Fire Damage Inspection and Analysis for a Prestressed Concrete Girder Bridge

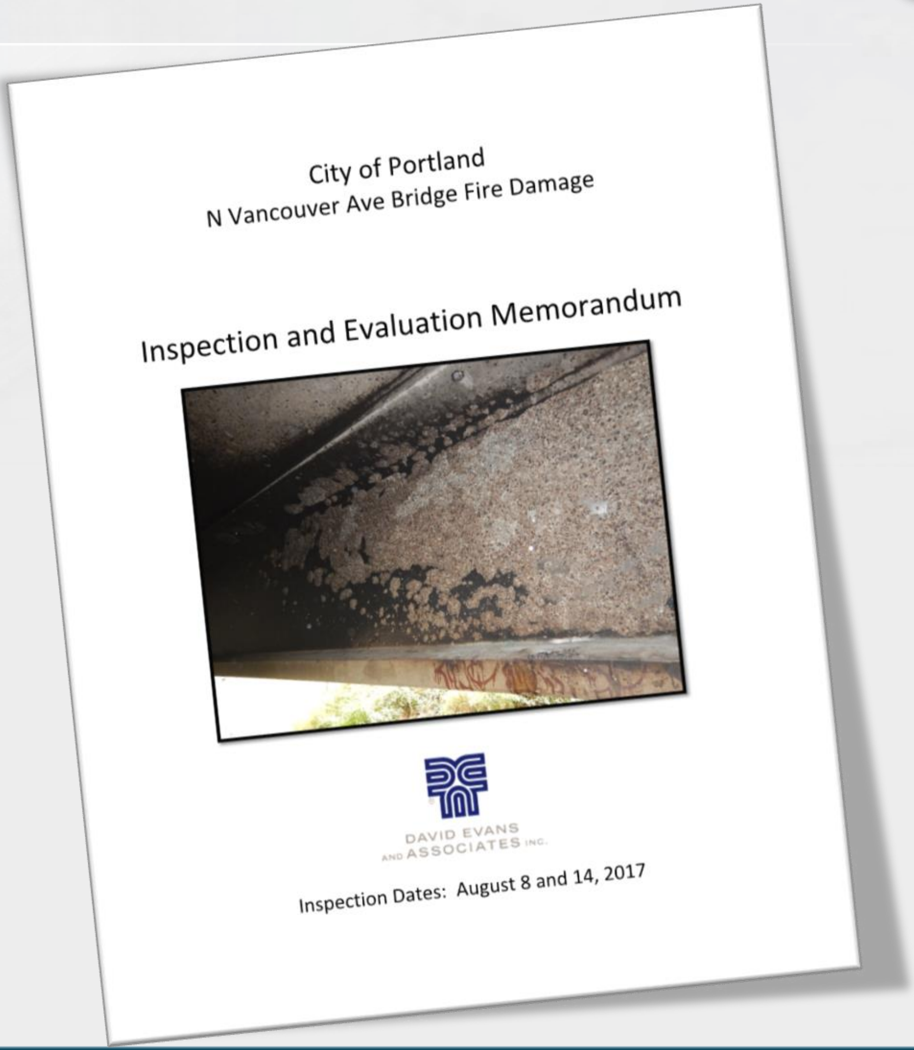
Matthew Harlan, PE
David Evans and Associates, Inc.

NATIONAL BRIDGE PRESERVATION PARTNERSHIP CONFERENCE 2018
PRACTICES WE CAN NOT AFFORD TO DEFER

Presentation Outline

DAVID EVANS AND ASSOCIATES INC.

- Introduction
- Research Findings
- Inspection
- Analysis
- Conclusions
- Questions


City of Portland
N Vancouver Ave Bridge Fire Damage

Inspection and Evaluation Memorandum

DAVID EVANS AND ASSOCIATES INC.

Inspection Dates: August 8 and 14, 2017

Introduction

- N. Vancouver Ave. over Columbia Slough
- Portland, OR
- 3-Span Prestressed BT72 girders with CIP Concrete Deck
- Built in 2011
- Large transient camps were present at both abutments
- Current bridge replaced an existing 14-span timber bridge
- The original bridge was severely damaged by a transient fire

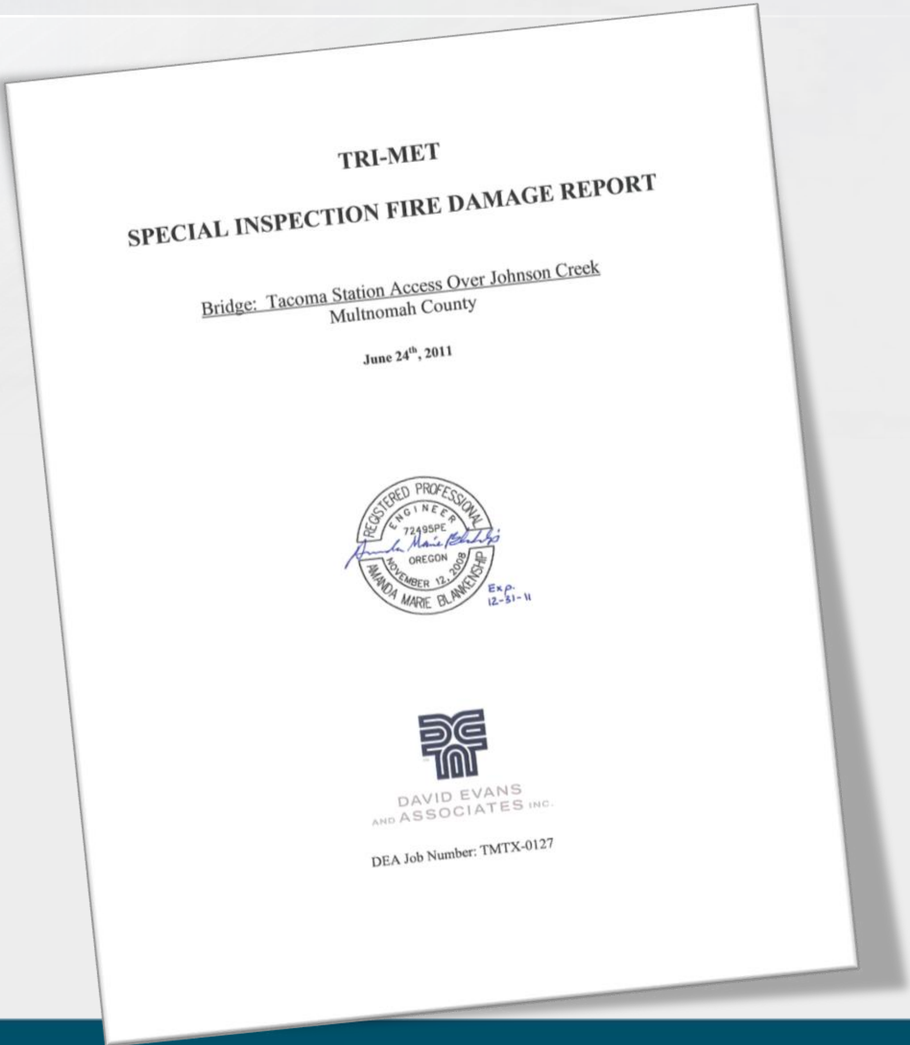
Introduction

Introduction

Introduction

Research Findings

- Special Inspection Fire Damage Report
- Amanda Blankenship (DEA) 6/24/2011
- Tacoma Station Access Over Johnson Creek, Portland, OR



TRI-MET

SPECIAL INSPECTION FIRE DAMAGE REPORT

Bridge: Tacoma Station Access Over Johnson Creek
Multnomah County

June 24th, 2011

REGISTERED PROFESSIONAL ENGINEER
72495PE
OREGON
NOVEMBER 12, 2008
AMANDA MARIE BLANKENSHIP
Exp. 12-31-11

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DEA Job Number: TMTX-0127

Research Findings

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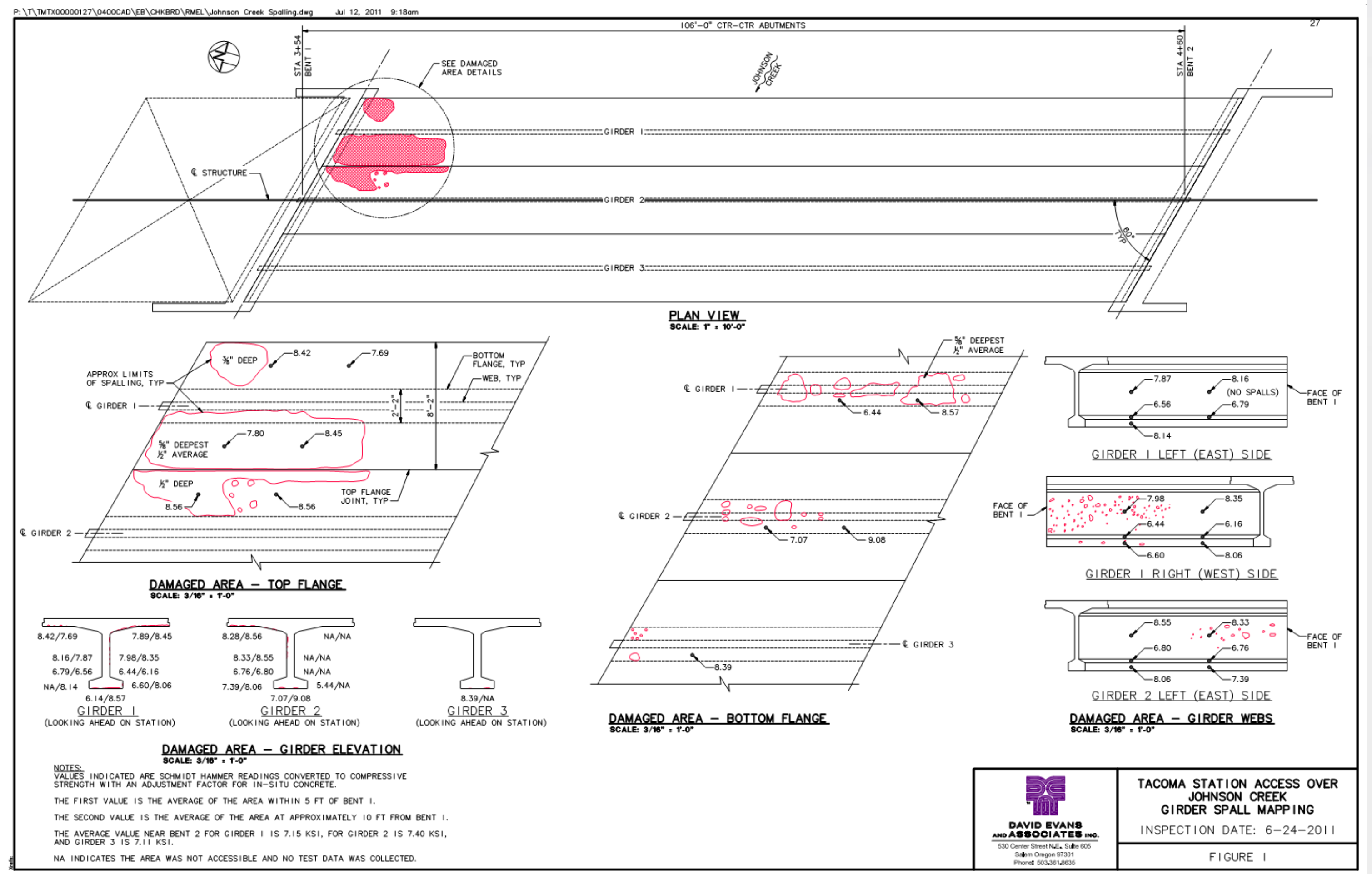
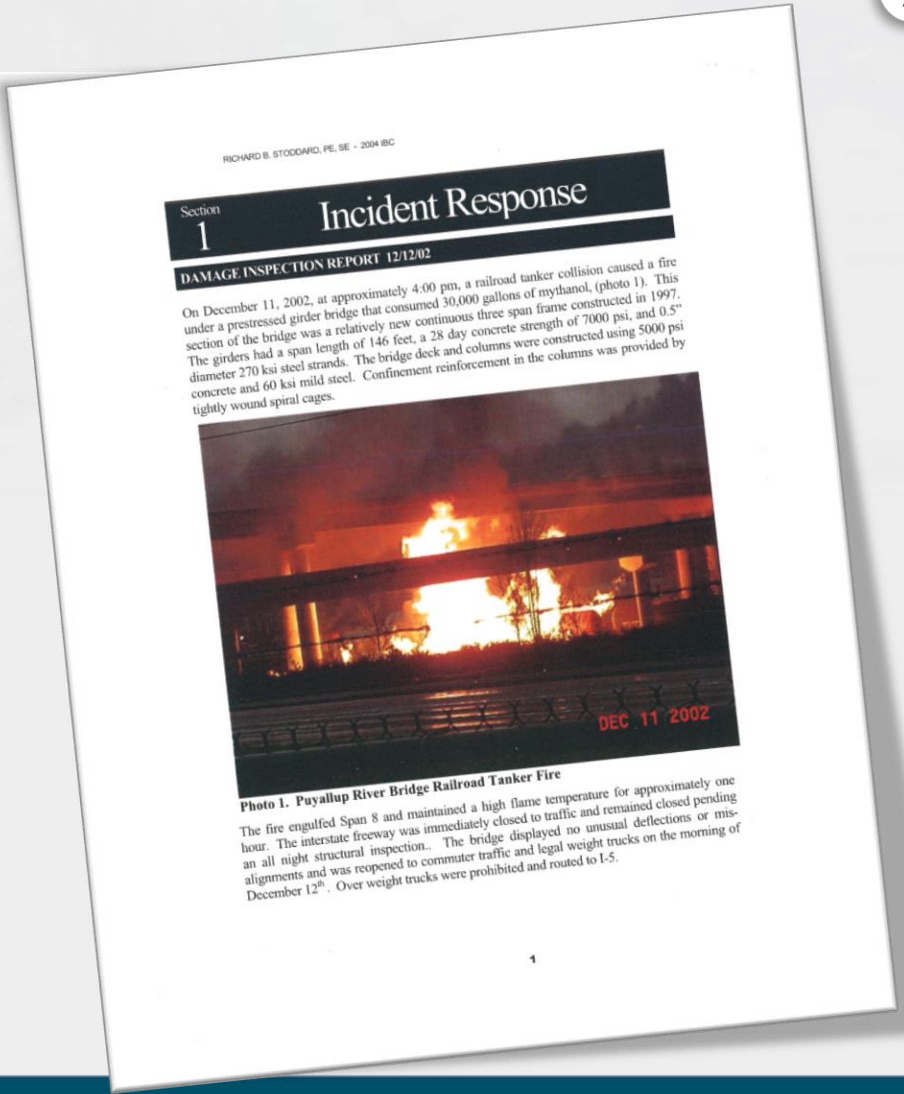


Research Findings

Research Findings

- Inspection and Repair of a Fire Damaged Prestessed Girder Bridge
- By Richard Stoddard (WSDOT), 12/12/2002
- Puyallup River Bridge, Tacoma, WA
- 2004 International Bridge Conference



RICHARD B. STODDARD, PE, SE - 2004 IBC

Section 1 **Incident Response**

DAMAGE INSPECTION REPORT 12/12/02

On December 11, 2002, at approximately 4:00 pm, a railroad tanker collision caused a fire under a prestressed girder bridge that consumed 30,000 gallons of mythanol, (photo 1). This section of the bridge was a relatively new continuous three span frame constructed in 1997. The girders had a span length of 146 feet, a 28 day concrete strength of 7000 psi, and 0.5" diameter 270 ksi steel strands. The bridge deck and columns were constructed using 5000 psi concrete and 60 ksi mild steel. Confinement reinforcement in the columns was provided by tightly wound spiral cages.

DEC 11 2002

Photo 1. Puyallup River Bridge Railroad Tanker Fire

The fire engulfed Span 8 and maintained a high flame temperature for approximately one hour. The interstate freeway was immediately closed to traffic and remained closed pending an all night structural inspection.. The bridge displayed no unusual deflections or mis-alignments and was reopened to commuter traffic and legal weight trucks on the morning of December 12th. Over weight trucks were prohibited and routed to I-5.

1

Research Findings

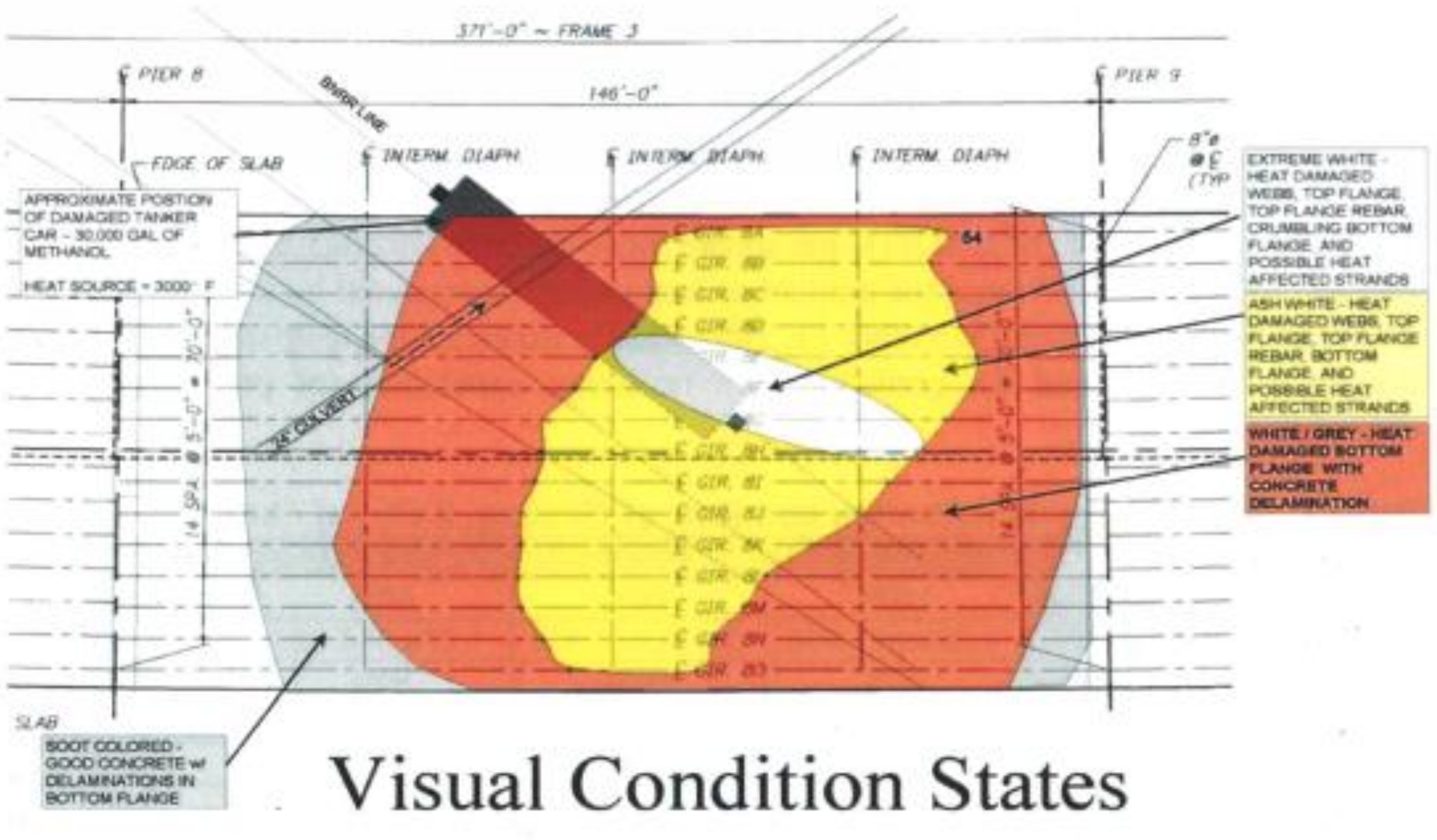


Figure 3. Bottom Flange Visual Condition States

Research Findings

- Design for Fire Resistance of Precast Prestressed Concrete
- PCI, 1989

Table 9.1 Melting Points of Some Common Materials

Material	Approximate Melting Temperature, °F
Polyethylene	230 to 250
Lead	620
Zinc	790
Aluminum alloys	900 to 1200
Aluminum	1200
Glass	Softens at 1100 to 1350
Silver	1760
Brass and Bronze	1600 to 1800
Copper	1980
Cast Iron	2100 to 2500
Steel	2550 +

It is sometimes possible to determine the temperatures to which concrete was heated by its color. Concrete which has been heated and then cooled and is not discolored probably was not heated above about 600°F. If the concrete has become pink, it may have been heated to a temperature between about 600°F and 1100°F. Concrete heated above 1100°F and then cooled tends to become a whitish-gray, and above 1700°F some concretes turn to a buff color.

Prestressing steel that has been heated to temperatures below about 750°F and then cooled retains its room temperature strength. If the steel is heated 900°F and then is cooled retains about 70% of its room temperature strength while prestressing steel heated to 1100°F and then cooled retains about half its original strength. Reinforcing bars and welded wire fabric heated to temperatures below about 900°F and then cooled retain their original strength. Yield strengths of bars heated to temperatures between 900°F and 1400°F are reduced up to about 30%.[82] If steel is directly exposed to fire and is quenched with water, the steel's ductility may be adversely affected. Thus if there is a question about ductility, representative samples of bars should be tested and stress-strain diagrams obtained.

In severe fires, significant distortion of columns, walls, and beams can occur. Concrete in the heated area tends to expand and push against adjoining construction. The investigator should note such distortions. A structural engineer should then determine if the distortions have affected the structural serviceability of the affected members.

Load tests of slightly damaged units are sometimes warranted to aid in assessing the extent of fire damages. Such tests can be time-consuming and expensive but the results of carefully controlled and monitored tests are reliable especially if there is some doubt as to the behavior of the unit under load.

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Research Findings

- Proper use of the Rebound Hammer
- By Cemex, 2013
- ASTM C805-13 is the standard test method

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CEMEX USA - Technical Bulletin **2.1**

Proper use of the Rebound Hammer
Updated to reflect the changes to ASTM C805

The Rebound Hammer has been around since the late 1940's and today is a commonly used method for estimating the compressive strength of in-place concrete. Developed in 1948 by a Swiss engineer named Ernst Schmidt, the device measures the hardness of concrete surfaces using the rebound principle. The device is often referred to as a Swiss Hammer.

The Swiss Hammer, at times, is not used properly. This usually happens when someone attempts to solely use the rebound values obtained and the correlation chart provided by the equipment producer to determine the compressive strength of the concrete. The ASTM standard test method has been revised several times in recent years and the current revision of the document is ASTM C805-13, Standard Test Method for Rebound Number of Hardened Concrete.

How does it work?

ASTM C805, "Standard Test Method for Rebound Number of Hardened Concrete", summarizes the procedure as "A steel hammer impacts, with a predetermined amount of energy, a steel plunger in contact with a surface of concrete, and the distance that the hammer rebounds is measured."

The device consists of a plunger rod and an internal spring loaded steel hammer and a latching mechanism. When the extended plunger rod is pushed against a hard surface, the spring connecting the hammer is stretched and when pushed to an internal limit, the latch is released causing the energy stored in the stretched spring to propel the hammer against the plunger tip. The hammer strikes the shoulder of the plunger rod and rebounds a certain distance. There is a slide indicator on the outside of the unit that records the distance traveled during the rebound. This indication is known as the rebound number. By pressing the button on the side of the unit, the plunger is then locked in the retracted position and the rebound number (R-number) can be read from the graduated scale. A higher R-number indicates a greater hardness of the concrete surface.

The tests can be performed in horizontal, vertically upward, vertically downward or any intermediate angled positions in relation to the surface (Figs 1 and 2). The devices are furnished with correlation curves by the manufacturer. ASTM C805 now states that these references to the relationship between the rebound number and compressive strength provided by the manufacturer "*shall be used only to provide indications of relative concrete strength at different locations in a structure.*" To obtain greater accuracy of test results, it is

Research Findings

Inspection

- Pre-Inspection Photos
- Chalk / Wax Marker Lines
- Area and Depth Mapping
- Concrete Color
- Sounding
- Crack Inspection
- Soot Mapping
- Damage Mapping

- Schmidt Hammer Testing
  - Determining testing locations
  - Performing testing

Inspection

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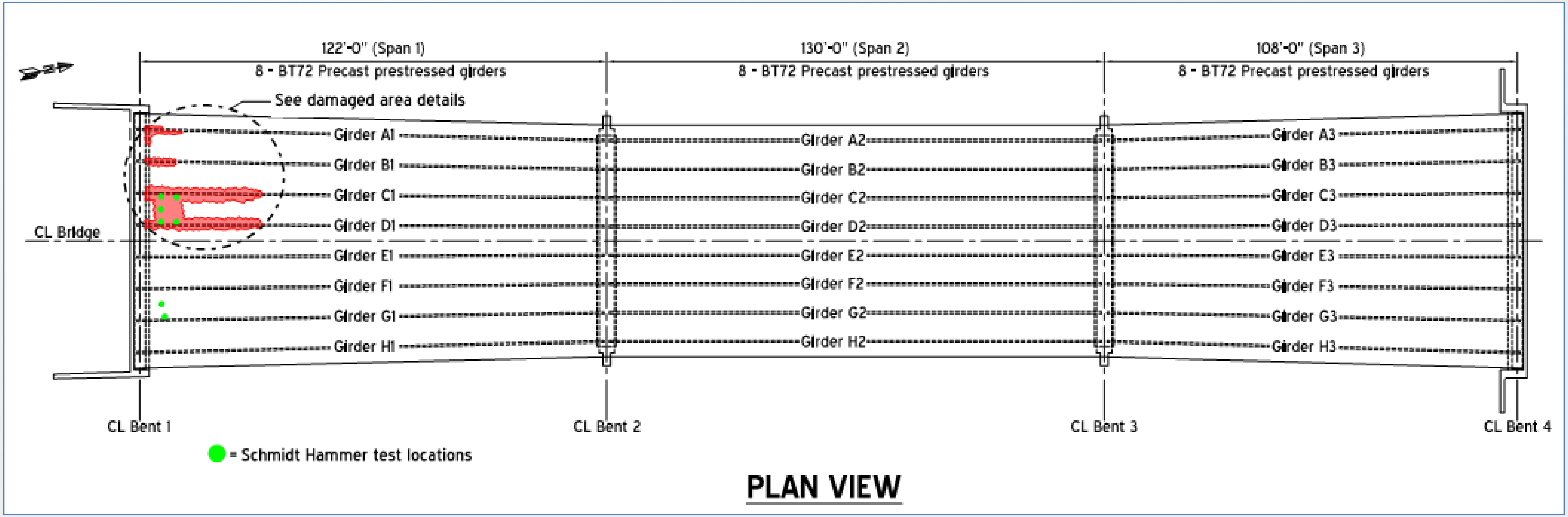
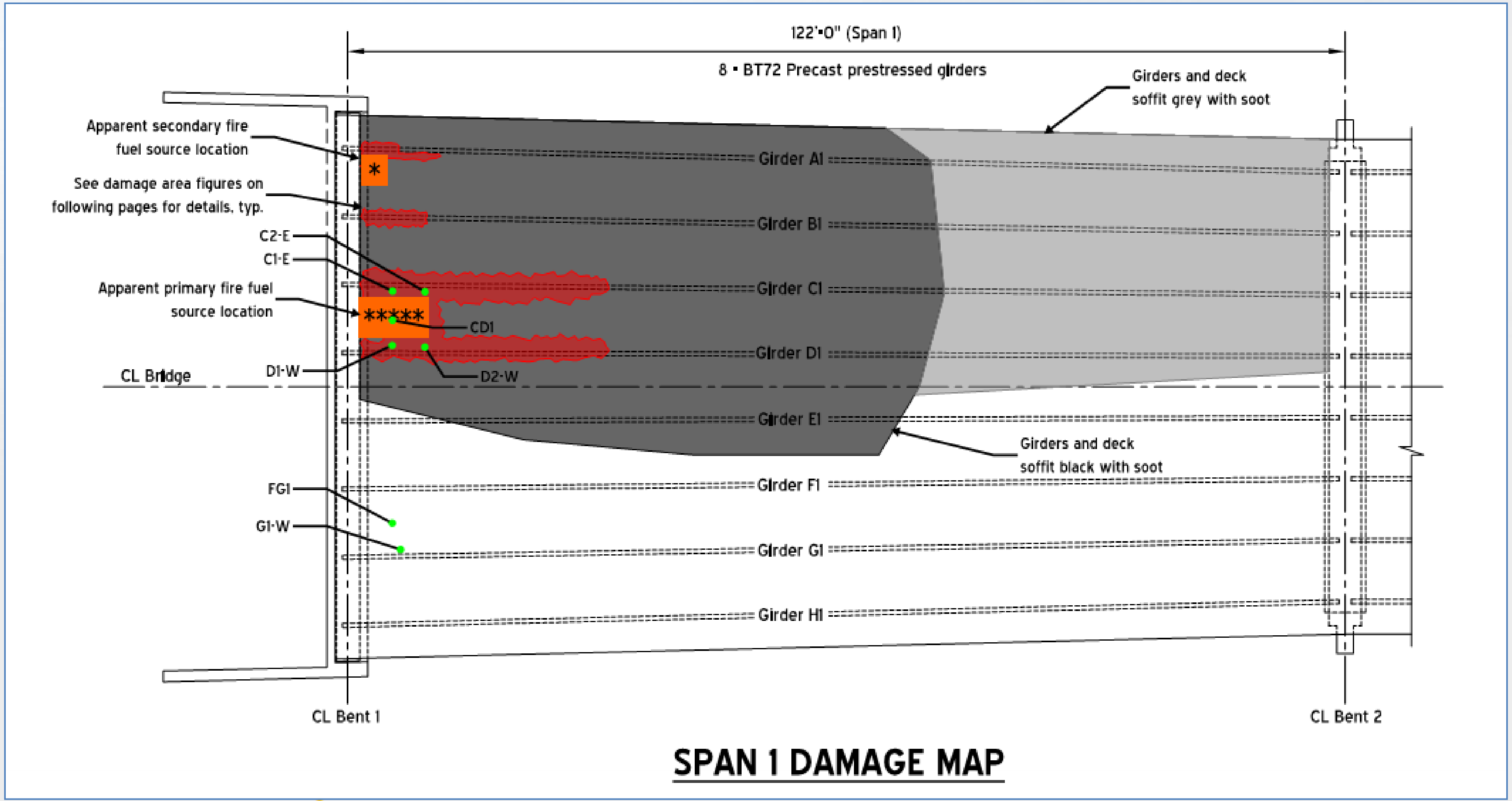
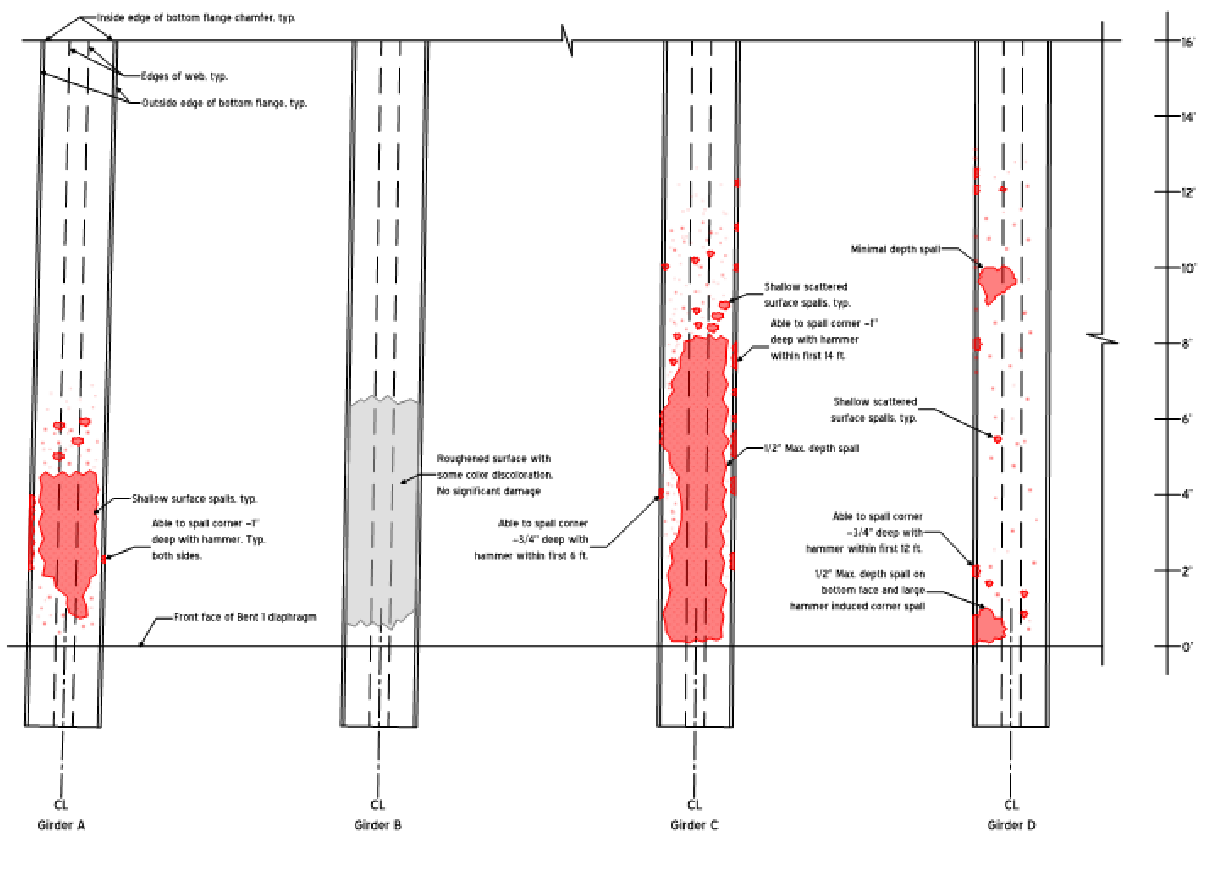


Inspection


122'-0" (Span 1)
8 - BT72 Precast prestressed girders
Girders and deck soffit grey with soot
Apparent secondary fire fuel source location
See damage area figures on following pages for details, typ.
C2-E
C1-E
Apparent primary fire fuel source location
CD1
D1-W
D2-W
CL Bridge
Girder A1
Girder B1
Girder C1
Girder D1
Girder E1
Girder F1
Girder G1
Girder H1
Girders and deck soffit black with soot
FG1
G1-W
CL Bent 1
CL Bent 2
SPAN 1 DAMAGE MAP

Inspection



DAMAGED AREA - BOTTOM FACE OF BOTTOM FLANGE
(Looking up)

Inspection

Inspection

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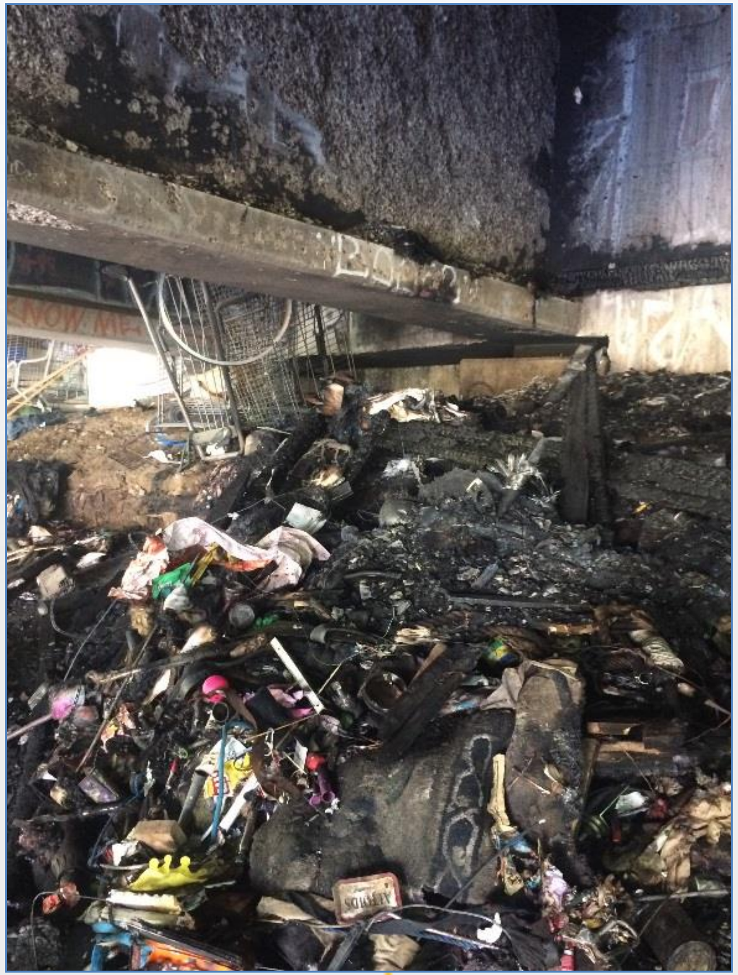
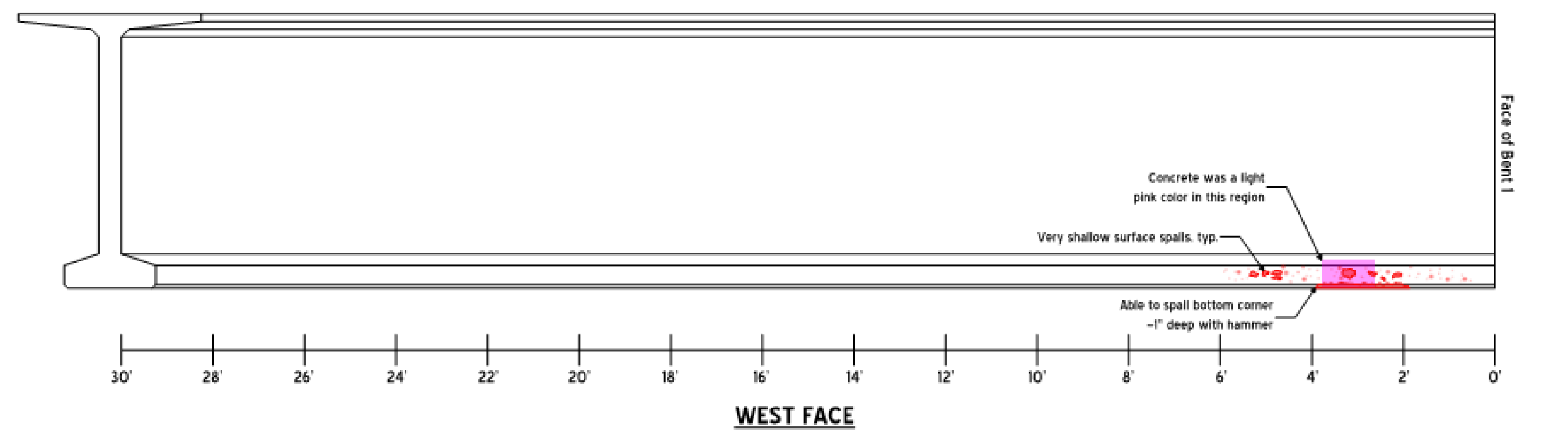
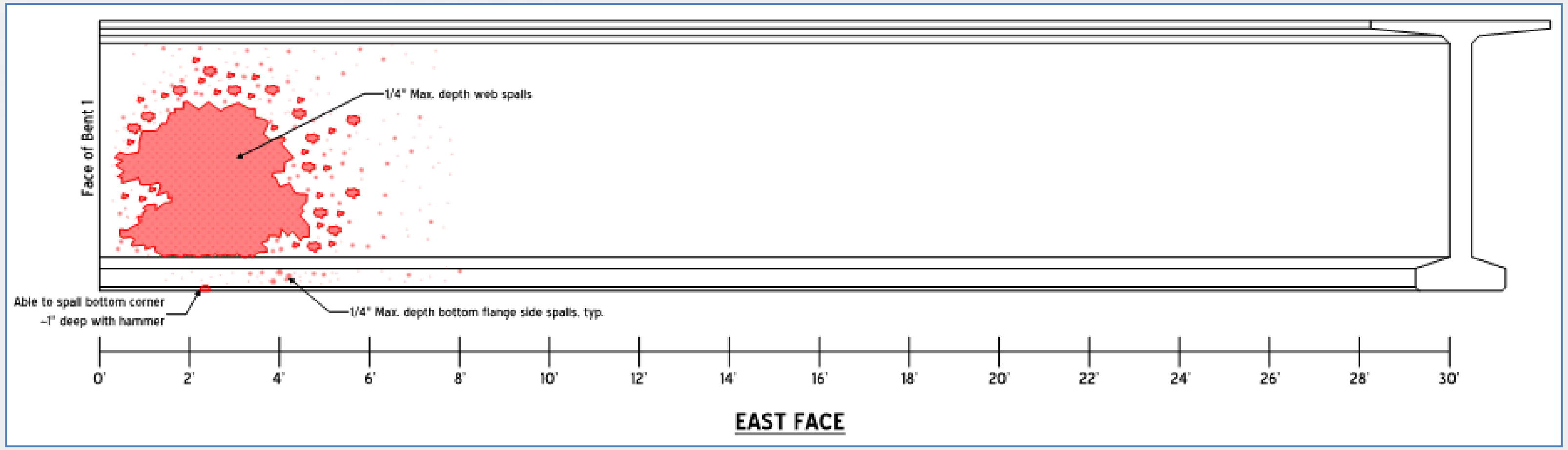


Inspection – Girder A

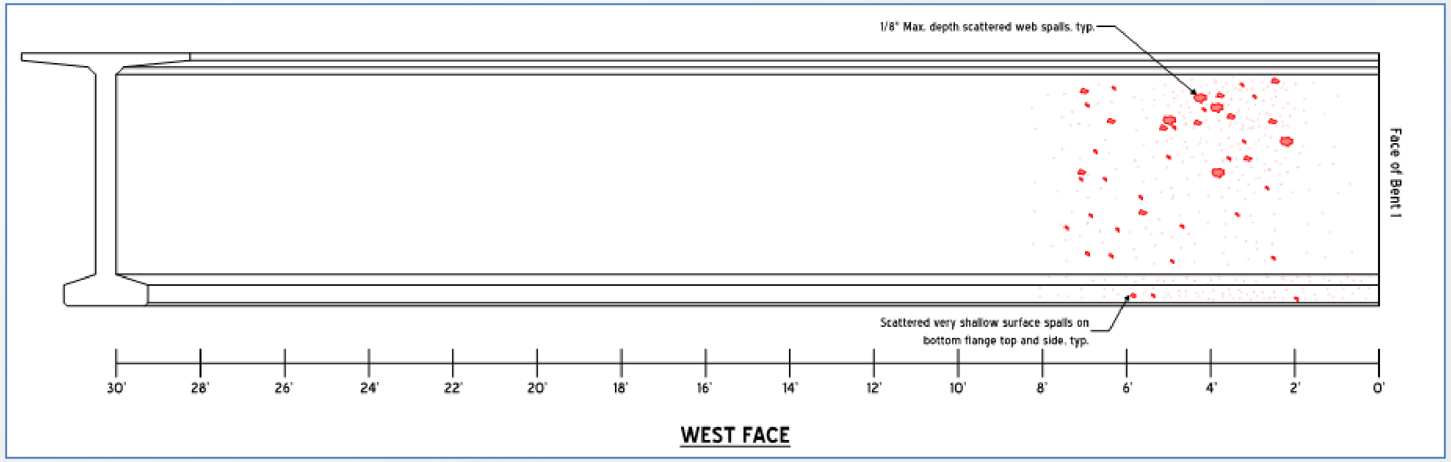


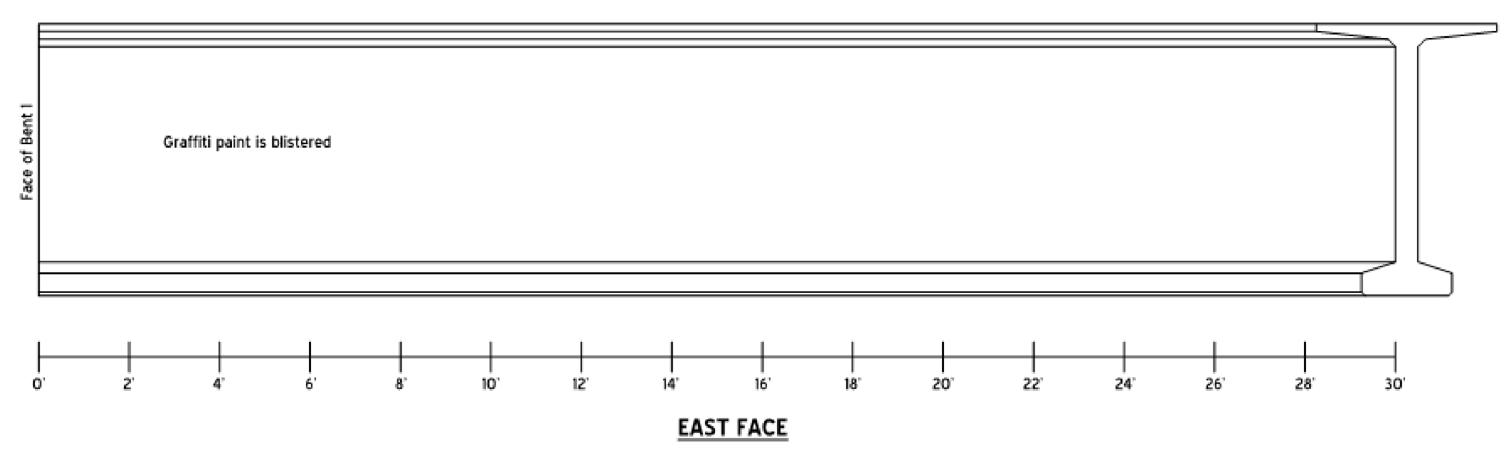


Inspection – Girder A

Inspection – Girder A

Inspection – Girder B





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Inspection – Girder C

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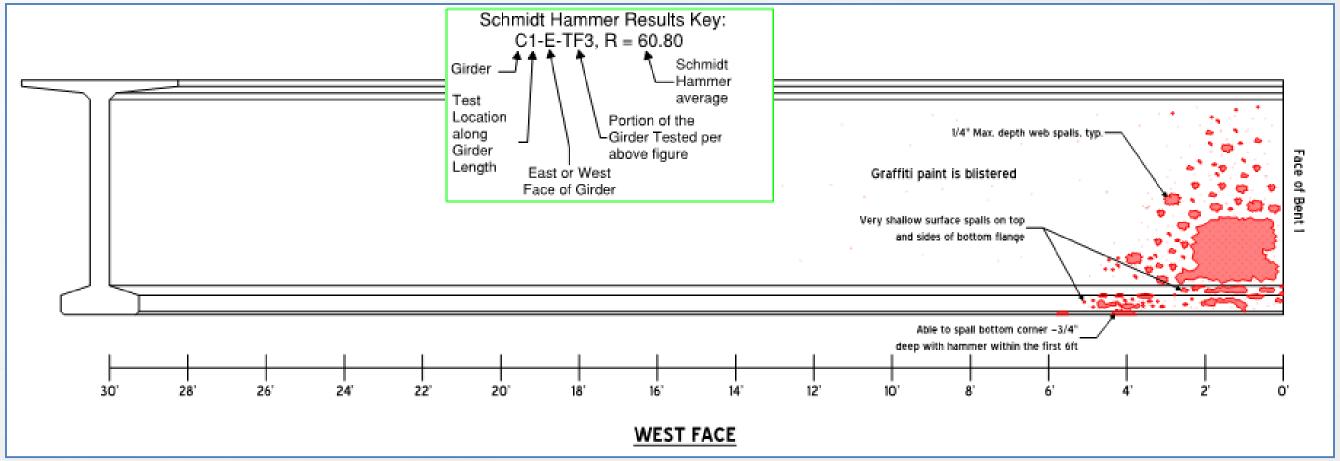
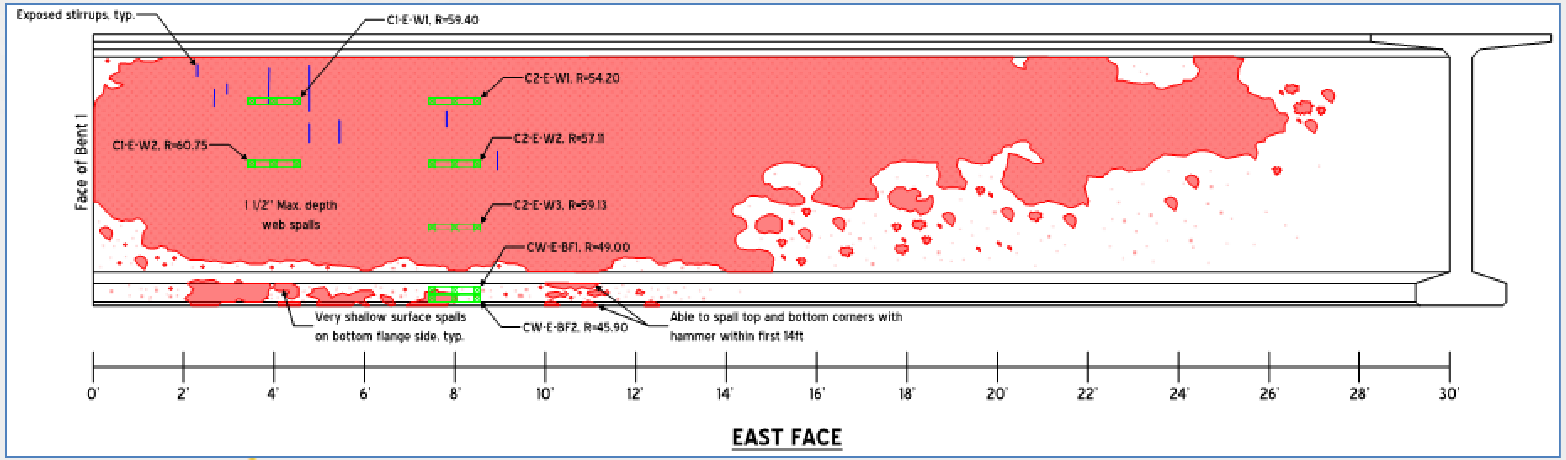
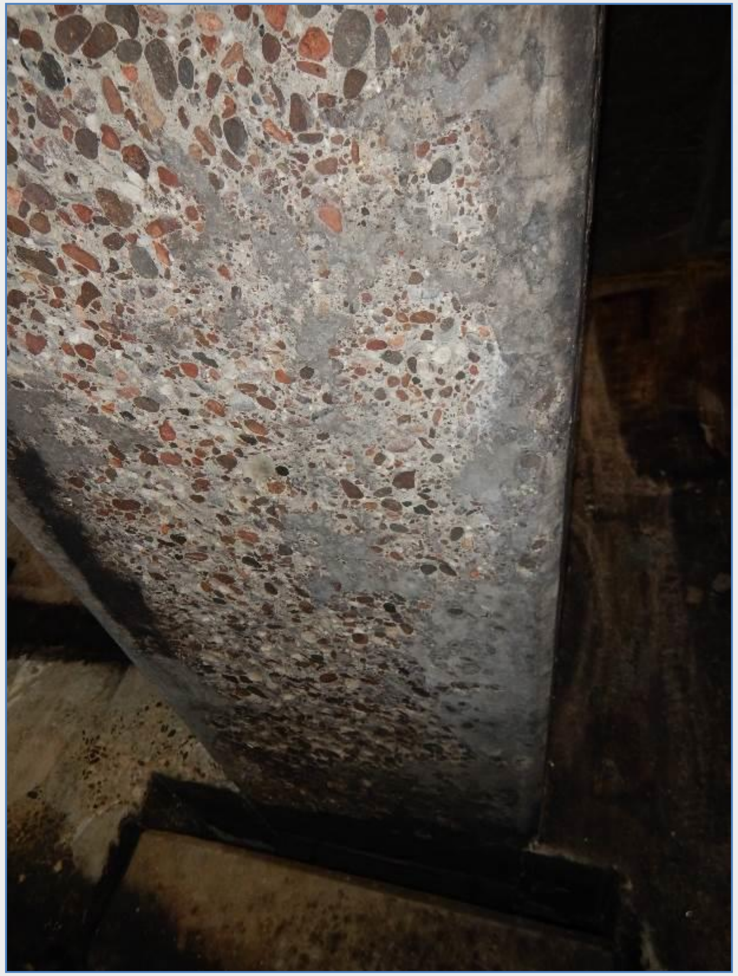




Inspection – Girder C

Inspection – Girder C



Inspection – Girder C

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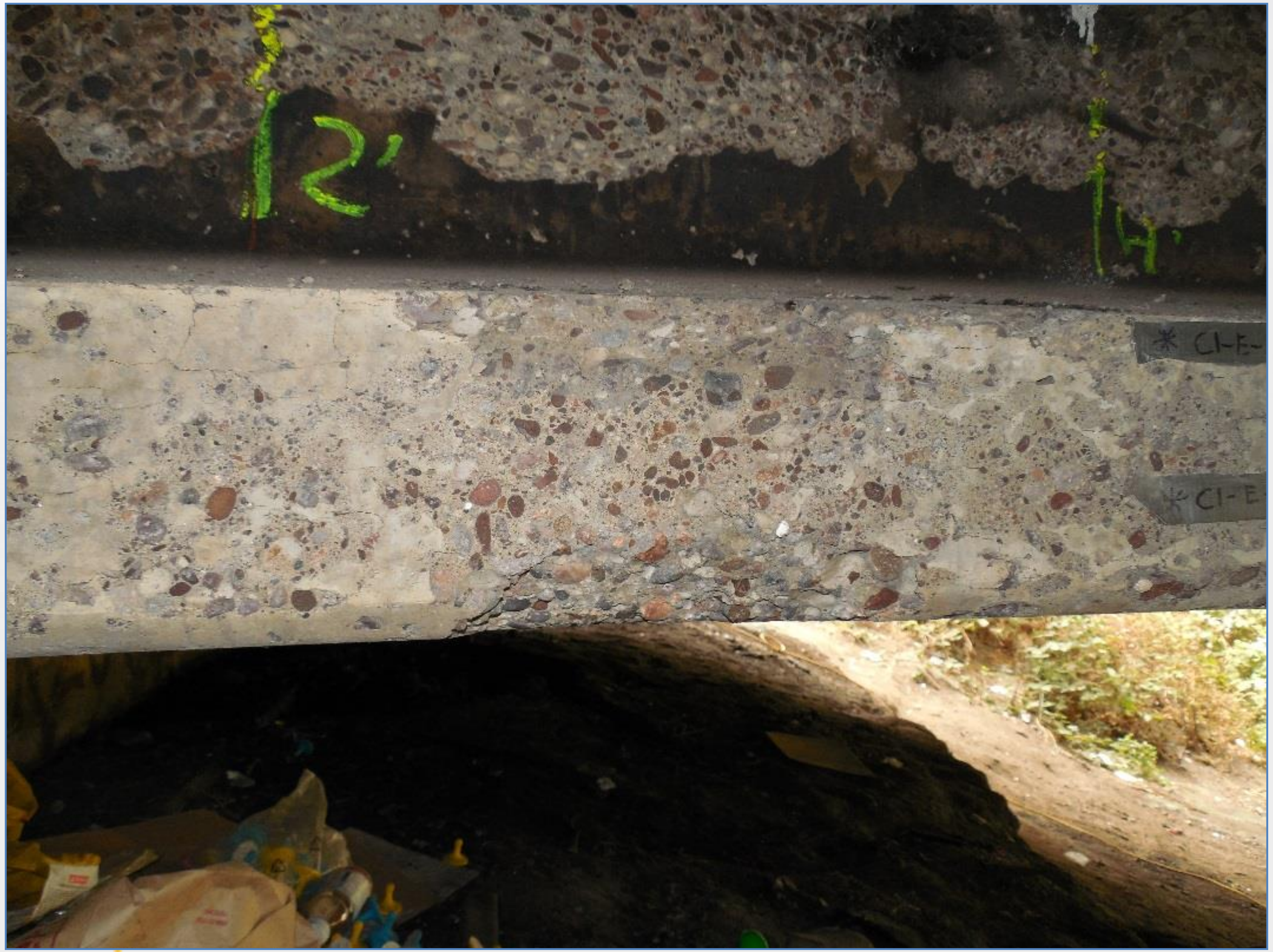


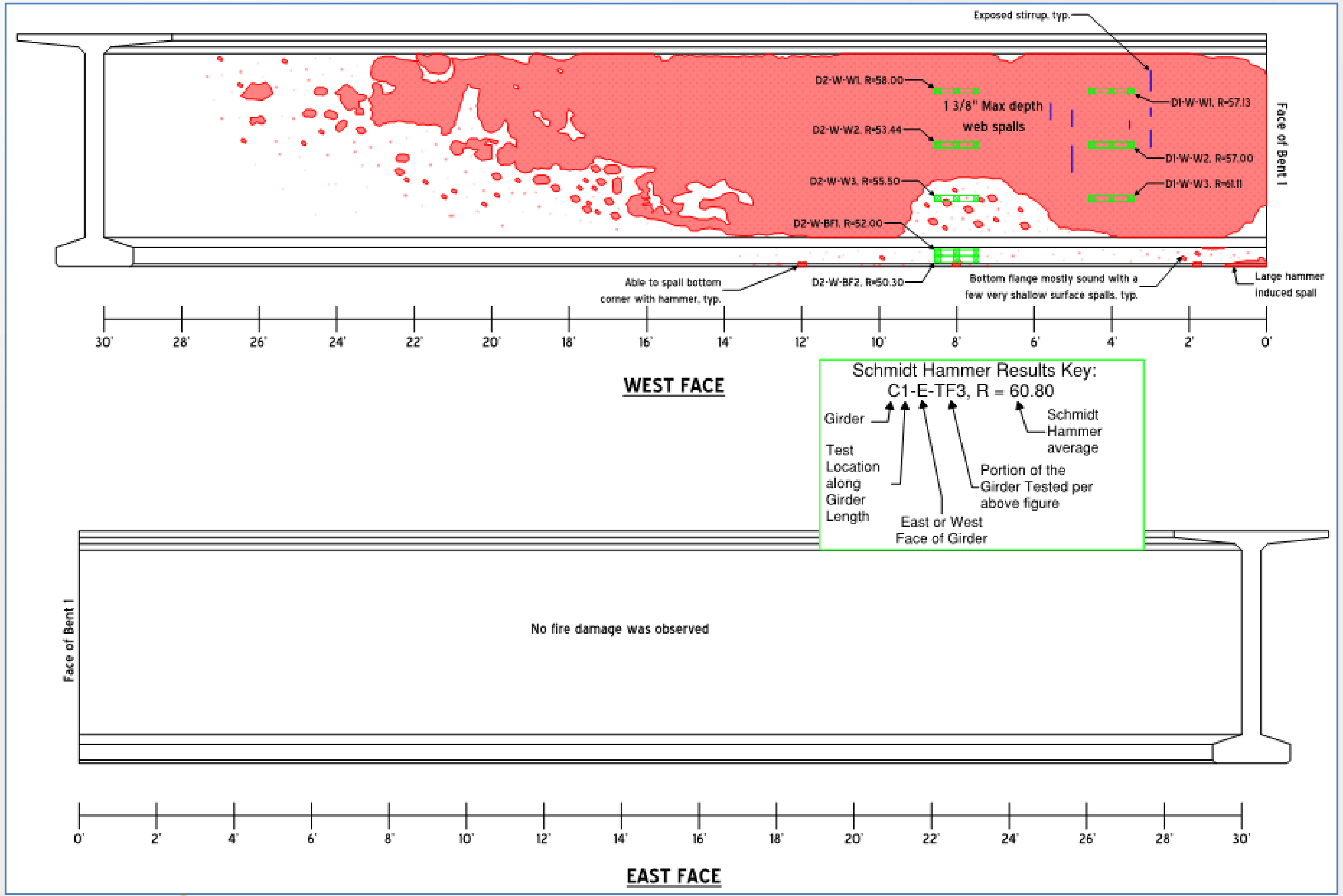
Inspection – Girder C

Inspection – Girder C

Inspection – Girder C

Inspection – Girder C

Inspection – Girder D



Inspection – Girder D

Inspection – Girder D

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Inspection – Girder D

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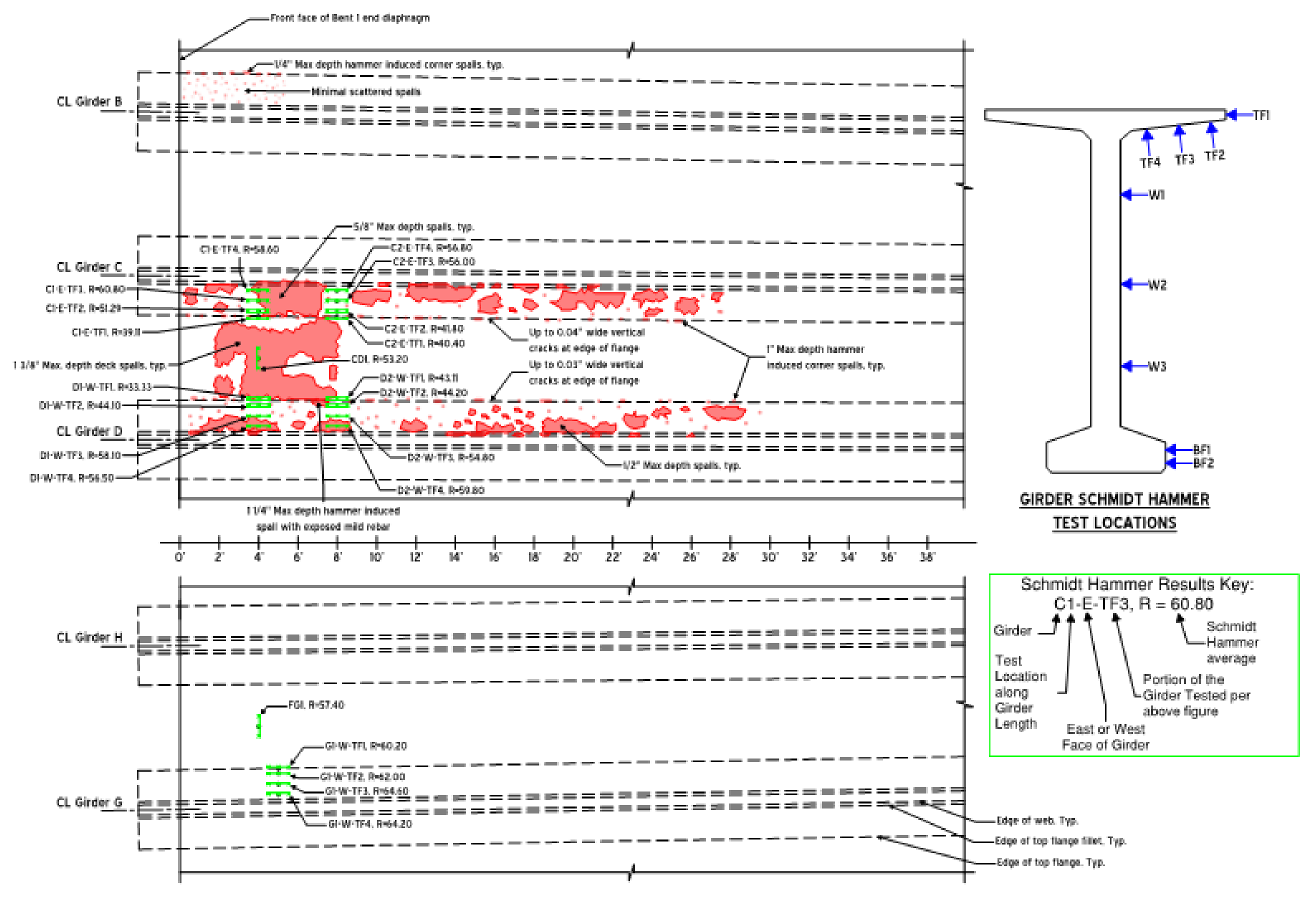
Inspection – Girder D

Inspection



DAMAGED AREA - TOP FLANGE

Inspection

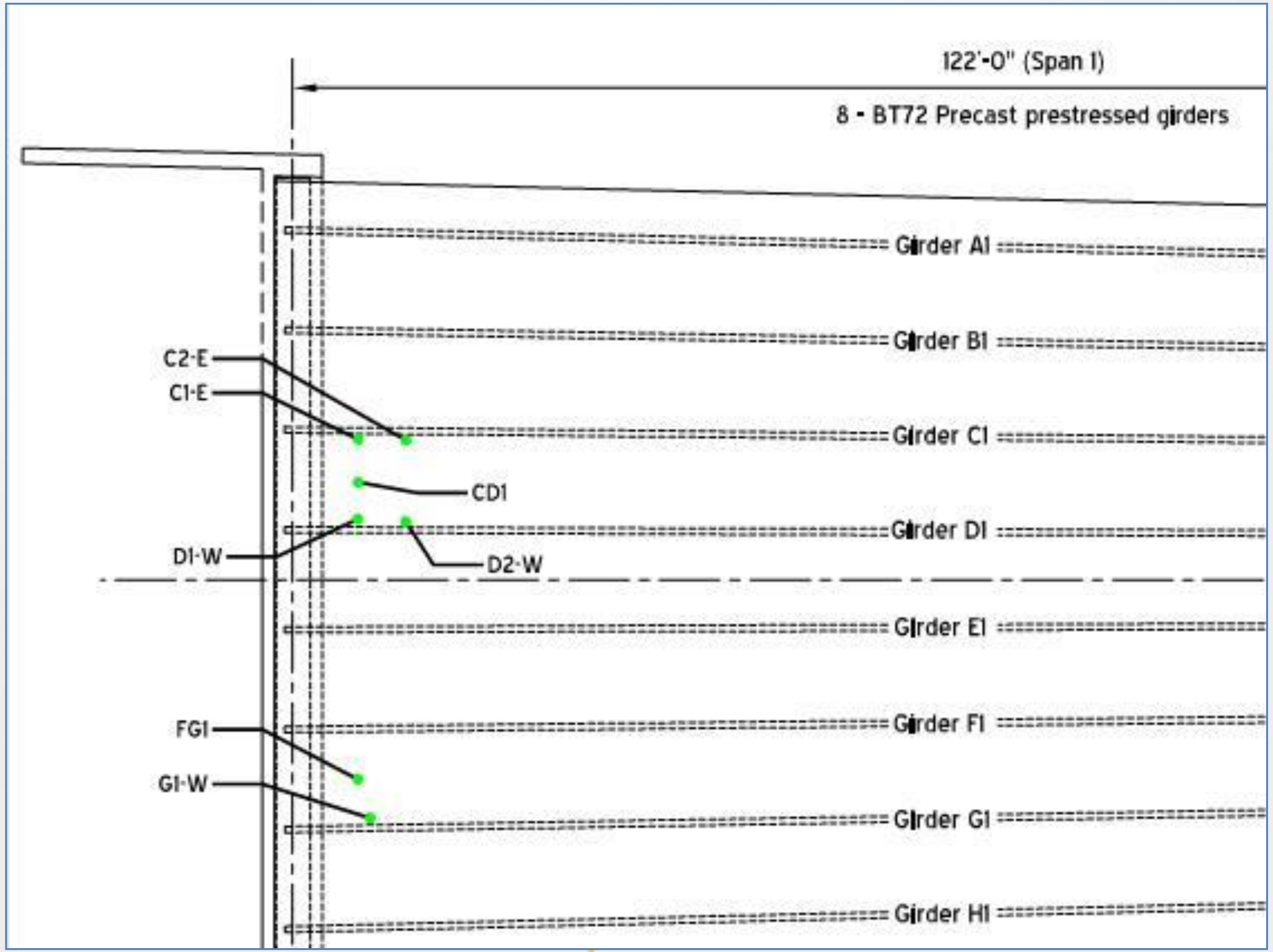
Inspection

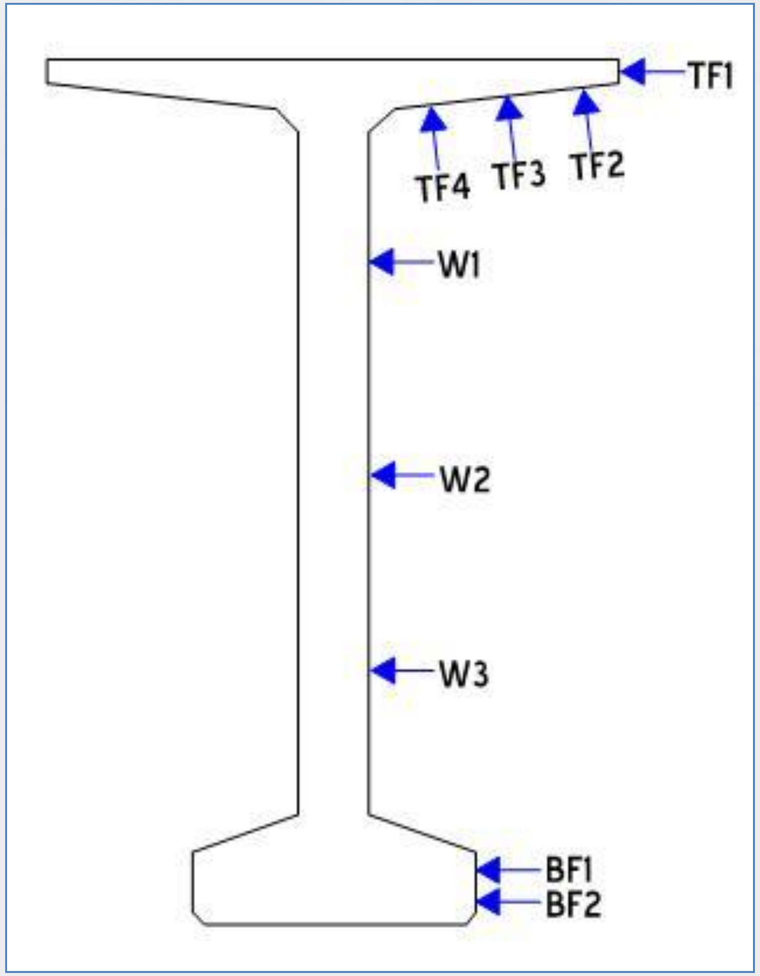
Inspection

Inspection – Testing

- Northwest Geotech, Inc. / Northwest Testing, Inc.
- Bottom flange, web, top flange, and deck
  - Damaged girders and a non-damaged girder
- Results were used to investigate any loss of concrete compressive strength of the fire damaged areas

Inspection – Testing





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Inspection – Testing

Analysis

- Procedure Summary
- Schmidt Hammer Correlation
- Section Properties
- Shear Capacity
- Moment Capacity
- Service Checks (Stresses)
- Deck Capacity

Analysis

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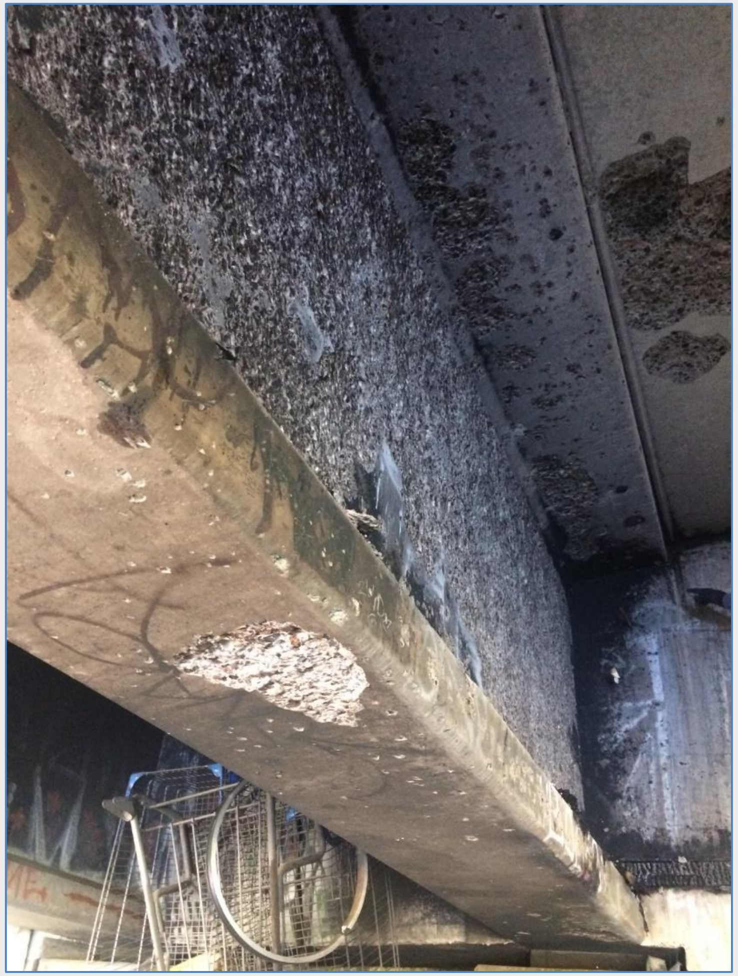
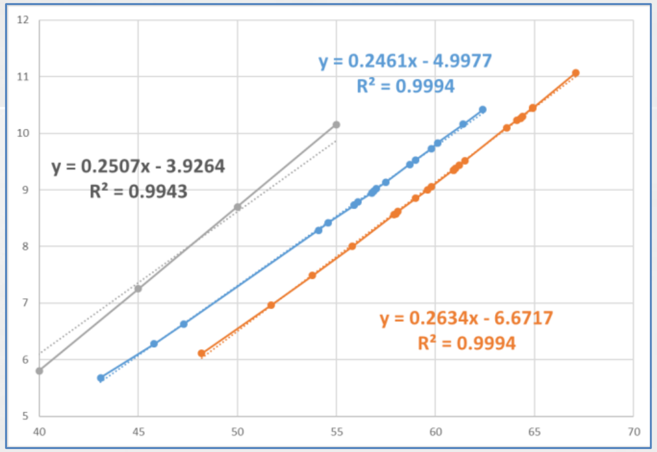
- Procedure Summary
  - Damaged girder capacity compared against as-built girders
  - Reduced cross-section
  - Reduced concrete strength
  - Utilized original bridge design calculations



Analysis

- Schmidt Hammer Correlation
  - Readings used to estimate deck and girder concrete compressive strength
  - Average of 10 measurements
  - Removed outliers
  - Used data from Tacoma Station Access to derive a linear relationship



		Hammer Reading, R											
	Label	1	2	3	4	5	6	7	8	9	10	Adjusted Average*	Std. Dev.
Girder C East Face at ~4ft, C1	C1-E-TF1	36	36	48	42	40	42	40	40	38	38	39.11	3.53
	C1-E-TF2	48	50	55	52	54	60	54	46	40	44	51.29	5.93
	C1-E-TF3	60	64	60	62	60	58	58	64	62	60	60.80	2.15
	C1-E-TF4	62	64	56	56	62	58	60	56	54	58	58.60	3.27
	C1-E-W1	60	60	58	56	57	61	60	58	60	64	59.40	2.27
	C1-E-W2	52	60	60	61	62	50	61	60	62	60	60.75	4.21
	C1-E-W3	Location was not tested											
	C1-E-BF1	Location was not tested											
	C1-E-BF2	Location was not tested											

Analysis

- Schmidt Hammer Correlation
  – Average of the calculated f'c values for each of the different components was used for the design check
  – Scale factor determined by "normalizing" the as-built girder
  – Calculated f'c values were then adjusted by the scale factor

Table 4: Shear Capacity Analysis Girder Concrete Strengths

9.00 ksi	= Design 28 day concrete strength				
1.16	= Scale factor				
8.31 ksi	= Controlling analysis concrete strength				
	C1	C2	D1	D2	G1
Base Value*:	8.03 ksi	7.37 ksi	7.69 ksi	7.13 ksi	7.73 ksi
Scaled Value:	9.35 ksi	8.58 ksi	8.96 ksi	8.31 ksi	9.00 ksi

*Values are the average of the W1, W2, and W3 test locations

Analysis

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Table 5: Positive Moment Capacity Analysis Girder Concrete Strengths

9.00 ksi	= Design 28 day concrete strength
1.13	= Scale factor
6.68 ksi	= Controlling analysis concrete strength

	C1
Base Value*:	6.67 ksi
Scaled Value:	7.55 ksi

*Values are the average of all

Table 6: Flexural Capacity Analysis Deck Concrete Strength

4.35 ksi	= Design 28 day concrete strength
0.66	= Scale factor
3.78 ksi	= Controlling analysis concrete strength

	CD1	FG1
Base Value:	5.73 ksi	6.59 ksi
Scaled Value:	3.78 ksi	4.35 ksi

Analysis

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Table 7: Extreme Top Fiber Service Stress Checks Analysis Girder Concrete Strengths

9.00 ksi	= Design 28 day concrete strength
1.12	= Scale factor
2.94 ksi	= Controlling analysis concrete strength

	C1
Base Value*:	3.79 ksi
Scaled Value:	4.24 ksi

*Values are from the TF1 test

Table 8: Extreme Bottom Fiber Service Stress Checks Analysis Girder Concrete Strengths

9.00 ksi	= Design 28 day concrete strength
1.14	= Scale factor
5.90 ksi	= Controlling analysis concrete strength

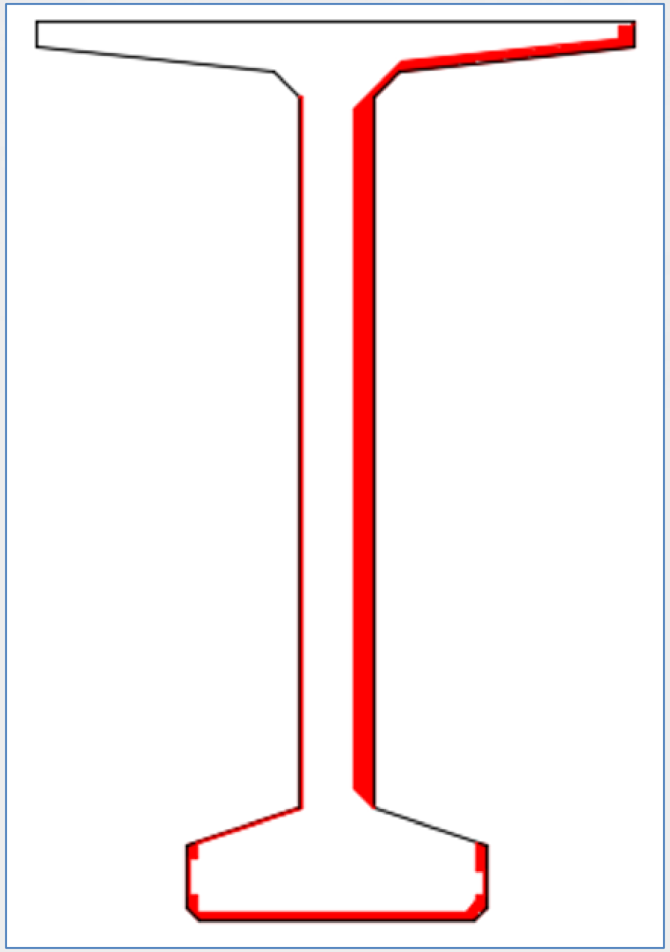
	C1	C2	D1	D2	G1
Base Value*:		5.16 ksi		6.05 ksi	7.88 ksi
Scaled Value:		5.90 ksi		6.92 ksi	9.00 ksi

*Values are from the BF2 test location

Analysis

- Section Properties

	Damaged Girder	Undamaged Girder
Girder height (in):	71.50	72.00
Girder area (in^2):	570.31	700.00
Distance from girder centroid to extreme bottom fiber (in):	35.98	36.40
Web thickness (in):	4.25	6.00
Moment of inertia (in^4):	421317	483700
Deck thickness (in):	7.77	8.00
Build-up thickness (in):	0.23	0.00



Analysis

- Shear Capacity Evaluation

	f'c (ksi)	bv (in)	Controlling Design Ratio (ΦVn/Vu)	φVn at Controlling Design Ratio (kips)
Undamaged Girders:	9.00	6.00	2.12	389.81
Damaged Girders:	8.30	4.25	1.85	339.75

Analysis

- Moment Capacity Evaluation

	Positive Moment at Controlling Section - Final/Continuous Condition	
	Design Ratio* (ΦMn/Vu)	ϕMn (kip-ft)
Undamaged Girders:	1.46	135863
Damaged Girders:	1.37	127709

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Analysis

- Service Checks (Stresses)

	Bottom Fiber Tension Stress - Final Condition (ksi) at x=36ft			
	Simply Supported (All Loads)		Continuous (PE + DL + LL)	
	σ_b	$\sigma_{b\_Allowed}$	[illegible]	[illegible]
Undamaged Girders:	0.09	-0.57	0[illegible]	[illegible]
Damaged Girders:	0.21	-0.46	0[illegible]	[illegible]

	Bottom Fiber Compression Stress - Final Condition (ksi) at x=2ft					
	All Loads		PE + DL		LL + 0.5(PE +DL)	
	σ_b	$\sigma_{b\_Allowed}$	σ_b	$\sigma_{b\_Allowed}$	σ_b	$\sigma_{b\_Allowed}$
Undamaged Girders:	2.93	5.40	3.03	3.60	1.41	3.60
Damaged Girders:	3.39	3.54	3.50	2.36	1.64	2.36

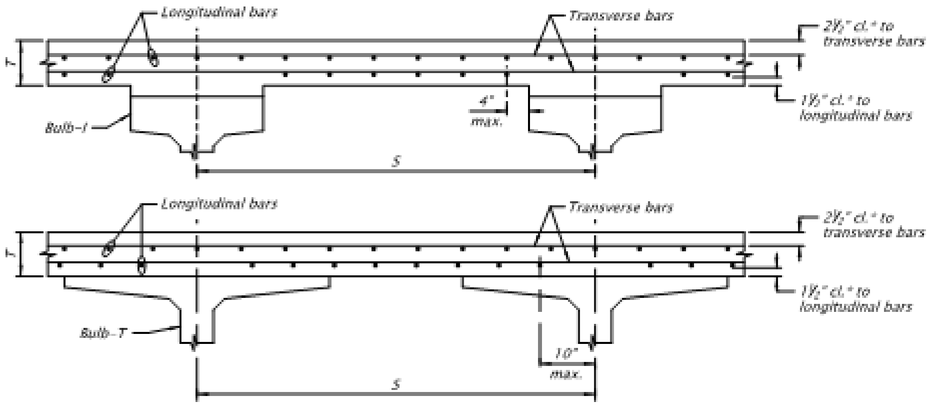
	Top Fiber Compression Stress - Final Co[illegible]					
	All Loads		PE + DL		LL + 0.5(PE +DL)	
	σ_t	$\sigma_{t\_Allowed}$	σ_t	$\sigma_{t\_Allowed}$	σ_t	$\sigma_{t\_Allowed}$
Undamaged Girders:	2.01	5.40	1.58	3.60	1.22	3.60
Damaged Girders:	2.38	3.58	1.96	2.39	1.39	2.39

Analysis

- Deck Capacity

CONCRETE DECK REINFORCEMENT (LRFD DESIGN) with TRANSVERSE BARS ON TOP

Standard Precast Prestressed Concrete members - Simple Spans



Precast Prestressed Concrete Members

Girder Spacing	Deck Thickness	Transverse Bars	Longitudinal Bars
5'-0"	8"	#4 @ 6½"	#4 @ 8"
5'-3"	8"	#4 @ 6½"	#4 @ 8"
5'-6"	8"	#4 @ 6½"	#4 @ 8"
5'-9"	8"	#4 @ 6½"	#4 @ 8"
6'-0"	8"	#4 @ 6½"	#4 @ 8"
6'-3"	8"	#4 @ 6"	#4 @ 8"
6'-6"	8"	#4 @ 6"	#4 @ 8"
6'-9"	8"	#4 @ 6"	#4 @ 8"
7'-0"	8"	#4 @ 5½"	#4 @ 8"
7'-3"	8"	#4 @ 5½"	#4 @ 8"
7'-6"	8"	#4 @ 5½"	#4 @ 8"
7'-9"	8"	#4 @ 5½"	#4 @ 8"
8'-0"	8"	#5 @ 7½"	#5 @ 8"

Conclusions

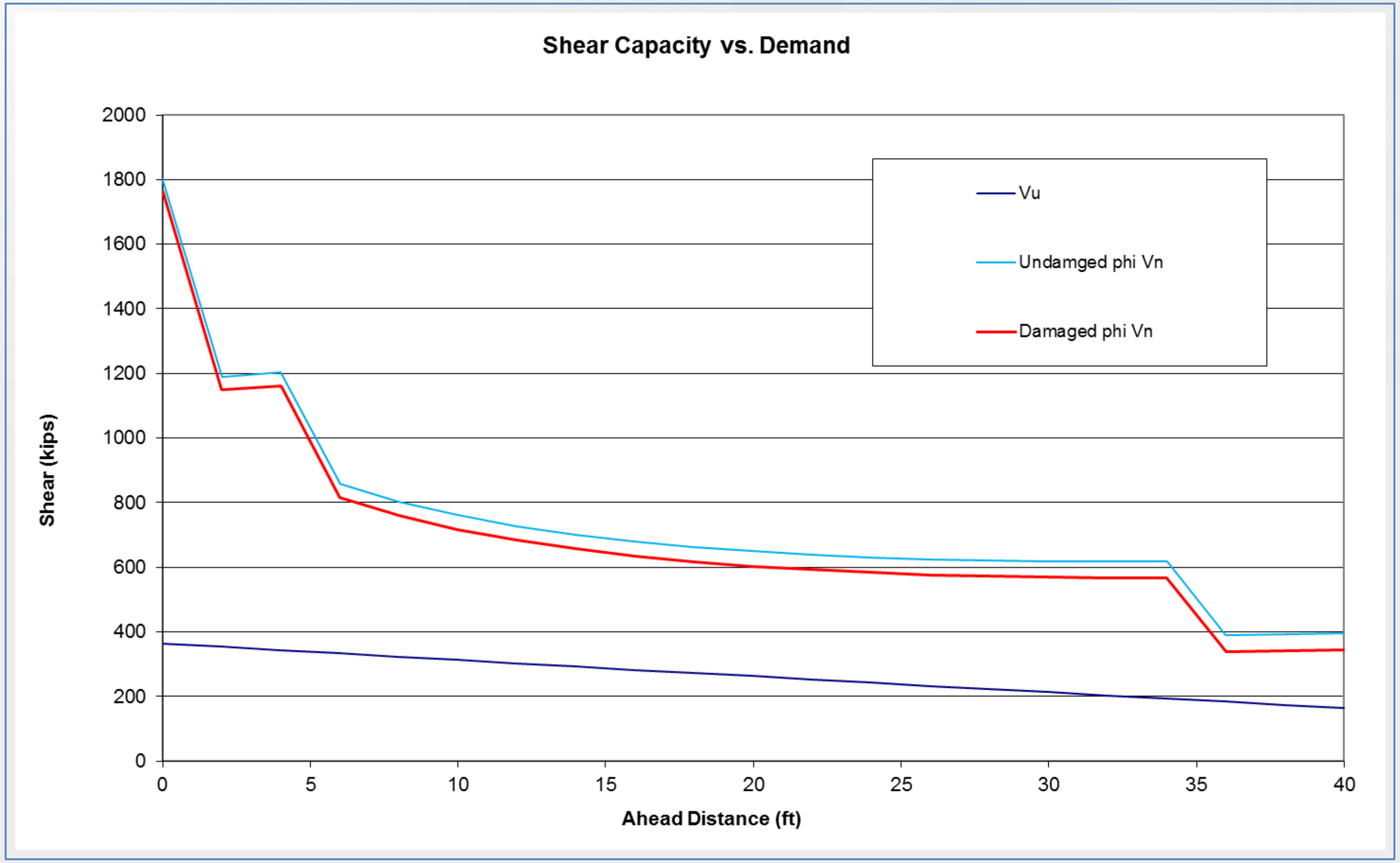
- Summary of findings
  - Possible increase in deflections - monitor
  - Strengthening not required
  - No load posting required

- Repair recommendations

- Lessons learned

Conclusions

- Shear Strength – ***Adequate Reserve Capacity***



Conclusions

- Flexural Strength – ***Adequate Reserve Capacity***

Table 12: Positive Moment Capacity

	Positive Moment at Controlling Section - Final/Continuous Condition	
	Design Ratio* (ΦMn/Vu)	ϕMn (kip-ft)
Undamaged Girders:	1.46	135863
Damaged Girders:	1.37	127709

Conclusions

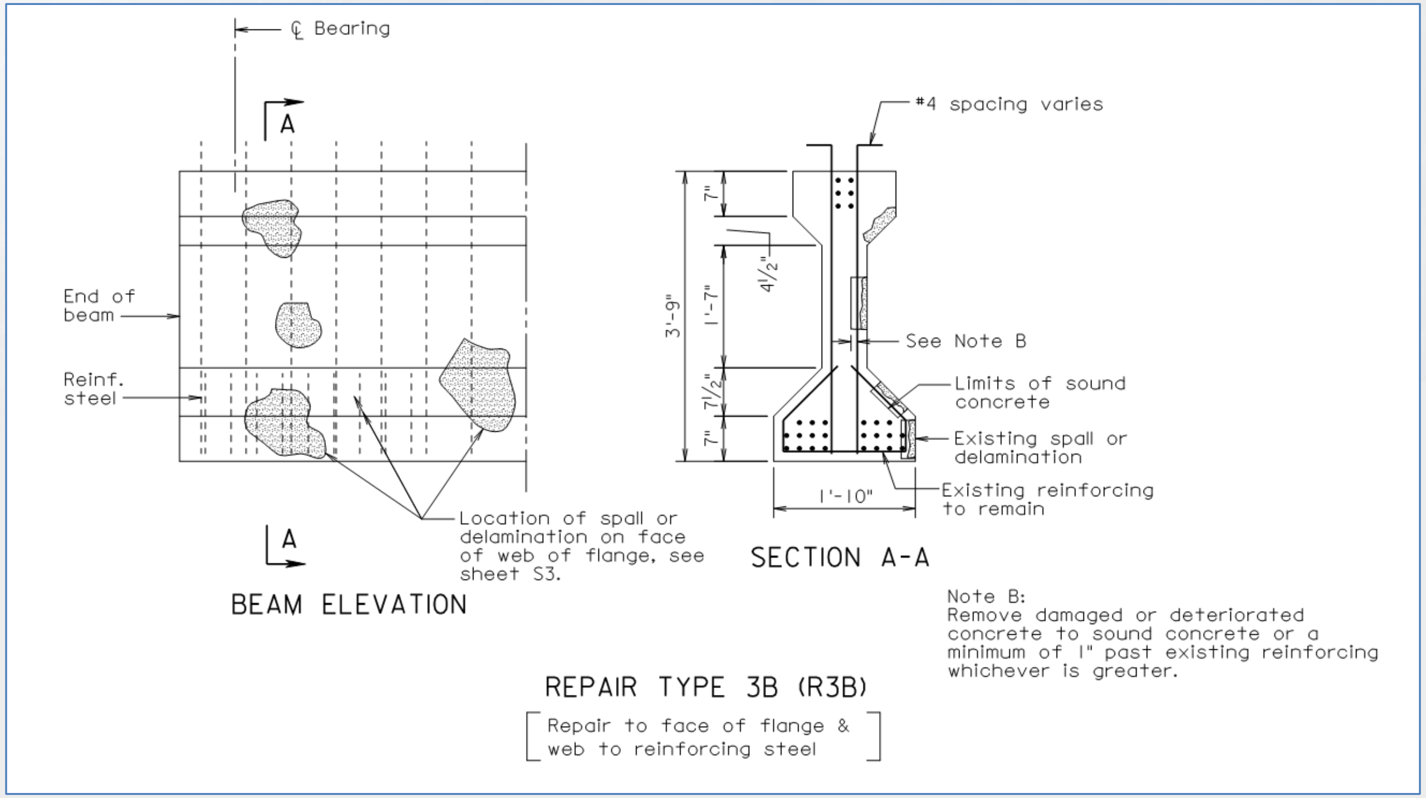
- Girder Stresses
  - *Bottom Surface within Tension Limits*
  - *Top Surface within Compression Limits*
  - *Bottom Surface EXCEEDS Compression Limits*

Table 14: Flexural Bottom Fiber Compressive Stress Checks

	Bottom Fiber Compression Stress - Final Condition (ksi) at x=2ft					
	All Loads		PE + DL		LL + 0.5(PE +DL)	
	σ_b	$\sigma_{b\_Allowed}$	σ_b	$\sigma_{b\_Allowed}$	σ_b	$\sigma_{b\_Allowed}$
Undamaged Girders:	2.93	5.40	3.03	3.60	1.41	3.60
Damaged Girders:	3.39	3.54	3.50	2.36	1.64	2.36

Conclusions

- Repair Recommendations
  - Restore rebar concrete cover to extend service life
  - Clean spalls and patch
    - ~ $50k Construction Estimate
  - Prevention of future transient fires



Conclusions

- Lessons Learned
  - Consider fire protection during design of new structures
    - Concrete cover
    - Prevention – Restrict transient access
  - Schmidt Hammer testing can be time consuming
  - Fire Damage Investigation
    - Basic or advanced
    - Visual versus concrete cores, load testing, etc.
  - Difficult to gain quantitative certainty on the damaged capacity
  - Concrete bridges generally perform well in fire

Fire Damage Inspection and Analysis for a Prestressed Concrete Girder Bridge

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NATIONAL BRIDGE PRESERVATION PARTNERSHIP CONFERENCE 2018
PRACTICES WE CAN NOT AFFORD TO DEFER