Combining Link Slab, Deck Sliding over Backwall, and Revising Bearings

FINAL REPORT – AUGUST 2008
(APPENDICES)

Western Michigan University
Department of Civil & Construction Engineering
College of Engineering and Applied Sciences
COMBINING LINK SLAB, DECK SLIDING OVER BACKWALL, AND REVISING BEARINGS
(Appendices)

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Submitted to:

MDOT

Submitted by

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**APPENDIX A**

![Diagram](image)

<table>
<thead>
<tr>
<th>PCI BEAM TYPE III</th>
<th>PCI BEAM TYPE III</th>
<th>PCI BEAM TYPE III</th>
</tr>
</thead>
<tbody>
<tr>
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<td>PCI BEAM TYPE II</td>
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<td>PCI BEAM TYPE II</td>
<td>PCI BEAM TYPE III</td>
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<td>PCI BEAM TYPE III</td>
<td>PCI BEAM TYPE III</td>
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</tbody>
</table>

**SKEW = 0°**

![Figure A-1. Plan and elevation of S04-1, 2 of 63174](image)
Figure A-2. Plan and elevation of S08 of 41027
Figure A-3. Plan and elevation of S12-3 and 4 of 25042
Figure A-4. Plan and elevation of S12-7 and 8 of 25042
Figure A-5. Plan and elevation of B01 of 10042 and B01 of 51041
APPENDIX B

Field inspection data of the following bridges

<table>
<thead>
<tr>
<th>No</th>
<th>Bridge ID</th>
<th>Description</th>
<th>Inspection Date</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S04-1-63174</td>
<td>I-75 NB over 13 Mile Rd</td>
<td>12/03/2006</td>
<td>Detailed inspection</td>
</tr>
<tr>
<td>2</td>
<td>S04-2-63174</td>
<td>I-75 SB over 13 Mile Rd</td>
<td>12/03/2006</td>
<td>Photo log</td>
</tr>
<tr>
<td>3</td>
<td>S08-41027</td>
<td>I-196 EB over Monroe Av</td>
<td>11/04/2006</td>
<td>Detailed inspection</td>
</tr>
<tr>
<td>4</td>
<td>B01-10042</td>
<td>M115 over Betsie Rive</td>
<td>11/04/2000</td>
<td>Detailed inspection</td>
</tr>
<tr>
<td>5</td>
<td>S12-3-25042</td>
<td>I-69 EB over I-75</td>
<td>11/05/2006</td>
<td>Detailed underside inspection</td>
</tr>
<tr>
<td>6</td>
<td>S12-4-25042</td>
<td>I-69 WB over I-75</td>
<td>11/05/2006</td>
<td>Detailed inspection</td>
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<tr>
<td>7</td>
<td>S12-7-25042</td>
<td>I-69 EB Ramp over I-75</td>
<td>11/05/2006</td>
<td>Detailed inspection</td>
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<tr>
<td>8</td>
<td>S12-8-25042</td>
<td>I-69 WB Ramp over I-75</td>
<td>11/05/2006</td>
<td>Detailed inspection</td>
</tr>
</tbody>
</table>
**STAY-IN-PLACE FORMS**
**NO EROSION OR SETTLEMENTS**
**OF BACKFILL**
**P1-BRIDGE PLATE**
**EXPANSION JOINTS @ SLEEPER**
SLABS ARE FILLED WITH DEBRIS AND THEY CONTAIN CRACKS SHOWING THAT EXPANSION JOINTS ARE FUNCTIONING

**OVERVIEW PLAN**

**SOUTH APPROACH SLAB**

**SOUTH SPAN 1**

**SOUTH SPAN 2**

**SOUTH SPAN 3**

**NORTH APPROACHING SLAB**

**NORTH PIER**
**PIER 2**

**SOUTH PIER**
**PIER 1**

**P1- BRIDGE PLATE**

**INSPECTOR:**
**DATE:** 12/03/06
**PAGE:** 1/13
FIELD INSPECTION TEMPLATE

Bridge ID: S04-1 of 63174

**north is out of the page.

SOUTH ABUTMENT

---

**LEAKAGE CRACKING**

---

INSPECTOR:

DATE: 12/03/06

PAGE: 11/13
Field Inspection Template
Bridge ID: SD4-1 of 63174

South Span 3

**Cannot see if cracks go all the way through since it is stay-in-place form**

P 71  P 72  P 73
P 76  P 77  P 78

End of Link Slab

P 89  P 90  P 91

39'

Inspector:

Date: 12/03/06
Page: 6/13
FIELD INSPECTION TEMPLATE
Bridge ID: S04-1 of 63174

NORTH APPROACH SLAB

SAND ACCUMULATION

SLEEPER SLAB

CONCRETE SPALL

INSPECTOR:

DATE: 12/03/06

PAGE: 3/13
FIELD INSPECTION TEMPLATE
Bridge ID: S04-1 of 63174

**north is into the page.

NORTH ABUTMENT

INSPECTOR:  

DATE: 12/03/06
PAGE: 10/13
FIELD INSPECTION TEMPLATE
Bridge ID: S04-1 of 63174

**north is into the page.

SOUTH PIER (PIER 1)

NORTH SIDE

OVERALL PRETTY GOOD CONDITION

SOUTH SIDE

INSPECTOR: DATE: 12/03/06
PAGE: 12/13
FIELD INSPECTION TEMPLATE
Bridge ID: S04-1 of 63174

**north is out of the page.**

NORTH PIER (PIER 2)

<table>
<thead>
<tr>
<th>EBM1</th>
<th>EBM2</th>
<th>EBM3</th>
<th>EBM4</th>
<th>EBM5</th>
<th>EBM6</th>
<th>EBM7</th>
<th>EBM8</th>
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<tr>
<td>P79</td>
<td>P80</td>
<td>P81</td>
<td>P82</td>
<td>P83</td>
<td>P84</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SOUTH SIDE

NORTH SIDE

INSPECTOR: 

DATE: 12/03/06

PAGE: 13/13
**NO SIGNS OF EROSION OF BACKFILL**
**STAY-IN-PLACE FORMS**
**EXPANSION JOINTS**
AT SLEEPER SLABS ARE FILLED WITH DEBRIS
**THERE WERE CRACKS SHOWING THAT JOINTS WORK**
**LINK SLABS SHOWED NO CRACKING ON TOP**

---

**OVERVIEW PLAN**

**SOUTH APPROACH SLAB**

**SOUTH SPAN 1**

**SOUTH PIER PIER 1**

**SOUTH SPAN 2**

**NORTH PIER PIER 2**

**SOUTH SPAN 3**

**NORTH APPROACHING SLAB**

---

**INVESTIGATOR:**

**DATE:** 12/03/06

**PAGE:** 1/ 13
FIELD INSPECTION TEMPLATE
Bridge ID: S04-2 of 63174

north is out of the page.

SOUTH ABUTMENT

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<th>EBM4</th>
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</tbody>
</table>

INSPECTOR: DATE: 12/03/06
PAGE: 11/13
FIELD INSPECTION TEMPLATE
Bridge ID: S04-2 of 63174

SOUTH APPROACH SLAB

SLEEPER SLAB

INSPECTOR:  

DATE: 12/03/06

PAGE: 2/13
FIELD INSPECTION TEMPLATE
Bridge ID: 504-2 of 63174

N

BRIDGE DECK
SOUTH SPAN 2

END OF LINK SLAB

END OF LINK SLAB

INSPECTOR:

DATE: 12/03/06
PAGE: 5/13
FIELD INSPECTION TEMPLATE
Bridge ID: S04-2 of 63174

**north is into the page.**

NORTH ABUTMENT

<table>
<thead>
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<th>EBM7</th>
<th>EBM6</th>
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INSPECTOR:  

DATE: 12/03/06  
PAGE: 10/13
FIELD INSPECTION TEMPLATE
Bridge ID: S04-2 of 63174

**north is into the page.

SOUTH PIER (PIER 1)

<table>
<thead>
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<th>EBM7</th>
<th>EBM6</th>
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<td></td>
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</tr>
</tbody>
</table>

NORTH FACE

P23  P24  P25  P26  P27  P28

SOUTH FACE

INSPECTOR:  DATE: 12/03/06
PAGE: 12/13
FIELD INSPECTION TEMPLATE
Bridge ID: S04-2 of 63174

**north is out of the page.

NORTH PIER (PIER 2)

SOUTH FACE

<table>
<thead>
<tr>
<th>EB1</th>
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<th>EB4</th>
<th>EB5</th>
<th>EB6</th>
<th>EB7</th>
<th>EB8</th>
<th>EB9</th>
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</tr>
</tbody>
</table>

P39  
P40  
P41

NORTH FACE

INSPECTOR:  

DATE: 12/03/06  

PAGE: 13/13
FIELD INSPECTION TEMPLATE
For SO8 of 41027 EASTBOUND I-196 OVER MONROE AVE, KENT COUNTY GRAND REGION

**DECK WAS NOT INSPECTED ON 11/04/06**
**STEEL BEAM BRIDGE**
STAY-IN-PLACE FORM

INSPECTOR: ___________________________  DATE: 11/04/06
PAGE: 1/13

N

OVERVIEW PLAN

---

S/E APPROACHING SLAB
S/E SPAN 1
S/E SPAN 2
S/E SPAN 3
N/W APPROACHING SLAB

---

P1
P2
P3
P4
P5
FIELD INSPECTION TEMPLATE
Bridge ID: SOB of 41027

**N/W is out of the page.

S/ E ABUTMENT

BRIDGE ID
P79
P80

P81
P82
P83
P84

MINOR CRACK
0.005'

BEARING DEFORMING
0.005'

0.030' GROOVE CRACK
0.030'

0.025'

0.050'

INSPECTOR:

DATE: 11/04/06

PAGE: 11/13
FIELD INSPECTION TEMPLATE
Bridge ID: S08 of 41027

S/E APPROACH SLAB

SLEEPER SLAB

INSPECTOR:                DATE: 11/04/06

PAGE: 2/13
FIELD INSPECTION TEMPLATE
Bridge ID: S08 of 41027

BRIDGE DECK
S/E SPAN 1

END OF LINK SLAB

LEAKAGE

INSPECTOR:

DATE: 11/04/06
PAGE: 4/13

LEAKAGE RUSTING

PIN & HANGER CL

4'
FIELD INSPECTION TEMPLATE

Bridge ID: S08 of 41027

N/W APPROACH SLAB

SLEEPER SLAB

INSPECTOR: DATE: 11/04/06

PAGE: 3/13
FIELD INSPECTION TEMPLATE
Bridge ID: S08 of 41027

* N/W is into the page.

N/W ABUTMENT

P8
P7
P6
P9
P10
P11
P12

P14
P15
P16
P17

SIDE CRACK

0.020

P18
P19

P20
P21

P22

P23
P24
P25
P26
P27

001°-0.02°

ABOUT JOINT
CRACK 0.934°

INSPECTOR:
P13

DATE: 11/04/06
PAGE: 10/13
FIELD INSPECTION TEMPLATE
Bridge ID: B01 OF 10042

BRIDGE DECK
S/E SPAN 3

INSPECTOR:

DATE:

PAGE: 6/13
EXPANSION JOINTS ARE DIRT-FILLED AND WITH CRACKS SHOWING THAT THEY WORK

OVERVIEW PLAN

S/W APPROACHING SLAB

S/W SPAN 1

S/W SPAN 2

S/W SPAN 3

S/W SPAN 4

S/W APPROACHING SLAB

40'

DATE: 11/05/06

PAGE: 1/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-3 of 25042

**north is out of the page.

S/ W ABUTMENT

INSPECTOR: ___________________________ DATE: ___________________________

PAGE: 13/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-3 of 25042

BRIDGE DECK
S/W SPAN 1

INSPECTOR:

DATE:

PAGE: 5/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-3 of 25042

BRIDGE DECK
S/W SPAN 3

END OF LINK SLAB

INSPECTOR: 

DATE: 

PAGE: 5/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-3 of 25042

N/E APPROACH SLAB

INSPECTOR: P 98 P 99 P 100 P 101 P 102
DATE: P 103 P 104 P 105 P 106 P 107

PAGE: 3/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-3 of 25042

**north is into the page.**

N/E ABUTMENT

EBM4  EBM3  EBM2  EBM1

CRACK ON FLANGE
OF BEAM

SPALL

SAND ACCUM.

P 43  P 44

P 45  P 47  P 49  P 51
P 46  P 48  P 50  P 52

CJ (CRACKED JOINT)

CJ

INSPECTOR:

DATE:

PAGE: 12/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-4 of 25042

**north is out of the page.

**DEBRIS ACCUM.
BTW. BACKWALL
& ABUTMENT

S/ W ABUTMENT

**DEBRIS BEARING
DEFORMED

BEARING
DEFORMED

P 16

P 14
P 15

P 11
P 12
P 13

P 6
P 7

P 8
P 9
P 10

P 4
P 5

CJ
0.025"

0.025" - 0.035"

0.01"

FULL LENGTH
0.015"

INSPECTOR:

DATE:

PAGE: 13/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-4 of 25042

S/W APPROACH SLAB

**JOINT BETWEEN SLEEPER SLAB & PAVEMENT NOT VISIBLE**
FIELD INSPECTION TEMPLATE

Bridge ID: S12-4 of 25042

N/E APPROACH SLAB

SLEEPER SLAB

INSPECTOR:

DATE:

PAGE: 3/16
FIELD INSPECTION TEMPLATE

Bridge ID: S12-4 of 25042

BEAM S/W SPAN 1

<table>
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<th>EBM4</th>
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<td>P 32</td>
<td>P 34</td>
<td>P 37</td>
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<td>P 30</td>
<td>P 33</td>
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<td>P 31</td>
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<td>P 36</td>
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INSPECTOR:

DATE:

PAGE: 8/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-4 of 25042

**north is out of the page.

PIER 3

SOUTH FACE

<table>
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<th>EBM4</th>
<th>EBM5</th>
<th>EBM6</th>
<th>EBM7</th>
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</thead>
</table>

P 60

P64, P65

0.3°
LEA
EFF

P68, P69

P70, P71

P72

P73, P74

NORTH FACE

INSPECTOR:

DATE:

PAGE: 16/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-7 of 25042

**north is out of the page.

S/ W ABUTMENT

**THERE IS CRACKING BTW BRIDGE 1 & 2 ON BACKWALL

DEEP CRACK

INSPECTOR: DATE: PAGE: 13/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-7 of 25042

BRIDGE DECK

S/W SPAN 1

END OF LINK SLAB

INSPECTOR:

DATE:

PAGE: 4/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-7 of 25042

**north is into the page.

N/E ABUTMENT

DEBRIS ACCUM
BEARING LOST

P 41
P 42

0.015'
P 43
P 44
P 45

CJ

0.015' 0.0025'
0.015'

P 46
P 47
P 48
P 49
P 50
P 51

0.020'

DEBRIS ACCUM.
BEARING LOST

P 52
P 53
P 54

0.01'

(CRACKED JOINT)

INSPECTOR: [Signature]

DATE: [Date]

PAGE: 12/16
FIELD INSPECTION TEMPLATE
FOR S12-8 OF 25042 ON I-69 RAMP WB OVER I-75, GENESEE COUNTY, BAY REGION

- Expansion joints are dirt-filled and cracks showing that they work.
- No stay-in-place foams.
- Only one lane of traffic.

INSPECTOR: ___________________________ DATE: 11/05/06
PAGE: 1/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-8 of 25042

**north is out of the page.

S/ W ABUTMENT

INSPECTOR: 

DATE: 

PAGE: 13/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-8 of 25042

S/W APPROACH SLAB

CRACK CONT. ON TO SPAN 1

5'

INSPECTOR:  

DATE: 11/05/06

PAGE: 2/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-8 of 25042

BRIDGE DECK
S/W SPAN 3

END OF LINK SLAB

3.5'

69.5'

END OF LINK SLAB

INSPECTOR:

DATE:

PAGE: 6/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-8 of 25042

N/E APPROACH SLAB

**CRACK CONT. ON TO SPAN 4

SLEEPER SLAB

INSPECTOR:

DATE: 11/05/06

PAGE: 3/16
FIELD INSPECTION TEMPLATE
Bridge ID: S12-8 of 25042

**north is into the page.**

N/E ABUTMENT

P 51  P 52  P 53

P 54  P 55

P 56  P 57

P 58  P 59  P 60

P 61  P 62  P 63

P 64  P 65  P 66  P 67

JOINT CRACK

INSPECTOR:  DATE:

PAGE: 12/16
APPENDIX C

(a) I-75 over 13 Mile Road

Photo C - 1. I-75 over 13 mile road

(a) Saw cut on the link slab above the pier centerline

(b) Full depth link slab cracks – deck overhang

North Bound

South Bound

Photo C - 2. Link slab condition
(a) Debris filled expansion joint

(b) Cracks on debris filled expansion joint

Photo C - 3. Expansion joint condition
Photo C - 4. Diagonal cracking at the bridge deck corner

Photo C - 5. Sleeper slab condition (I-75 south bound)
Photo C - 6. Abutment condition of I-75 north bound
Photo C - 7. Abutment condition of I-75 south bound
(b) S08 of 41027 (I-196 EB over Monroe Ave)

Photo C - 8. I-196 EB over Monroe avenue

(a) (b)

Photo C - 9. (a) Bridge deck underside and (b) link slab underside
Photo C - 10. Abutment wall cracking

Photo C - 11. Deformed bearing
(c) B01 of 10042 (M-115 over Betzie river)

Photo C - 12. M-115 over Betzie river

Photo C - 13. Link slab cracking
Photo C - 14. Approach slab cracking

Photo C - 15. Expansion joints
(a) Abutment wall  
(b) Backwall

Photo C - 16. Cracking of (a) abutment wall and (b) backwall
(d) S12-3, 4 of 25042 (I-69 EB and WB over I-75)

Photo C - 17. I – 69 EB and WB bridges and EB and WB ramp bridges

Photo C - 18. Link slab condition of I – 69 (a) EB and (b) WB
Photo C - 19. Saw cut provided on the link slab over the pier (I-69 EB)

Photo C - 20. Approach slab cracking over the abutment (I-69 EB)

Photo C - 21. Debris filled joint with cracks (I-69 EB)
Photo C - 22. Transverse and diagonal cracks on I-69 EB bridge deck

(a) I-69 EB  (b) I-69 WB

Photo C - 23. Abutment and pier cap conditions
(e) S12-7, 8 of 25042 (I-69 EB and WB ramps over I-75)

(a) I – 69 EB Ramp
(b) I – 69 WB Ramp

Photo C - 24. Link slab condition (a) I-69 EB ramp and (b) I-69 WB ramp

(a) I – 69 EB Ramp
(b) I – 69 WB Ramp

Photo C - 25. Saw cut on link slab over the piers
Photo C - 26. Approach slab condition of I-69 (a) EB ramp and (b) WB ramp
(a) I – 69 EB Ramp  (b) I – 69 WB Ramp

Photo C - 27. Expansion joint condition of I-69 (a) EB ramp and (b) WB ramp
(a) I – 69 EB Ramp  
(b) I – 69 WB Ramp

Photo C - 28. Abutment wall condition of I-69 (a) EB ramp and (b) WB ramp

(a) I – 69 EB Ramp  
(b) I – 69 WB Ramp

Photo C - 29. Backwall cracking at the vicinity of bearings
## Table D-1. Inspector Comments on Abutment Condition of S04-1-63174

<table>
<thead>
<tr>
<th>Inspection Date</th>
<th>Inspector Comments - Abutment Conditions</th>
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<tbody>
<tr>
<td></td>
<td>North Abutment</td>
</tr>
<tr>
<td>6/25/1999</td>
<td>Vertical cracks &amp; incipient spall under beam 4W.</td>
</tr>
<tr>
<td>6/30/2000</td>
<td>Vertical cracks &amp; incipient spall under beam 4W.</td>
</tr>
<tr>
<td>12/3/2006</td>
<td>Abutment wall vertical cracks. Abutment wall vertical cracks under beams 1W, 3W, 4W, 8W. Beam 1W bottom flange delamination close to bearing. Abutment wall cracks, delamination and incipient spall at beam 7W.</td>
</tr>
<tr>
<td>North Abutment</td>
<td>South Abutment</td>
</tr>
<tr>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td><img src="image1" alt="Crack in beam 1W" /></td>
<td><img src="image2" alt="Horizontal backwall crack at beam 1W" /></td>
</tr>
<tr>
<td><img src="image3" alt="Vertical crack under bm 1W" /></td>
<td><img src="image4" alt="Abutment wall D-crack with incipient spall under beam 2W" /></td>
</tr>
<tr>
<td><img src="image5" alt="Delamination, cracks, incipient spall, and patch work under beam 7W" /></td>
<td><img src="image6" alt="Vertical crack under beam 7W" /></td>
</tr>
</tbody>
</table>

Photo D-1. Abutment Distress of S04-01-63174
<table>
<thead>
<tr>
<th>Inspection Date</th>
<th>Inspector Comments - Abutment Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Abutment</td>
<td></td>
</tr>
<tr>
<td>South Abutment</td>
<td></td>
</tr>
<tr>
<td>6/25/1999</td>
<td>Vertical cracks &amp; incipient spall under beam 5W.</td>
</tr>
<tr>
<td>6/30/2000</td>
<td>Vertical cracks &amp; incipient spall under beam 5W.</td>
</tr>
<tr>
<td>6/9/2001</td>
<td>No inspector comments.</td>
</tr>
<tr>
<td>2/17/2006</td>
<td>No inspector comments.</td>
</tr>
<tr>
<td>North Abutment</td>
<td>South Abutment</td>
</tr>
<tr>
<td>------------------------------------------------------------</td>
<td>------------------------------------------------------------</td>
</tr>
<tr>
<td>Abutment wall D-crack and incipient spall - beam 1W</td>
<td>Vertical crack under beam 1W</td>
</tr>
<tr>
<td>Horizontal and vertical cracks at beam 3W</td>
<td>Cracks and patch work at beam 4W. Horizontal backwall crack</td>
</tr>
<tr>
<td>Abutment wall delamination and spall - beam 5W</td>
<td>Delamination, incipient spall, and vertical crack under beam 5W.</td>
</tr>
<tr>
<td>Abutment wall D-crack and incipient spall - beam 6W</td>
<td>Abutment wall D-crack and backwall horizontal cracks at beam 9W</td>
</tr>
</tbody>
</table>

Photo D-2. Abutment Distress of S04-02-63174
<table>
<thead>
<tr>
<th>Inspection Date</th>
<th>Inspector Comments - Abutment Conditions</th>
<th>Northwest Abutment</th>
<th>Southeast Abutment</th>
</tr>
</thead>
</table>

**Northwest Abutment**

- Side crack on SW side underneath the backwall
- Vertical crack under beam 4W

**Southeast Abutment**

- Vertical crack under beam 3W
- Deformation of bearing beam 6W

*Photo D-3. Abutment Distress of S08-51027*
<table>
<thead>
<tr>
<th>Inspection Date</th>
<th>Inspector Comments--Abutment Conditions</th>
<th>Northwest Abutment</th>
<th>Southeast Abutment</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/6/1996</td>
<td>No inspector comments.</td>
<td>No inspector comments.</td>
<td></td>
</tr>
<tr>
<td>Northwest Abutment</td>
<td>Southeast Abutment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image1.png" alt="Image" /> Vertical crack under beam 2W</td>
<td><img src="image2.png" alt="Image" /> Vertical crack under beam 1W</td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image3.png" alt="Image" /> Vertical crack under 3W and backwall cracking near beam end</td>
<td><img src="image4.png" alt="Image" /> Diagonal backwall crack between beam 1W and 2W</td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image5.png" alt="Image" /> Backwall crack next to beam 5W</td>
<td><img src="image6.png" alt="Image" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image7.png" alt="Image" /> Horizontal crack at bearing beam 6W</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Photo D-4. Abutment Distress of B01 - 10042
### Table D-5. Inspector Comments on Abutment Condition of S12-3-25042

<table>
<thead>
<tr>
<th>Inspection Date</th>
<th>Inspector Comments--Abutment Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Northeast Abutment</td>
</tr>
<tr>
<td></td>
<td>Concrete appears sound.</td>
</tr>
<tr>
<td></td>
<td>Concrete appears sound.</td>
</tr>
<tr>
<td></td>
<td>Vertical abutment wall cracking near bm 1W.</td>
</tr>
</tbody>
</table>

### Photo D-5. Abutment Distress of S12-3-25042

- Vertical crack under beam 1W
- Vertical crack under beam 2W
- Spall at bearing under beam 4W
Table D-6. Inspector Comments on Abutment Condition of S12-4-25042

<table>
<thead>
<tr>
<th>Inspection Date</th>
<th>Inspector Comments--Abutment Conditions</th>
<th>Northeast Abutment</th>
<th>Southwest Abutment</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/5/2006</td>
<td>Vertical abutment wall cracking between beams. Vertical abutment wall cracking near beams 1W and 4W. Backwall cracking at bearing of beams 1W, 3W, and 4W.</td>
<td>Vertical abutment wall cracks between beams. Vertical abutment wall cracking near beams 1W and 2W. Beam end spalling near bearing of beam 1W. Horizontal backwall cracking near bearing of beams 2W, 3W, and 4W.</td>
<td></td>
</tr>
<tr>
<td>Northeast Abutment</td>
<td>Southwest Abutment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>--------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image1" alt="Northeast Abutment" /></td>
<td><img src="image2" alt="Southwest Abutment" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical abutment wall cracking and backwall cracking near bearing of beam 1W</td>
<td>Vertical crack under beam 1W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal backwall cracks at beam 3W</td>
<td>Spalling at beam bearing 1W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical crack under beam 4W</td>
<td>Horizontal backwall crack at beam bearing 2W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss of bearing and backwall cracks at beam 4W</td>
<td>Beam end spall at beam bearing 4W</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Photo D-6. Abutment Distress of S12-4-25042
<table>
<thead>
<tr>
<th>Inspection Date</th>
<th>Northeast Abutment</th>
<th>Southwest Abutment</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/24/1996</td>
<td>A few cracks in abutment wall.</td>
<td>A few cracks in abutment wall.</td>
</tr>
<tr>
<td>10/20/2000</td>
<td>A few cracks in abutment wall. Concrete appears sound.</td>
<td>A few cracks in abutment wall. Concrete appears sound.</td>
</tr>
<tr>
<td>10/3/2002</td>
<td>A few cracks in abutment wall. Concrete appears sound. Will function as designed.</td>
<td>A few cracks in abutment wall. Concrete appears sound. Will function as designed.</td>
</tr>
<tr>
<td>11/5/2006</td>
<td>Vertical abutment wall cracks between beams. Vertical abutment wall cracks near beams 1W and 2W. Beam end and backwall cracking in the vicinity of bearing of beam 3W.</td>
<td>Vertical abutment wall cracks between beams. Beam end spall in the vicinity of the bearing of beam 1W. Horizontal backwall cracking near bearing of beams 1W and 2W.</td>
</tr>
<tr>
<td>Northeast Abutment</td>
<td>Southwest Abutment</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------</td>
<td></td>
</tr>
<tr>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td></td>
</tr>
<tr>
<td>Horizontal backwall and vertical abutment wall cracks at beam 1W</td>
<td>Beam end spall and backwall cracks at bearing of beam 1W</td>
<td></td>
</tr>
<tr>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
<td></td>
</tr>
<tr>
<td>Vertical abutment wall crack under beam 2W</td>
<td>Horizontal backwall crack at beam bearing 2W</td>
<td></td>
</tr>
<tr>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
<td></td>
</tr>
<tr>
<td>Crack at bearing under beam 3W</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Photo D-7. Abutment Distress of S12-7-25042
Table D-8. Inspector Comments on Abutment Condition of S12-8-25042

<table>
<thead>
<tr>
<th>Inspection Date</th>
<th>Inspector Comments - Abutment Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Northeast Abutment</strong></td>
</tr>
<tr>
<td>10/20/2000</td>
<td>Several vertical cracks in abutment wall. Concrete appears sound.</td>
</tr>
<tr>
<td>10/7/2002</td>
<td>Several vertical cracks in abutment wall. Concrete appears sound.</td>
</tr>
<tr>
<td>11/5/2006</td>
<td>Vertical abutment wall cracking between beams. Vertical abutment wall cracking near beam 2W. Beam end spalling near bearing of beam 2W. Beam and cracking near bearing of beam 3W.</td>
</tr>
</tbody>
</table>

Northeast Abutment

- Vertical cracks under beam 2W
- Beam end crack near beam bearing 3W

Southwest Abutment

- Beam end crack near beam bearing 1W
- Crack in beam 3W and horizontal backwall crack

Photo D-8. Abutment Distress of S12-8-25042

110


APPENDIX E

Table E-1. Moments and Axial Forces for Different Debonded Lengths

<table>
<thead>
<tr>
<th>Debonded %</th>
<th>0.00%</th>
<th>2.50%</th>
<th>5.00%</th>
<th>7.50%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L₁ (HRRR)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M (ft-k)</td>
<td>-193</td>
<td>-83</td>
<td>-51</td>
<td>-34</td>
</tr>
<tr>
<td>N (k)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>L₂ (RHHR)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M (ft-k)</td>
<td>-63</td>
<td>-28</td>
<td>-19</td>
<td>-13</td>
</tr>
<tr>
<td>N (k)</td>
<td>151</td>
<td>157</td>
<td>159</td>
<td>160</td>
</tr>
<tr>
<td><strong>L₃ (RRHR)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M (ft-k)</td>
<td>-193</td>
<td>-83</td>
<td>-51</td>
<td>-34</td>
</tr>
<tr>
<td>N (k)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>TP₁ (HRRR)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M (ft-k)</td>
<td>142</td>
<td>80</td>
<td>61</td>
<td>53</td>
</tr>
<tr>
<td>N (k)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>TP₂ (RHHR)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M (ft-k)</td>
<td>74</td>
<td>50</td>
<td>44</td>
<td>42</td>
</tr>
<tr>
<td>N (k)</td>
<td>-79</td>
<td>-86</td>
<td>-84</td>
<td>-87</td>
</tr>
<tr>
<td><strong>TP₃ (RRHR)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M (ft-k)</td>
<td>142</td>
<td>80</td>
<td>61</td>
<td>53</td>
</tr>
<tr>
<td>N (k)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>TN₁ (HRRR)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M (ft-k)</td>
<td>-43</td>
<td>-24</td>
<td>-18</td>
<td>-16</td>
</tr>
<tr>
<td>N (k)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>TN₂ (RHHR)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M (ft-k)</td>
<td>-22</td>
<td>-15</td>
<td>-13</td>
<td>-13</td>
</tr>
<tr>
<td>N (k)</td>
<td>24</td>
<td>26</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td><strong>TN₃ (RRHR)</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>M (ft-k)</td>
<td>-43</td>
<td>-24</td>
<td>-18</td>
<td>-16</td>
</tr>
<tr>
<td>N (k)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Figure E-1. Stresses YY distribution along the width for L1 case for one lane straight full bridge
Figure E-2. Stresses YY distribution along the width for L2 case for one lane straight full bridge
Figure E-3. Stresses YY distribution along the width for L3 case for one lane straight full bridge
Figure E-4. Stresses YY distribution along the width for $T_1$ case for one lane straight full bridge
Figure E-5. Stresses YY distribution along the width for T2 case for one lane straight full bridge
Figure E-6. Stresses YY distribution along the width for T3 case for one lane straight full bridge
Figure E-7. Stresses YY distribution along the width for L₁ case for two lane straight full bridge
Figure E-8. Stresses YY distribution along the width for L2 case for two lane straight full bridge
Figure E-9. Stresses YY distribution along the width for L₃ case for two lane straight full bridge
Figure E-10. Stresses YY distribution along the width for $T_1$ case for two lane straight full bridge
Figure E-11. Stresses YY distribution along the width for T2 case for two lane straight full bridge
Figure E-12. Stresses YY distribution along the width for T3 case for two lane straight full bridge
Figure E-13. Stresses YY distribution along the width for L₁ case for one lane 20° skew full bridge (parallel to skew angle)
Figure E-14. Stresses YY distribution along the width for L₂ case for one lane 20° skew full bridge (parallel to skew angle)
Figure E-15. Stresses YY distribution along the width for L₃ case for one lane 20° skew full bridge (parallel to skew angle)
Figure E-16. Stresses YY distribution along the width for T₁ case for one lane 20° skew full bridge (parallel to skew angle)
Figure E-17. Stresses YY distribution along the width for T2 case for one lane 20º skew full bridge (parallel to skew angle)
Figure E-18. Stresses YY distribution along the width for T3 case for one lane 20° skew full bridge (parallel to skew angle)
Figure E-19. Stresses YY distribution along the width for L₁ case for two lane 20° skew full bridge (parallel to skew angle)
Figure E-20. Stresses YY distribution along the width for L2 case for two lane 20° skew full bridge (parallel to skew angle)
Figure E-21. Stresses YY distribution along the width for L₃ case for two lane 20° skew full bridge (parallel to skew angle)
Figure E-22. Stresses YY distribution along the width for T1 case for two lane 20° skew full bridge (parallel to skew angle)
Figure E-23. Stresses YY distribution along the width for T2 case for two lane 20° skew full bridge (parallel to skew angle)
APPENDIX F
DESIGN PROCEDURE FOR LINK SLABS

DESIGN MOMENT

Design Procedure described in the appendix will follow the rationale developed by Caner and Zia (1998). AASHTO LRFD (2004) requires forces calculated from the combined effects of live and thermal loads for the service limit state design. Link slab design moments are calculated using the girder end rotations. HL-93 loading is used to calculate the girder end rotations under live load. Girder end rotations caused by temperature gradient are calculated using the procedure described by Saadeghvaziri and Hadidi (2002).

First step of the load analysis is to establish composite girder-deck cross-section with an effective width as per AASHTO LRFD (2004) Section 4.6.2.6, the composite moment of inertia, and define the modulus of elasticity for concrete.

Girder End Rotations due to Live Load

AASHTO LRFD (2004) procedures are followed:

Apply HL-93 loading [HS-20 truck with impact and distribution factor (LRFD section 3.6.2.1 and 4.6.2.2.2) + 0.64 kips/ft lane loading (LRFD 3.6.1.2.4)] on the simply supported spans to compute maximum girder end rotations (Note: the position of the truck is not necessarily coincident with positions that lead to either maximum midspan moment or deflection).

Girder End Rotations due to Temperature Gradient

The girder-deck composite cross-section is subjected to temperature gradient as described in AASHTO LRFD section 3.12.3 (Figure F-1).

Figure F-2 illustrates the strain compatibility of the sections, associated forces and moments developed in the sections and the temperature gradient profile along the depth of the cross-section.
Strain Compatibility

Using the relationship between forces and strains and using strain compatibility between sections 1 and 2, the following relationship is obtained;

\[
\begin{align*}
\varepsilon_{\text{Bottom1}} &= \alpha_1(T_2) + \frac{M_1}{E_1S_{b1}} + \frac{F_1}{E_1A_1} + \frac{F_1d_{b1}}{E_1S_{b1}} = \varepsilon_{\text{Top2}} \\
\varepsilon_{\text{Top2}} &= \alpha_2(T_2) + \frac{M_2 - M_1}{E_2S_{t2}} + \frac{F_2 - F_1}{E_2A_2} + \frac{F_2d_{b2} + F_1d_{t2}}{E_2S_{t2}} 
\end{align*}
\]

(F-1)
Repeating the formulation with using the strain compatibility between sections 2 and 3;

\[
\varepsilon_{\text{Bottom}2} = \alpha_2(T_3) + \frac{M_2 - M_1}{E_2 S_{b2}} + \frac{F_2 - F_1}{E_2 A_2} + \frac{F_2 d_{b2} + F_2 d_{b2}}{E_2 S_{b2}} = \varepsilon_{\text{Top}3}
\]

\[
\varepsilon_{\text{Top}3} = \alpha_3(T_3) + \frac{M_3 - M_2}{E_3 S_{b3}} + \frac{F_3 - F_2}{E_3 A_3} + \frac{F_3 d_{b3} + F_3 d_{b3}}{E_3 S_{b3}} = \varepsilon_{\text{Top}3}
\]

(F-2)

Repeating the formulation with using the strain compatibility between sections 3 and 4;

\[
\varepsilon_{\text{Bottom}3} = \alpha_3(T_4) + \frac{M_3 - M_2}{E_3 S_{b3}} + \frac{F_3 - F_2}{E_3 A_3} + \frac{F_3 d_{b3} + F_3 d_{b3}}{E_3 S_{b3}} = \varepsilon_{\text{Top}4}
\]

\[
\varepsilon_{\text{Top}4} = \alpha_4(T_4) - \frac{M_3}{E_4 S_{t4}} + \frac{F_3}{E_4 A_4} + \frac{F_3 d_{t4}}{E_4 S_{t4}}
\]

(F-3)

**Curvature Compatibility**

Curvature compatibility between sections provides the following relationships:

Between sections 1 and 2;

\[
\frac{1}{R_1} = \alpha_1(T_2 - T_1) + \frac{M_1}{E_1 I_1} + \frac{F_1 d_{b1}}{E_1 I_1} = \frac{1}{R_2}
\]

\[
\frac{1}{R_2} = \alpha_2(T_2 - T_1) + \frac{M_2 - M_1}{E_2 I_2} + \frac{F_2 d_{b2}}{E_2 I_2} = \frac{1}{R_3}
\]

(F-4)

Between sections 2 and 3;

\[
\frac{1}{R_2} = \alpha_2(T_3 - T_2) + \frac{M_2 - M_1}{E_2 I_2} + \frac{F_2 d_{b2}}{E_2 I_2} = \frac{1}{R_3}
\]

\[
\frac{1}{R_3} = \alpha_3(T_4 - T_1) + \frac{M_3 - M_2}{E_3 I_3} + \frac{F_3 d_{b3}}{E_3 I_3} = \frac{1}{R_3}
\]

(F-5)

Between sections 3 and 4;

\[
\frac{1}{R_3} = \alpha_3(T_4 - T_3) + \frac{M_3 - M_2}{E_3 I_3} + \frac{F_3 d_{b3}}{E_3 I_3} = \frac{1}{R_4}
\]

\[
\frac{1}{R_4} = \alpha_4(T_5 - T_4) - \frac{M_3}{E_4 I_4} + \frac{F_3 d_{t4}}{E_4 I_4}
\]

(F-6)
where

- $\alpha_i$: Coefficient of thermal expansion for Section i
- $T_i$: Girder and deck temperature changes as given in Figure F-1 and Figure F-2
- $F_i$: Force resultant of stresses between section i and i+1
- $M_i$: Moment resultant of stresses between section i and i+1
- $d_{bi}$: Distance from centroid to bottom fiber of Section i
- $d_{ti}$: Distance from centroid to top fiber of Section i
- $S_{bi}$: Bottom section modulus for Section i
- $S_{ti}$: Top section modulus for Section i
- $E_i$: Modulus of elasticity of Section i
- $A_i$: Cross-sectional area of Section i
- $I_i$: Moment of inertia of Section i

Solving the above six equations F-1 through F-6 simultaneously for six unknowns ($F_1, F_2, F_3, M_1, M_2, M_3$), and plugging the forces back into F-4, F-5 and F-6 curvature values can be obtained.

End-slopes can be obtained from curvatures by integrating along the length as given below;

$$\frac{d\theta}{dx} = \frac{1}{R_1} = \frac{1}{R_2} = \frac{1}{R_3} = \frac{1}{R_4} = \frac{1}{R} \quad \theta(x) = \int \frac{1}{R} dx = \frac{x}{R} + C_1$$  \hspace{1cm} (F-7)

Eq. F-7 includes an integration constant $C_1$. For a simply supported span with length L, and since the slope at mid-span is zero due to symmetry under gradient loading, integration constant $C_1$ can be evaluated as;

$$\theta(\frac{L}{2}) = \frac{L}{2R} + C_1 = 0 \quad C_1 = -\frac{L}{2R}$$  \hspace{1cm} (F-8)

Then, the slope equation and the slope at the beam end will be equal to;

$$\theta(x) = \frac{x}{R} - \frac{L}{2R} \quad \theta(L) = \frac{L}{R} - \frac{L}{2R} = \frac{L}{2R}$$  \hspace{1cm} (F-9)

Link slab moment can be calculated from the girder end rotations under live and thermal gradient loads as given below:

$$M_a = \frac{2E_i I_a \theta}{L_L}$$  \hspace{1cm} (F-10)
where,

- $I_d$: Moment of inertia of the link slab
- $L_L$: Length of the link slab (Debond zone length: sum of 5% of each adjacent girder span + gap distance between beam ends)

**DESIGN AXIAL FORCE**

For a two-span system with RHHR supports, tensile force developed in the link slab would be equal to the horizontal reactions at the interior supports. The horizontal reaction is equal to the continuity moment divided by the distance between the centroid of deck and bearing location (Figure F-3).

![Figure F-3. Effect of RHHR type support condition on continuity (Okeil and El-Safty 2005)](image)

**Continuity Moment due to Live Load**

Under live load, each span is loaded so as to create maximum negative moment at the interior support (Figure F-4) with composite cross-section properties. Any structural analysis program can be used to perform this analysis.

![Figure F-4. Continuity moment at the interior support under live load](image)

**Continuity Moment due to Temperature Gradient**

For a two-span-continuous system with constant cross-section in both spans, continuity moment $M_{\text{continuity}}$ can be calculated as:

$$M_{\text{continuity}} = \frac{(F_2d_{rg} - M_3)(3E_{\text{Composite}}I_{\text{Composite}})}{2E_{\text{Girder}}I_{\text{Girder}}} \quad \text{(F-11)}$$
where 

\( F_2 \): Force resultant of stresses between section 2 and 3 calculated from six simultaneous equations 

\( M_3 \): Moment resultant of stresses between section 2 and 3 calculated from six simultaneous equations 

\( d_{tg} \): Distance from centroid to top fiber of girder 

\( E_{Composite} \): Modulus of elasticity of composite section 

\( I_{Composite} \): Moment of inertia of composite section 

\( E_{Girder} \): Modulus of elasticity of girder 

\( I_{Girder} \): Moment of inertia of girder 

Once the continuity moment is found, tensile force in the link slab is;

\[
T = \frac{M_{\text{continuity}}}{h}
\]  

(F-12)

where \( h \) is the distance between the centroid of deck and the top of the bearing.
Numerical Example

Cross-section properties of the girder and the composite section are given in Figure F-5.

[Figure F-5. Girder and composite section geometric properties]

The compressive strength of the girder and deck concrete ($f_{c'}$) = 5000 psi.
Concrete modulus of elasticity ($E_c$) = 4031 ksi.
Reinforcement yield strength ($f_y$) = 60 ksi.
The deck overhang = 30 in. (on either side of the beam).
Composite inertia ($I_{\text{composite}}$) = 392,892 in$^4$.

**DESIGN MOMENT**

Live Load:

HL-93 (AASHTO LRFD 2004) loading is applied at a location to create maximum end rotation on the 69.5 ft span of the bridge. The impact factor is taken as 1.33 from Section 3.6.2.1 of AASHTO LRFD (2004). As per Section 3.6.1.3 AASHTO LRFD (2004), lane load of 0.64 k/ft is used in addition to the axle loads. Distribution factor is calculated as 0.571 assuming two or more lanes are loaded from the formulation in AASHTO LRFD (2004) Table 4.6.2.2b-1.

From the analysis maximum end rotation is calculated as 0.00154 radians when front axle is located 18.4 feet away from the end of the span.

Link slab length = $69.5 \times 12 \times 5\% \times 2 + 1$ in. gap = 84.4 inches
Gross moment of inertia of concrete link slab = 4617 in$^4$
Moment induced by live load:

\[
M_a = \frac{2EI_a \theta}{L_L} = \frac{2 \times 4031 \times 4617 \times 0.00154}{84.4 \times 12} = -56.6 \text{ ft.kips}
\]

for 76 in. wide effective section or

\[
M_a = \frac{2EI_a \theta}{L_L} = \frac{2 \times 4031 \times 729 \times 0.00154}{84.4 \times 12 \times (76/12)} = -8.9 \text{ ft} - \frac{kips}{ft}
\]

Moment induced by temperature Gradient Loading:

\begin{align*}
&b_1 = 76 \text{ in.}, \ b_2 = 16 \text{ in.} \\
&h_1 = 4 \text{ in.}, \ h_2 = 5 \text{ in.}, \ h_3 = 7 \text{ in.}, \ h_4 = 38 \text{ in.} \\
&T_1 = 41^\circ\text{F}, \ T_2 = 11^\circ\text{F}, \ T_3 = 6.42^\circ\text{F}, \ \text{Positive temperature gradient (LRFD 3.12.3)} \\
&T_4 = T_5 = 0 \\
&E_c = 5000 \text{ ksi and } \alpha = 6 \times 10^{-6} \text{ in./in./}^\circ\text{F} \text{ for both deck and girder concrete}
\end{align*}

For section 4 of Figure F-1:

\begin{align*}
&A_4 = 447.5 \text{ in}^2, \ I_4 = 61889.67 \text{ in}^4, \ d_{t4} = 23.09 \text{ in.}, \ S_{t4} = 2680 \text{ in}^3 \\
&L_L = 84.4 \text{ in. and } I_d = 4617 \text{ in}^4 \text{ for the 76 in.} \times 9 \text{ in. deck cross-section}
\end{align*}

Solving simultaneous equations F-1 through F-6, internal forces and moments can be calculated as:

\begin{align*}
&F_1 = -48.15 \text{ kips}, \ F_2 = 32.90 \text{ kips}, \ F_3 = 51.53 \text{ kips} \\
&M_1 = 195.31 \text{ in-kips}, \ M_2 = 270.47 \text{ in-kips}, \ M_3 = -3.61 \text{ in.kips}
\end{align*}

Then, the curvature can be calculated from any equation F-4 through F-6.

\[
\frac{d\theta}{dx} = \frac{R_1}{1} = \frac{R_2}{1} = \frac{R_3}{1} = \frac{R_4}{1} = \frac{R}{1} = 3.857 \times 10^{-6}
\]

Then, the end rotation can be calculated with equation F-9.

\[
\theta(L) = \frac{L}{R} - \frac{L}{2R} = \frac{L}{2R} = \frac{834}{2} \times 3.857 \times 10^{-6} = 1.638 \times 10^{-3} \text{ rad}
\]
Finally, moment generated by positive temperature gradient load, according to equation F-10 is:

\[ M_a = \frac{2E_I a \theta}{L_L} = \frac{2 \times 4031 \times 4617 \times 1.608 \times 10^{-3}}{84.4 \times 12} = 59.1 \text{ ft.kips} \]

for 76 in. wide effective section or

\[ M_a = \frac{2E_{cl_a} \theta}{L_L} = \frac{2 \times 4031 \times 729 \times 1.608 \times 10^{-3}}{84.4 \times 12 \times (76/12)} = 9.4 \text{ ft} - \text{kips/ft} \]

Moment caused by negative thermal gradient will be -0.3 times the positive gradient loading.

\[ M_a = 59.1 \times -0.3 = -17.7 \text{ ft.kips} \text{ for 76 in. wide effective section or} \]

\[ M_a = 9.4 \times -0.3 = -2.8 \text{ ft.kips/ft} \]

Load Combinations:

Thermal gradient loading [i.e., negative thermal gradient (NTG) and positive thermal gradient (PTG)] and live load need to be combined to create critical load combinations.

Service I-NTG: 1.0 Live Load + 0.5 Negative Thermal Gradient
Service I-PTG: 1.0 Positive Thermal Gradient

Service I-NTG Load Combination:

\[ M_a = -56.6 + 0.5 \times -17.7 = -65.5 \text{ ft.kips} = -10.35 \text{ ft.kips/ft} \]

Service I-PTG Load Combination:

\[ M_a = 59.1 \text{ ft.kips} = 9.34 \text{ ft.kips/ft} \]

Cracking Moment:

Using AASHTO LRFD section 5.4.2.6 and 5.7.3.6.2

\[ f_c' = 536 \text{ psi (0.24}\sqrt{f_c'},ksi) \text{ and } M_{cr} = f_c'I_g/y = 7.2 \text{ ft.kips/ft} \]

\[ M_a > M_{cr} \text{ Slab will crack. In that case relief cut is required.} \]

Negative Moment Reinforcement (i.e., top fiber in tension)

Based on allowable stress limit in the reinforcement per AASHTO LRFD section 5.7.3.4, and assuming \( d = 6.7 \) inches, an area of steel of \( 0.793 \text{ in.}^2/\text{ft} \) is required for a moment of -10.35ft-kips/ft.
Use #6 bars @ 6 inches = \( A_{\text{steel}} = 0.88 \text{ in}^2 > 0.793 \text{ in}^2 \)

\[ f_{\text{steel}} = 22.7 \text{ ksi} < f_{\text{allowable}} = 32.4 \text{ ksi} \]

Positive Moment Reinforcement (i.e., bottom fiber in tension)

Based on allowable stress limit in the reinforcement per AASHTO LRFD section 5.7.3.4 and assuming \( d=6.7 \) inches, an area of steel of 0.715 in.\(^2\) /ft is required for a moment of 9.34 ft-kips/ft.

Use #6 bars @ 6 inches = \( A_{\text{steel}} = 0.88 \text{ in}^2 > 0.715 \text{ in}^2 \)

\[ f_{\text{steel}} = 20.5 \text{ ksi} < f_{\text{allowable}} = 32.4 \text{ ksi} \]

**DESIGN AXIAL LOAD**

For RHHR boundary condition, axial force in the link slab needs to be calculated using the maximum negative moment at the interior support of a two-span continuous system. HL-93 (AASHTO LRFD 2004) loading is applied at both spans to create maximum negative moment of -724 ft. kips at the interior support.

Axial force acting on the link slab due to HL-93 loading:

\[
T = \frac{M_{\text{continuity}}}{h} = \frac{-724 \times 12}{(54 - 9/2)} = -176 \text{ kips} = -27.8 \text{ kips/ft} \quad \text{(Tension)}
\]

Axial force acting on the link slab due to positive temperature gradient:

\[
M_{\text{continuity}} = \frac{(F_d I_{\text{tg}} - M_s)(3E_{\text{Composite}} I_{\text{Composite}})}{2E_{\text{Girder}} I_{\text{Girder}}} = \frac{(32.89 \times 24.73 + 3.61)(3 \times 4031 \times 392892)}{2 \times 4031 \times 125390} = 3840 \text{ in.kips}
\]

\[
T = \frac{M_{\text{continuity}}}{h} = \frac{3840}{(54 - 9/2)} = 78 \text{ kips/ft} = 12.3 \text{kips/ft} \quad \text{(Compression)}
\]

Axial force acting on the link slab due to negative temperature gradient:

\[
T_{NG} = -0.3T_{PG} = -0.3 \times 78 = 23.4 \text{ kips} = -3.7 \text{ kips/ft} \quad \text{(Tension)}
\]

**DESIGN LOAD COMBINATIONS**

Service I-NTG Load Combination:

\[ M_d = -10.35 \text{ ft.kips / ft} \quad (N = 27.8 + 3.7 / 2 = 29.7 \text{ kips / ft for RHHR}) \]

Service I-PTG Load Combination:
\[ M_a = 9.34 \text{ ft} \cdot \text{kips/ft} \quad (N = -12.32 \text{kips/ft} \quad \text{for RHHR}) \]

Figure F-6. Moment and Interaction Diagram under Service Loads for unit link slab width
Figure F-6. Moment and Interaction Diagram under Service Loads for unit link slab width
APPENDIX G

Proposed Design Details in MDOT Design Guide Format
TYPICAL SECTION AT BRIDGE APPROACH

* CONTINUE BOTTOM BARS 24" PAST CONSTRUCTION JOINT INTO THE APPROACH SLAB
PLAN NOTES:
* WHERE CONSTRUCTION JOINTS ARE USED, THERE WILL BE NO PAYMENT FOR THE REQUIRED JOINT WATERPROOFING.

NOTES:
INTEGRAL AND SEMI-INTEGRAL ABUTMENT BRIDGES SHALL BE CONSIDERED FOR STEEL BRIDGES LESS THAN 300' AND CONCRETE BRIDGES LESS THAN 400' IN LENGTH.

APPROACH SLAB THICKNESS WILL MATCH THE ROAD APPROACH THICKNESS (9' MIN.

** USE FOR INTEGRAL ABUTMENT BRIDGES ONLY.

SEMI-INTEGRAL ABUTMENTS SHOULD BE USED AT STREAM CROSSINGS.

D = BACKWALL THICKNESS. SEE GUIDE 6.20.01 FOR DEFINITION.

*** EAO6 BAR