REHABILITATION OF COLLISION DAMAGED BEAMS USING HEAT STRAIGHTENING FOR I-66 OVER ROUTE 29

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BIOGRAPHY

Ali Hedayati, PE is a Vice President in WSP USA Inc.'s Complex Bridge Division, and he is based in Herndon, Virginia. He has over 38 years of experience in design and managing projects in various aspects of bridge engineering. Ali's specialty is bridge rehabilitation. He earned a BS in engineering from University of Tehran, Iran, and an MS degree in structural engineering from the University of Michigan, Ann Arbor. Ali is an active member of ASCE and the AASHTO/NSBA task groups.

SUMMARY

The I-66 over Route 29 bridge is in a heavily-traveled area of Fairfax County, Virginia, west of Washington, DC. The bridge's steel beams have been damaged by several collisions because of low vertical clearance. The Virginia Department of Transportation (VDOT) contracted WSP's Herndon office (under the firm's Region IV Bridge Maintenance and Repair contract) to study and develop final plans for repair of the damaged steel beams and other repairs. WSP staff provided in-depth inspection of the bridge and load ratings, and then developed final plans for repairs to restore the bridge's capacity.

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Introduction

I-66 is a major interstate in Northern Virginia, west of Washington, DC that carries a heavy traffic volume. From 2009 to 2010, several beams over NB Route 29 were damaged due to vehicular collision. A couple of beams over SB Route 29 had minor collision damage from earlier incidents.

Under the firm's VDOT Region IV Bridge Maintenance and Repair contract, WSP provided visual inspection, Stage I Study Report, load rating analysis, and final plans and specifications for the repair and rehabilitation of the damaged beams.

The I-66 EB and WB dual structures over Route 29 are each four simple span bridges (59'-68'-61'-61') with a total length of 252' and 52-degree skew.

Both bridges were built in 1961 and were widened three times in 1977, 1989, and 1994. The beams are a combination of plate girders and rolled beams with and without cover plates. The I-66 WB Bridge has a total bridge width of 89'-4" and carries five lanes. The EB Bridge has a total bridge width of 77'-4" and carries four lanes. The steel beams are grade 50 for the final widening in 1994. All other beams are grade 36. The piers are multi-column type. The original bridge has spill-through type abutments; the widenings have stub abutments.

The minimum vertical clearance at the bridge is 14'-7" above NB Route 29 and 14'-10" above SB Route 29. The I-66 EB Bridge carried a 2008 Annual Average Daily Traffic (AADT) of 61,000 vehicles. The combined AADT for NB and SB Route 29 passing under the bridge was 17,000 vehicles in 2008.

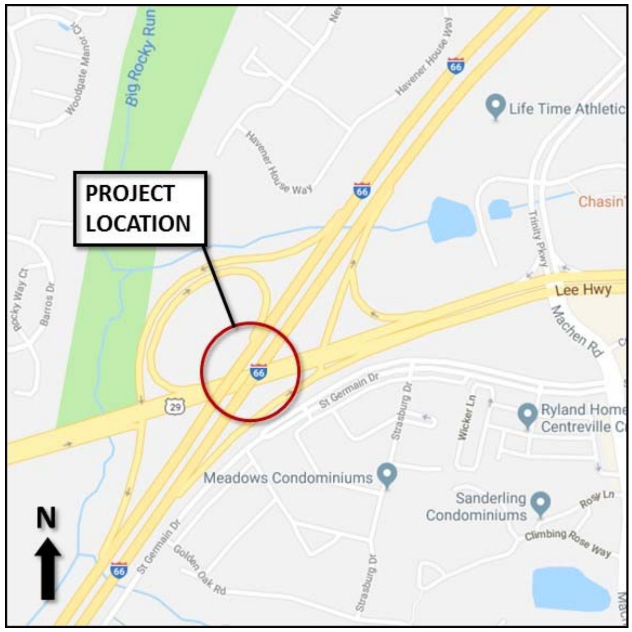


Figure 1: Location Plan

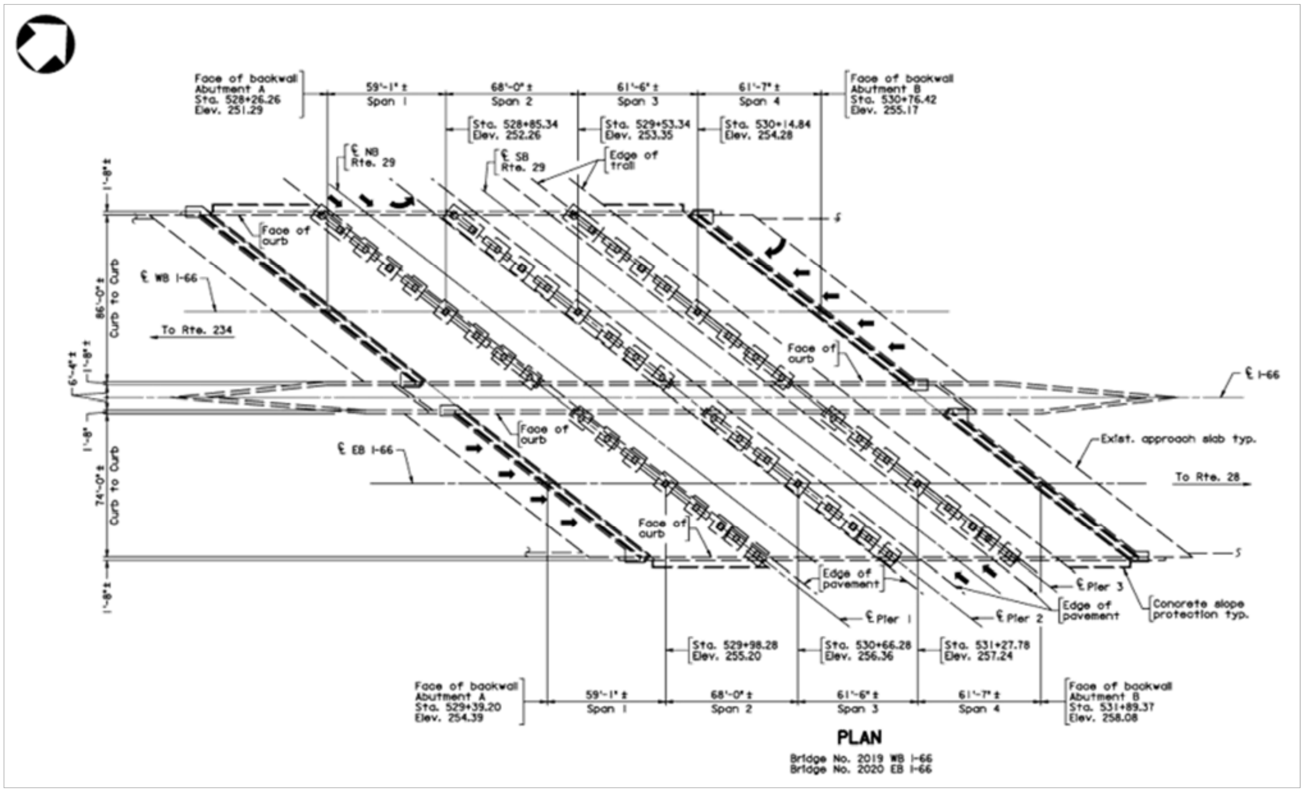


Figure 2: Bridge Plan

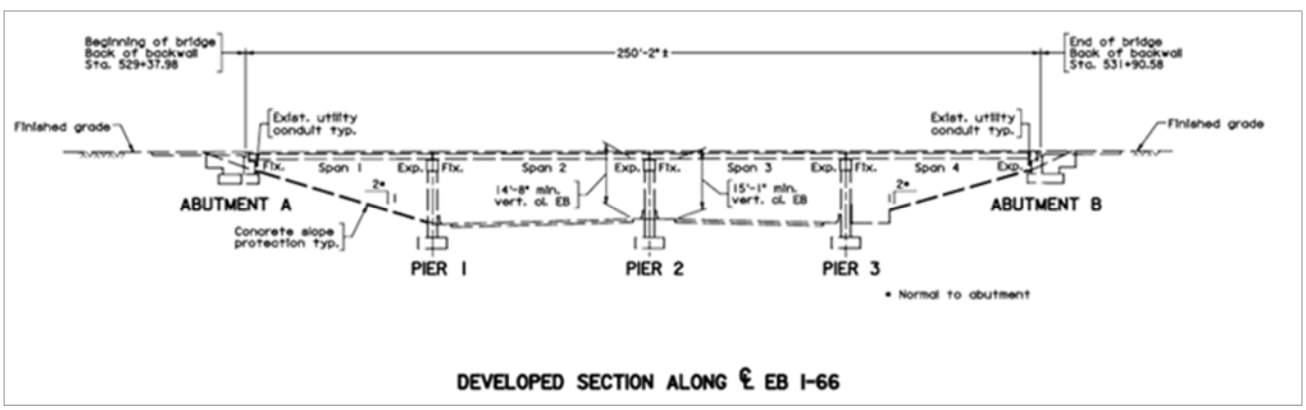


Figure 3: Bridge Evaluation

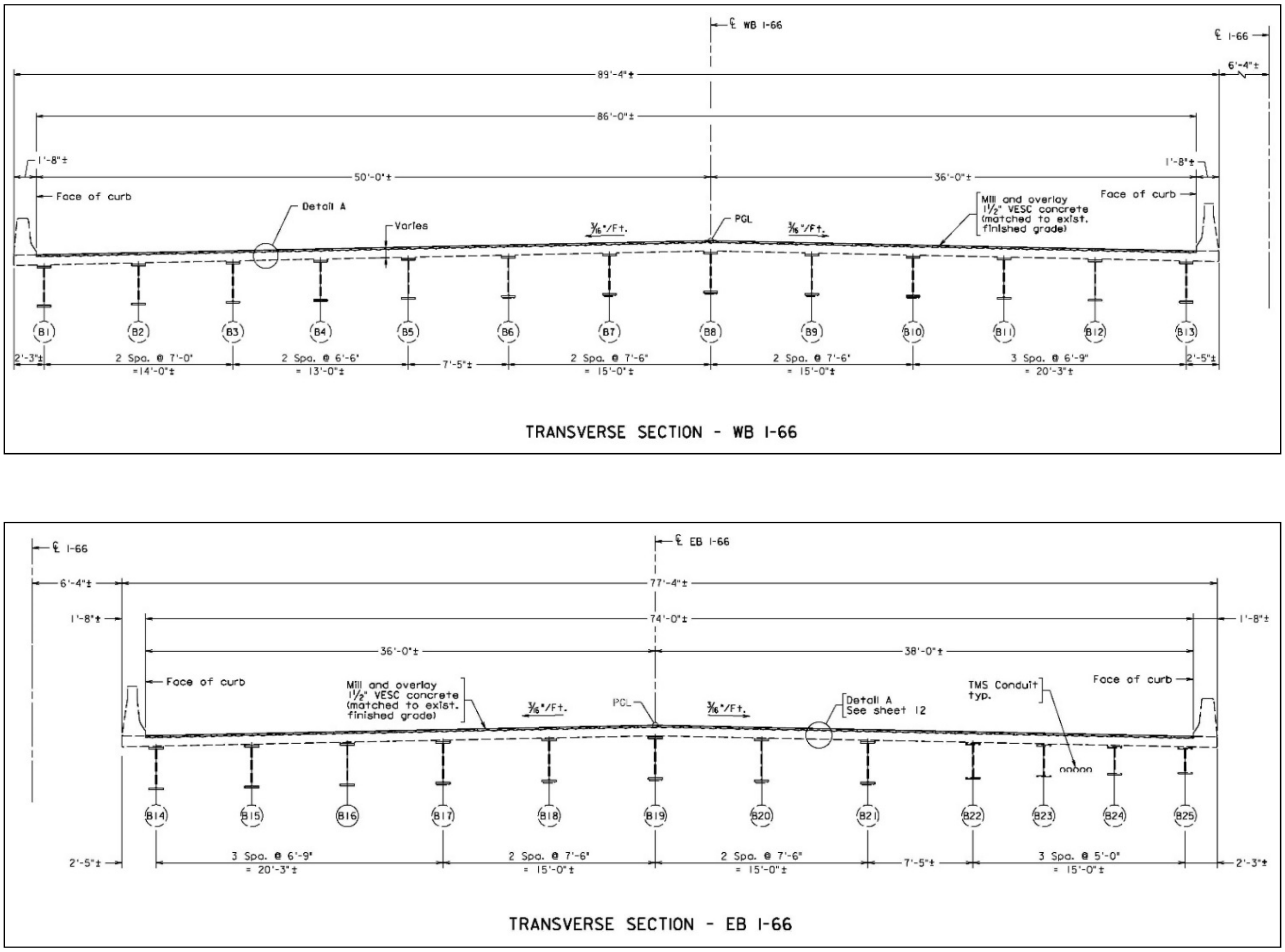


Figure 4: Bridge Traverse Section

Assessment/Inspection

In December of 2009, WSP conducted a visual inspection of the damaged beams in Spans 2 and 3 of the EB and WB Bridges using a bucket truck and lane closures. Most of the impact damage was to the EB Bridge Span 2 over NB Route 29, where the minimum vertical clearance ranged from 14’-7” to 15’-2.” Eleven beams in Span 2 over NB Route 29 and one beam in Span 3 over SB Route 29 were damaged.

As shown in Figures 5 and 6, damage to the bottom flanges included vertical deformation up to 3½” and horizontal deformation up to 4¾”.

Most of the impact areas had gouges or tears at the edge of the bottom flanges and out of plane bulging of the webs up to 2⅝”, as shown in Figures 6 and 7.

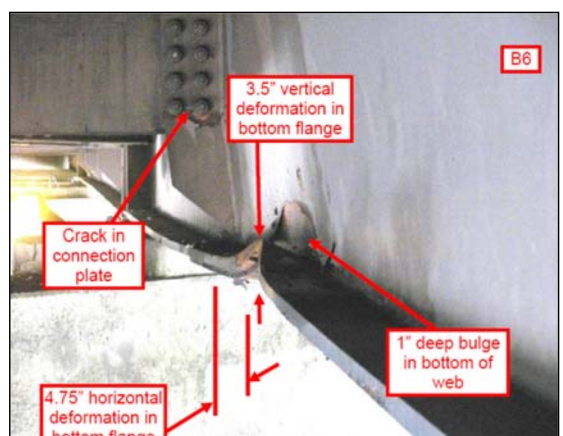


Figure 5: I-66 EB, Span 2 Beam #6, Bottom Flange Collision Damage

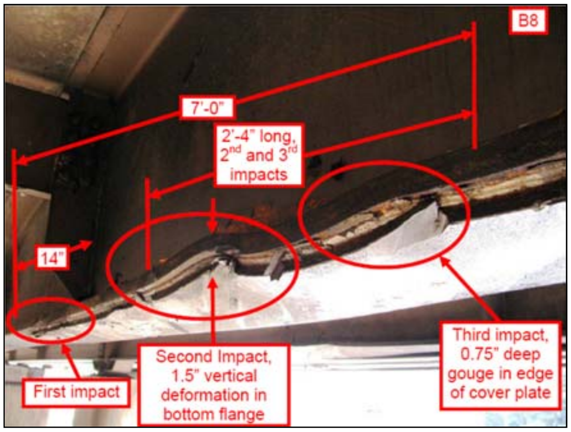


Figure 6: I-66 EB, Span 2 Beam #8, Collision Damage at Three Locations

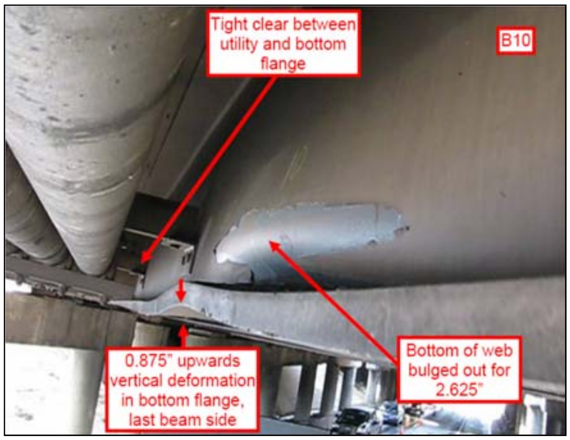


Figure 7: I-66 EB, Span 2 Beam #10, Bulge in Beam Web

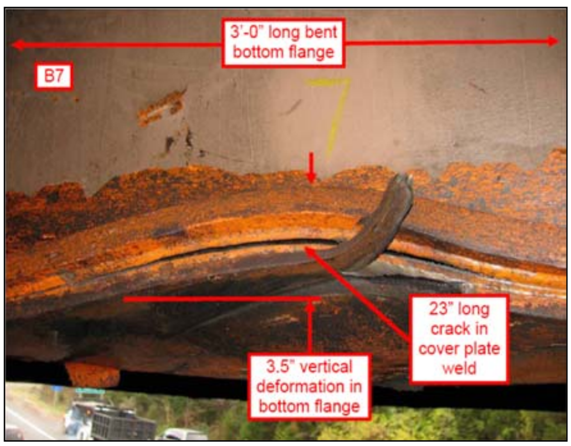


Figure 8: I-66 EB, Span 2 Beam #7, Crack in Cover Plate Weld

Some of the welds between bottom flanges and cover plates were damaged cracked and have separated, as shown in Figure 8.

Several connection plates were cracked through existing bolt hole locations and buckling as shown in Figures 9 and 10.

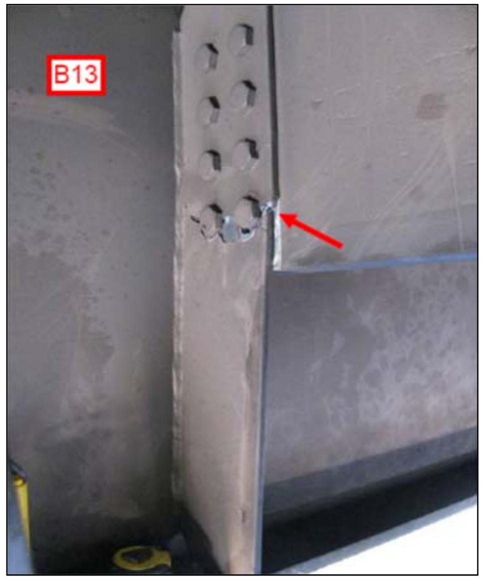


Figure 9: I-66 WB, Span 2 Beam #13, Cracked Connection Plate

Figure 10: I-66 EB, Span 2 Beam #6, Buckled Connection Plate

Some utility support hangers that had a vertical clearance similar to the adjacent beams were also damaged, as shown in Figure 11.

Figure 11: I-66 EB, Span 2, Damaged Utility Hanger

During a follow-up visual inspection in December 2010, a truck again struck the bridge. The impact split the bottom flange and half the web of Beam 22 in Span 2 of the EB Bridge as shown in Figures 12 and 13. The right lane and shoulder of EB I-66 were immediately closed to traffic, and all traffic lanes shifted to the left until beam repairs were completed.

Figure 12: I-66 EB, Span 2 Beam #22, Collision Damage (Split Beam)

Figure 13: I-66 EB, Span 2 Beam #22, Collision Damage (Split Beam)

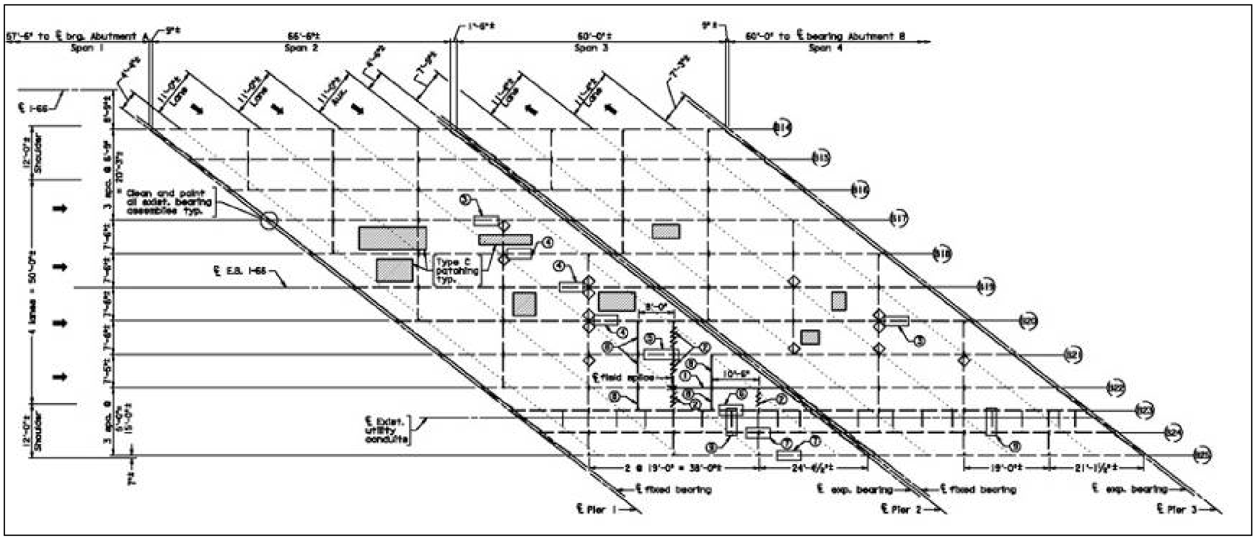


Figure 14: I-66 EB, Spans 2 and 3, Collision Damage Location Plan

Evaluation

To evaluate the reduction in beam capacity due to impact damage recorded during the inspection, a bridge load rating was performed with beam section properties adjusted for deformation and section loss. A load rating of both the I-66 EB and WB Bridges was performed using Virtis V6.0. The rating was performed using Load Factor Rating (LFR).

A summary of the beam properties and damage used for the load rating is shown in the table in Figure 15.

Excessive deformation, damage (section loss) in the bottom flanges, cover plates, and webs were considered in the Virtis model. "LARSA Section Composer" was used to calculate section properties of the deformed beams. The adjusted moment of inertia for the damaged beams was reduced by 10% to 30% from the original section. Figure 16 shows the deformed shape for the damaged beams and moment of inertia before and after deformation.

Summary of beam deformations, I-66 EB Bridge

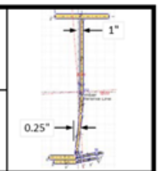
	Beam	Length	Shape	Top Flange		Web		Bottom Flange		Cover Plate		Bot. Flange Max. Hor.	Location and description of deformations/damages
		(ft)		w	t	h	t	w	t	w	t	Def. (in)	
EBL Span 2	#1	66.5	W36x160									0	None
	#2	66.5	W36x160									0	None
	#3	66.5	W36x160									0	None
	#4	66.5	W36x170 + CP:10"x1"	12	1.1	34	0.68	12	1.1	10	1	1.25	from 46.25, L=2, bent in bottom flange and cover plate
	#5	66.5	W36x170 + CP:10"x1"	12	1.1	34	0.68	12	1.1	10	1	2.875	from 47, L=2.66, bent in bottom flange and cover plate, bulge in web
	#6	66.5	W36x170 + CP:10"x1"	12	1.1	34	0.68	12	1.1	10	1	4.75	from 45.66, L=4, bent in bottom flange and cover plate, bulge in web
	#7	66.5	W36x170 + CP:10"x1"	12	1.1	34	0.68	12	1.1	10	1	3.75	from 46.62, L=3, bent in bottom flange and cover plate, bulge in web
	#8	66.5	W36x170 + CP:10"x1"	12	1.1	34	0.68	12	1.1	10	1	1.5	from 46.25, L=2.33, bent in bottom flange and cover plate, bulge in web from 52, L=1.16, bent in bottom flange and cover plate
	#9	66.5	PG	12	0.75	28	0.38	12	1.25			2.125	from 45.5, L=6, bent in bottom flange, bulge in web from 55.16, L=1.5, gouge in bottom flange
	#10	66.5	PG	12	0.75	25	0.38	12	1.25			2.5	from 46.56, L=6, bent in bottom flange, bulge in web, web depth = 23.3
	#11	66.5	PG	12	0.75	22	0.38	14	1.25			0	from 46.56, L=4, bent in bottom flange
	#12	66.5	PG	12	0.75	20	0.38	14	1.38			0.5	from 47.73, L=2.33, bent in bottom flange

	Beam	Length	Shape	Top Flange		Web		Bottom Flange		Cover Plate		Bot. Flange Max. Hor.	Location and description of deformations/damages
		(ft)		w	t	h	t	w	t	w	t	Def. (in)	
EBL Span 3	#1	60	W36x135									0	None
	#2	60	W36x135									0	None
	#3	60	W36x135									0	None
	#4	60	W36x150 + CP:10"x0.75"	12	0.94	34	0.68	12	0.94	10	0.75	0	None
	#5	60	W36x150 + CP:10"x0.75"	12	0.94	34	0.68	12	0.94	10	0.75	0	None
	#6	60	W36x150 + CP:10"x0.75"	12	0.94	34	0.68	12	0.94	10	0.75	0	None
	#7	60	W36x150 + CP:10"x0.75"	12	0.94	34	0.68	12	0.94	10	0.75	2	from 40.33, L=2, bent in bottom flange and cover plate
	#8	60	W36x150 + CP:10"x0.75"	12	0.94	34	0.68	12	0.94	10	0.75	0	Gouge in bottom flange, full length
	#9	60	PG	12	0.75	28	0.38	12	1.25			0	None
	#10	60	PG	12	0.75	25	0.38	12	1			0	None
	#11	60	PG	12	0.75	22	0.38	12	1.25			0	None
	#12	60	PG	12	0.75	20	0.38	12	1.25			0	from 40.1, L=1.33, gouge in bottom flange

Summary of beam deformations, I-66 WB Bridge

	Beam	Length	Shape	Top Flange		Web		Bottom Flange		Cover Plate		Bot. Flange Max. Hor.	Location and description of deformations/damages
		(ft)		w	t	h	t	w	t	w	t	Def. (in)	
WBL Span 2	#12	60	W36x160	12	1.02	34	0.65	12	1.02			0.25	from 18.3, L=2.5, bent in bottom flange
	#13	60	W36x160	12	1.02	34	0.65	12	1.02			3.5	from 17, L=4.5, bent in bottom flange, bulge in web

Figure 15: Summary of Beam Deformations in spans 2 and 3, I-66 EB over Route 29

EBL	Span 2	Beam #4	W36x170 + Bottom Cover PL: 10"x1"	I_{xx} **without** Section loss (in^4)	13226	
				I_{xx} **with** Section loss (in^4)	11536	
		Beam #5	W36x170 + Bottom Cover PL: 10"x1"	I_{xx} **without** Section loss (in^4)	13226	
				I_{xx} **with** Section loss (in^4)	9867	

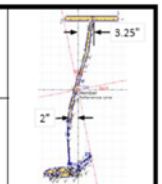
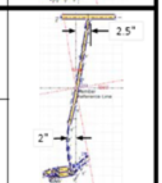
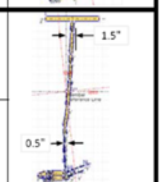
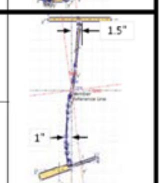
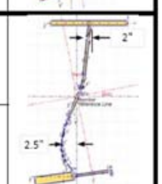
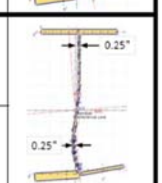
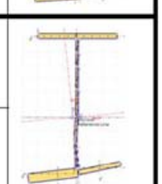
EBL	Span 2	Beam #6	W36x170 + Bottom Cover PL: 10"x1"	I_{xx} **without** Section loss (in^4)	13226	
				I_{xx} **with** Section loss (in^4)	9867	
		Beam #7	W36x170 + Bottom Cover PL: 10"x1"	I_{xx} **without** Section loss (in^4)	13226	
				I_{xx} **with** Section loss (in^4)	9867	
		Beam #8	W36x170 + Bottom Cover PL: 10"x1"	I_{xx} **without** Section loss (in^4)	13226	
				I_{xx} **with** Section loss (in^4)	9978	
		Beam #9	Plate Girder, TF: 12"x0.75", Web: 28"x0.375", BF:12"x1.25"	I_{xx} **without** Section loss (in^4)	5522	
				I_{xx} **with** Section loss (in^4)	4503	
		Beam #10	Plate Girder, TF: 12"x0.75", Web: 25"x0.375", BF:12"x1.25"	I_{xx} **without** Section loss (in^4)	4370	
				I_{xx} **with** Section loss (in^4)	2952	
		Beam #11	Plate Girder, TF: 12"x0.75", Web: 22"x0.375", BF:14"x1.25"	I_{xx} **without** Section loss (in^4)	3571	
				I_{xx} **with** Section loss (in^4)	3082	
		Beam #12	Plate Girder, TF: 12"x0.75", Web: 20"x0.375", BF:14"x1.375"	I_{xx} **without** Section loss (in^4)	3068	
				I_{xx} **with** Section loss (in^4)	2751	

Figure 16: Section Properties and Deformed Shape of Damaged Beams

The results of the load rating analysis showed that damaged EBL Span 2 Beams #5 through #10 had a load rating factor of less than 1.0 for an HS-20 (INV) Design Load. The lowest load rating factor of 0.62 for Beam #8 corresponds with a rating of 22 TONS, which is 39% less than the VDOT-required rating of 36 TONS. Figure 17 shows load rating factors for damaged/deformed beams.

Bridge	Member	Controlling Location and Force	Load Rating Factor					
			Design Load		Permit Load		Legal Load	
			HS-20		BP-90	BP-115	VA Single	VA Semi
			Inv	Opr	Opr	Opr	Ave	Ave
EBL	Span 2, Beam #4	Moment, 70% Span	1.05	1.75	1.72	1.75	1.90	1.83
	Span 2, Beam #5	Moment, 70% Span	0.71	1.18	1.16	1.19	1.28	1.24
	Span 2, Beam #6	Moment, 70% Span	0.67	1.11	1.09	1.11	1.21	1.17
	Span 2, Beam #7	Moment, 70% Span	0.69	1.16	1.13	1.16	1.26	1.21
	Span 2, Beam #8	Moment, 70% Span	0.62	1.05	1.02	1.05	1.13	1.09
	Span 2, Beam #9	Shear, 80% Span	0.65	1.09	1.18	1.11	1.18	1.23
	Span 2, Beam #10	Shear, 80% Span	0.88	1.47	1.58	1.51	1.59	1.67
	Span 2, Beam #11	Moment, 70% Span	1.36	2.27	2.23	2.28	2.47	2.38
	Span 2, Beam #12	Moment, 70% Span	1.44	2.08	2.36	2.40	2.61	2.52
	Span 3, Beam #7	Moment, 67% Span	1.04	1.74	1.77	1.70	1.89	1.90
WBL	Span 2, Beam #12	Moment, 70% Span	1.62	2.70	2.65	2.70	2.94	2.84
	Span 2, Beam #13	Moment, 70% Span	1.04	1.74	1.70	1.73	1.88	1.83

Figure 17: Summary of Load Ratings for Damaged Beams

The analysis confirmed that repair of the damaged beams was required to restore load rating factors to greater than 1.0.

WSP also recommended that several additional damaged beams be strengthened to protect against safety issues or structural failures from future collisions, especially with a 14’-7” minimum vertical clearance for the existing bridge.

Repairs

The severity of collision damage to several beams required that the damaged beams be repaired quickly. Additional vehicular collision impact to the already damaged beams could cause safety issues, and in case of severe collision, structural failure. If not repaired, damaged beams and cracks in cover plate welds could further deteriorate and reduce beam capacity.

After completing the visual inspection, WSP contacted several contractors with heat straightening expertise to procure their professional opinions on proper repair types and details. After reviewing the inspection report, details, and extent of the beams' damage, we concluded that all beams could be repaired using heat straightening as the most economical, feasible repair option. Heat straightening could be conducted to straighten local deformed and twisted flanges, bulged webs and horizontally deformed bottom flanges. After the heat straightening operation, the beams would regain most of their capacity; however, due to the extent of damage to some of the beams, and the uncertainty of weld conditions between the cover plates and bottom flanges, additional retrofit measures were recommended for severely damaged beams to increase shear and moment capacity of members. Beam repair recommendations were divided into the following three repair categories.

Category I Beam Repair

Partial beam replacement. Damage to the I-66 EB Span 2, Beam #22, which included a split bottom flange and web, was too severe to be repaired. A portion of the beam from the damaged area to the beam end was removed, and a new section spliced in its place. A carrier beam was used to give temporary support for the bridge deck during the partial beam replacement. Carrier beam details are shown in Figures 18, 19, and 20.

The partial beam replacement was 25'-long from a few feet beyond the damage, to the beam end at Pier 2, and included the bottom flange and the web up to 2" below the top flange. The new beam was spliced to the existing beam, with a full penetration groove weld along the top of the web, and bolted splice plates connecting the side of the web and bottom flange.

Replacing only the damaged portion of the beam reduced the construction duration and cost, and minimized traffic disruption.

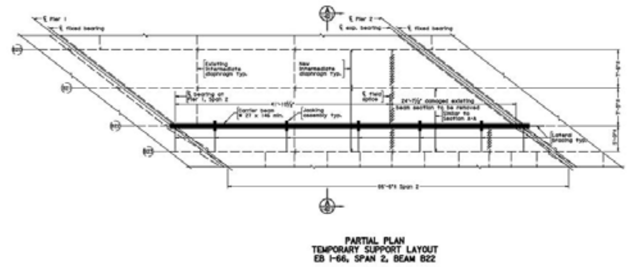


Figure 18: Plan of Carrier Beam

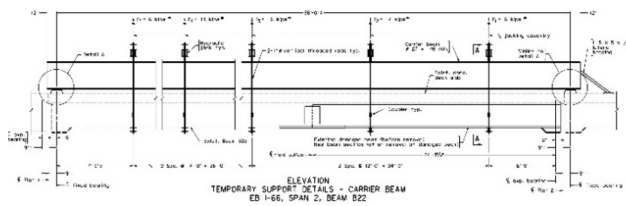


Figure 19: Elevation of Carrier Beam

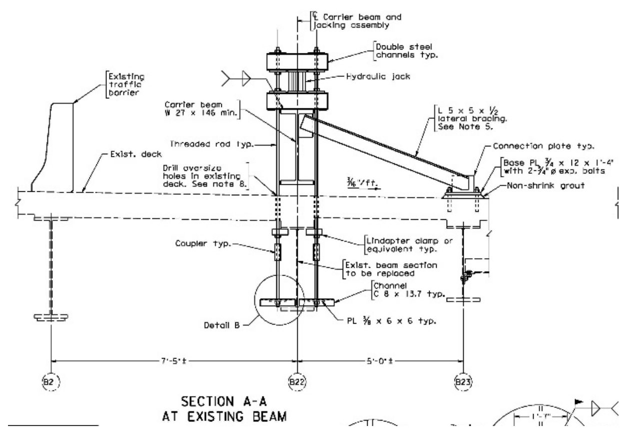
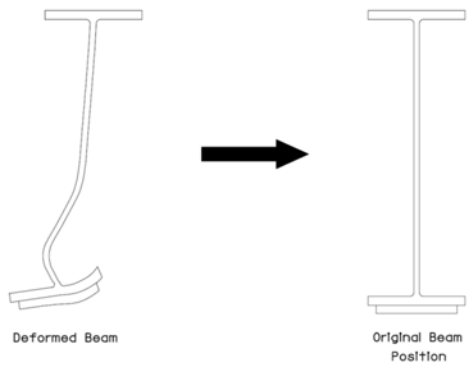


Figure 20: Section of Carrier Beam

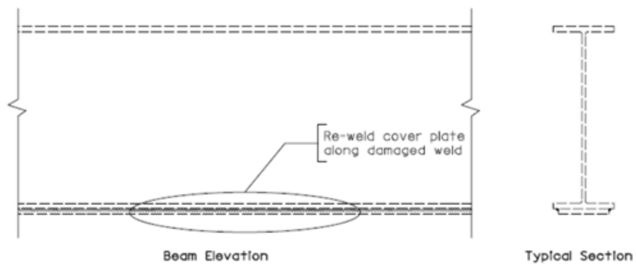
Category II Beam Repair

Severely damaged plate girders and rolled beams with and without cover plates, and with cracks in cover plate weld. This category includes six beams in Span 2 at the I-66 EB Bridge, and one beam in Span 2 at the I-66 WB Bridge.

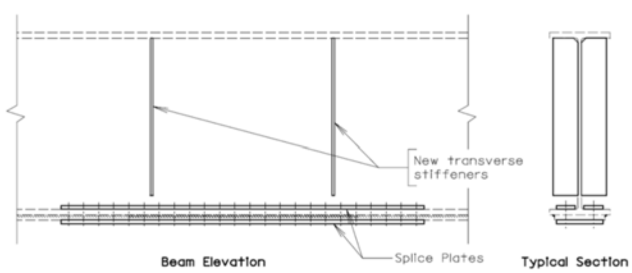
- **Step 1:** Remove damaged welds between cover plate and bottom flange where applicable. Heat straighten bulged web and deformed bottom flange (and cover plate) to original position. Bottom flange and cover plate are clamped together during the operation. Grind smooth the gouges and cuts along edges of bottom flange and cover plate.



- **Step 2:** Re-weld the cover plate to the bottom flange along damaged area where applicable.



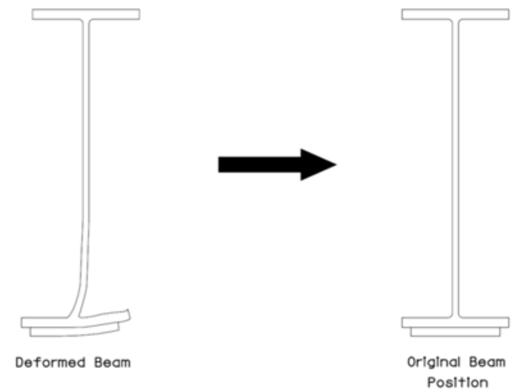
- **Step 3:** Add splice plates to top and bottom of bottom flange a minimum 2’ beyond damaged area to increase/restore moment capacity of the beam. Install additional transverse stiffeners to the web within the damaged area to increase shear capacity of the beam.



Category III Beam Repair

Damaged (not severely) plate girders and rolled beams with or without cover plate. This category includes three beams in Span 2 at the I-66 EB Bridge, one beam in Span 3 at the I-66 EB Bridge, and one beam in Span 2 at the I-66 WB Bridge.

- **Step 1:** Heat straighten deformed bottom flange (and cover plate). If applicable, the bottom flange and cover plate are clamped together during the operation. Grind smooth the gouges and cuts along edges of bottom flange and cover plate.



The summary of beam repair recommendations is shown in Figure 21.

Bridge	Member	Repair recommendation
EBL	Span 2, Beam #4	Heat Straightening
	Span 2, Beam #5	Heat Straightening + retrofit with splice and stiffeners
	Span 2, Beam #6	Heat Straightening + retrofit with splice and stiffeners
	Span 2, Beam #7	Heat Straightening + retrofit with splice and stiffeners
	Span 2, Beam #8	Heat Straightening + retrofit with splice and stiffeners
	Span 2, Beam #9	Heat Straightening + retrofit with splice and stiffeners
	Span 2, Beam #10	Heat Straightening + retrofit with splice and stiffeners
	Span 2, Beam #11	Heat Straightening
	Span 2, Beam #12	Heat Straightening
	Span 3, Beam #7	Heat Straightening
WBL	Span 2, Beam #12	Heat Straightening
	Span 2, Beam #13	Heat Straightening + retrofit with splice and stiffeners

Figure 21: Summary of Beam Repair Recommendations

Connection Plate Repair

After completion of beam straightening and beam repair, damaged diaphragm connection plates at 17 locations were removed and replaced.

Utility Hanger Repair

All damaged utility hangers and connections were replaced.

Spot Painting

After completion of the beam and connection plate repairs, all repair areas were spot painted.

Conclusion

Thorough evaluation and inspection of steel beam impact damage, selecting the appropriate repair method and identifying challenges to proposed repairs helped the design team provide cost effective solutions that achieved the desired service life for the owner.