 Rd, Cadillac	S06 of 83033	1800mm PCI	6.0	145	1	12	N/A	N/A	1998

## 2. COMPARISON CASE STUDIES

### 2.1 US-131 UNDER FRANKLIN STREET (R03 OF 41131), CITY OF GRAND RAPIDS

The subject structure was the first MDOT Bridge using the isotropic design. Constructed in 1960, the 25 span Franklin Street Bridge received a deck replacement in 1991. During the deck replacement, two spans were replaced with simply supported isotropic decks, spans 13 and 14, to be compared with spans 8 and 9, both replaced with simply supported conventional decks. Spans 13 and 14 are each 32 feet, have no skew, and are supported by AASHTO Type I prestressed concrete I-beams. Spans 8 and 9 are 47 feet and 35 feet, respectively, have a 13 degree skew, and are supported by AASHTO Type II prestressed concrete I-beams. Deck width and thickness is constant for spans 8 and 9, and 13 and 14. The ADT is 10,204 with 14 percent truck traffic.

As reported by Needham<sup>7</sup> and seen in Figure 2.1, the initial inspection showed slightly more cracking in the conventional deck than the isotropic deck, though subsequent inspections showed more cracking in the isotropic deck. Crack widths were less than 0.007 inch on the conventional spans and less than 0.005 inch on the isotropic spans.

The bridge inspection ratings for R03-41131 were reviewed; specifically the Bridge Inspection Rating (BIR) item #1, *Surface*, and BIR item #6, *Deck*. BIR item #1 rates the condition of the deck surface only, while BIR item #6 rates the overall condition of the deck, including the underside. Appendix B lists the complete coding and descriptions for BIR items #1 and #6. BIR item #1 was listed as a seven, or in good condition, and BIR item #6 was listed as a five, or in fair condition, for the most recent inspection, 2007. Comments in the bridge inspection report did not specifically address spans 8, 9, 13, or 14. Crack maps for the deck surface of spans 8, 9, 13, and 14 can be seen in Appendix Figures C1 and C2.

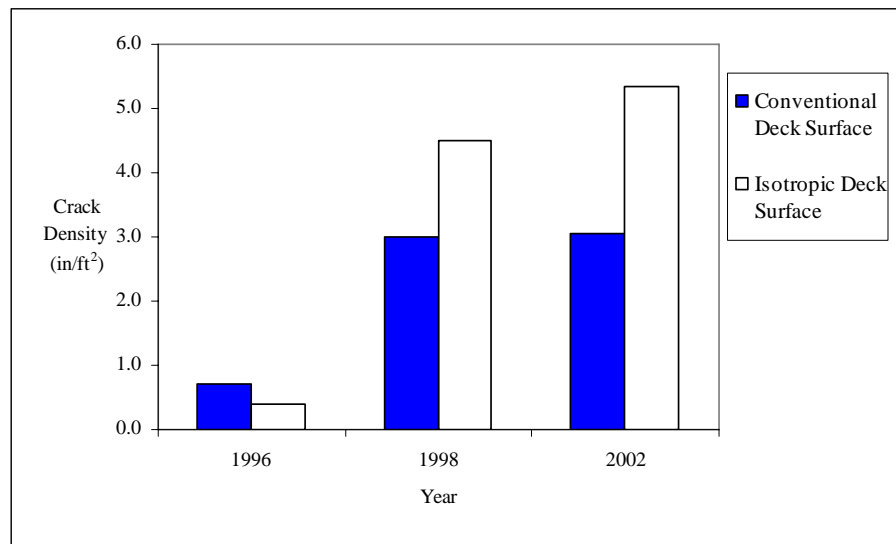


Figure 2.1 Crack densities for conventional and isotropic spans of R03 of 41131

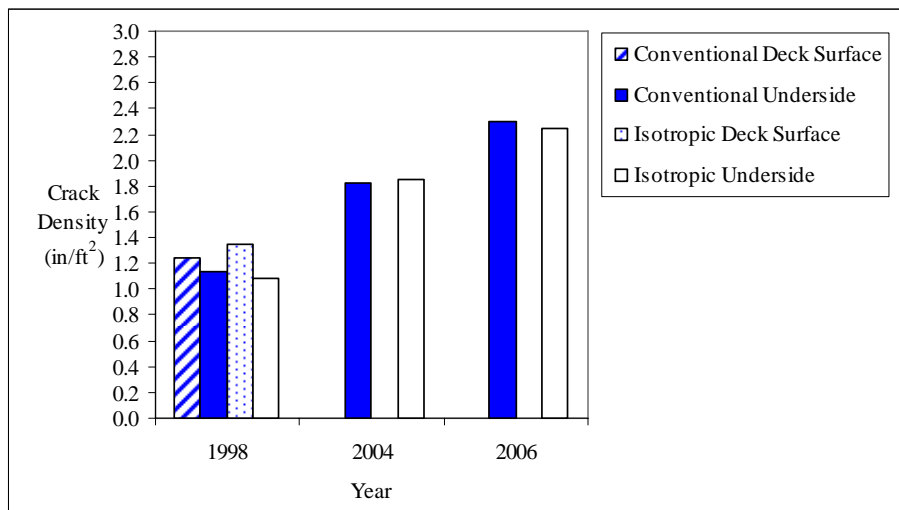


## 2.2 US-127 OVER THE GRAND RIVER (B04-1,2 OF 38111), CITY OF JACKSON

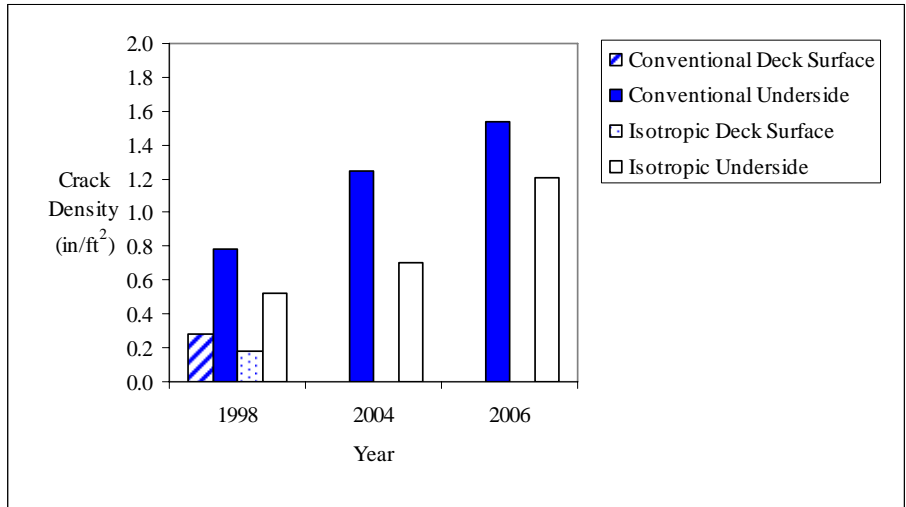
The two parallel subject structures received deck replacements in 1996. B04-38111-1 carries US-127 NB and has the conventional deck design; B04-38111-2 carries US-127 SB and has the isotropic deck design. Both decks are supported by 30 inch steel I-girders spaced at 5.5 feet on center. Both structures are three span simply supported bridges with main spans of 45 feet and tail spans of 36.6 feet. Both have a skew of two degrees and an ADT of 12,304 with 10 percent truck traffic.

Figures 2.2 through 2.5 show the crack densities for both structures, in total and separated according to crack orientation. Diagonal cracking was assumed as orientation greater than 20 degrees from the bridge reference lines. In 2001, both structures received flood-coat epoxy overlays, preventing further inspection of the deck surfaces, so inspections in 2004 and 2006 were relegated to the underside of the decks. Reflective cracking through the flood-coat on the deck surface was not evident. As seen in Figures 2.2 through 2.5, the decks are performing similarly. The overall crack densities are comparable; the conventional deck shows more transverse cracking and the isotropic deck shows more longitudinal and diagonal cracking. These trends are similar for both the deck surfaces and the undersides of the decks. Crack maps for the deck surfaces and deck undersides for B04-38111-1,2 can be seen in Figures C3 through C6. Crack width measurements ranged from 0.003 inch to 0.006 inch on the deck surface of the conventional deck, and from 0.003 inch to 0.010 inch on the isotropic deck surface. Crack width measurements on the underside of both decks ranged from 0.004 inch to 0.010 inch.

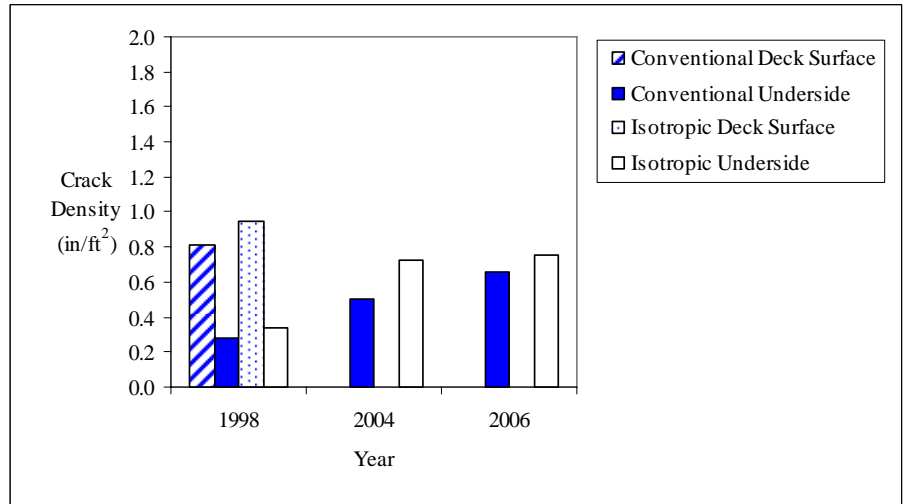
The most recent bridge inspection ratings, issued in 2007, list ratings of eight, or in good condition for both surfaces, and ratings of 6, or in fair condition for both decks.



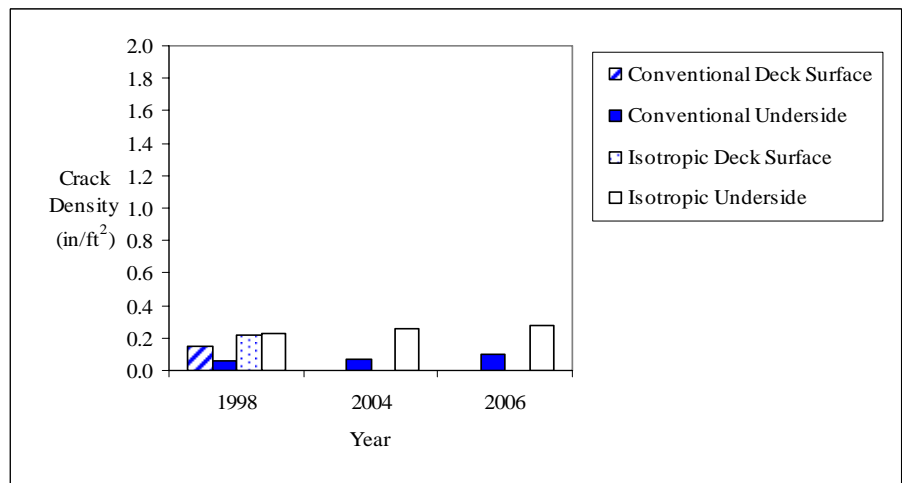
**Figure 2.2 Total crack densities for B04-1,2 of 38111**



**Figure 2.3 Transverse crack densities for B04-1,2 of 38111**



**Figure 2.4 Longitudinal crack densities for B04-1,2 of 38111**



**Figure 2.5 Diagonal crack densities for B04-1,2 of 38111**

### 2.3 M-66 OVER THE NORTH BRANCH OF THE CHIPPEWA RIVER (B01, B02, B03 OF 54032), VILLAGE OF BARRYTON

The three subject structures received isotropic deck replacements in 1999. All three structures have 24 inch steel girders spaced at 4.67 feet on center. B01 is a single span structure of 50 feet, B02 and B03 are both 80 feet structures with two equal length spans. B01 has a zero degree skew and an ADT of 4,325 with 6 percent truck traffic, B02 has 15 degree skew and B03 has a 45 degree skew. B02 and B03 have ADTs of 2,959 and 2,978, respectively, with 8 percent and 9 percent truck traffic, respectively.

Figures 2.6 through 2.9 show the deck surface crack densities for all three structures, in total and separated according to crack orientation. As seen in Figure 2.6, B01 has the highest total crack density, followed by B03, and then B02. B01 has significantly greater longitudinal cracking, while B02 has more transverse cracking and B03 has more diagonal cracking. Crack maps for the surfaces can be seen in Figures C7 through C9; all three structures have stay in place (SIP) forms that prevent inspection of the deck undersides. Crack widths ranged from 0.003 inch to 0.010 inch for all three decks, with the exception of cracking adjacent to the saw cut in the deck over the pier of B02, which measured from 0.010 inch to 0.030 inch and was accompanied by spalling.

The most recent bridge inspection ratings, issued in 2006, list surface ratings of six, seven, and six for B01, B02, and B03, respectively, and deck ratings of six, eight, and six for B01, B02, and B03, respectively.

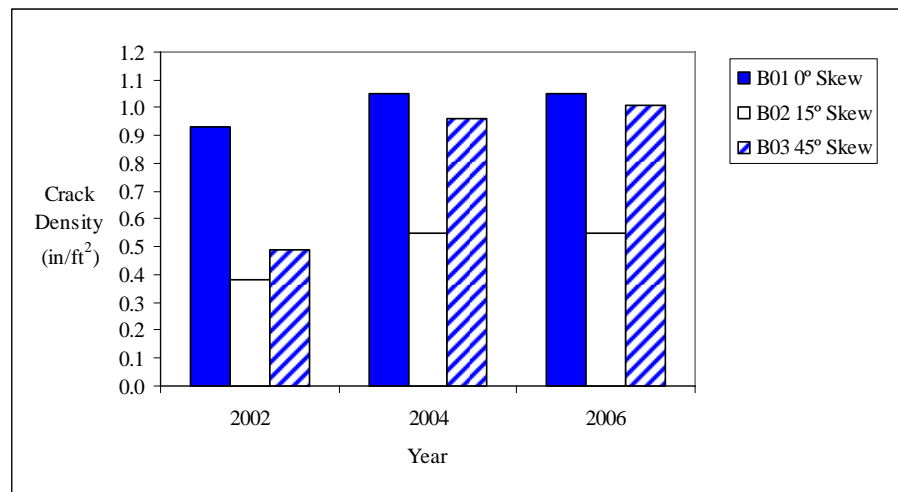
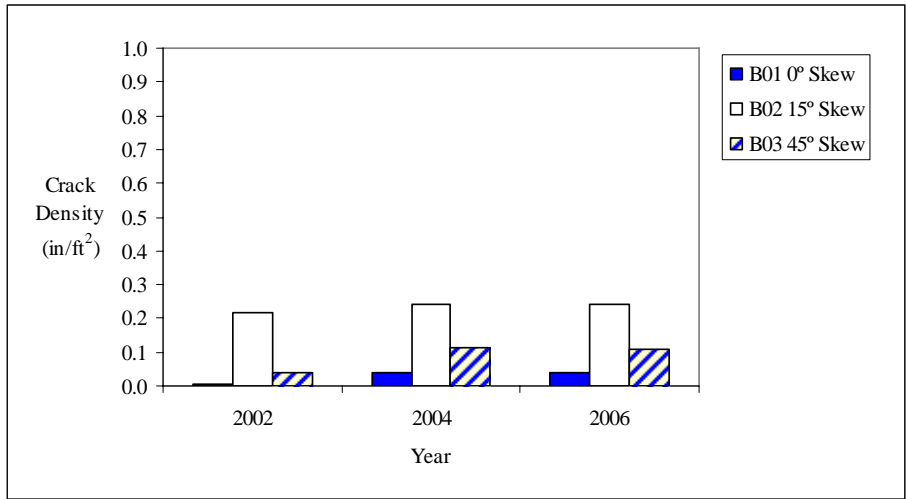
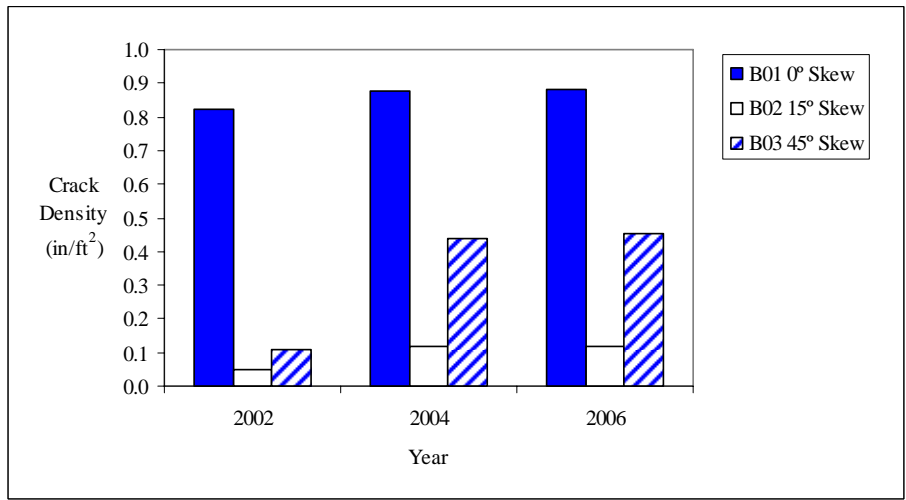


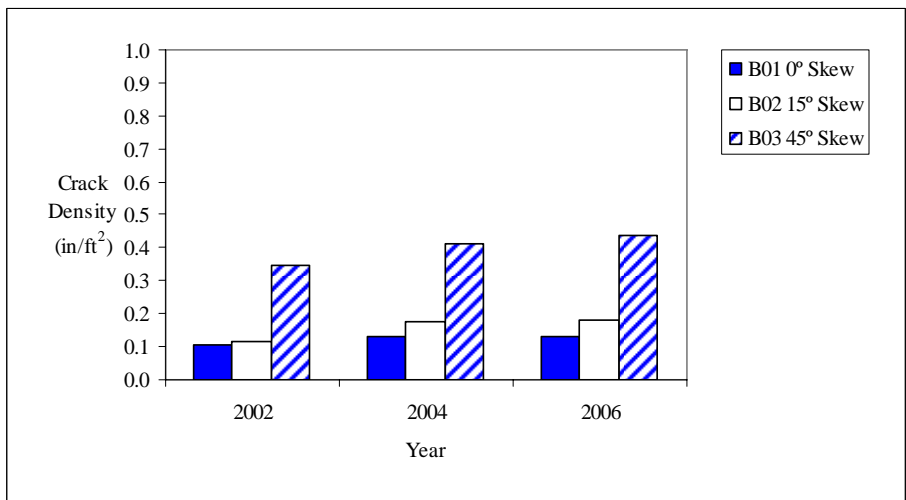
Figure 2.6 Total deck surface crack densities for B01, B02, B03 of 54032



**Figure 2.7 Transverse deck surface crack densities for B01, B02, B03 of 54032**



**Figure 2.8 Longitudinal deck surface crack densities for B01, B02, B03 of 54032**

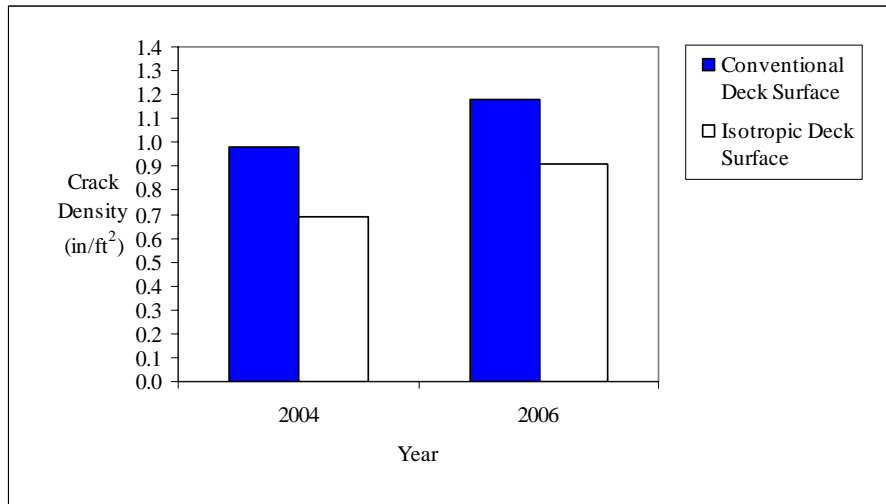


**Figure 2.9 Diagonal deck surface crack densities for B01, B02, B03 of 54032**

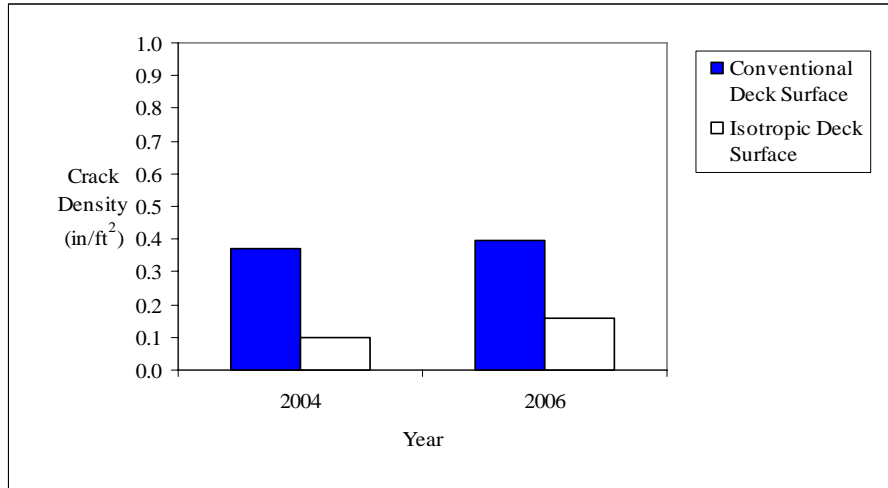
## 2.4 US-131 OVER STATE ROAD 43 (S01, S02 OF 83033), CITY OF CADILLAC

The subject parallel structures were constructed in 1999. S01 carries US-131 NB and was constructed with the isotropic deck design; S02 carries US-131 SB and was constructed with the conventional deck design. Each structure carries two lanes of traffic, has prestressed Michigan 1800 girders spaced at 6.25 feet on center, has a 47 degree skew, an ADT of 4,314 with 8 percent truck traffic, and three spans of approximately 52 feet, 147 feet, and 57 feet.

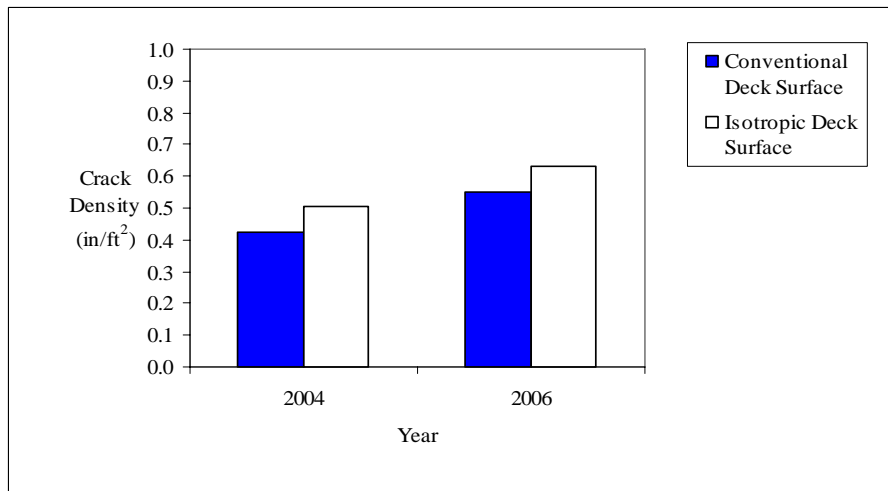
Figures 2.10 through 2.13 show the deck surface crack densities for both structures, in total and separated according to crack orientation. The isotropic deck shows more longitudinal cracking and the conventional deck shows more transverse and diagonal cracking and has a higher total crack density. Deck surface crack maps can be seen in Figures C10 and C11 of the Appendix. Both structures had stay in place metal forms preventing underside inspections. The most recent bridge inspection ratings, issued in 2008, list surface ratings and deck ratings of seven, or in good condition, for both structures. Crack width measurements were less than 0.016 inch on the deck surface of the conventional deck, and less than 0.010 inch on the isotropic deck surface.



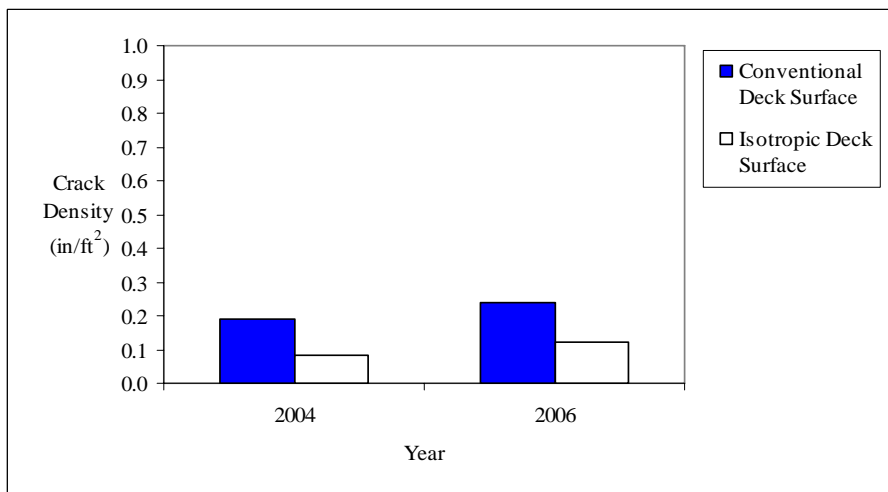
**Figure 2.10 Total crack densities for S01, S02 of 83033**



**Figure 2.11 Transverse crack densities for S01, S02 of 83033**



**Figure 2.12 Longitudinal crack densities for S01, S02 of 83033**

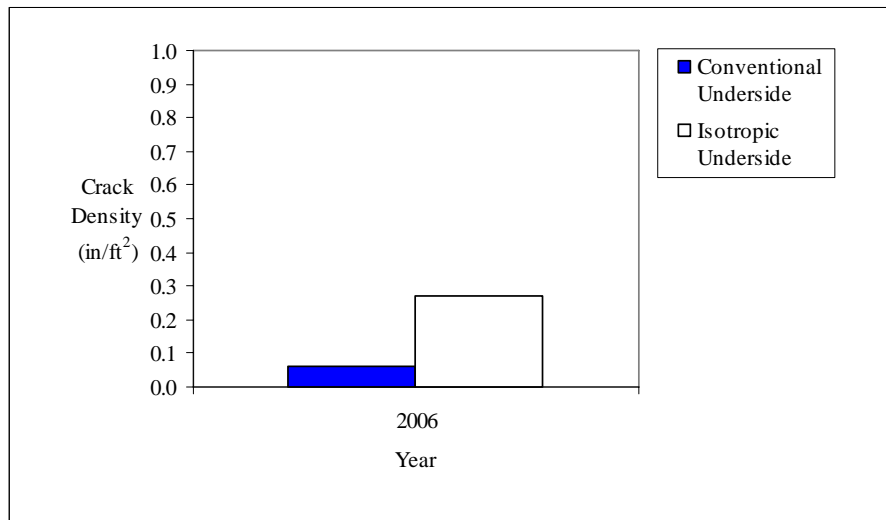


**Figure 2.13 Diagonal crack densities for S01, S02 of 83033**

## 2.5 US-131 OVER TSB RAILROAD (R01, R02 OF 83033), CITY OF CADILLAC

The subject similar structures were constructed in 1998. R01 carries US-131 NB and was constructed with the isotropic deck design; R02 carries US-131 SB and was constructed with the conventional deck design. Each structure carries two lanes of traffic, has 70 inch prestressed concrete I-girders spaced at 8.5 feet on center, a 13 degree skew, an ADT of 4,314 with 8 percent truck traffic, and single spans of 114 feet for R01 and 122 feet for R02. Prior to the first inspection, both R01 and R02 had been flood coated with an epoxy flood coat overlay, so crack measurement or mapping was not done on the deck surface. The undersides of the decks were inspected and the crack maps can be seen in Figures C12 and C13.

The crack densities were 0.27 in/ft<sup>2</sup> and 0.06 in/ft<sup>2</sup> for the isotropic and conventional deck undersides, respectively, as seen in Figure 2.14. No reflective cracking was evident through the flood coat on the deck surface. Both structures had similar diagonal cracking in one of the acute corners on the underside of the deck. The isotropic deck had several longitudinal cracks, while the conventional deck had no longitudinal or transverse cracks. The most recent bridge inspection ratings, issued in 2008, list surface ratings of eight, or in good condition for both structures, while R01 has a deck rating of seven and R02 has a deck rating of eight, both in good condition.



**Figure 2.14 Total crack densities for R01, R02 of 83033**

### 3. ADDITIONAL INSPECTIONS OF ISOTROPIC DECKS

#### 3.1 US-131 UNDER WHALEY ROAD (S03 OF 83033), CITY OF CADILLAC

The subject structure was constructed in 1998. S03 is a two span structure with span lengths of 116 feet and 129 feet, 70 inch prestressed concrete I-girders spaced at 8.58 feet on center, a 14 degree skew and an ADT of 1,200 with 5 percent truck traffic. S03 was flood coated with an epoxy overlay prior to the first inspection in 2006, so a deck surface crack inspection was not possible. Inspection of the deck underside showed mostly transverse cracking near the pier between the construction joints in spans one and two, and a crack density of 0.46 in/ft<sup>2</sup>, as seen in Figure 3.1. No reflective cracking was evident through the epoxy overlay. The crack map can be seen in Figure C14 in the Appendix. The most recent bridge inspection ratings issued in 2008 rated both the surface and deck an eight, or in good condition.

#### 3.2 US-131 UNDER NO. 36 ROAD (S06 OF 83033), CITY OF CADILLAC

The subject structure was constructed in 1998. S06 is one span structure 145 feet in length, with prestressed Michigan 1800 girders spaced at 6.0 feet on center and a 12 degree skew. The ADT was not available. An inspection of the deck in 1999 found mostly longitudinal cracking on the surface with a crack density of 0.31 in/ft<sup>2</sup>, as seen in Figure 3.1. The most recent bridge inspection ratings issued in 2007 rated both the surface and deck an eight, or in good condition. The crack map can be seen in Figure C15 in the Appendix.

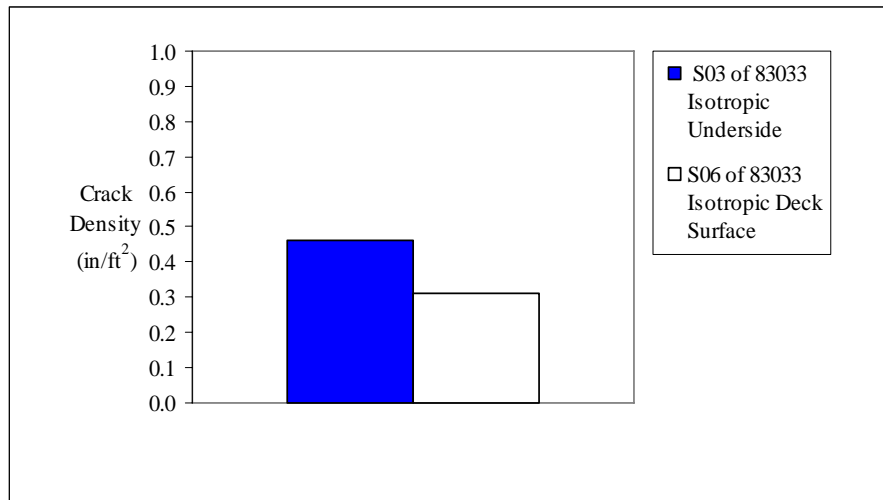


Figure 3.1 Crack densities for S03, S06 of 83033

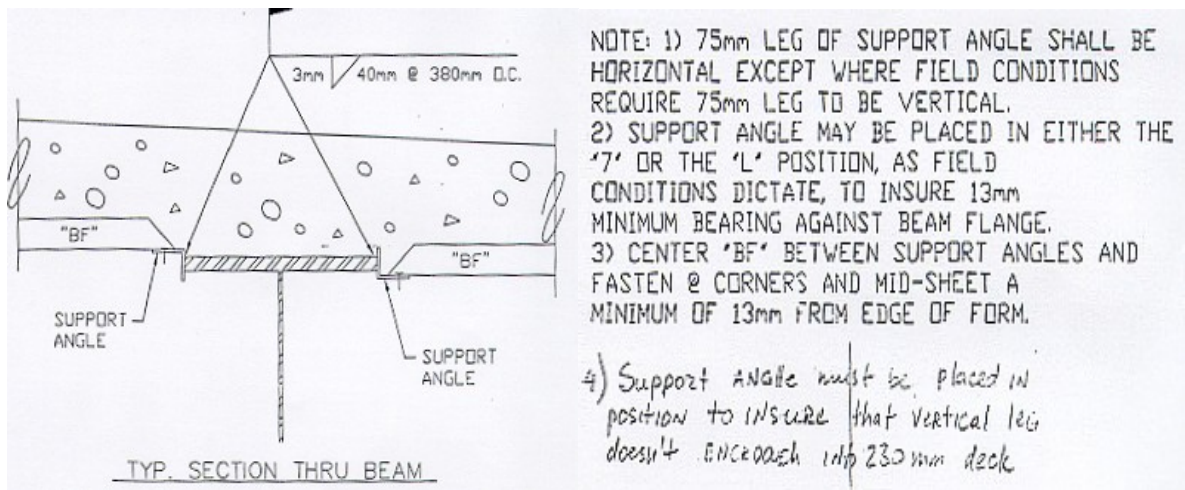
#### 3.3 I-75 OVER CENTRAL MICHIGAN RAILROAD (R01-1 OF 09035), CITY OF BAY CITY

The subject structure was constructed in 1960 and received a deck replacement and widening in 2001. R01-1 is a three span structure with identical span lengths of 46.4 feet, steel I-girders spaced at an average of six feet, a skew of less than one degree, and an ADT of 38,776 with 9 percent truck traffic. R01-1 was investigated in 2003 after several longitudinal cracks were



found in the deck shortly after construction, and was found to have a crack density of 0.19 in/ft<sup>2</sup>. The crack map can be seen in Figure C16 in the appendix. Several of the longitudinal cracks were located over edges of the beams and had crack widths of 0.01 inch to 0.02 inch.

Investigating extensive early age deck cracking on R01 of 73171 in 2001<sup>4</sup>, Juntunen found that many of the longitudinal cracks were located directly above the edge of the beams and hence along the edge of the SIP forms. Cores taken through the longitudinal cracks showed that the vertical flanges of the angles used to support the SIP forms were encroaching into the deck creating stress concentrations in the concrete. As a result of the findings, a note was added on the shop plans for R01 of 09035, as seen in Figures 3.1a and 3.1b.



**Figure 3.1a SIP form detail with support angles in flange up and flange down position.**

**Figure 3.1b Plan notes for support angles.**

An inspection of the underside of the deck of R01-1 of 09035 found that the variously sized support angles for the SIP forms were placed with the vertical flanges up and down with no discernable pattern, as seen in Figures 3.2 and 3.3. Cores taken through the longitudinal cracks found results similar to Juntunen's findings. Figures 3.4a and 3.4b show one of the cores taken through a full depth longitudinal crack emanating from the flange up support angle. The depth of the concrete over the support angle was 7.375 inches, indicating that support angles were placed contradictory to plan note number four in Figure 3.1b, creating a plane of weakness in the concrete.



**Figure 3.2 SIP support angles placed both flange up and flange down.**



**Figure 3.3 Different size support angles.**



**Figure 3.4a Core hole showing support angle in flange up position.**



**Figure 3.4b Core through full depth longitudinal crack.**

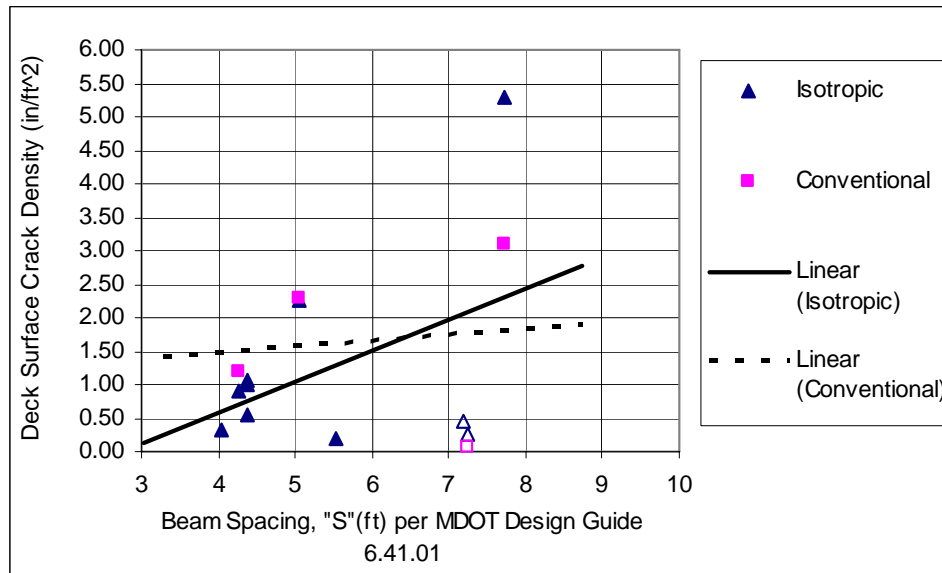
The most recent bridge inspection ratings issued in 2007 rated both the surface and deck a seven, or in good condition, and indicated that cracks in the deck surface had been sealed.

## 4. CONCLUSIONS

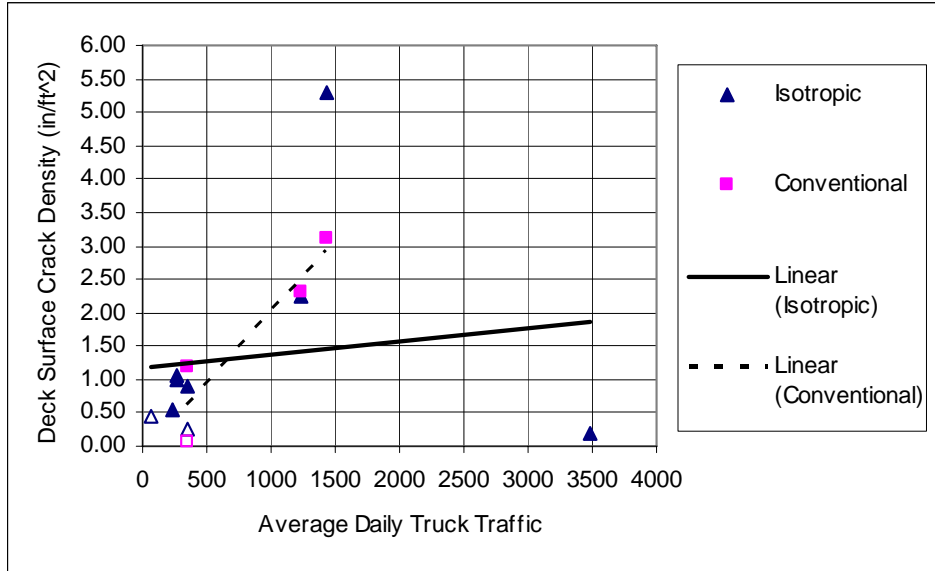
### 4.1 PERFORMANCE

The isotropic decks inspected are performing satisfactorily and none of the decks showed unusual or premature deterioration. The isotropic decks inspected showed various crack densities ranging from 0.19 in/ft<sup>2</sup> to 5.3 in/ft<sup>2</sup>, and exhibited transverse, longitudinal, and diagonal cracking. Where parallel structures allowed a comparison of the isotropic design to the conventional design, the total crack densities were similar, though the isotropic decks typically had less transverse cracking but more longitudinal cracking. For the case of at least two of the isotropic decks (B01 of 54032 and R01-1 of 09035), it was verified that longitudinal cracking on the deck surface was present directly over SIP form support angles placed in the flange up position, which may increase cracking. Diagonal cracking was found to be largely a function of skew. Crack widths were found to be comparable for both deck design types.

The total crack densities for all decks inspected were plotted as a function of several parameters to determine the relationship to beam spacing, ADTT, skew, and age. Based on the data available, crack density appears to be proportional to beam spacing and ADTT for both the isotropic and conventional decks, as seen in Figures 4.1 and 4.2. However, this is based on a small sample size and would be better confirmed through a larger sample size.

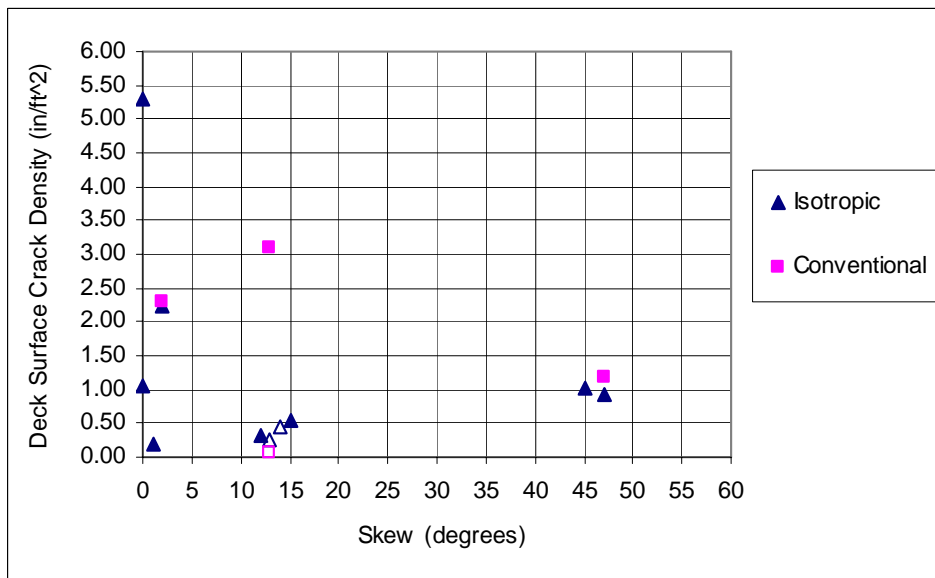


**Figure 4.1 Total crack density related to beam spacing  
(Un-shaded data points indicate deck underside crack density)**



**Figure 4.2 Total crack density related to ADTT**  
 (Un-shaded data points indicate deck underside crack density)

The effects of skew on crack density were inconclusive, as seen in Figure 4.3. For the case of three similar structures with the isotropic design, B01, B02, and B03 of 54032, the bridge with no skew had the highest total crack density. Comparing the structures of 83033, the undersides of heavily skewed S01 and S02 could not be inspected because of SIP forms, and the surfaces of moderately skewed R01, R02, and S06 could not be inspected because of the epoxy flood coating.



**Figure 4.3 Total crack density related to skew**  
 (Un-shaded data points indicate deck underside crack density)

The crack density of structures that were inspected more than once, both isotropic decks and conventional decks, were plotted as a function of age, as seen in Figure 4.4. As expected, the crack density increases with age. With the exception of R03 of 41131, both the isotropic spans and conventional spans, as the structures age the increase of crack density over time is largely dependent on the initial crack density.

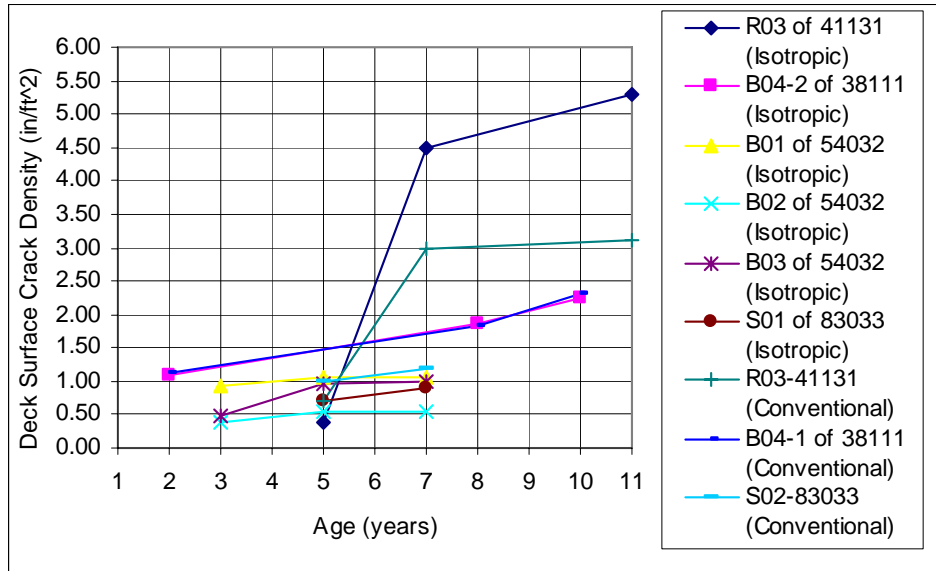


Figure 4.4 Crack density related to age

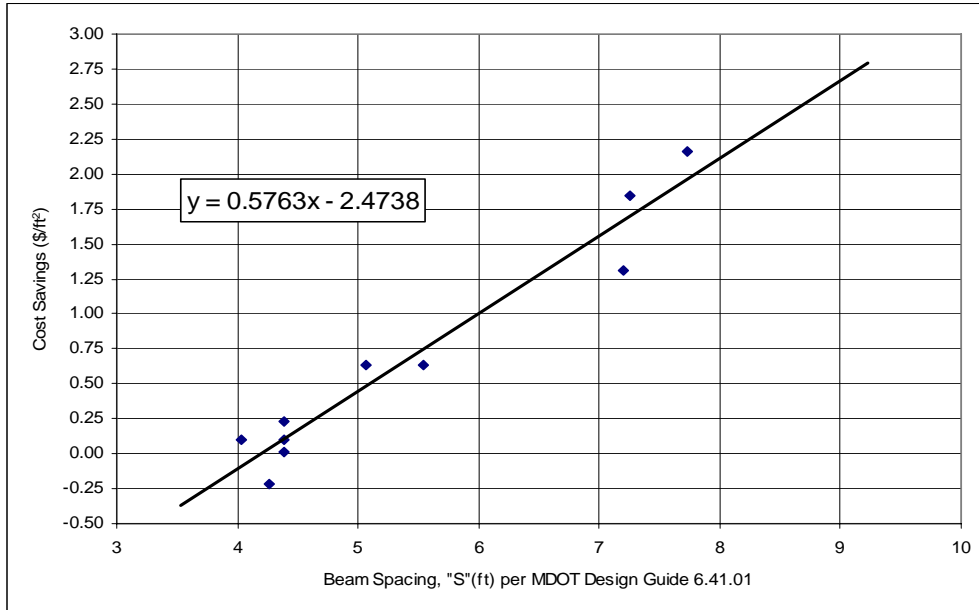
## 4.2 COST

One of the advantages of the isotropic design is the cost savings realized by the use of less reinforcement steel. To evaluate this, the cost of the steel reinforcement in each isotropic deck evaluated for this project was compared to the cost of steel reinforcement if the deck had been designed using the conventional method. For those structures with isotropic decks that had parallel structures, the actual amount of steel deck reinforcement in the parallel structure was used. For the isotropic decks without parallel structures, the size and spacing of reinforcement for the conventional deck was selected from MDOT Bridge Design Guide 6.41.01. Table 4-1 lists the isotropic decks compared to the conventional decks. The cost savings was calculated using \$1.00 per pound for epoxy coated steel. The shaded cells in Table 4-1 indicate that steel reinforcement for the conventional deck was taken from a parallel structure. For the case of R03 of 41131, the cost savings represent the difference between all four spans that were replaced being isotropic compared to conventional.

**Table 4-1 Isotropic deck cost savings**

Structure Location	Bridge ID	Amount less of Steel Reinf. (%)	Cost Savings (\$)	Area of Deck (ft <sup>2</sup> )	Savings in Steel Reinf. (\$/ft <sup>2</sup> )
US-131 under Franklin St, Grand Rapids	R03 of 41131	34.6	19,405	9,000	2.16
US-27 over the Grand River, Jackson	B04-2 of 38111	15.0	6,714	10,714	0.63
US-131 over State Rd 43, Cadillac	S01 of 83033	-6.0	-5,466	24,672	-0.22
US-131 over TSB Railroad, Cadillac	R01 of 83033	33.1	19,806	10,774	1.84
US-131 under Whaley Rd, Cadillac	S03 of 83033	26.7	15,158	11,553	1.31
M-66 over North Branch Chippewa River, Barryton	B01 of 54032	5.9	429	1,843	0.23
M-66 over North Branch Chippewa River, Barryton	B02 of 54032	5.7	310	3,025	0.10
M-66 over North Branch Chippewa River, Barryton	B03 of 54032	0.5	26	3,000	0.01
I-75 over Central Michigan Railroad, Bay City	R01-1 of 09035	15.1	12,640	20,170	0.63
US-131 under No. 36 Road, Cadillac	S06 of 83033	2.3	719	6,908	0.10

The cost savings were found to be dependent upon beam spacing. Plotting the data in Table 4-1, the trend of increased savings can be seen with increased beam spacing, as seen in Figure 4.5. For bridges with smaller beam spacing the isotropic design may provide little or no cost savings.



**Figure 4.5 Cost savings of the isotropic design as a function of beam spacing**

### 4.3 RECOMMENDATIONS

1. Continue to use the isotropic design as specified in the MDOT Bridge Design Guide 6.41.02, *Standard Bridge Slab (Empirical Design)*.
2. Evaluate the cost savings when determining whether to use the isotropic design.
3. Require angles supporting SIP forms to be placed such that the angle legs perpendicular to the plane of the deck are pointing downwards to decrease the chance of cracking.
4. Continue to study the isotropic deck performance to verify that long-term serviceability and durability are not decreased as compared to conventionally designed bridge decks.



## 5. REFERENCES

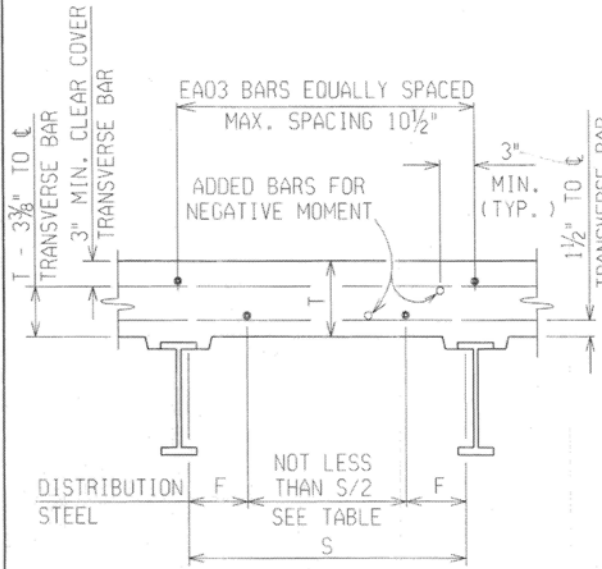
1. AASHTO, *LRFD Bridge Design Specifications*, Third Edition, with 2006 Interim Revisions, Washington D.C., 2006.
2. AASHTO, *Standard Specifications for Highway Bridges*, 16<sup>th</sup> Edition, with 2002 Interim Revisions, Washington D.C., 2002.
3. Personal communication with Harry L. White, Structural Design Engineer, New York State Department of Transportation, 2008.
4. Juntunen, David, *Investigate Early-Age Deck Cracking Structure Number R01-73171*, Research Project TI-1956, Michigan Department of Transportation, 2001.
5. Michigan Department of Transportation, *Bridge Design Guides*, Michigan Department of Transportation, Lansing, MI, 2006.
6. Michigan Department of Transportation, *Structure Inventory and Appraisal Coding Guide*, Michigan Department of Transportation, Lansing, MI, 2003.
7. Needham, Douglas, J., *Performance Evaluation of Isotropic Bridge Decks (Ontario Design)-Interim Report*, Michigan Department of Transportation, Lansing, MI, 1997.
8. Novak, Andrej, S., et al, *Analytical Design Procedures and Load Rating for Isotropic Bridge Decks*, Research Report No. RC-1430 submitted to Michigan Department of Transportation, Lansing, MI, 2003.
9. New York State Department of Transportation, *Bridge Manual*, 4<sup>th</sup> Edition with 2008 updates, New York State Department of Transportation, Albany, NY, 2008.
10. Pezze, Frank P., Fu, Gongkang, *Comparative Performance of AASHTO and Lightly Reinforced Bridge Deck Slabs*, New York State Department of Transportation, Albany, NY, 1992.

**Appendix A**  
MDOT Bridge Design Guides 6.41.01 and 6.41.02

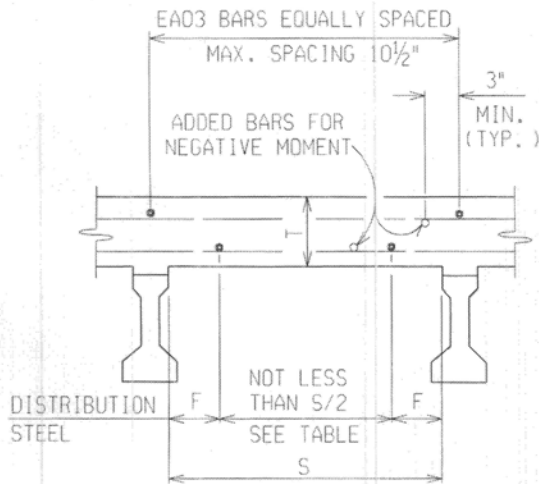
DRAWN BY: BLT  
 CHECKED BY: VZ  
 APPROVED BY:

MICHIGAN DEPARTMENT OF TRANSPORTATION  
 BUREAU OF HIGHWAY DEVELOPMENT  
**STANDARD BRIDGE SLABS**  
 (LOAD FACTOR DESIGN)

ISSUED: 05/04/06  
 SUPERSEDES: 11/27/01



S = BEAM SPACING MINUS 1/2 FLANGE WIDTH  
 SLAB ON STEEL BEAMS



S = BEAM SPACING MINUS TOP FLANGE WIDTH  
 SLAB ON PRESTRESSED I-BEAMS

FOR 70° PRESTRESSED I-BEAMS AND MICHIGAN 1800 GIRDER,  
 S = BEAM SPACING MINUS 1/2 TOP FLANGE WIDTH.  
 FOR SPREAD BOX BEAMS, S = BEAM SPACING MINUS TOP FLANGE WIDTH.

**NOTES:**

ADDITIONAL BARS ARE REQUIRED IN REGIONS OF NEGATIVE MOMENT (SEE AASHTO SPECIFICATION 10.38.4.3).  
 DISTRIBUTION STEEL BASED ON  $220/\sqrt{S}$  OF TRANSVERSE STEEL (67% MAX.)

DESIGN INCLUDES ALLOWANCE OF 25 psf DEAD LOAD FOR FUTURE WEARING SURFACE.

CONCRETE  $f'_c = 4,000$  psi; STEEL REINFORCEMENT CONFORMS TO ASTM A615 GRADE 60 ( $f_s = 24,000$  psi).

"F" SHOULD NOT EXCEED THE SPACING OF THE DISTRIBUTION STEEL.

DISTRIBUTION STEEL FOR SPREAD BOX BEAMS AND MICHIGAN 1800 GIRDER SHALL BE EQUALLY SPACED SUCH THAT THE DISTANCE BETWEEN THE END BARS AND THE BEAM  $\epsilon$  DOES NOT EXCEED 1'-0".

DESIGN IS FOR SLABS CONTINUOUS OVER 3 OR MORE SUPPORTS OF SIMILAR STRUCTURAL CAPACITY.

WHERE THE ANGLE OF CROSSING IS 70° OR GREATER, TRANSVERSE BARS MAY BE PLACED PARALLEL TO THE REFERENCE LINES IF "S" ALONG THE SKEW" FALLS IN THE SAME BEAM SPACING RANGE AS "S" NORMAL TO THE BEAMS" OR THE NEXT LARGER RANGE. "S" ALONG THE SKEW" SHOULD BE USED TO DETERMINE THE SLAB REINFORCEMENT.

FOR UNIFORM SPACING OF TOP AND BOTTOM TRANSVERSE STEEL, USE THE TOP TRANSVERSE STEEL SPACING FOR BOTH THE TOP AND BOTTOM STEEL.

INFORMATION IN CHART IS BASED ON A SLAB THICKNESS (T) OF 9".

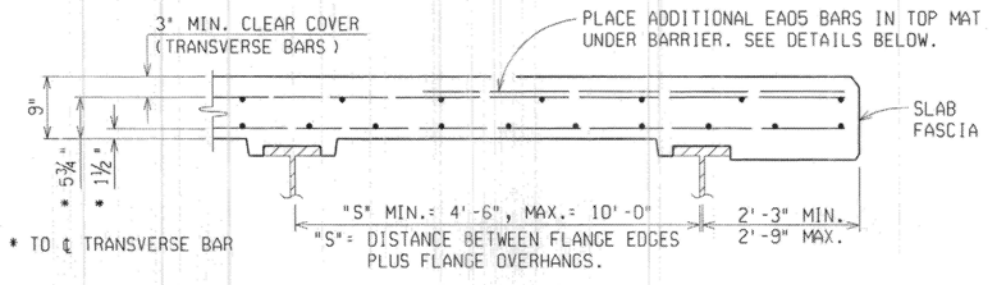
32 kip SINGLE AXLE AND ALL LEGAL LOADS						
"S"	TRANSVERSE STEEL (TOP)		TRANSVERSE STEEL (BOTTOM)		DISTRIBUTION STEEL	
	BAR SIZE	SPACE in	BAR SIZE	SPACE in	BAR SIZE	SPACE in
9'-10" to 10'-2"	06	7 1/2"	06	7 1/2"	05	8 1/2"
9'-6" to 9'-10"	06	7 1/2"	06	7 1/2"	05	8 1/2"
9'-2" to 9'-6"	06	8"	06	8"	05	8 1/2"
8'-10" to 9'-2"	06	8"	06	8"	05	9"
8'-6" to 8'-10"	06	8 1/2"	06	8 1/2"	05	9"
8'-2" to 8'-6"	06	8 1/2"	06	8 1/2"	05	9 1/2"
7'-10" to 8'-2"	06	9"	06	9"	05	10"
7'-6" to 7'-10"	05	7"	05	7"	04	7"
7'-2" to 7'-6"	05	7"	05	7"	04	7 1/2"
6'-10" to 7'-2"	05	7 1/2"	05	7 1/2"	04	7 1/2"
6'-6" to 6'-10"	05	8"	05	8"	04	8"
6'-2" to 6'-6"	05	8"	05	8"	04	8 1/2"
5'-10" to 6'-2"	05	8 1/2"	05	8 1/2"	04	8 1/2"
5'-6" to 5'-10"	05	9"	05	9"	04	9"
5'-3" to 5'-6"	05*	9 1/2"	05	9 1/2"	04	9 1/2"
4'-11" to 5'-3"	05*	9 1/2"	05	9 1/2"	04	10"
4'-7" to 4'-11"	05*	10 1/2"	05	10"	04	10"

\* AT OVERHANG, SPACE ADDITIONAL #03 BARS BETWEEN #05 TRANSVERSE BARS. BAR LENGTH (#03 BAR) SHALL BE THE DISTANCE FROM  $\epsilon$  FASCIA BEAM TO SLAB FASCIA PLUS 8".

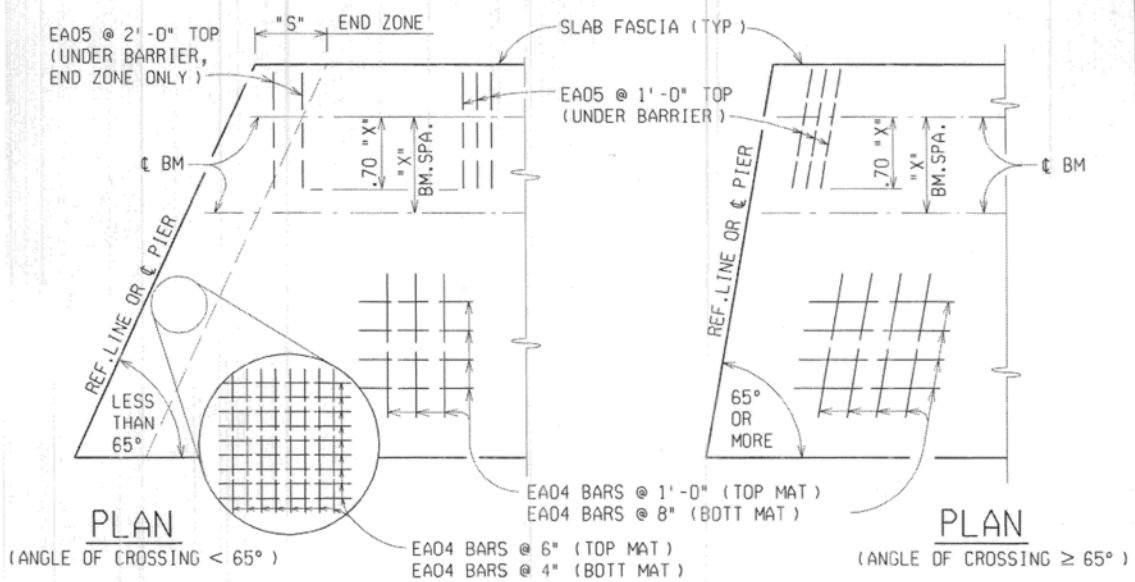
PREPARED BY  
 DESIGN SUPPORT AREA

6.41.01

DRAWN BY: MJB CHECKED BY: VZ APPROVED BY:	MICHIGAN DEPARTMENT OF TRANSPORTATION BUREAU OF HIGHWAYS TECHNICAL SERVICES	ISSUED: 11/27/01 SUPERSEDES: 05/28/99
	STANDARD BRIDGE SLAB (EMPIRICAL DESIGN)	



SECTION THRU DECK



NOTES:

- USE THESE DETAILS ONLY WHERE BARRIER TYPE BRIDGE RAILING IS USED AND SLAB IS MADE COMPOSITE WITH BEAMS OR GIRDERS. SHEAR CONNECTORS SHALL BE PLACED IN NEGATIVE MOMENT REGIONS OF CONTINUOUS BEAMS. (USE UNIFORM SHEAR STUD SPACING OVER ENTIRE LENGTH OF STEEL BEAMS.)
- WHERE THE ANGLE OF CROSSING IS 65° OR GREATER, TRANSVERSE BARS MAY BE PLACED PARALLEL TO THE REFERENCE LINES; OTHERWISE, TRANSVERSE REINFORCEMENT SHOULD BE PLACED PERPENDICULAR TO THE BRIDGE  $\epsilon$  AND SPACED IN EACH "END ZONE" AS SHOWN ABOVE. THE END ZONE REINFORCEMENT IS REQUIRED FOR BOTH CONTINUOUS AND SIMPLY SUPPORTED SPANS.
- INTERMEDIATE DIAPHRAGMS SHALL BE USED BETWEEN BOXES AT A SPACING NOT EXCEEDING 25'-0" FOR SPREAD BOX BEAMS.
- ADDITIONAL BARS ARE REQUIRED IN NEGATIVE MOMENT REGIONS OF CONTINUOUS SPANS. (SEE AASHTO SPECIFICATION 10.38.4.3).
- FLANGED REINFORCEMENT SPLICES CHOSEN FROM THE QUALIFIED PRODUCTS LIST MAY BE USED WITH STRUCTURE WIDENING OR PART WIDTH CONSTRUCTION.
- FOR PART WIDTH CONSTRUCTION, THE OVERHANG AND ADJACENT BAY SHALL BE REINFORCED WITH THE EQUIVALENT REINFORCEMENT OF A CONVENTIONAL BRIDGE DECK.
- CONCRETE  $f'_c = 4,000$  psi; STEEL REINFORCEMENT CONFORMS TO ASTM A615 GRADE 60 ( $f_s = 24,000$  psi).

PREPARED BY DESIGN DIV. 6.41.02

**Appendix B**  
Bridge Inspection Codes and Descriptions

**BIR #1. SURFACE (SI & A item 58A)**

This item is to rate the condition of the deck surface only. The inspector must note in the comment field on the Bridge Safety Inspection Report (BIR) if he / she is rating the structural deck surface or a protective wearing surface (ie, thin epoxy, wood, bituminous or, latex overlay). Refer to SI&A item 108 "Wearing Surface / Protective System" for type of wearing surface. If there is no protective wearing surface, rate the condition of the surface of the structure deck.

A concrete or bituminous wearing surface should be inspected for spalling, cracking, scaling, and delamination. Timber wearing surfaces should be inspected for deterioration, splitting, and crushing. Rate and code the condition in accordance with the following ratings.

Code Description

- N NOT APPLICABLE. Code N for culverts and other structures without decks, e.g., filled arch bridge.
- 9 NEW CONDITION. No noticeable or noteworthy deficiencies which affect the condition of the surface.
- 8 GOOD CONDITION. Minor cracking less than 1/32" wide (0.8mm) with no spalling, scaling or delamination.
- 7 GOOD CONDITION. Open cracks less than 1/16" wide (1.6mm) at a spacing of 10 ft or more, light shallow scaling allowed.
- 6 FAIR CONDITION. Surface has considerable number of open cracks greater than 1/16" wide (1.6mm) at a spacing of 5 ft or less. Surface area exhibits 2% or less of spalled or delaminated areas, including repaired areas. Medium scaling on the surface is 1/4" to 1/2" (6.4 mm to 13 mm) in depth.
- 5 FAIR CONDITION. Between 2% and 10% of the surface area is spalled or delaminated. There can be excessive cracking in the surface. Heavy scaling 1/2" to 1" in depth (13 mm to 26 mm) can be present. This includes repaired areas and/or areas in need of corrective action.
- 4 POOR CONDITION. Large areas of the surface, 10 - 25% is spalled or delaminated. This area includes repaired areas and/or areas in need of corrective action.
- 3 SERIOUS CONDITION. More than 25% of the surface area is spalled. This area includes repaired areas and/or areas in need of corrective action.
- 2 CRITICAL CONDITION. Emergency surface repairs required by the crews.
- 1 IMMINENT FAILURE CONDITION. Bridge is closed to traffic, but corrective action may put the bridge back in service.
- 0 FAILED CONDITION. Bridge closed.

Rev. 2/2002

**BIR #6. DECK (SI & A item 58)**

This item is to evaluate and rate the overall condition of the deck . Rate and code the condition in accordance with the general condition ratings. Code N for culverts and other structures without decks, such as a filled arch bridge. Refer to SI&A item 108 "Wearing Surface / Protective System" for type of wearing surface.

A concrete deck should be inspected for cracking, scaling, spalling, leaching, potholing, delamination, and full or partial depth failures. Steel grid decks should be inspected for broken welds, broken grids section loss, and growth of filled grids from corrosion. Timber decks should be inspected for splitting, crushing, fastener failure, and deterioration from rot.

The condition of the wearing surface / protective coating system (BIR item #1. Surface), joints, expansion devices, curbs, sidewalks, parapets, fascias, bridge railing, and scuppers shall not be considered in the overall deck evaluation. However, their condition will be noted on the form in their respective items.

The inspector must note in the comment field on the Bridge Safety Inspection Report (BIR) the factors and quantities that influenced the judgement for the rating.

Code   Description

- N NOT APPLICABLE. Code N for culverts and other structures without decks, e.g., filled arch bridge.
- 9 NEW CONDITION. No noticeable or noteworthy deficiencies which affect the condition of the deck.
- 8 GOOD CONDITION. Minor cracking less than 1/32" wide (0.8mm) with no spalling, scaling or delamination on the deck surface or underneath.
- 7 GOOD CONDITION. Open cracks less than 1/16" wide (1.6mm) at a spacing of 10 ft or more, light shallow scaling allowed on the deck surface or underneath. Deck will function as designed.
- 6 FAIR CONDITION. Deterioration on the surface or underneath, including repaired areas, is 2% or less of the total area. There may be a considerable number of open cracks greater than 1/16" wide (1.6mm) at a spacing of 5 ft or less on the deck surface or underneath. Medium scaling on the surface is 1/4" to 1/2" (6.4 mm to 13 mm) in depth. Deck will function as designed.
- 5 FAIR CONDITION. Deterioration on the surface or underneath, including repaired areas, is between 2% and 10% of the surface area. There can be excessive cracking in the surface. Heavy scaling 1/2" to 1" in depth (13 mm to 26 mm) can be present. Deck will function as designed.
- 4 POOR CONDITION. Deterioration on the surface or underneath, including repaired areas, is between 10 - 25% . Deck will function as designed.
- 3 SERIOUS CONDITION. Deterioration on the surface or underneath, including repaired areas, is more than 25% of the surface area. Structural and/or load analysis may be necessary to determine if the structure can continue to function without restricted loading.
- 2 CRITICAL CONDITION. Deterioration has progressed to the point where the deck will not support design loads and must be posted for reduced loads. Emergency surface repairs may be required by the crews.
- 1 IMMINENT FAILURE CONDITION. Bridge is closed to traffic, but corrective action may put the bridge back in service.
- 0 FAILED CONDITION. Bridge closed.

Rev. 2/2002

**Appendix C**  
Bridge Deck Crack Maps



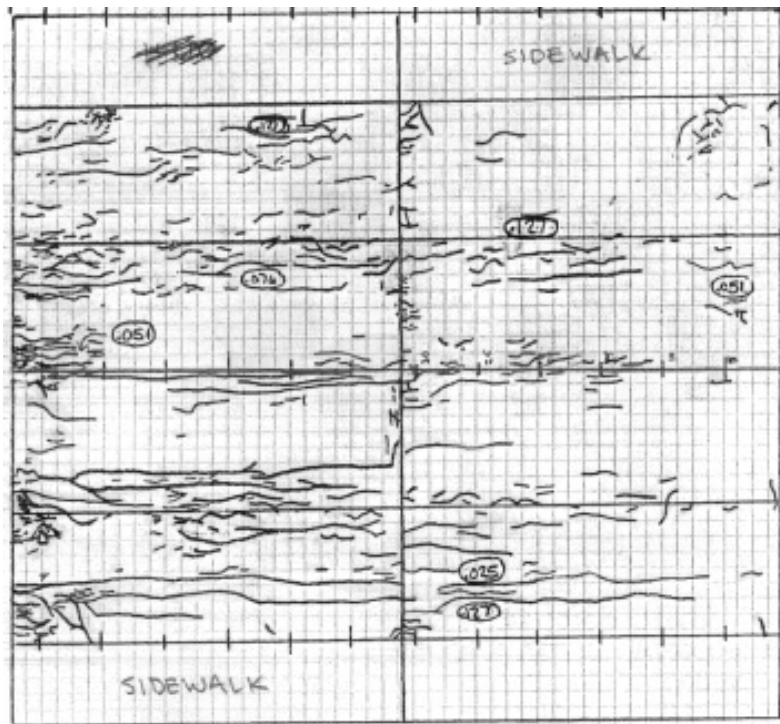


Figure C1. R03 of 41131 Isotropic deck spans 13 and 14, 2002.

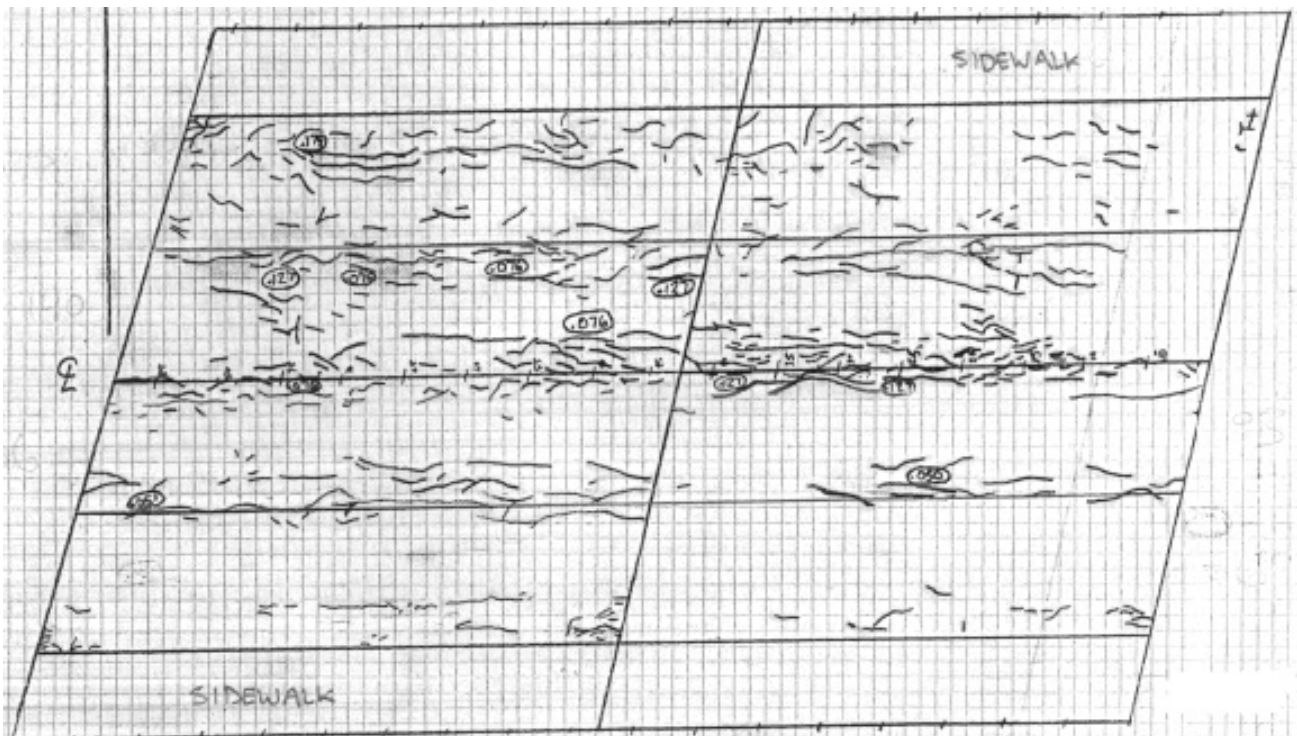
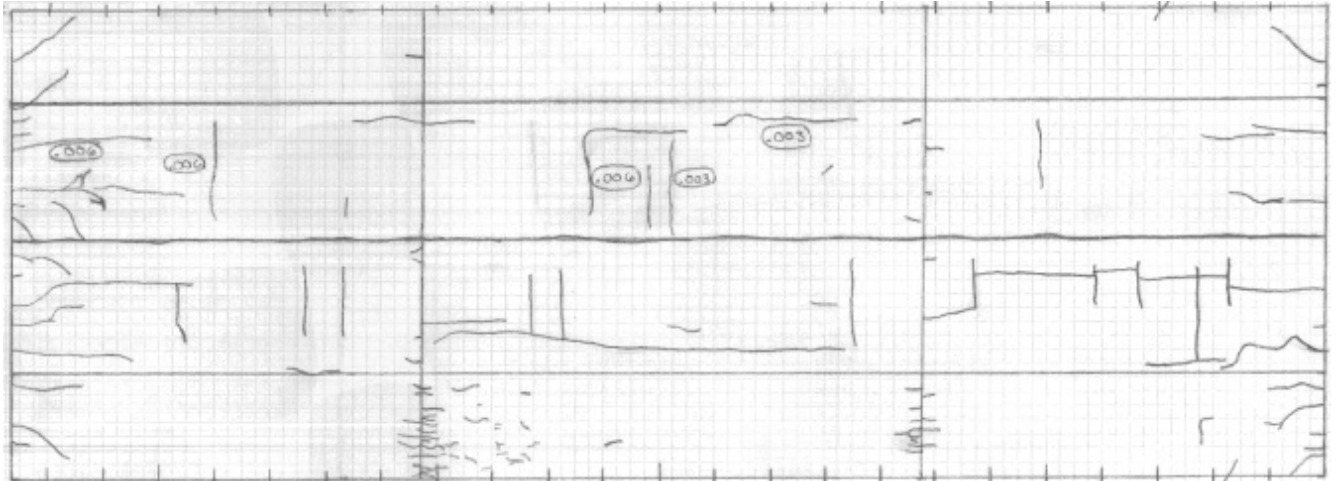
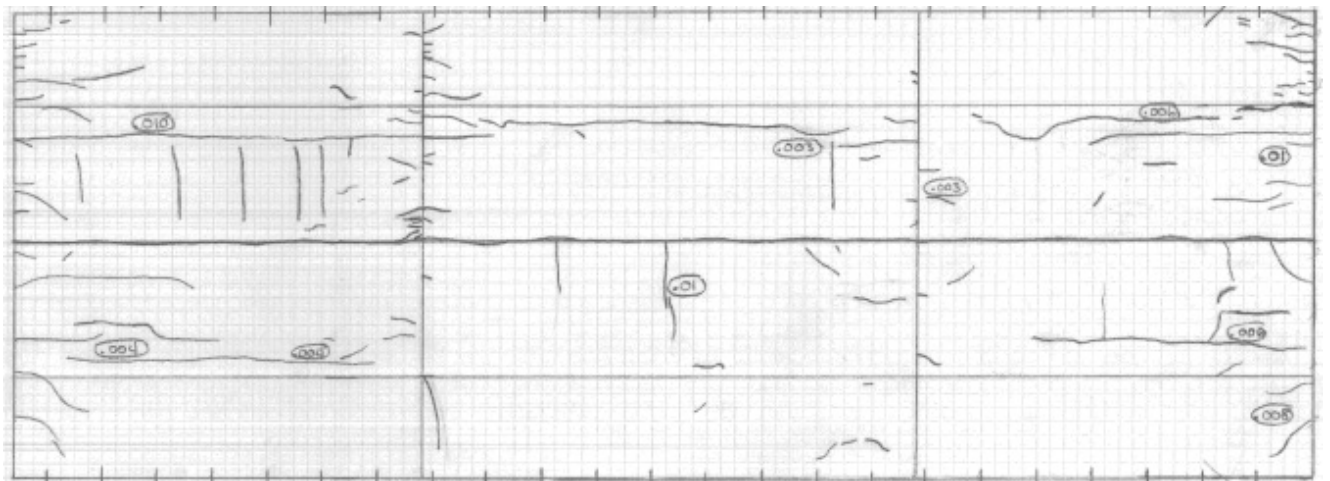


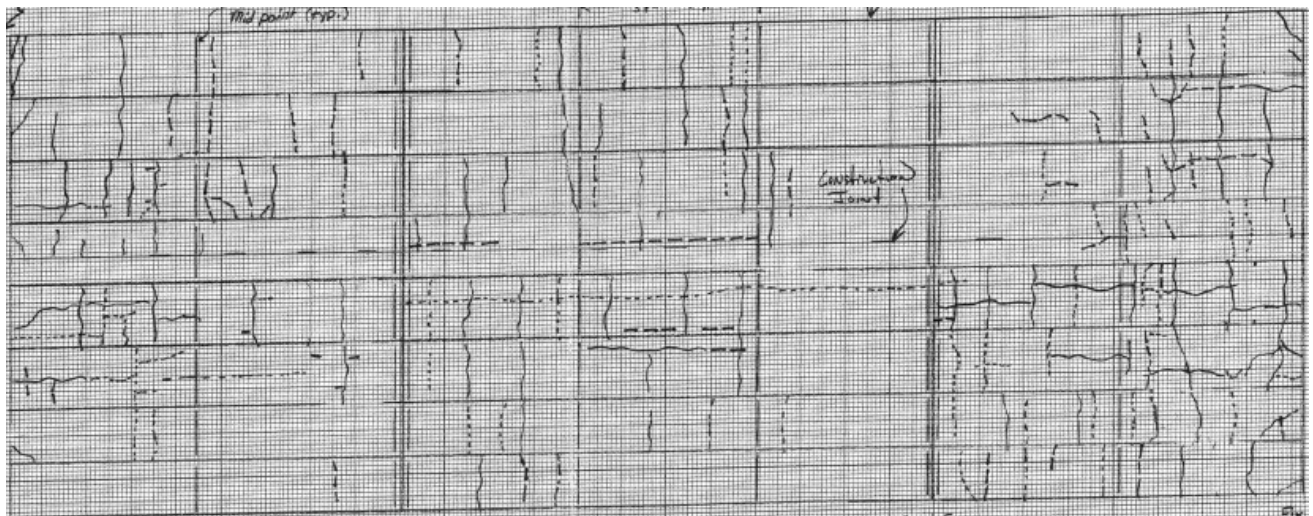
Figure C2. R03 of 41131 Conventional deck spans eight and nine, 2002.



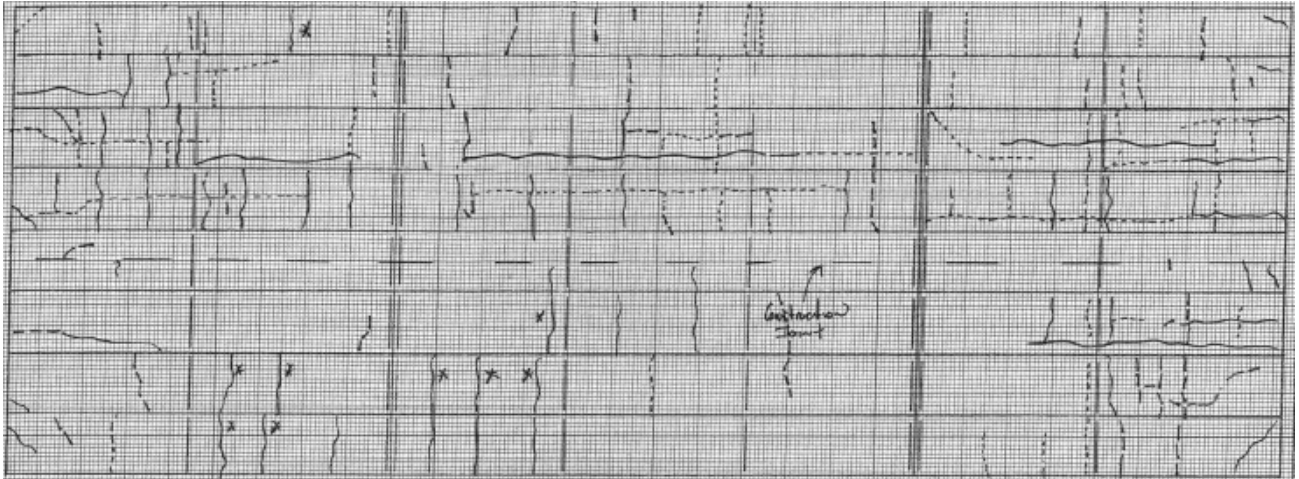
**Figure C3. B04-1 of 38111 Conventional deck surface, 1998.**



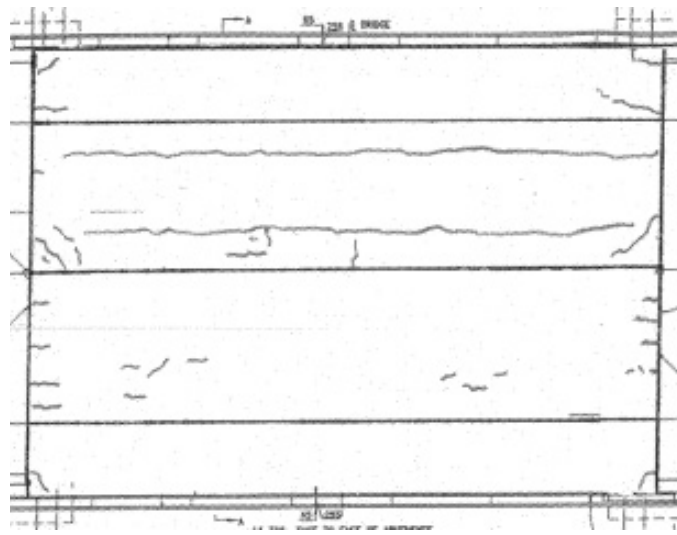
**Figure C4. B04-2 of 38111 Isotropic deck surface, 1998.**



**Figure C5. B04-1 of 38111 Conventional deck underside, 2006.**



**Figure C6. B04-2 of 38111 Isotropic deck underside, 2006.**



**Figure C7. B01 of 54032 Isotropic deck, zero degree skew, 2006.**

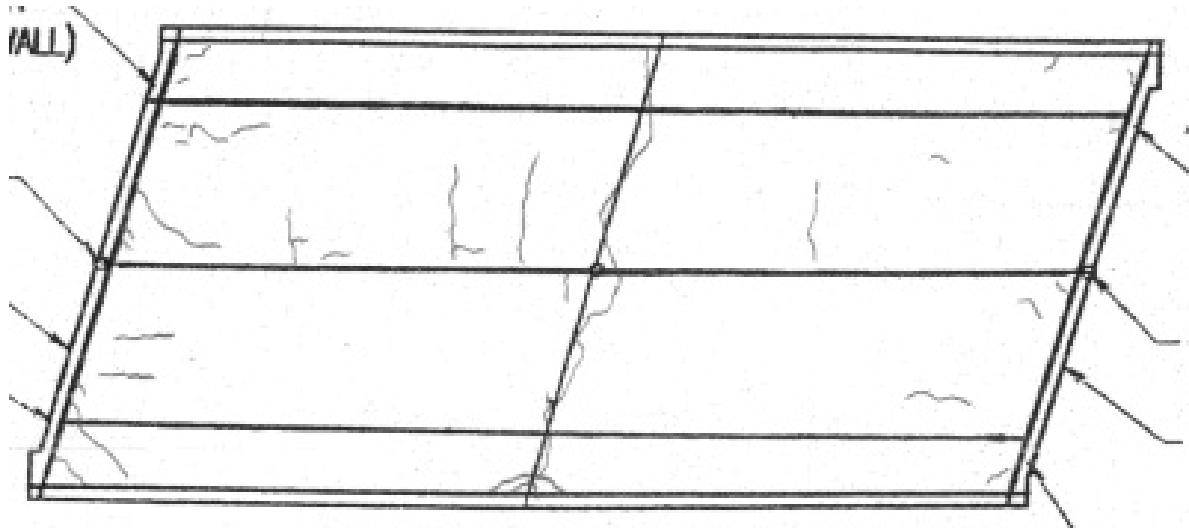


Figure C8. B02 of 54032 Isotropic deck, 15 degree skew, 2006.

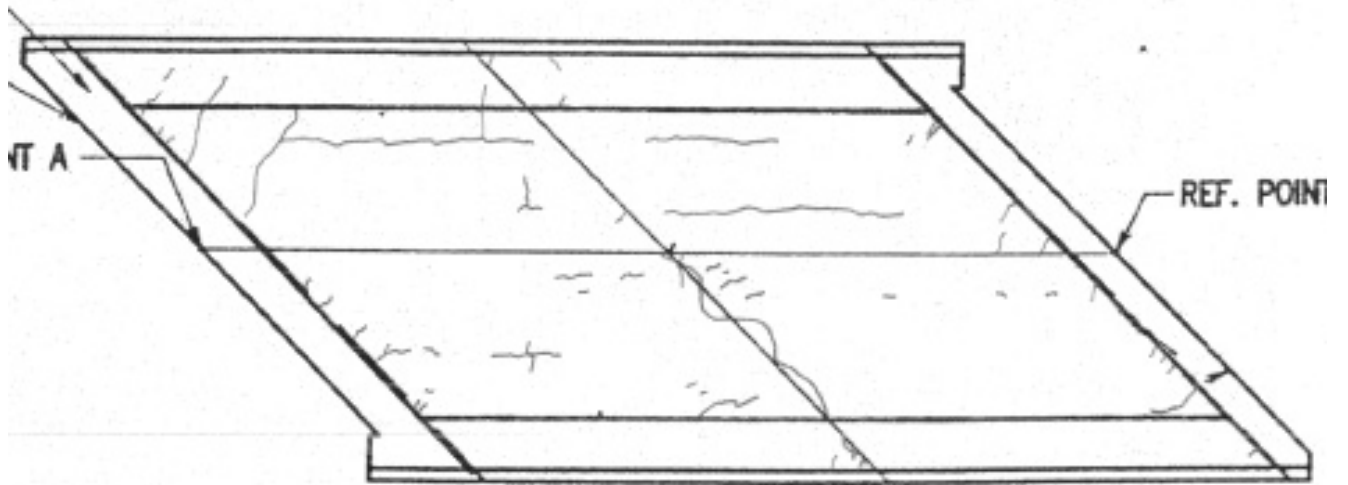


Figure C9. B03 of 54032 Isotropic deck, 45 degree skew, 2006.

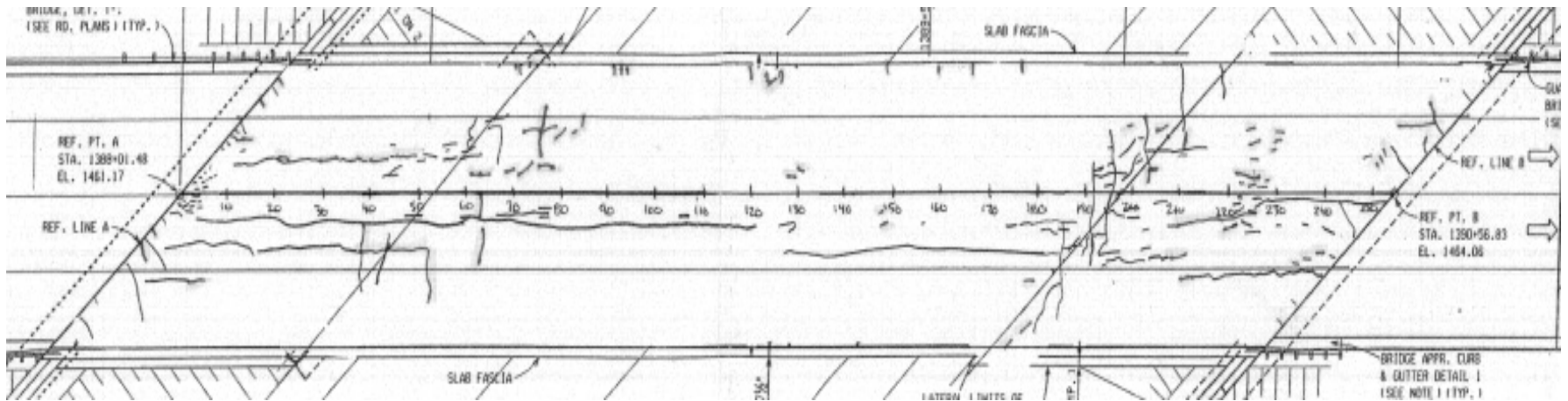


Figure C10. S01 of 83033 Isotropic deck, 2006.

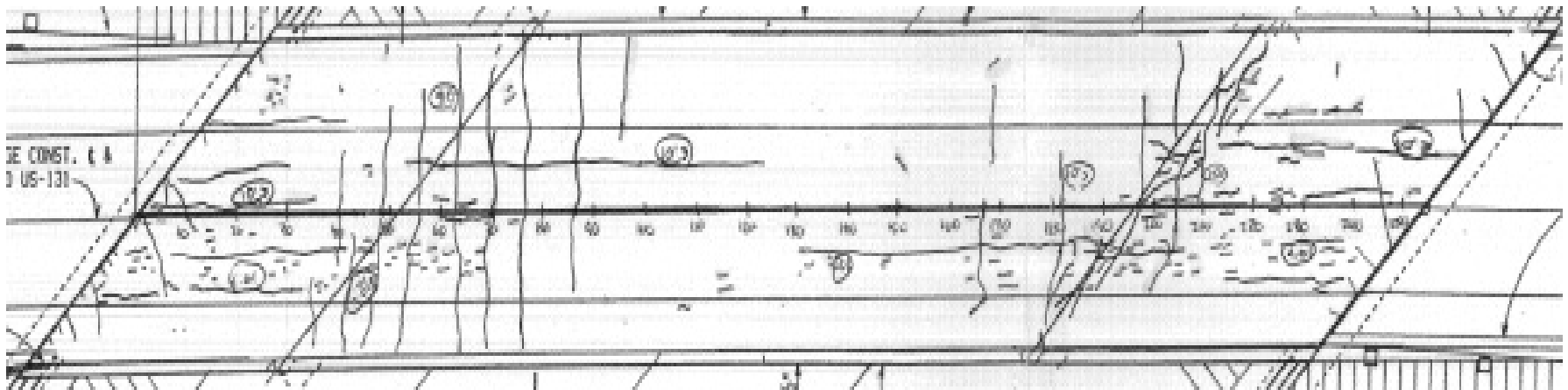
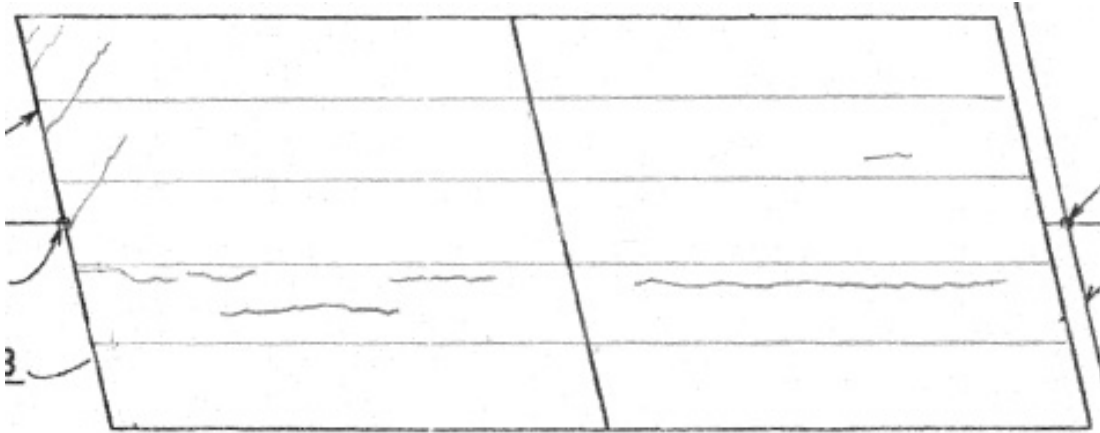
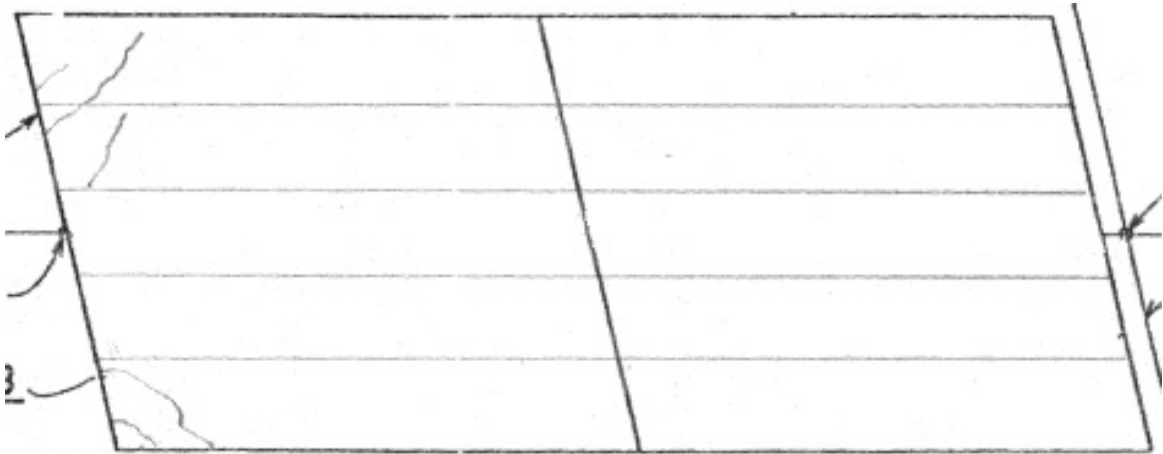


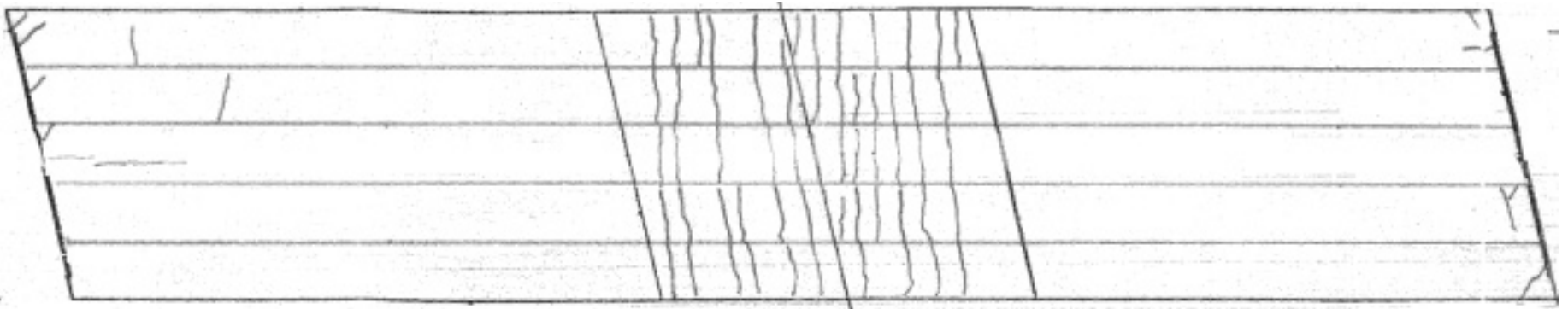
Figure C11. S02 of 83033 Conventional deck, 2006.



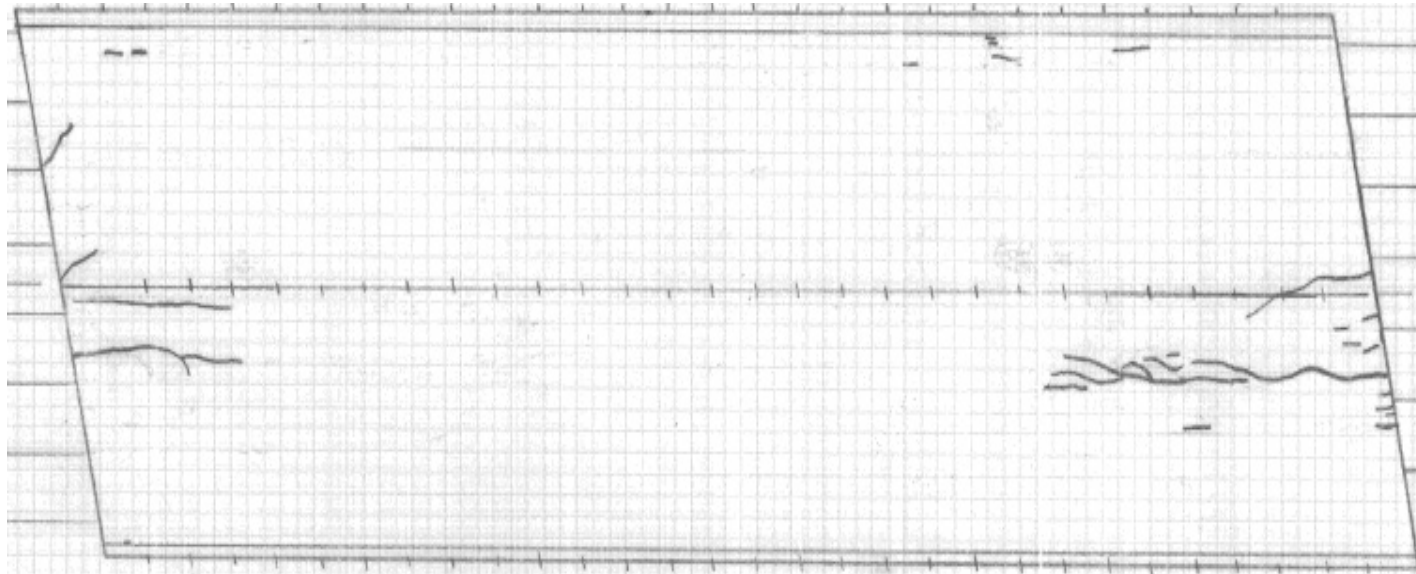
**Figure C12. R01 of 83033 Isotropic deck underside, 2006.**



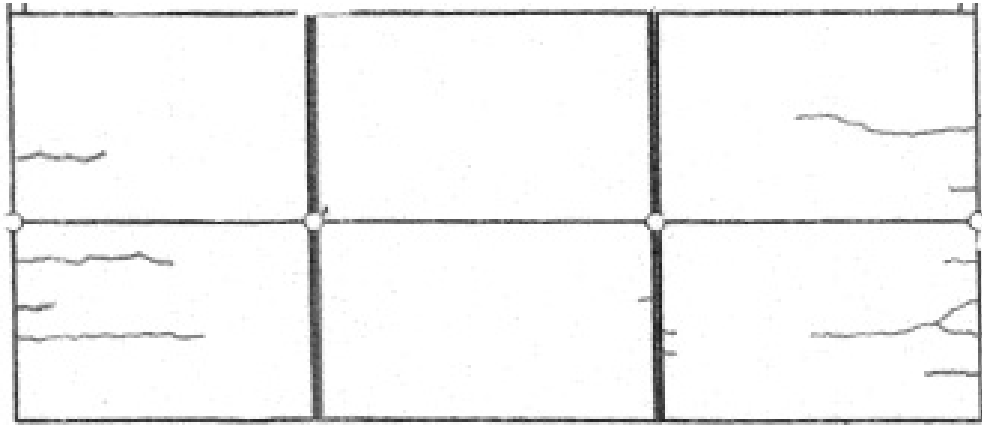
**Figure C13. R02 of 83033 Conventional deck underside, 2006.**



**Figure C14. S03 of 83033 Isotropic deck underside, 2006.**



**Figure C15. S06 of 83033 Isotropic deck surface, 1999.**



**Figure C16. R01-1 of 09035 Isotropic deck surface, 2003.**