Bridge Deck Cracking

Evaluation of Performance Based Concrete For Bridge Decks

Washington State
Department of Transportation

Objectives

1. Document the difference in cracking between bridge decks constructed using the traditional WSDOT specification and those constructed with the current performance based specification.

2. Identify trends or issues with the current performance based specification that could be improved.

Performance Based Specification

1. Implemented mid-2011 as project specific specification

2. Included in WSDOT 2014 Standard Specifications (amended April 6, 2015)

3. Used in 30+ new bridges and a handful of deck replacement projects

Mix Design Requirements

	Traditional	Performance Based
Minimum 28-day Compressive Strength	4,000 psi	4,000 psi
Cement	Type I or II Portland	Type I or II Portland
Cementitious Content	735 lbs minimum (660 lbs cement & 75 lbs fly ash)	No set limits
Fly Ash	Required	Optional
Nominal Max. Size Aggregate	1-inch	1½-inch
Water Reducing Admixture	Required	Optional

Mix Design Requirements

	Traditional	Performance Based
Air Content	4.5% to 7.5%	4.5% to 7.5%
Freeze-Thaw Durability (instead of above air content requirement)	Not an option	3.0% min. air content 90% minimum durability factor after 300 cycles (AASHTO T 161)
Permeability	No requirement	Less than 2000 coulombs at 56 days (AASHTO T 277)
Length Change (shrinkage)	No requirement	Less than 0.032% at 28 days (AASHTO T 160)
Scaling	No requirement	Visual rating ≤ 2 after 50 cycles (ASTM C 672)

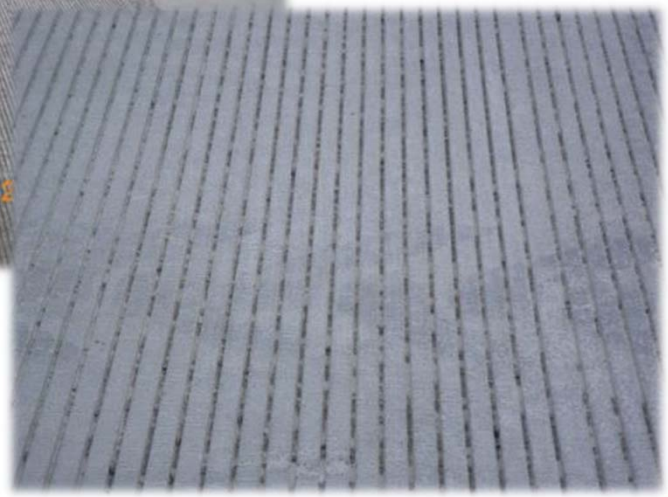
Placing, Curing and Finishing Requirements

	Traditional	Performance Based
Temperature During Placement	Between 55°F and 90°F	Between 55°F and 75°F
Temperature Monitoring After Placement	Not Required	Seven days after placement
Curing & Finishing	1. Transverse grooves are tined into the deck with metal combs after the concrete is sufficiently stiff 2. Curing compound applied to surface a max. of 15 min. after tining 3. Presoaked wet burlap and soaker hoses are applied to deck surface when deck has taken initial set. 4. Wet burlap is kept in place for 14 days	1. Fog the deck immediately after finishing machine passes 2. Apply presoaked burlap to top surface (no curing compound) 3. Keep the burlap wet by fog spraying until initial set and it can be covered with soaker hoses and white reflective sheeting 4. Wet burlap is kept in place for 14 days 5. After cured, longitudinal grooves are ground into the deck using a diamond tipped saw.

Placing Concrete

Curing Concrete

Finishing Concrete



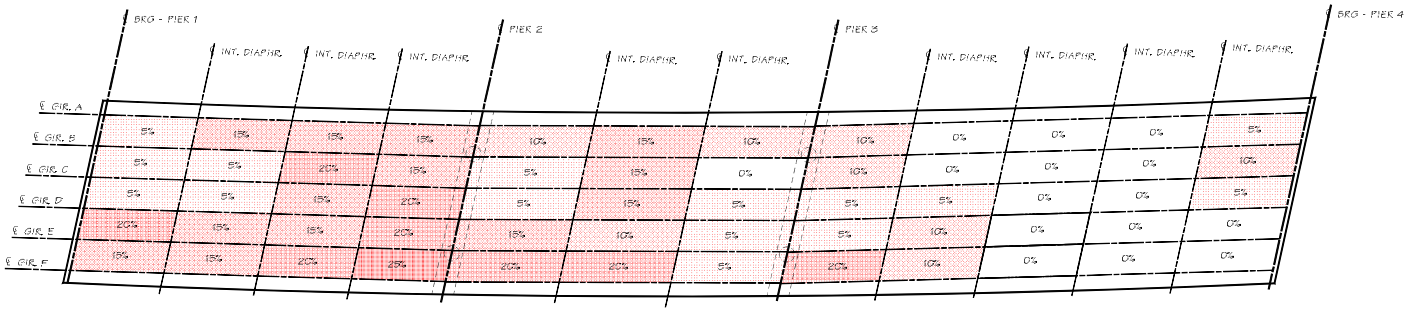
Evaluation Method

- Develop a “Crack Intensity” diagram for each bridge.
- Easily identified cracks (leaching or large enough to see from the ground) in the underside of the deck are counted
- Cracks are grouped into “bays” (bounded by girders and diaphragms)
- A crack intensity percentage is calculated for each bay = N_{cr}/N_{100}

  N_{cr} = counted number of cracks

  N_{100} = No. of cracks for 100% intensity
- 100% crack intensity = a crack spaced every 2-feet

Sample Crack Intensity Diagram



CRACKING SEVERITY ~ BRIDGE 5/234W

100% = CRACK EVERY 2 FT.

LESS CRACKING — MORE CRACKING

BRIDGE #	5/234W
BRIDGE NAME	I-5 OVER BLAKESLEE JCT RR
INSPECTION DATE	4/6/2015
DECK CONCRETE	PERFORMANCE BASED

Bridges Evaluated

- A total of 28 bridges were evaluated
  - 15 constructed using the Performance Based Specification
  - 13 constructed using the Traditional WSDOT Specification
- Prestressed I-girders or Steel Plate girders selected for ability to inspect the underside of the deck between girders from the ground.
- Bridges are grouped into 4 “Trips”
  - South Trip (Centralia Area)
  - West Trip (Willapa Bay Area)
  - East Trip (Hyak and Spokane Areas)
  - North Trip (Nalley Valley, Marysville and Bremerton Areas)

South Trip

Br. No.	Bridge Name	Str. ID	Contract	Region	Projet Engineer	Contractor	Year	Perform.
5/302E	PRAIRIE CREEK NB	0017465A	7465	OR	Mcnutt/Engel	Scarsella Bros.	2009	No
5/302W	PRAIRIE CREEK SB	0017465B	7465	OR	Mcnutt/Engel	Scarsella Bros.	2010	No
5/229	MELLON STREET COUPLET	0018473B	8473	SW	Colin Newell	Scarsella Bros.	2014	Yes
5/234W	I-5 OVER BLAKESLEE JCT RR	0018272C	8272	SW	Colin Newell	Cascade Bridge	2013	Yes
5/232SCD	SKOOKUMCHUCK RIVER SCD	0018272B	8272	SW	Colin Newell	Cascade Bridge	2013	Yes
5/232NCD	SKOOKUMCHUCK RIVER NCD	0018272A	8272	SW	Colin Newell	Cascade Bridge	2013	Yes
6/115	S FORK CHEHALIS R	0017587A	7587	SW	Colin Newell	Scarsella Bros.	2009	No

West Trip

Br. No.	Bridge Name	Str. ID	Contract	Region	Projet Engineer	Contractor	Year	Perform.
105/3	SMITH CREEK	0018345A	8345	SW	Lori Figone	Scarsella Bros., Inc.	2013	Yes
105/4	NORTH RIVER	0018345B	8345	SW	Lori Figone	Scarsella Bros., Inc.	2014	Yes
101/44	BONE RIVER	0018292A	8292	SW	Lori Figone	Cascade Bridge, LLC	2013	Yes
101/31	MIDDLE NEMAH RIVER	0018344A	8344	SW	Lori Figone	SB Structures, LLC	2014	Yes
6/8	WILLAPA RIVER	0018464A	8464	SW	Colin Newell	Rotschy, Inc.	2014	Yes

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East Trip

Br. No.	Bridge Name	Str. ID	Contract	Region	Projet Engineer	Contractor	Year	Perform.
90/106N	GOLD CREEK WB	0017852D	7852	SC	Will Smith	Max J. Kuney Company	2012	No
90/105.5N	GOLD CREEK ANIMAL CROSSING WB	0017852B	7852	SC	Will Smith	Max J. Kuney Company	2012	No
90/105.5S	GOLD CREEK ANIMAL CROSSING EB	0017852A	7852	SC	Will Smith	Max J. Kuney Company	2010	No
195/117	CHENEY SPOKANE RD OVER US 195	0018378A	8378	ER	Chad Simonson	Selland Construction	2014	Yes
395/441N-E	N-E RAMP OVER N-N RAMP	0017610E	7610	ER	Bob Hilmes	Graham Construction & Manage.	2011	Yes
2/651W-S	W-S RAMP OVER US 2/US 395	0017610D	7610	ER	Bob Hilmes	Graham Construction & Manage.	2011	No
395/442W	US 395 OVER US 2	0017610B	7610	ER	Bob Hilmes	Graham Construction & Manage.	2011	No

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North Trip

Br. No.	Bridge Name	Str. ID	Contract	Region	Projet Engineer	Contractor	Year	Perform.
5/434SCD	SBCD OVER SR 16 HOV & RAMPS	0018189B	8189	OR	Neal Uhlmeyer	Mowat Construction Company	2013	Yes
16/3W	SR 16 OVER HOV	0018189A	8189	OR	Neal Uhlmeyer	Mowat Construction Company	2014	Yes
16/7S-E	S SPRAGUE RAMP	0017594E	7594	OR	Jon Deffenbacher	Guy F. Atkinson Construction	2010	No
303/4A	MANETTE BRIDGE	0017926A	7926	OR	Michele Britton	Manson-Mowat, A Joint Venture	2011	No
2/8.5N-W	N-W RAMP (BICKFORD AVE) OVER US 2	0018286A	8286	NW	Mark Sawyer	Granite Construction Company	2013	Yes
529/25	EBEY SLOUGH	0017948A	7948	NW	Mark Sawyer	Granite Construction Company	2012	No
9/133	SR 9 OVER HARVEY CRK RD	0017267A	7267	NW	Janice Fahning	Scarsella Bros., Inc.	2008	No
9/134	PILCHUCK CREEK	0018363A	8383	NW	Dave Crisman	Granite Construction Company	2014	Yes

Single Span Prestressed Girder Bridges

Bridges 5/302W & 5/302E

Single Span WF42G Girders

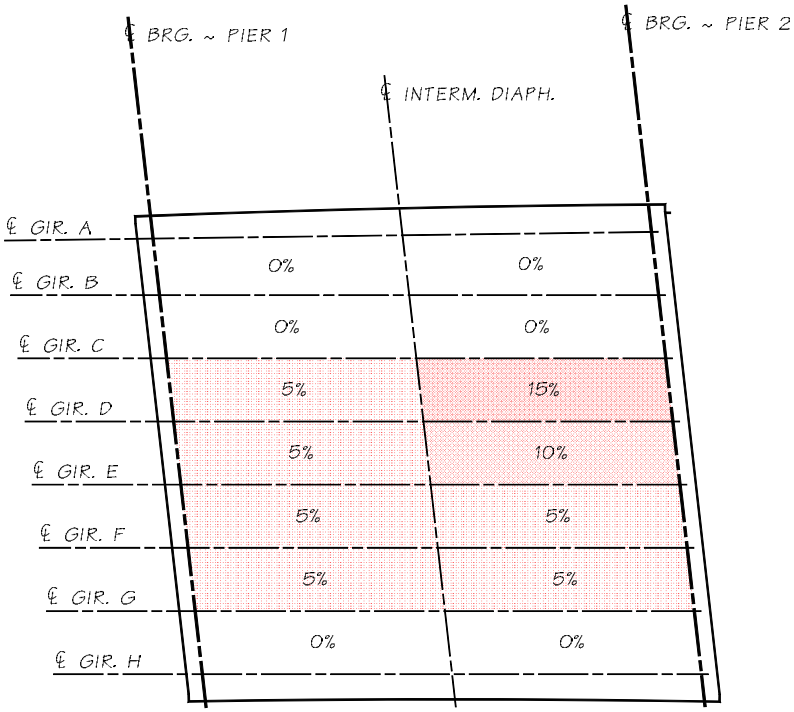
Washington State Department of Transportation

Traditional

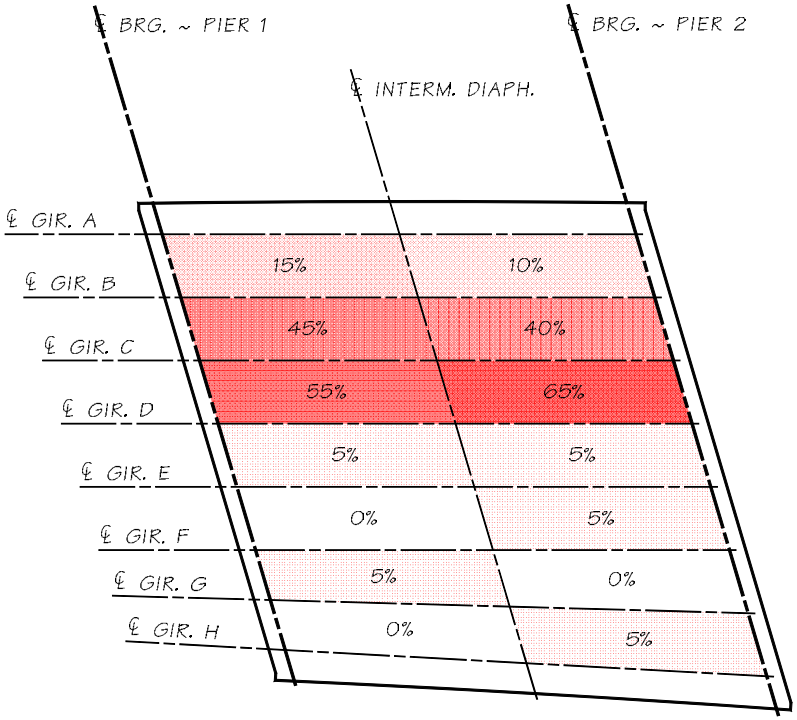
Bridges 5/302W & 5/302E

Single Span WF42G Girders

LESS CRACKING — MORE CRACKING



Average Intensity = 4%



Average Intensity = 18%

Washington State Department of Transportation

Traditional

Bridges 5/302W & 5/302E

Single Span WF42G Girders

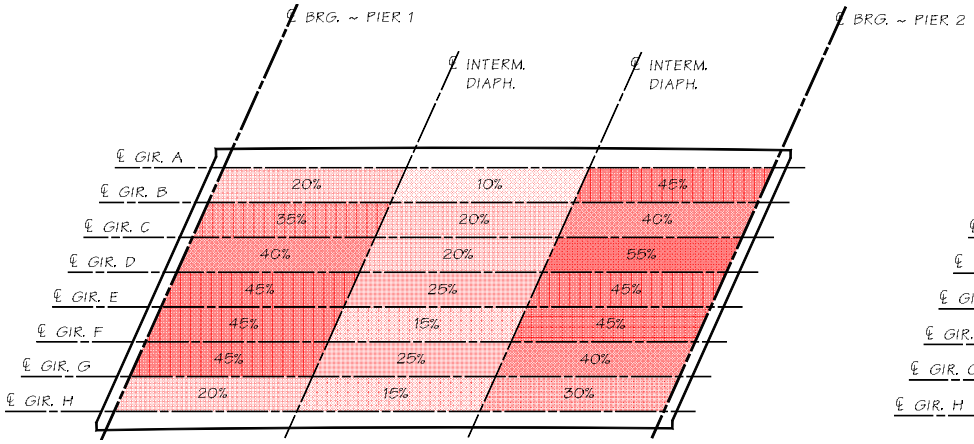
Br. 90/105.5N & 90/105.5S

Single Span WF50G Girders

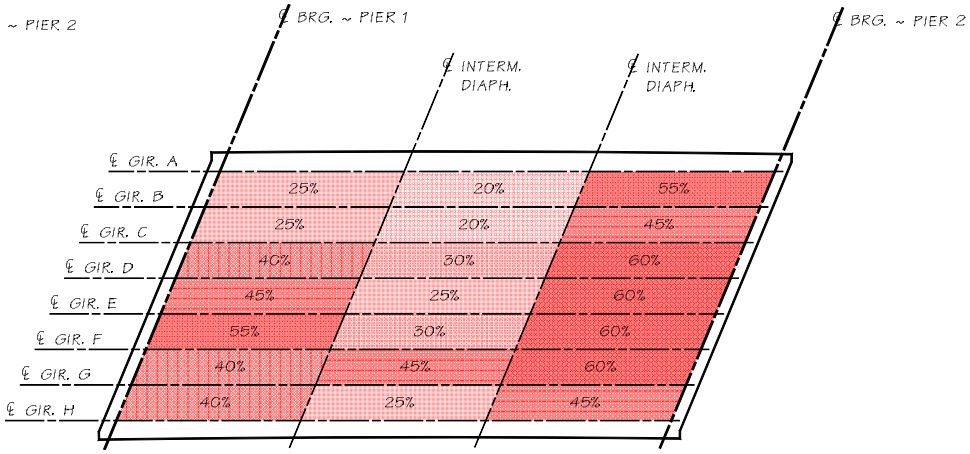
Br. 90/105.5N & 90/105.5S

Single Span WF50G Girders

LESS CRACKING — MORE CRACKING



Average Intensity = 32%



Average Intensity = 40%

Br. 90/105.5N & 90/105.5S

Single Span WF50G Girders

Bridge 9/133

Single Span WF83G Girders

Bridge 9/133

Single Span WF83G Girders

LESS CRACKING — MORE CRACKING

	℄ BRG. ~ PIER 1	℄ INTERM. DIAPH.	℄ INTERM. DIAPH.	℄ INTERM. DIAPH.	℄ INTERM. DIAPH.	℄ BRG. ~ PIER 2
℄ GIR. A						
℄ GIR. B	10%	0%	10%	5%	0%	
℄ GIR. C	45%	0%	0%	0%	0%	
℄ GIR. D	25%	0%	5%	5%	5%	
℄ GIR. E	35%	0%	5%	10%	5%	
℄ GIR. F	25%	0%	5%	5%	5%	

Average Intensity = 8%

Bridge 9/133

Single Span WF83G Girders

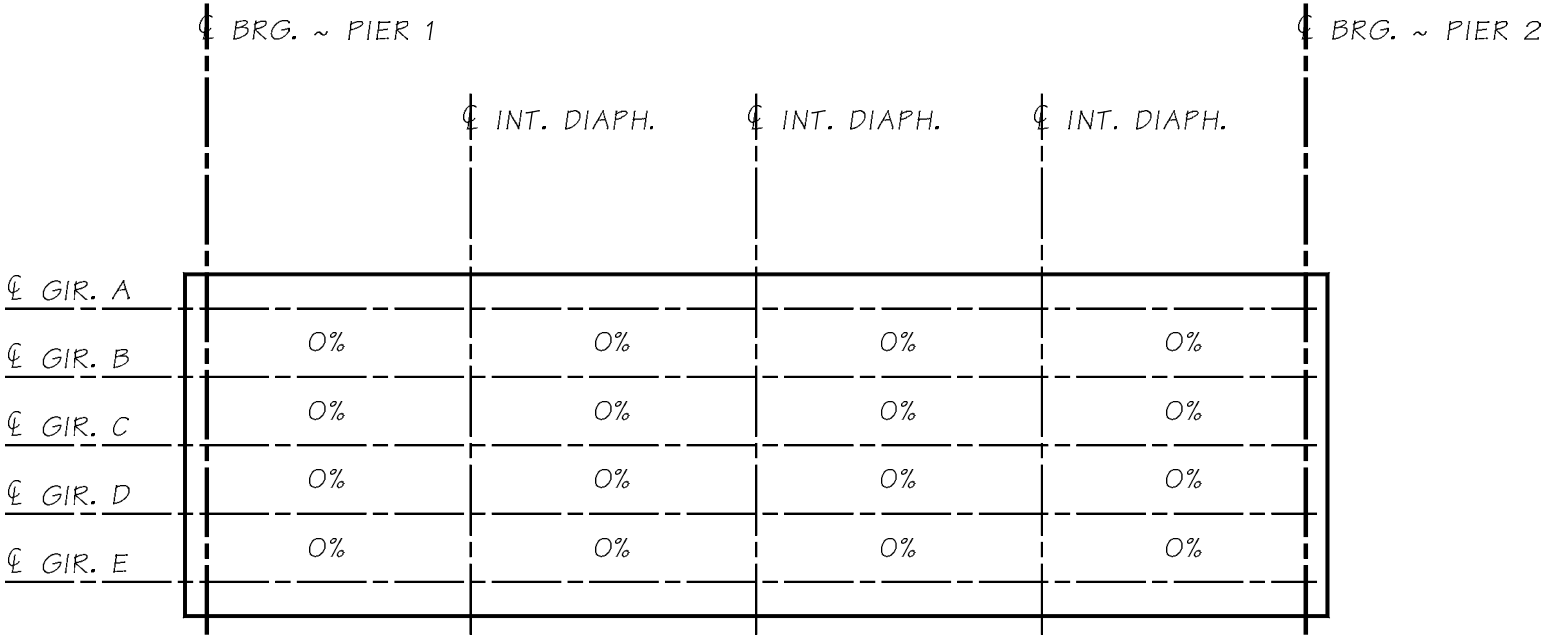
Bridge 101/31

Single Span WF50G Girders

Bridge 101/31

Single Span WF50G Girders

LESS CRACKING — MORE CRACKING



Average Intensity = 0%

Bridge 101/31

Single Span WF50G Girders

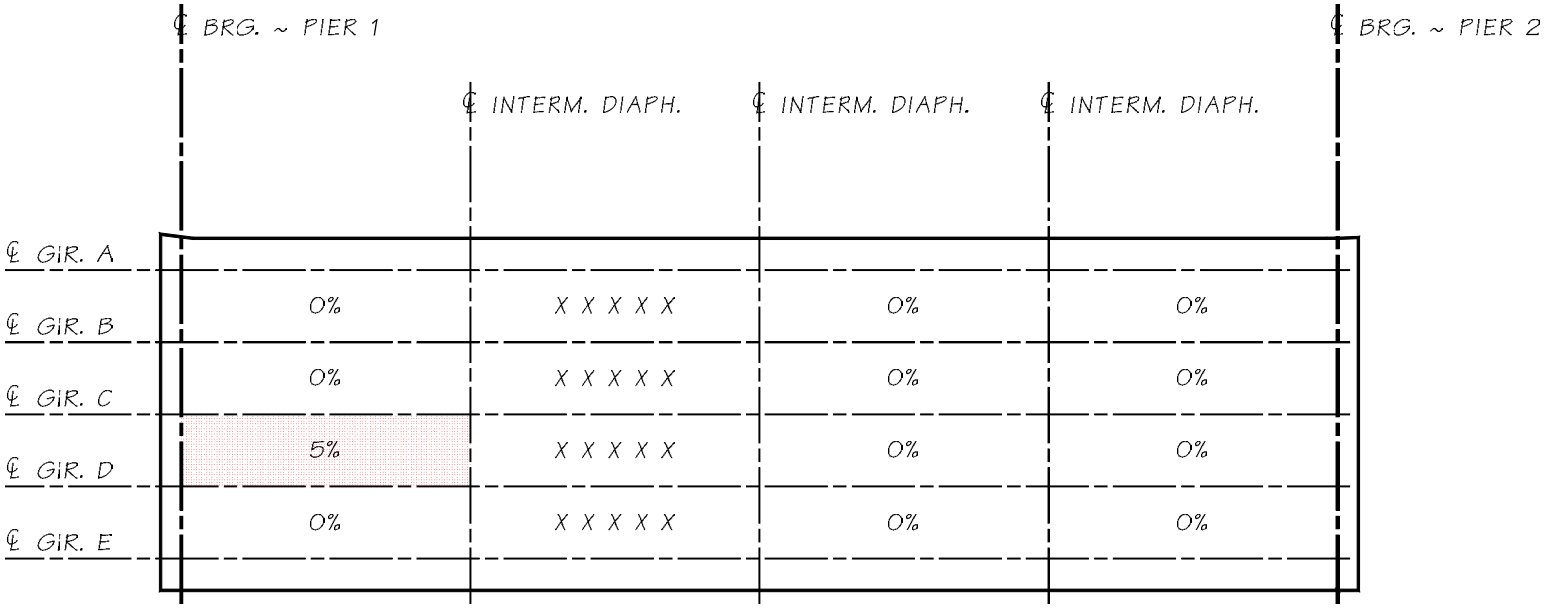
Bridge 5/229

Single Span WF74G Girders

Bridge 5/229

Single Span WF74G Girders

LESS CRACKING — MORE CRACKING



Average Intensity < 1%

Bridge 5/229

Single Span WF74G Girders

2-Span Prestressed Girder Bridges

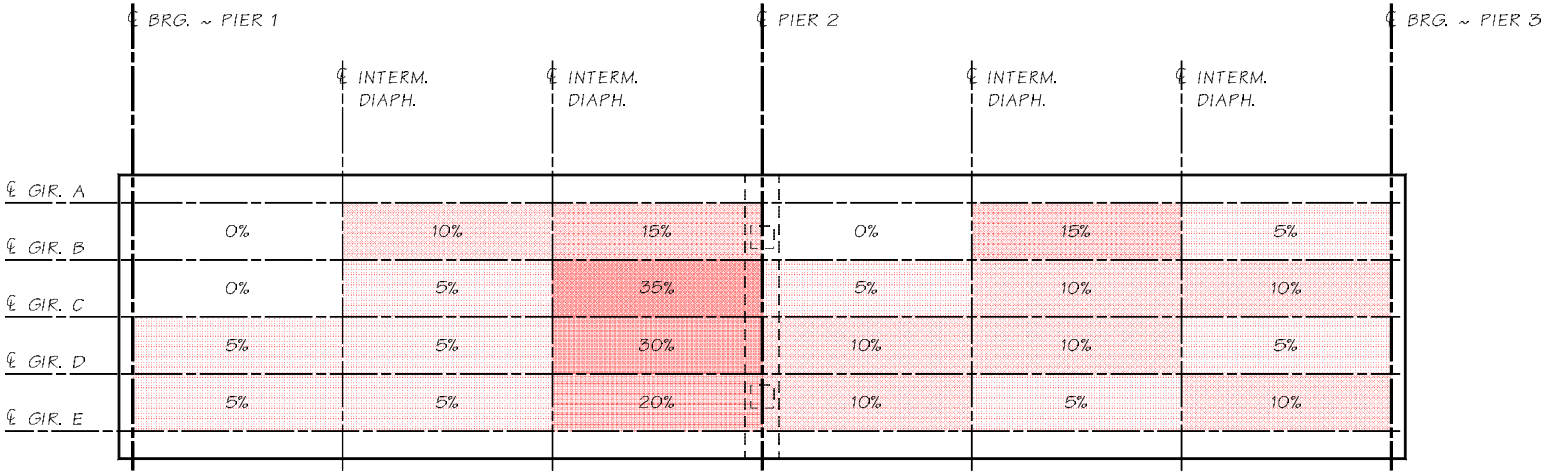
Bridge 195/117

2-Span WF50G Girders

Bridge 195/117

2-Span WF50G Girders

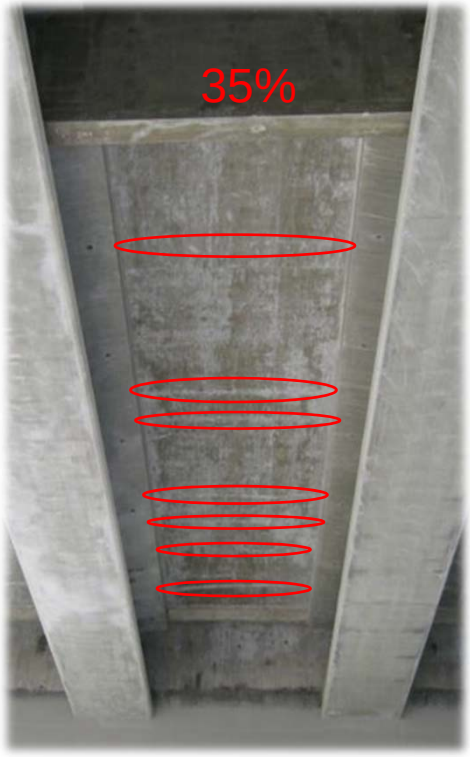
LESS CRACKING — MORE CRACKING



Average Intensity = 10%

Bridge 195/117

2-Span WF50G Girders



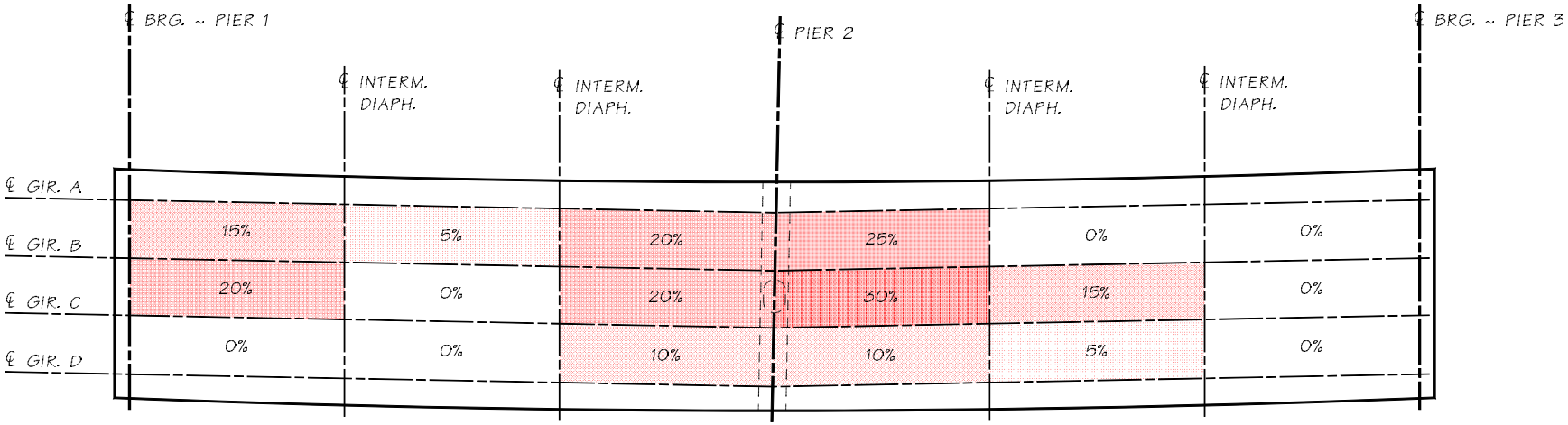
Bridge 395/442W

2-Span WF58G Girders

Bridge 395/442W

2-Span WF58G Girders

LESS CRACKING — MORE CRACKING



Average Intensity = 10%

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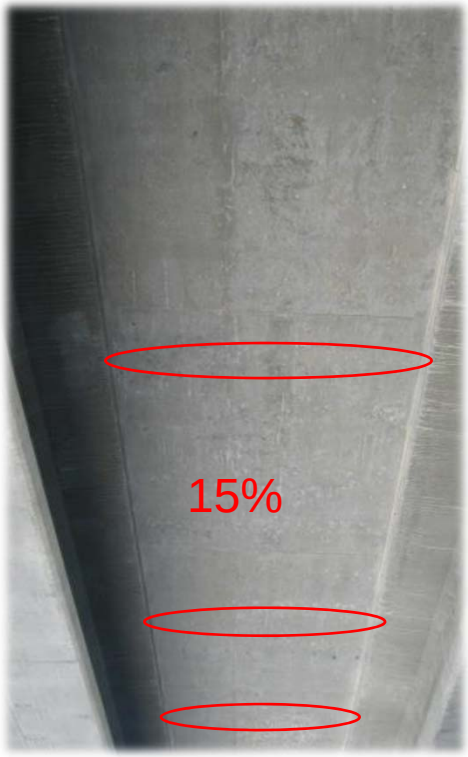
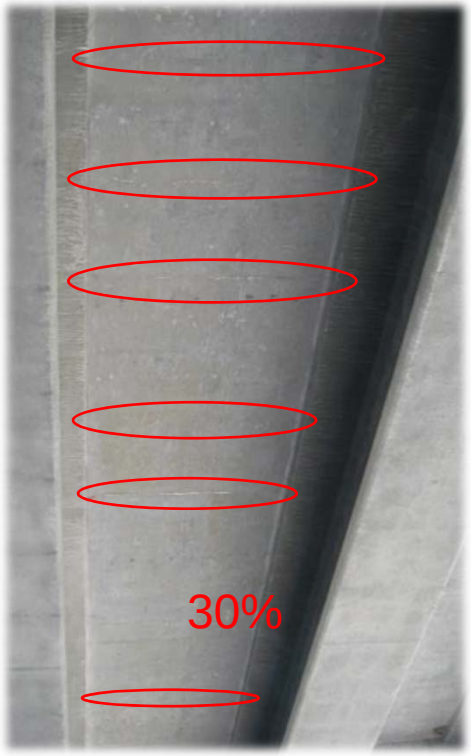
Traditional

Bridge 395/442W

2-Span WF58G Girders





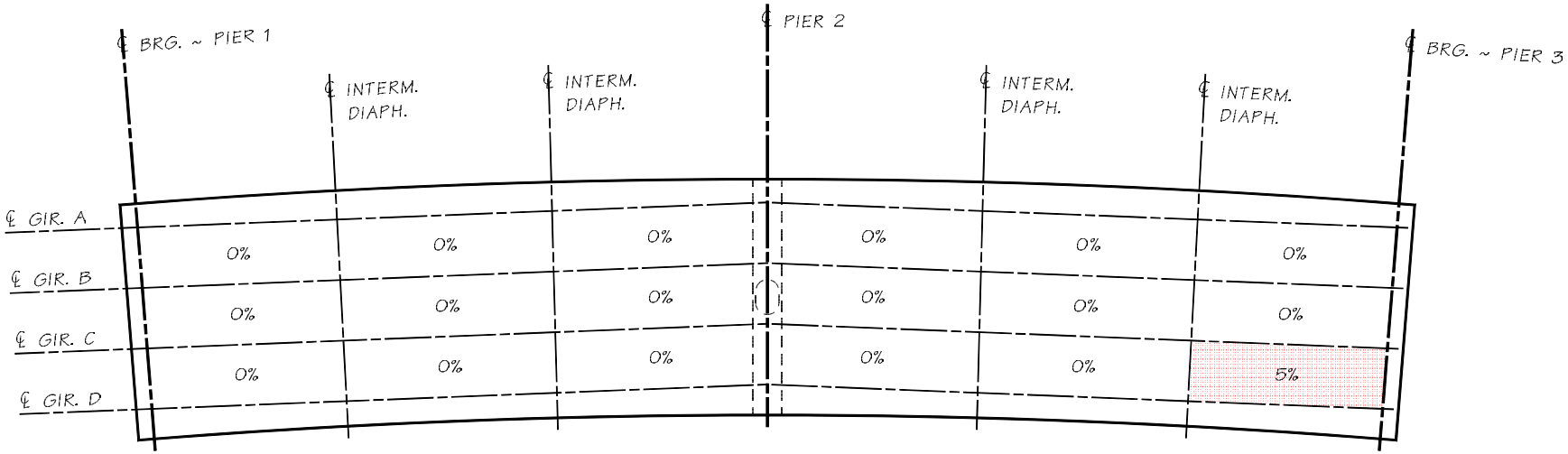
Bridge 395/441N-E

2-Span WF58G Girders

Bridge 395/441N-E

2-Span WF58G Girders

LESS CRACKING — MORE CRACKING



Average Intensity < 1%

Bridge 395/441N-E

2-Span WF58G Girders

small diagonal crack
at the abutment

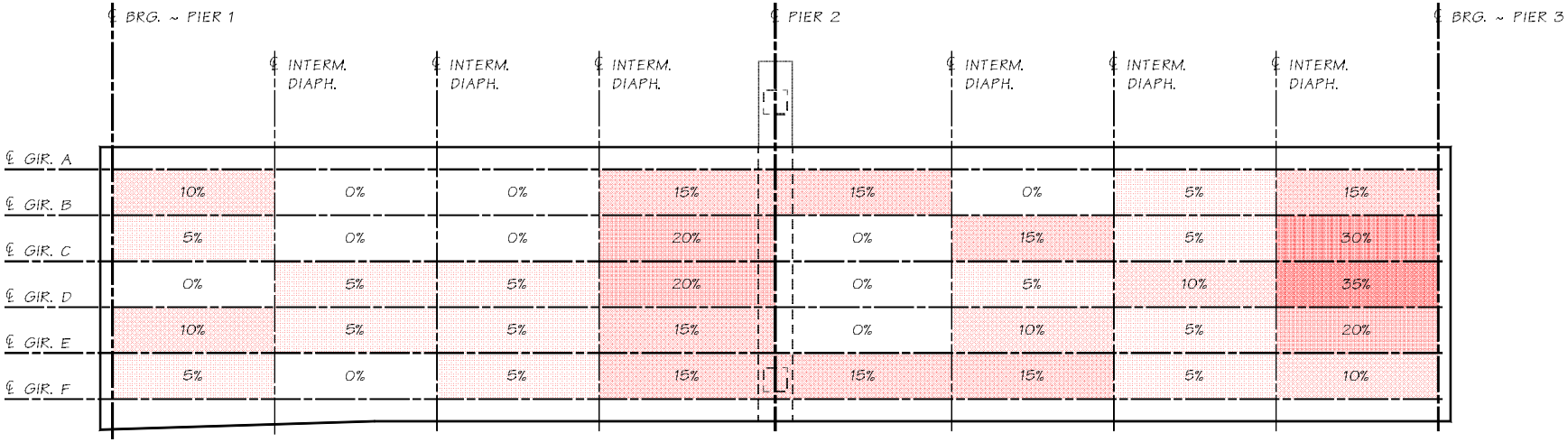
Bridge 16/3W

Single Span WF58G Girders

Bridge 16/3W

Single Span WF58G Girders

LESS CRACKING — MORE CRACKING



Average Intensity = 9%

Bridge 16/3W

Single Span WF58G Girders

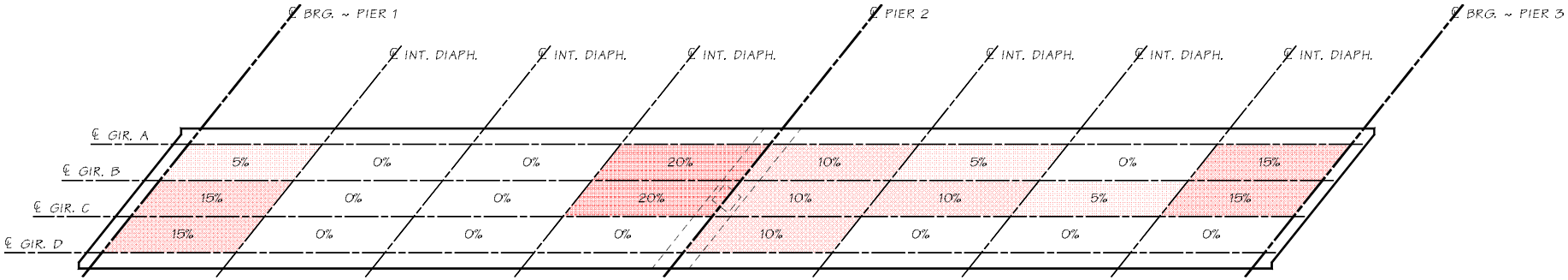
Bridge 2/8.5N-W

2-Span WF66G Girders

Bridge 2/8.5N-W

2-Span WF66G Girders

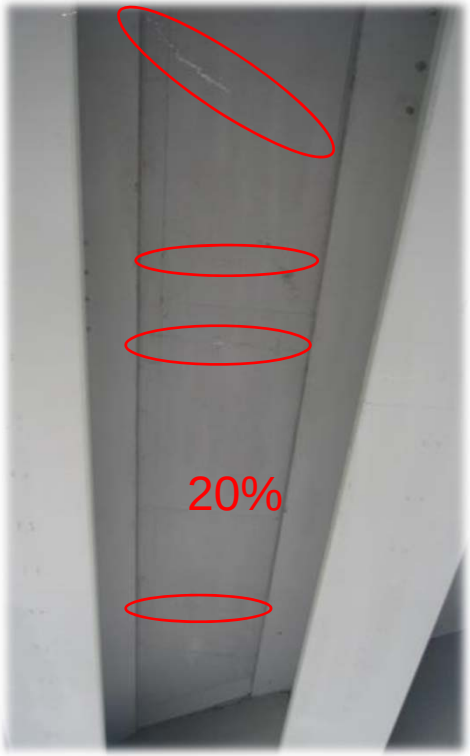
LESS CRACKING — MORE CRACKING



Average Intensity = 6%

Bridge 2/8.5N-W

2-Span WF66G Girders



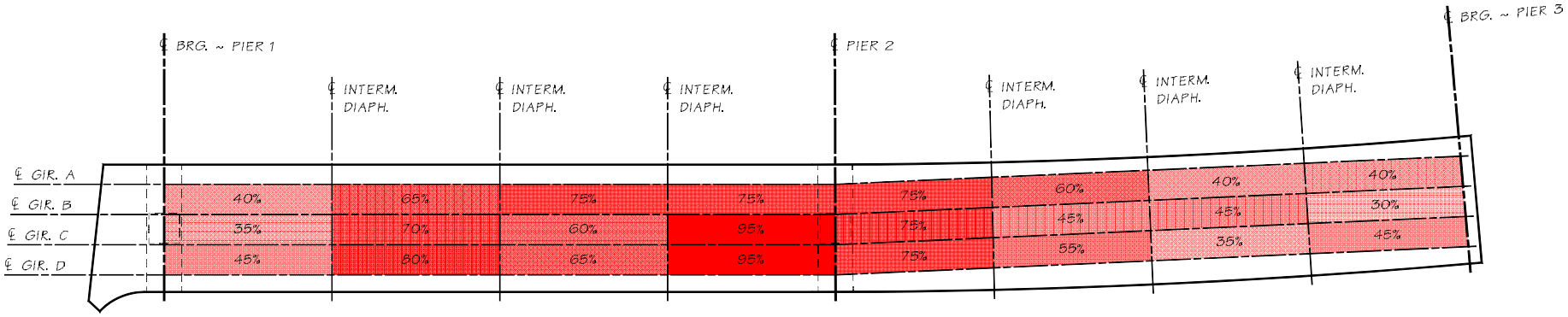
Bridge 16/7S-E

2-Span WF83G Girders

Bridge 16/7S-E

2-Span WF83G Girders

LESS CRACKING — MORE CRACKING



Average Intensity = 59%

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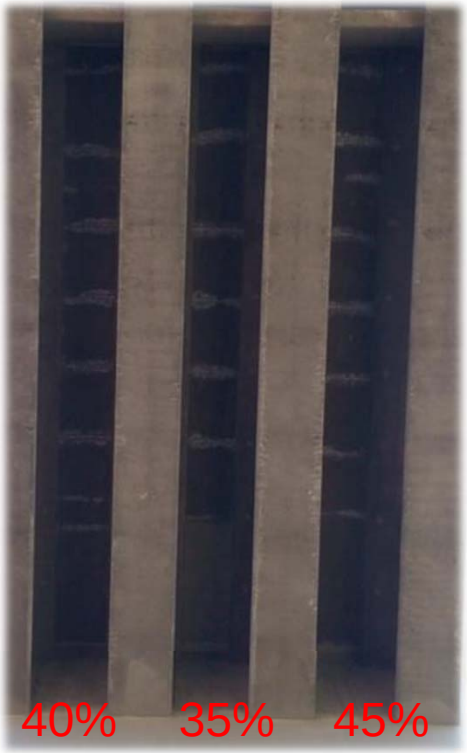
Traditional

Bridge 16/7S-E

2-Span WF83G Girders



3-Span+ Prestressed Girder Bridges

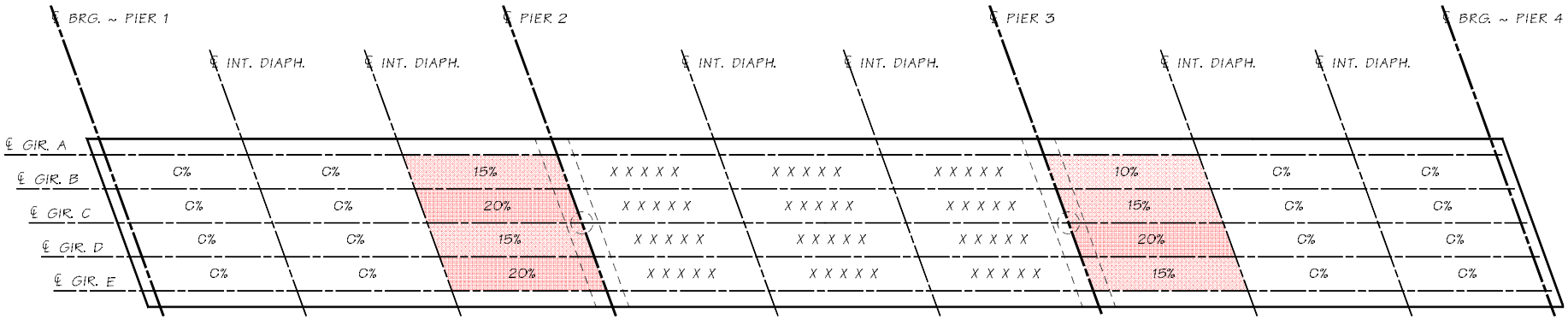
Bridge 105/3

3-Span WF42G Girders

Bridge 105/3

3-Span WF42G Girders

LESS CRACKING — MORE CRACKING



Average Intensity = 6%

Bridge 105/3

3-Span WF42G Girders

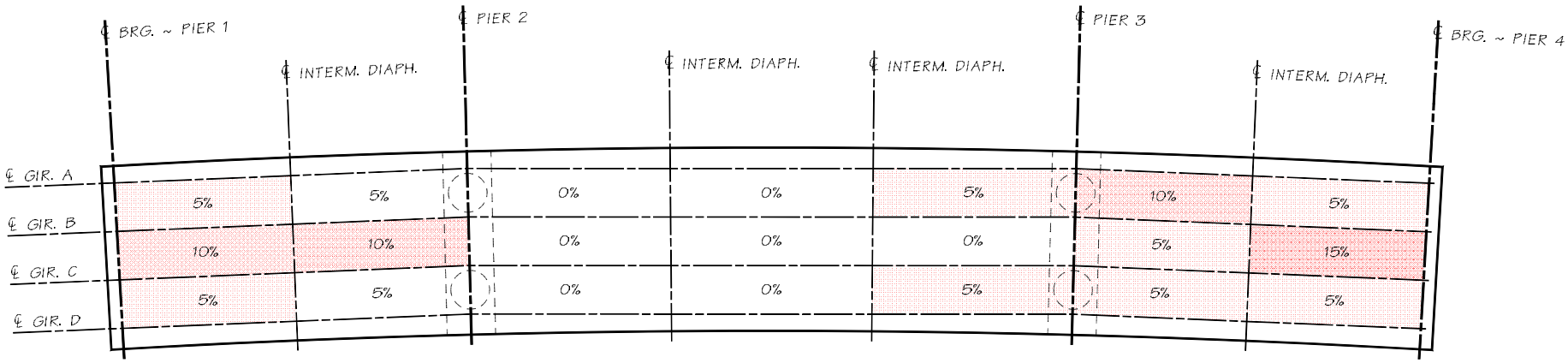
Bridge 6/8

3-Span WF58G Girders

Bridge 6/8

3-Span WF58G Girders

LESS CRACKING — MORE CRACKING



Average Intensity = 5%

Bridge 6/8

3-Span WF58G Girders

LESS CRACKING — MORE CRACKING

Br. 5/232SCD & 5/232NCD

3-Span WF66G Girder

Br. 5/232SCD & 5/232NCD

3-Span WF66G Girder

LESS CRACKING — MORE CRACKING

	℄ BRG. ~ PIER 1	℄ INTERM. DIAPH.	℄ PIER 2	℄ INTERM. DIAPH.	℄ INTERM. DIAPH.	℄ INTERM. DIAPH.	℄ PIER 3	℄ INTERM. DIAPH.	℄ BRG. ~ PIER 4
℄ GIR. A									
℄ GIR. B	0%	0%	0%	0%	0%	0%	5%	0%	
℄ GIR. C	0%	0%	0%	0%	0%	0%	0%	0%	
℄ GIR. D	0%	0%	0%	0%	0%	0%	0%	0%	
℄ GIR. E	0%	0%	0%	0%	0%	10%	5%	5%	

Average Intensity = 1%

	℄ BRG. ~ PIER 1	℄ INTERM. DIAPH.	℄ PIER 2	℄ INTERM. DIAPH.	℄ INTERM. DIAPH.	℄ INTERM. DIAPH.	℄ PIER 3	℄ INTERM. DIAPH.	℄ BRG. ~ PIER 4
℄ GIR. A									
℄ GIR. B	0%	0%	0%	X X X X X	X X X X X	0%	0%	0%	
℄ GIR. C	5%	0%	0%	X X X X X	X X X X X	0%	0%	5%	
℄ GIR. D	10%	5%	0%	X X X X X	X X X X X	10%	0%	0%	
℄ GIR. E	5%	5%	0%	X X X X X	X X X X X	0%	0%	0%	

Average Intensity = 2%

Br. 5/232SCD & 5/232NCD

3-Span WF66G Girder

Bridge 6/115

5-Span WF74G Girder

Bridge 6/115

5-Span WF74G Girder

LESS CRACKING — MORE CRACKING

Average Intensity = 32%

Washington State Department of Transportation

Traditional

Bridge 6/115

5-Span WF74G Girder

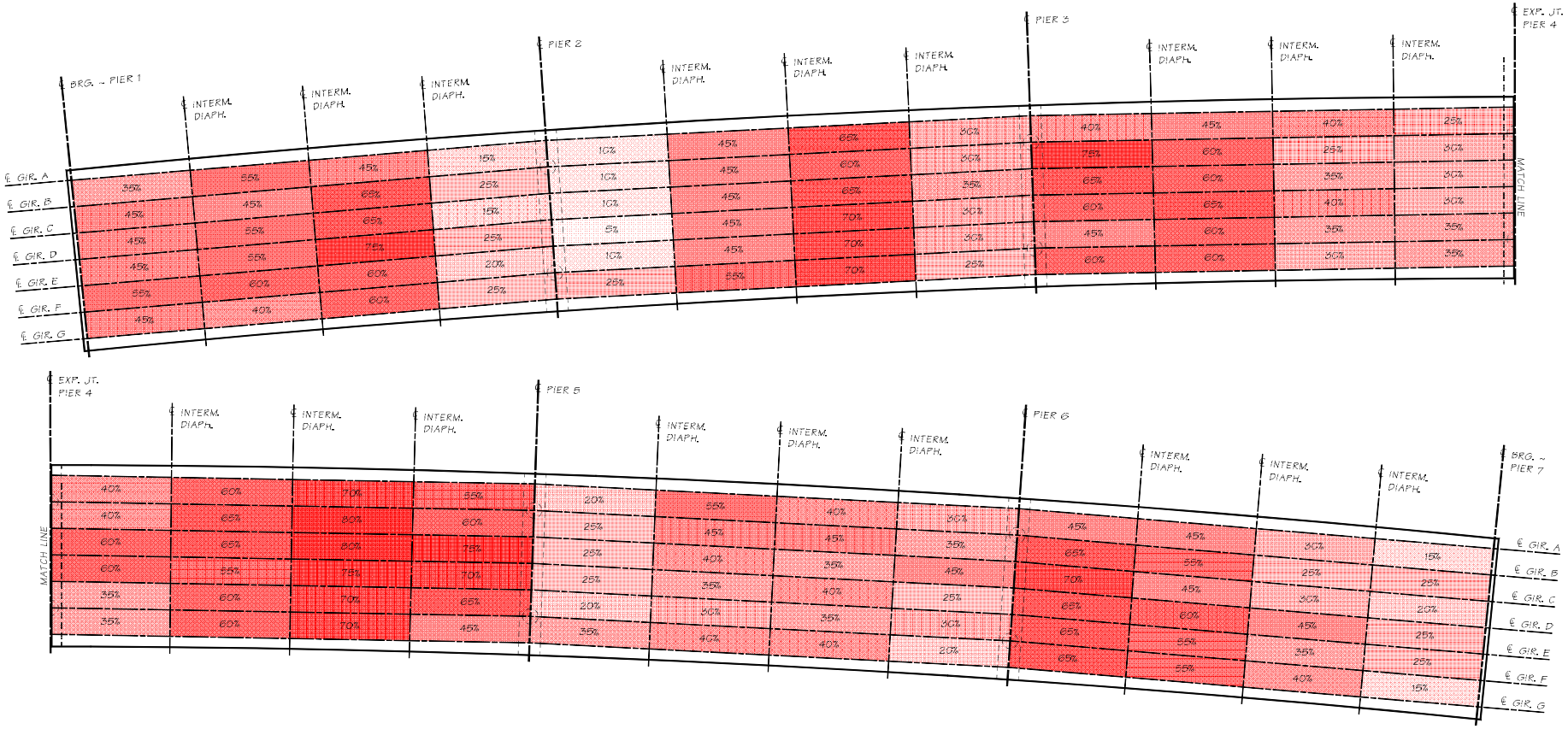
Bridge 90/106N

6-Span WF74G Girders

Bridge 90/106N

6-Span WF74G Girders

LESS CRACKING — MORE CRACKING



Average Intensity = 44%

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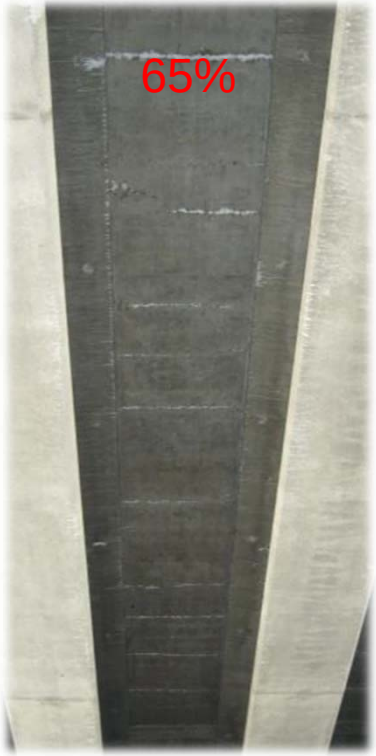
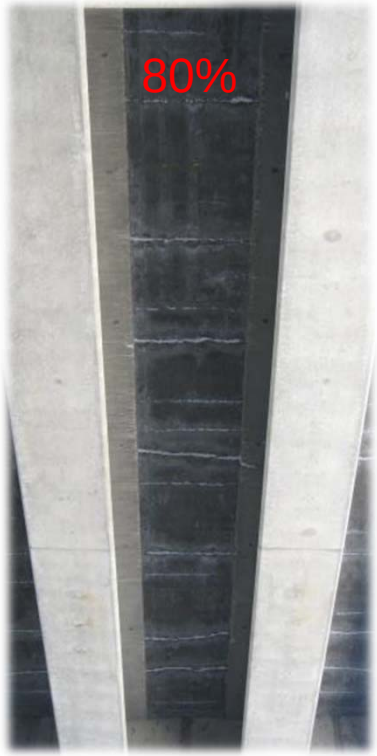
Traditional

Bridge 90/106N

6-Span WF74G Girders





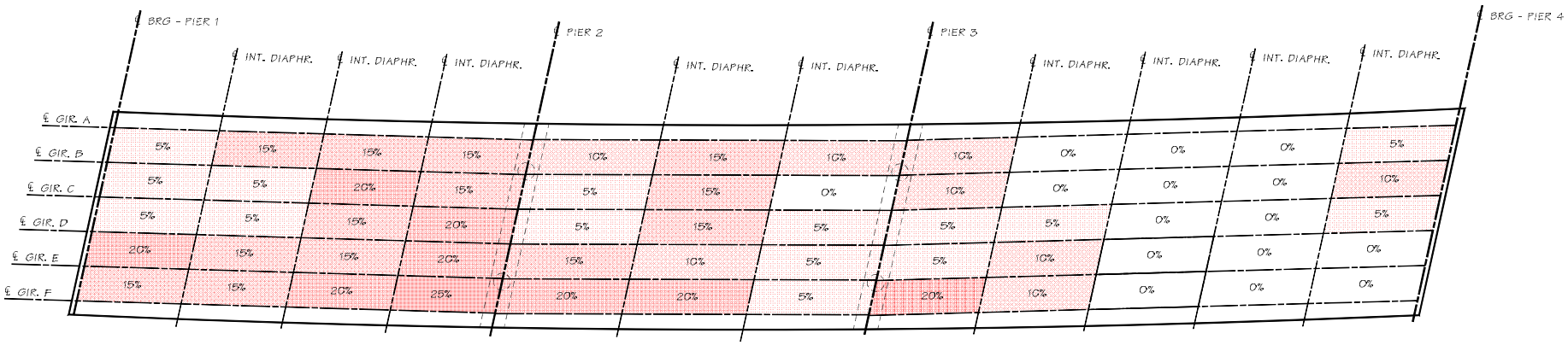
Bridge 5/234W

3-Span WF74G Girders

Bridge 5/234W

3-Span WF74G Girders

LESS CRACKING — MORE CRACKING

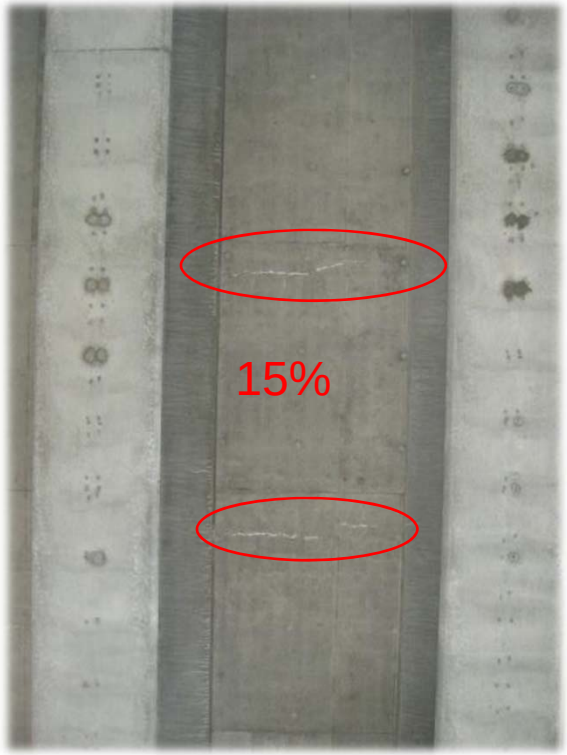


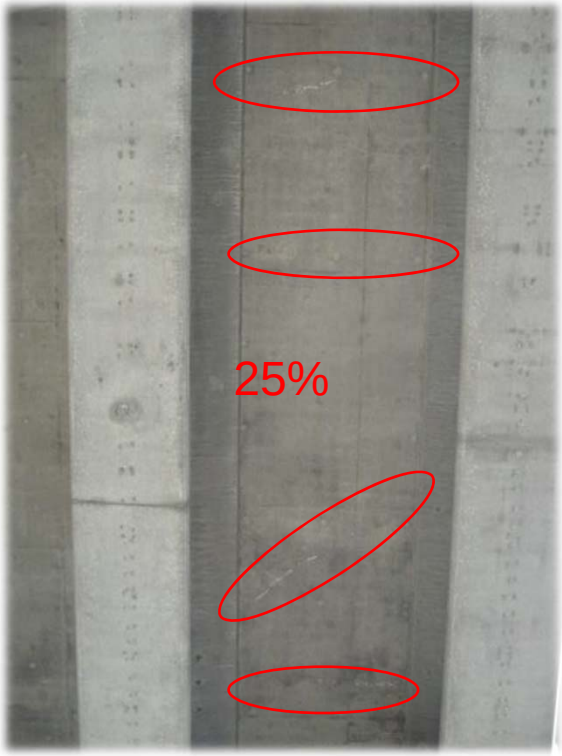
Average Intensity = 9%

Bridge 5/234W

3-Span WF74G Girders

LESS CRACKING — MORE CRACKING





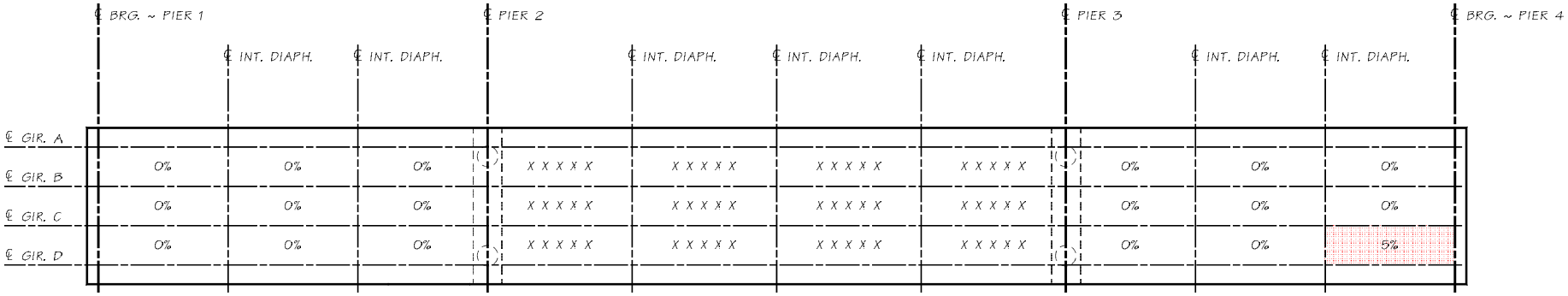
Bridge 101/44

3-Span WF74G Girders

Bridge 101/44

3-Span WF74G Girders

LESS CRACKING — MORE CRACKING



Average Intensity < 1%

Washington State Department of Transportation

Performance Based

Bridge 101/44

3-Span WF74G Girders

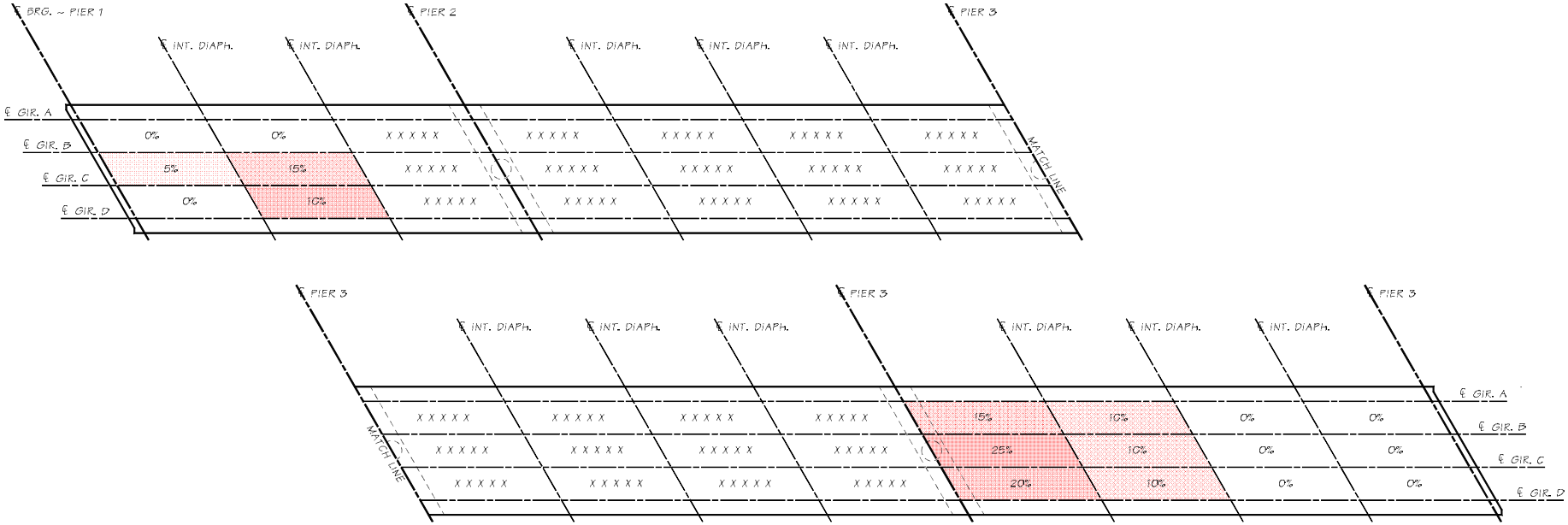
Bridge 105/4

4-Span WF83G Girders

Bridge 105/4

4-Span WF83G Girders

LESS CRACKING — MORE CRACKING



Average Intensity = 7%

Bridge 105/4

4-Span WF83G Girders

Bridge 303/4A

7-Span Prestressed-Post-Tensioned Girders

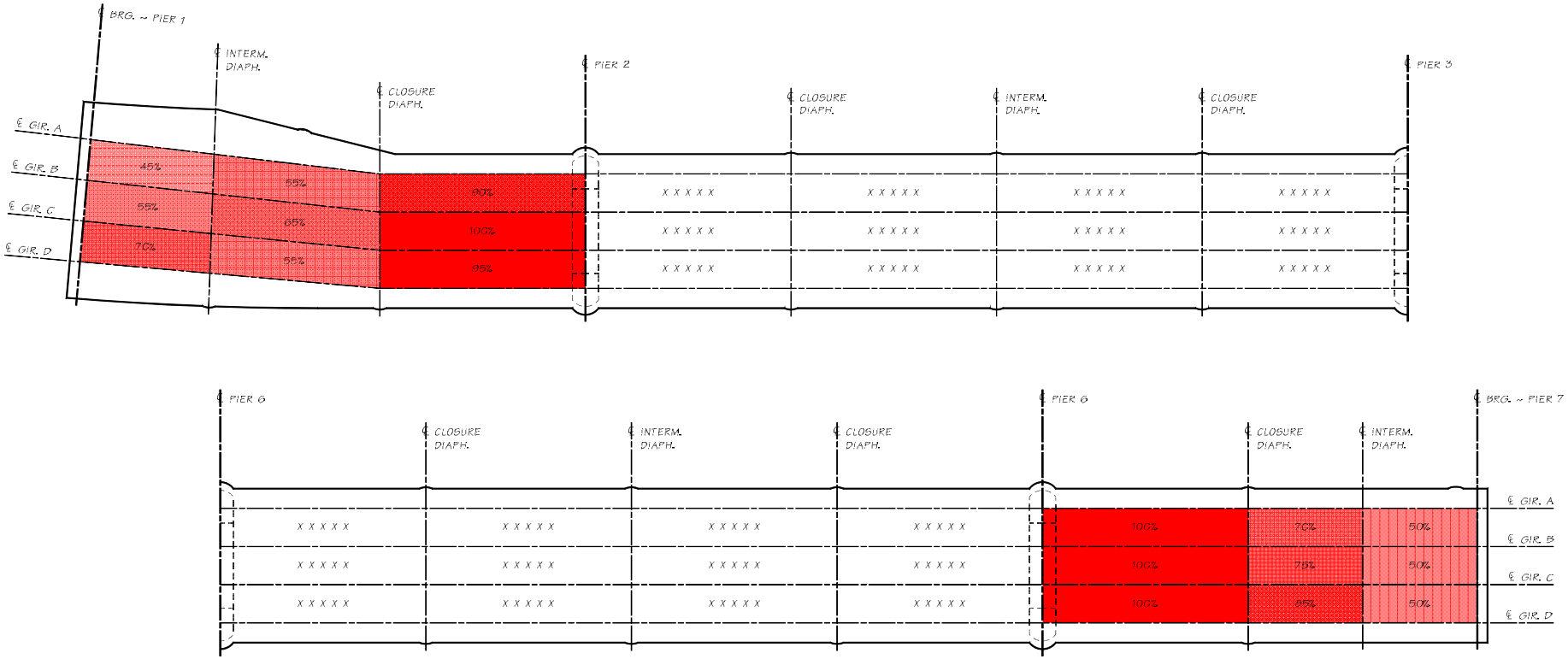
Washington State
Department of Transportation

Traditional

Bridge 303/4A

7-Span Prestressed-Post-Tensioned Girders

LESS CRACKING — MORE CRACKING



Average Intensity = 73%

Washington State Department of Transportation

Traditional

Bridge 303/4A

7-Span Prestressed-Post-Tensioned Girders

Multi-Span Steel Plate Girder Bridges

Bridge 2/651W-S

6-Span Steel Plate Girder

Washington State
Department of Transportation

Traditional

Bridge 2/651W-S

6-Span Steel Plate Girder

LESS CRACKING — MORE CRACKING

Average Intensity = 13%

Washington State Department of Transportation

Traditional

Bridge 2/651W-S

6-Span Steel Plate Girder

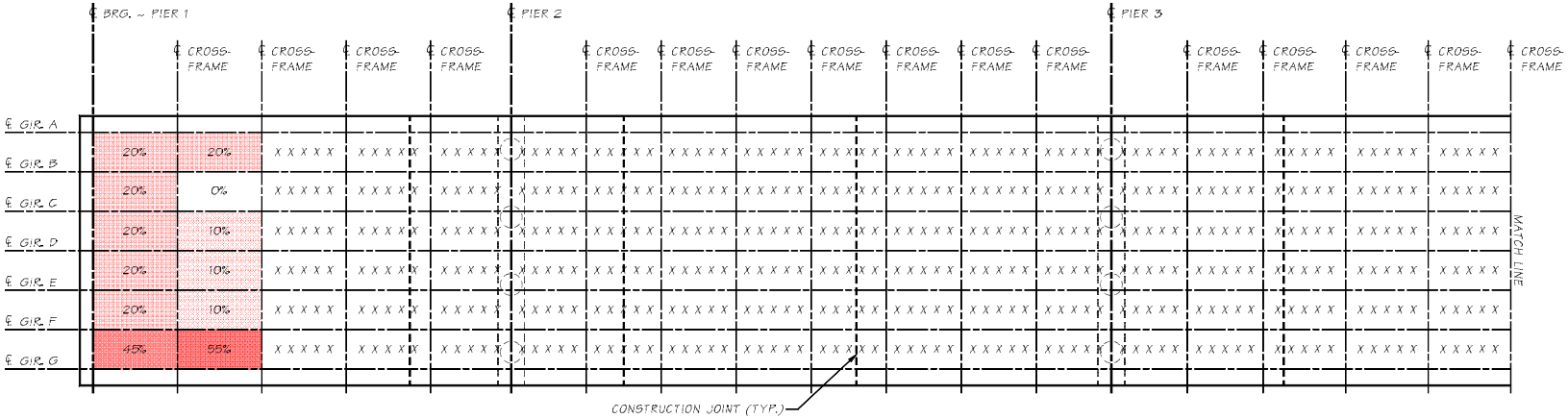
Bridge 529/25

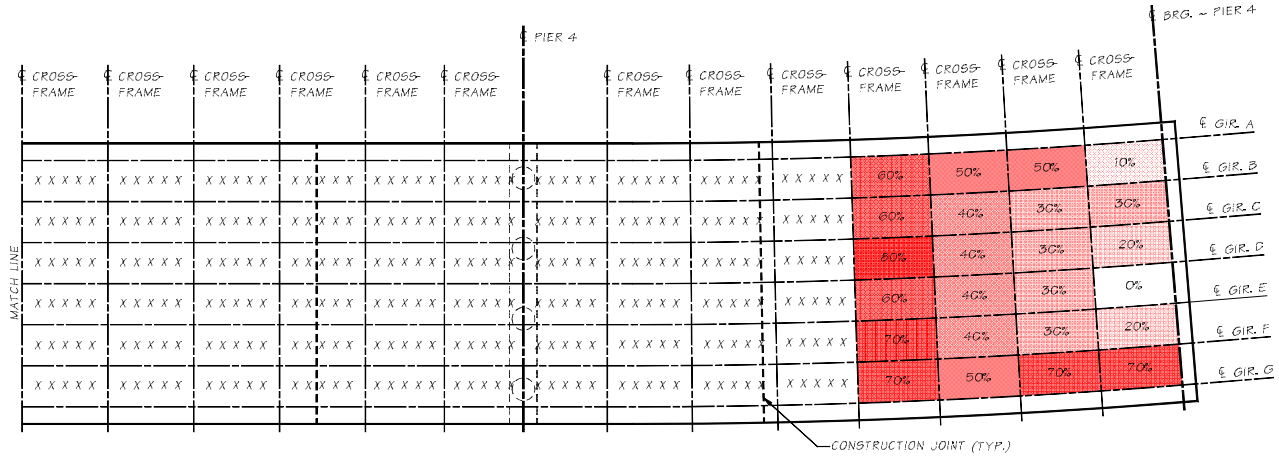
4-Span Steel Plate Girder

Bridge 529/25

4-Span Steel Plate Girder

LESS CRACKING — MORE CRACKING





Average Intensity = 36%

Washington State Department of Transportation

Traditional

Bridge 529/25

4-Span Steel Plate Girder

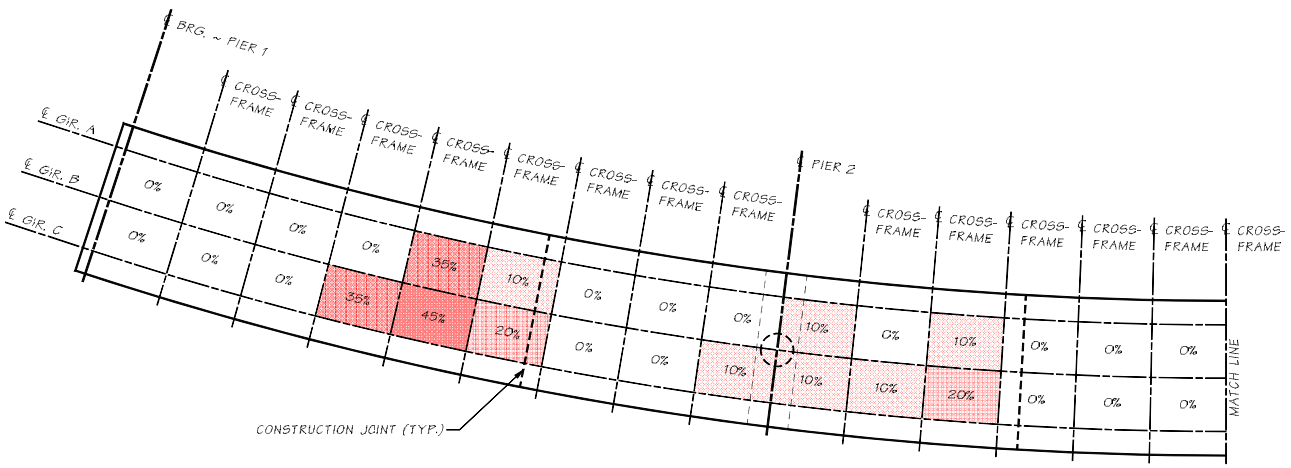
Bridge 9/134

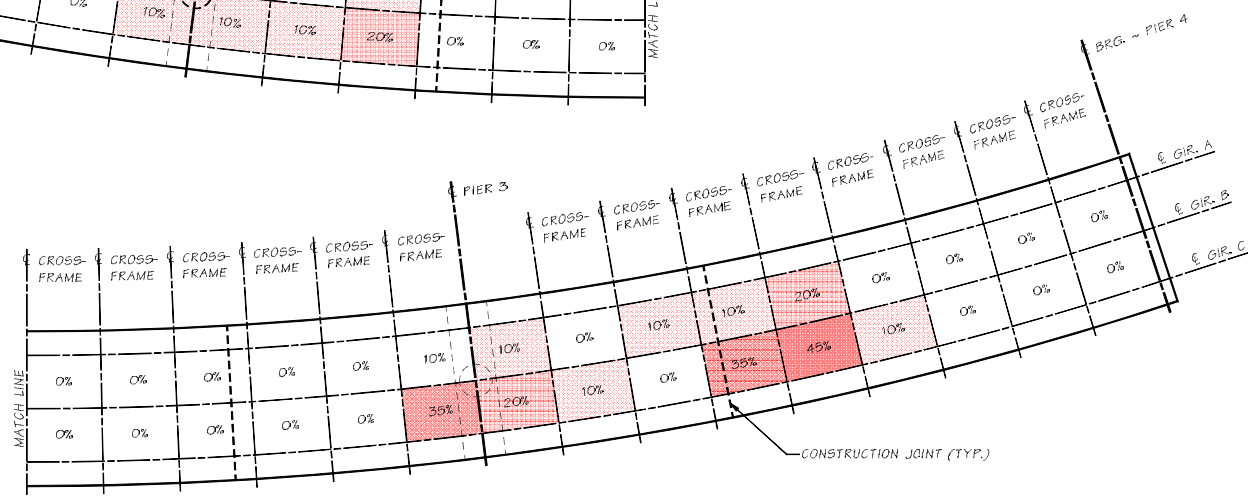
3-Span Steel Plate Girders

Bridge 9/134

3-Span Steel Plate Girders

LESS CRACKING — MORE CRACKING





Average Intensity = 7%

Bridge 9/134

3-Span Steel Plate Girders

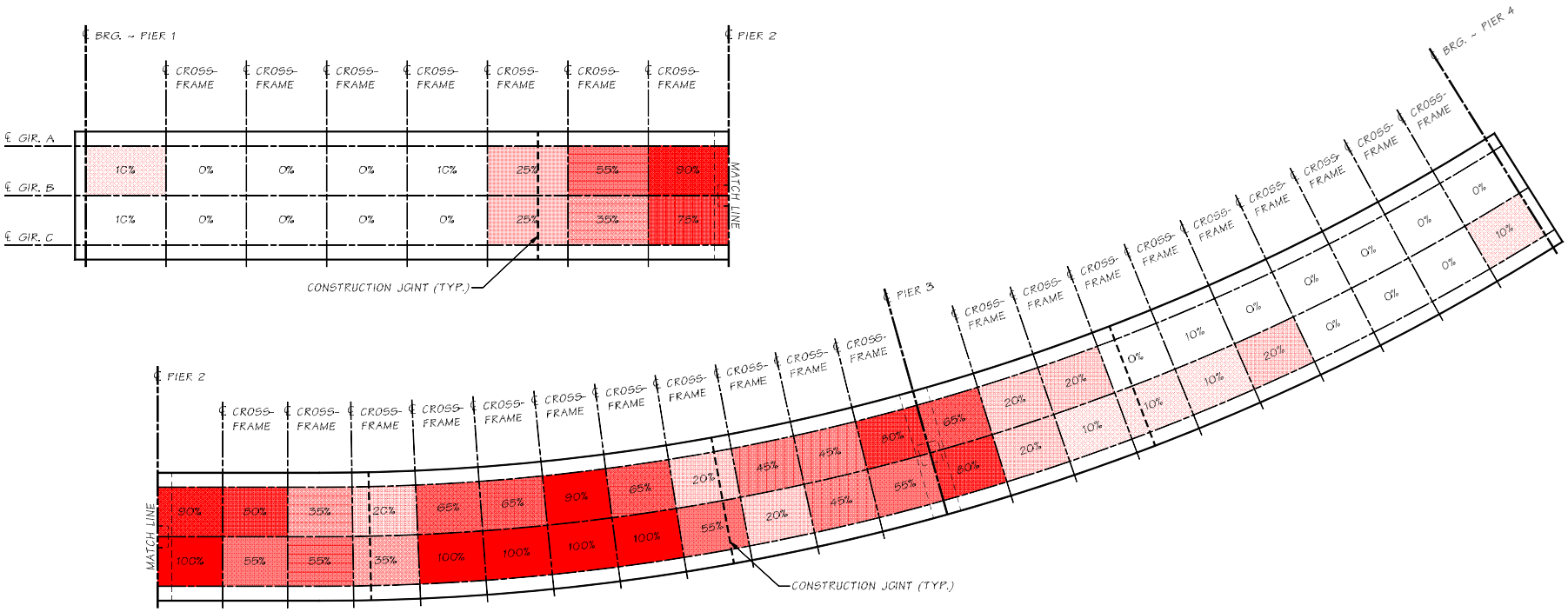
Bridge 5/434SCD

3-Span Steel Plate Girders

Bridge 5/434SCD

3-Span Steel Plate Girders

LESS CRACKING — MORE CRACKING



Average Intensity = 36%

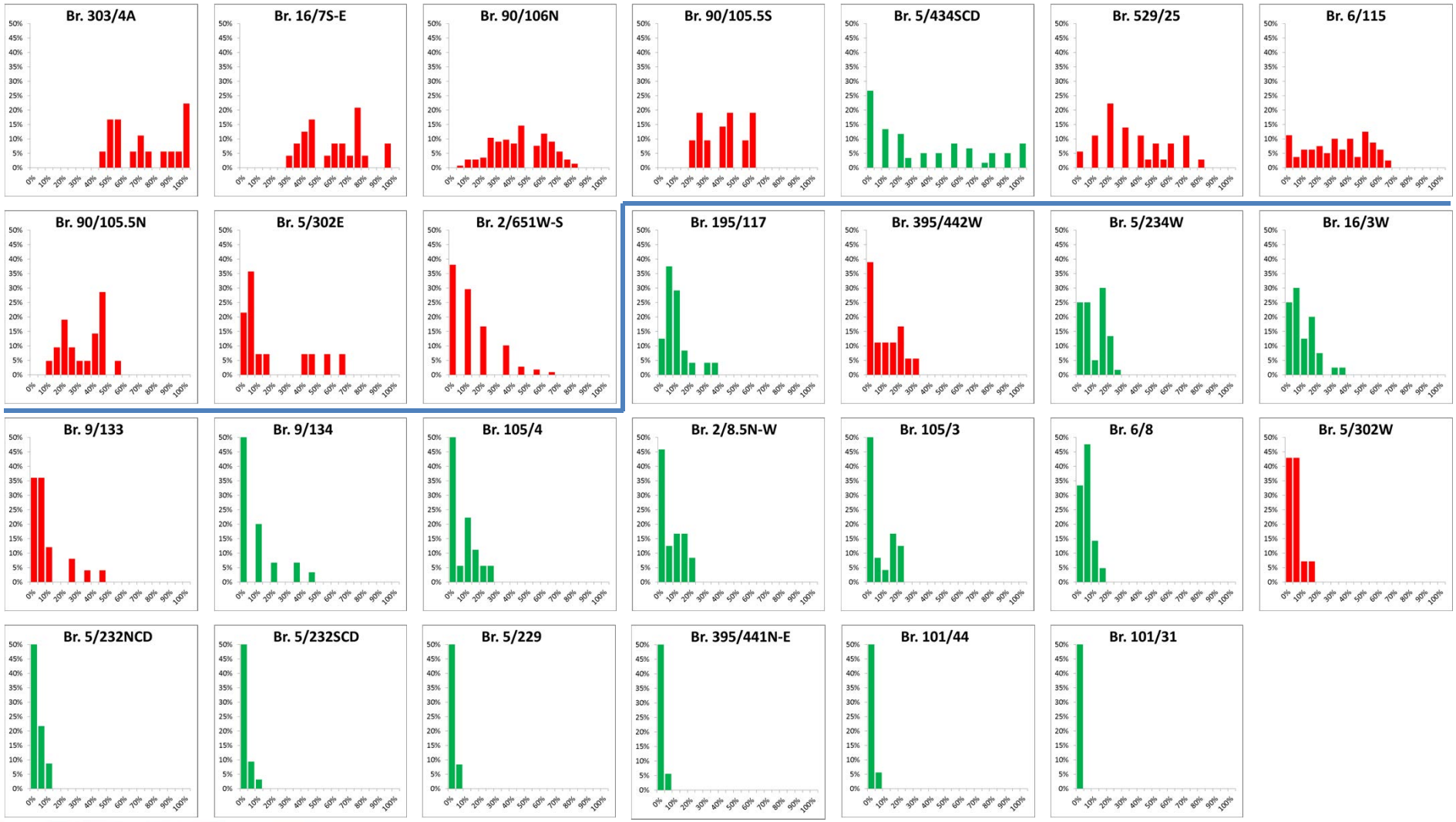
Bridge 5/434SCD

3-Span Steel Plate Girders

Summary

Br. No.	Bridge Name	Contract	Year	Perform.	Cement	Fly Ash	Microsilica	Total	Shrink.	Intensity
303/4A	MANETTE BRIDGE	7926	2011	No	660	75	--	735	--	73%
16/7S-E	S SPRAGUE RAMP	7594	2010	No	660	75	--	735	--	59%
90/106N	GOLD CREEK WB	7852	2012	No	660	75	--	735	--	44%
90/105.5S	GOLD CREEK ANIMAL CROSSING EB	7852	2010	No	660	75	--	735	--	40%
5/434SCD	SBCD OVER SR 16 HOV & RAMPS	8189	2013	Yes	480	85	--	565	0.028%	36%
529/25	EBEY SLOUGH	7948	2012	No	660	75	--	735	--	36%
6/115	S FORK CHEHALIS R	7587	2009	No	660	75	--	735	--	32%
90/105.5N	GOLD CREEK ANIMAL CROSSING WB	7852	2012	No	660	75	--	735	--	32%
5/302E	PRAIRIE CREEK NB	7465	2009	No	660	75	--	735	--	18%
2/651W-S	W-S RAMP OVER US 2/US 395	7610	2011	No	660	75	--	735	--	13%
195/117	CHENEY SPOKANE RD OVER US 195	8378	2014	Yes	---------- No Data Received ----------					10%
395/442W	US 395 OVER US 2	7610	2011	No	660	75	--	735	--	10%
5/234W	I-5 OVER BLAKESLEE JCT RR	8272	2013	Yes	464	116	--	580	0.030%	9%
16/3W	SR 16 OVER HOV	8189	2014	Yes	480	85	--	565	0.028%	9%
9/133	SR 9 OVER HARVEY CRK RD	7267	2008	No	660	75	--	735	--	8%
9/134	PILCHUCK CREEK	8383	2014	Yes	458	153	--	611	0.031%	7%
105/4	NORTH RIVER	8345	2014	Yes	460	150	--	610	0.018%	7%
2/8.5N-W	N-W RAMP (BICKFORD AVE) OVER US 2	8286	2013	Yes	480	90	10	580	0.032%	6%
105/3	SMITH CREEK	8345	2013	Yes	460	150	--	610	0.018%	6%
6/8	WILLAPA RIVER	8464	2014	Yes	460	150	--	610	0.018%	5%
5/302W	PRAIRIE CREEK SB	7465	2010	No	660	75	--	735	--	4%
5/232NCD	SKOOKUMCHUCK RIVER NCD	8272	2013	Yes	464	116	--	580	0.030%	2%
5/232SCD	SKOOKUMCHUCK RIVER SCD	8272	2013	Yes	464	116	--	580	0.030%	1%
5/229	MELLON STREET COUPLET	8473	2014	Yes	464	116	--	580	0.028%	< 1%
395/441N-E	N-E RAMP OVER N-N RAMP	7610	2011	Yes	435	130	--	565	0.034%	< 1%
101/44	BONE RIVER	8292	2013	Yes	460	150	--	610	0.018%	< 1%
101/31	MIDDLE NEMAH RIVER	8344	2014	Yes	460	150	--	610	0.018%	0%

Summary


Br. 303/4A
Br. 16/7S-E
Br. 90/106N
Br. 90/105.5S
Br. 5/434SCD
Br. 529/25
Br. 6/115
Br. 90/105.5N
Br. 5/302E
Br. 2/651W-S
Br. 195/117
Br. 395/442W
Br. 5/234W
Br. 16/3W
Br. 9/133
Br. 9/134
Br. 105/4
Br. 2/8.5N-W
Br. 105/3
Br. 6/8
Br. 5/302W
Br. 5/232NCD
Br. 5/232SCD
Br. 5/229
Br. 395/441N-E
Br. 101/44
Br. 101/31

Summary

Possible areas of change to current performance based specification:

- Improve shrinkage limit language to get more uniform shrinkage test reports
- Show locations of temperature sensors in contract plans
- Add a internal concrete temperature limit or temperature difference limit between concrete and air
- Add requirement for temperature measurement during mix design phase to get a better idea of temperature behavior before placing concrete

Summary

Miscellaneous Observations

- Concrete densities resulting from the performance based specification range between 140 pcf and 150 pcf. Current design practice assumes a reinforced concrete unit weight of 155 pcf.
- Cracking of the bridge deck is variable within same bridge. Sometimes it appears to be variable within the same concrete placement.

Summary

In general, the current performance based concrete specification results in fewer restraint cracks than the traditional concrete specification.

A few of the traditional bridge decks performed similar to the performance based bridge decks, but this appears to be the exception, not the rule.

Only one of the performance based concrete decks had a high intensity of cracking. It is unclear what contributed to the poor performance of this particular bridge deck.