DYNAMIC INTERACTION OF BRIDGE SUPERSTRUCTURE AND LIGHT RAIL VEHICLE

Western Bridge Engineer's Seminar 2017

Portland, Oregon

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CRENSHAW/LAX DESIGN-BUILD PROJECT

- Preliminary Planning Study - 1994
- Bid – **$2.058 Billion**
- Bid Announcement – Jun. 7, 2013
- Notice To Proceed (NTP) – Sep 2013
- Official Ground-Breaking Ceremony – Jan. 21, 2014
- **Forecasted Opening – 2019**

CRENSHAW/LAX DESIGN-BUILD PROJECT

- Total Length of Project - **8.5 miles** (13.7 km)
- 4 Underground Guideway Structures – 3 Cut-and-Cover Tunnels; a Dual TBM Tunnel
- 8 Stations – 3 Underground; 4 At-Grade; 1 Elevated on Aerial Guideway
- Miscellaneous Earth Retaining Walls and Other Structures
- **7 Aerial Guideway Structures**

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LIGHT RAIL TRANSIT (LRT) IN LOS ANGELES

- Currently operating on the Metro **Blue**, **Green**, and **Gold** Lines
- Operates on at-grade, below grade or above grade
- Electrically powered via overhead power connection
- Maximum Speed = Up to **55 mph**
- Maximum 3 cars per train
- Train Capacity: 500 passengers
- Approximate Station Spacing = 1 mile
- Approximate Station Length = 270 feet

MRDC (METRO RAIL DESIGN CRITERIA) REQUIREMENTS FOR VERTICAL VIBRATION

- **5.3.3 Special Design Consideration**s

5.3.3.1 Vertical Vibration

A moving vehicle exerts a dynamic effect on the guideway resulting from a highly complex interaction of the vehicle suspension system, vehicle speed, and roughness of the riding surface with the guideway. In order to avoid resonance and provide passenger comfort, an analysis of the dynamic interaction between the vehicles and the guideway structure shall be performed.

MRDC (METRO RAIL DESIGN CRITERIA) REQUIREMENTS FOR VERTICAL VIBRATION

To limit Vibration amplification due to the dynamic interaction between the superstructure and the rail car(s), the first-mode natural frequency of vertical vibration of each simple span guideway should generally be not less than 2.5 hertz and no more than one span in a series of three consecutive spans should have a first-mode natural frequency of less than 3.0 hertz.

Special analysis shall be performed for any bridge or for superstructures having a first mode of vertical vibration less than 2.5 hertz or for the condition when more than one span in a series of three consecutive spans has the first mode of vibration less than 3.0 hertz.

MRDC (METRO RAIL DESIGN CRITERIA) REQUIREMENTS FOR VERTICAL VIBRATION

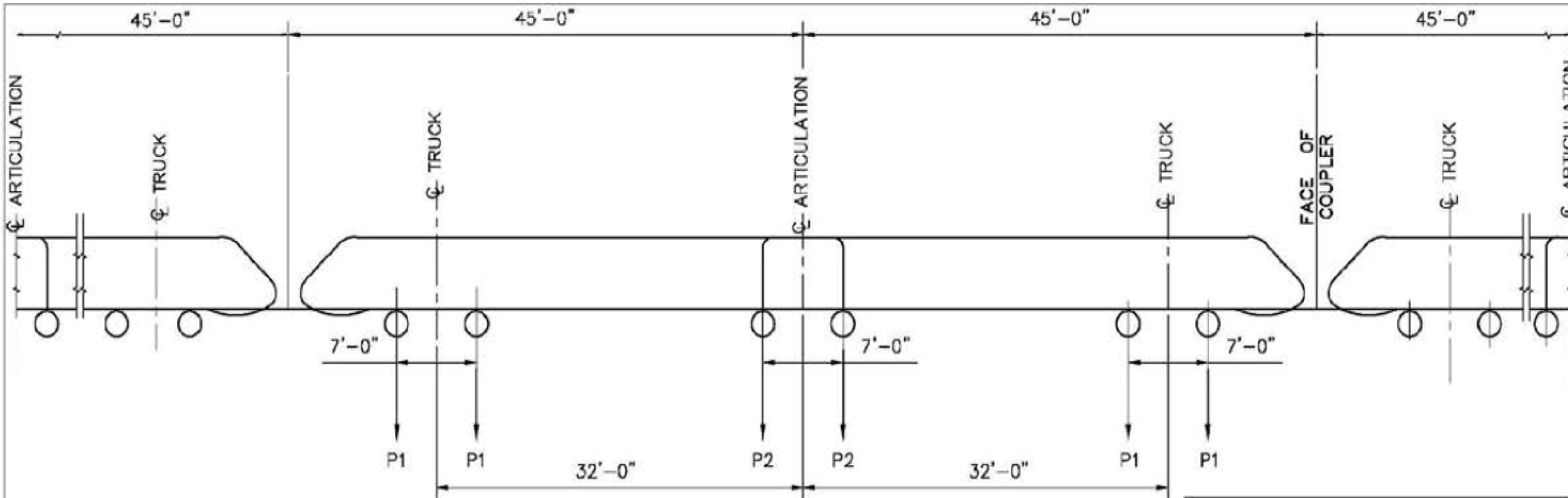
This special analysis shall model the proposed structure and the transit vehicle. The analysis shall contain a sufficient number of degrees of freedom to allow modeling of the suspension, and the car body. It shall make provision for the placement of the vehicle on the structure on various locations to model the passage of the transit vehicle. When the exact configuration of either the vehicle or the structure is not known, the analysis shall assume a reasonable range of parameters and shall model combinations of those parameters as deemed appropriate.

MRDC (METRO RAIL DESIGN CRITERIA) REQUIREMENTS FOR VERTICAL VIBRATION

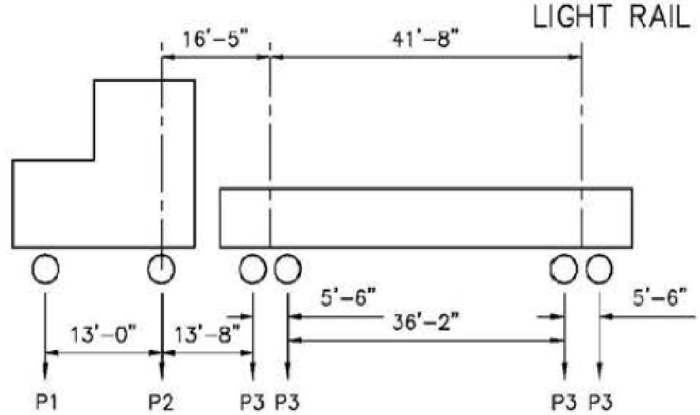
The analysis shall determine whether vertical dynamic load allowance loads in excess of 33 percent of LL are required for the design of the structure.

Thermal force interaction between the structural components and the trackwork system shall be considered, as specified in the section on force effects due to uniform temperature above.

LIGHT RAIL VEHICLE (LRV)
GEOMETRY



LIGHT RAIL VEHICLE (LRV)



LIGHT RAIL MAINTENANCE VEHICLE (LP) (MAX SPEED=35 MPH)

LOADING (LBS)

	LOADED
P1	30,000
P2	45,000
P3	18,500

LOADING DISTRIBUTION (LBS)

LOAD	END TRACK	CENTER TRACK	TOTAL
	P1	P2	
AW0	19,305	16,390	110,000
AW3	25,275	21,450	144,000
AW4	26,500	22,500	151,000

NOTE:
LOADING DISTRIBUTION SHALL BE VERIFIED PER PECIFICATIONS OF REVENUE RAIL VEHICLES.

LIGHT RAIL VEHICLE (LRV)
WEIGHT AND SUSPENSION PROPERTY

Truck spacing: 9450 mm

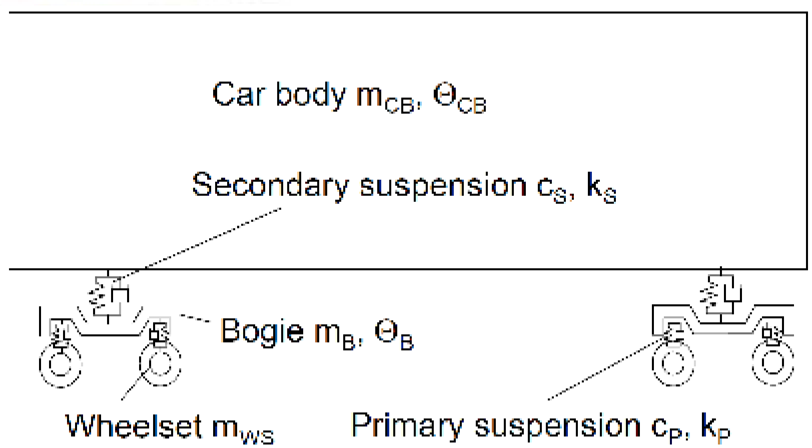
Primary suspension – Vertical	A end truck	Center Truck	B end truck
Dynamic (N/mm/wheel)	1690	1375	1690

Secondary suspension - vertical	AW0			AW3		
	A end truck	Center truck	B end truck	A end truck	C end truck	B end truck
Dynamic (N/mm/spring)	434	366	428	595	559	592

Weight data (kg):

	A end truck	Center truck	B end truck	Total
AW0	16,353	12,620	16,147	45,120
AW3	20,890	18,337	20,733	59,960

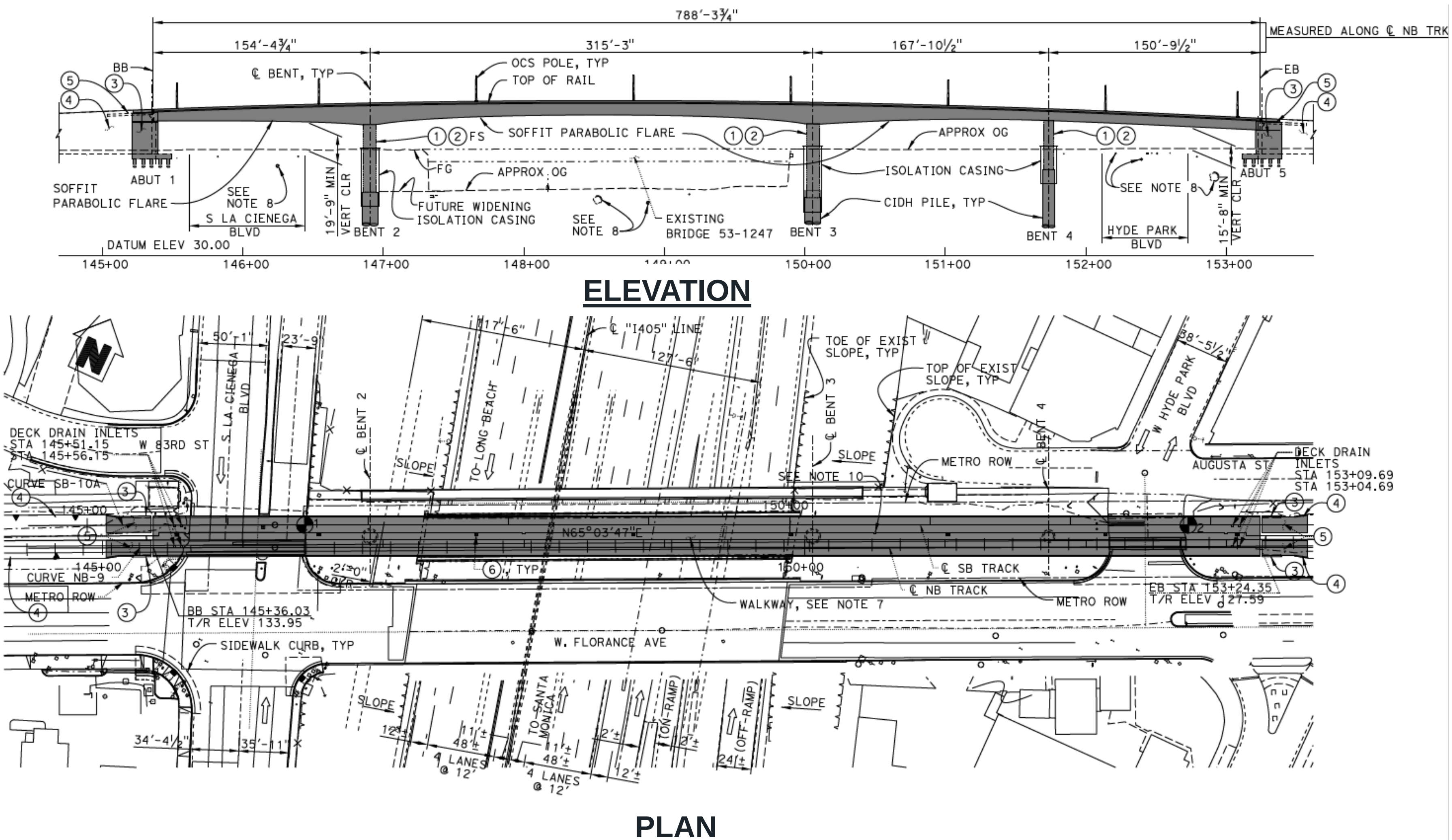
Note: The above weight information includes truck weight.



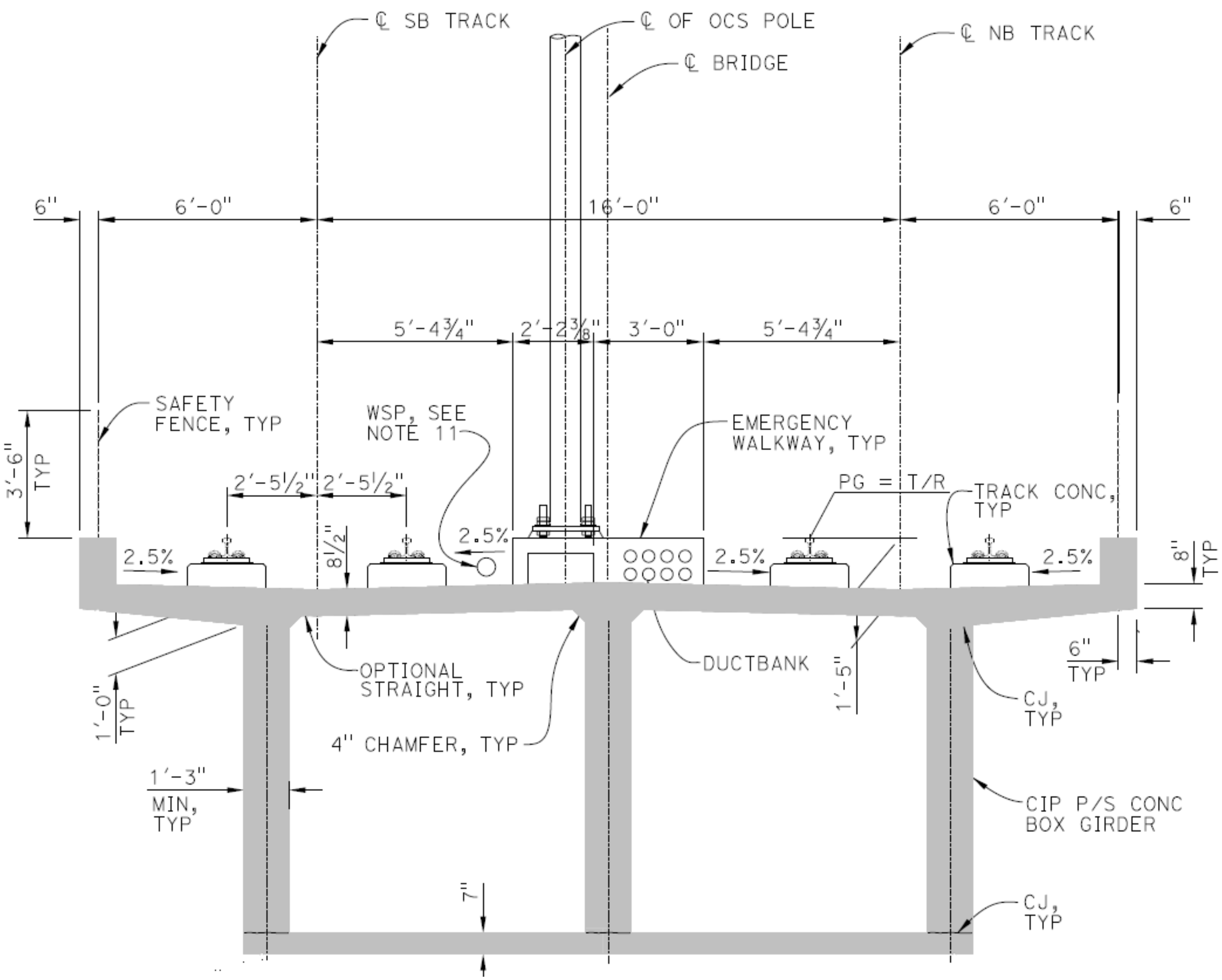
CRENSHAW/LAX DESIGN-BUILD PROJECT
I-405 UNDERPASS BRIDGE

- 4-Span Continuous P/S Box-Girder, Total Length = **788'- 3¾"**
- Main Span (Span 2) Length = **315'-3"**
- Mostly Tangent Alignment with Slight Curve at Bridge Approach
- 3 Single-Column Bents on Type-II Mono Shafts, 2 Seat-Type Abutments

I-405 UNDERPASS BRIDGE
PLAN and ELEVATION



I-405 UNDERPASS BRIDGE
TYPICAL SECTION



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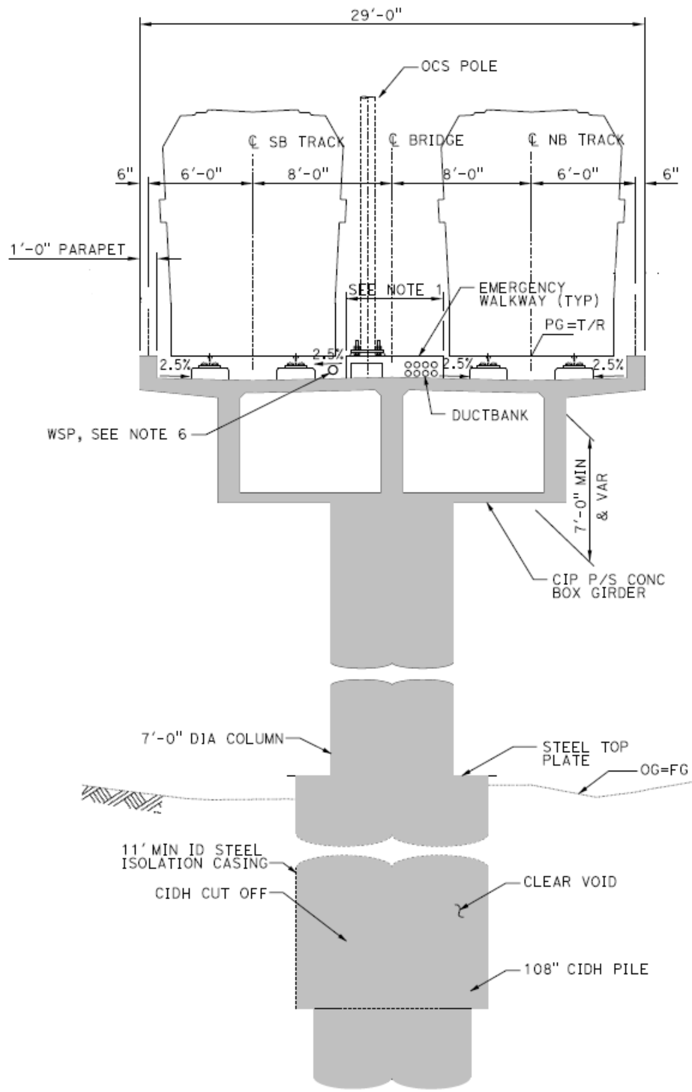
I-405 UNDERPASS BRIDGE
TYPICAL SECTION



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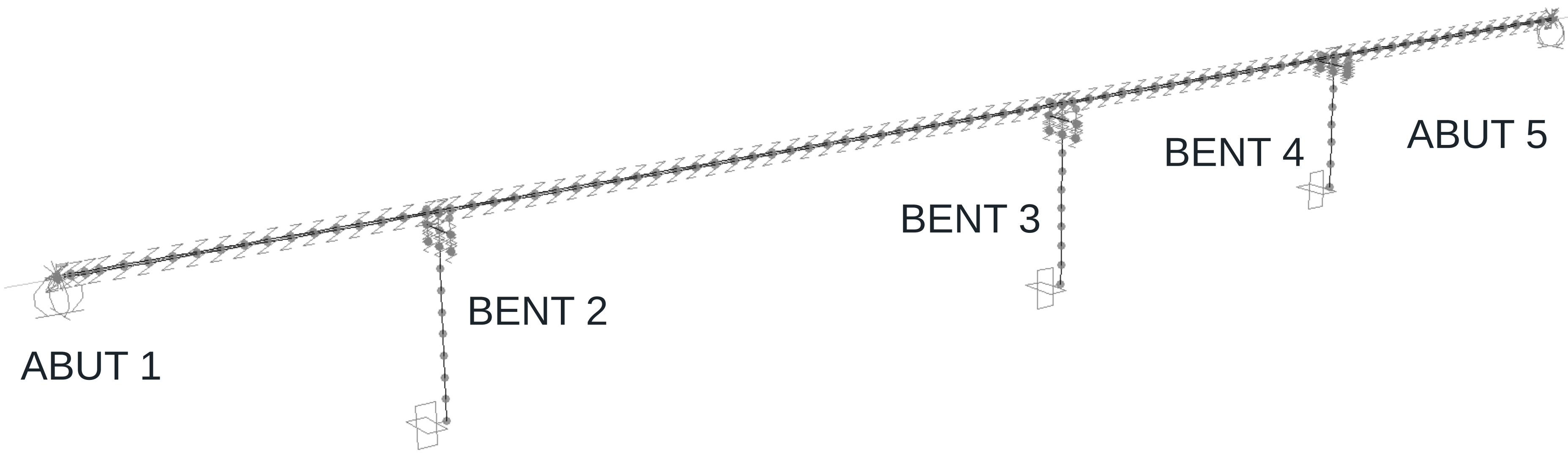
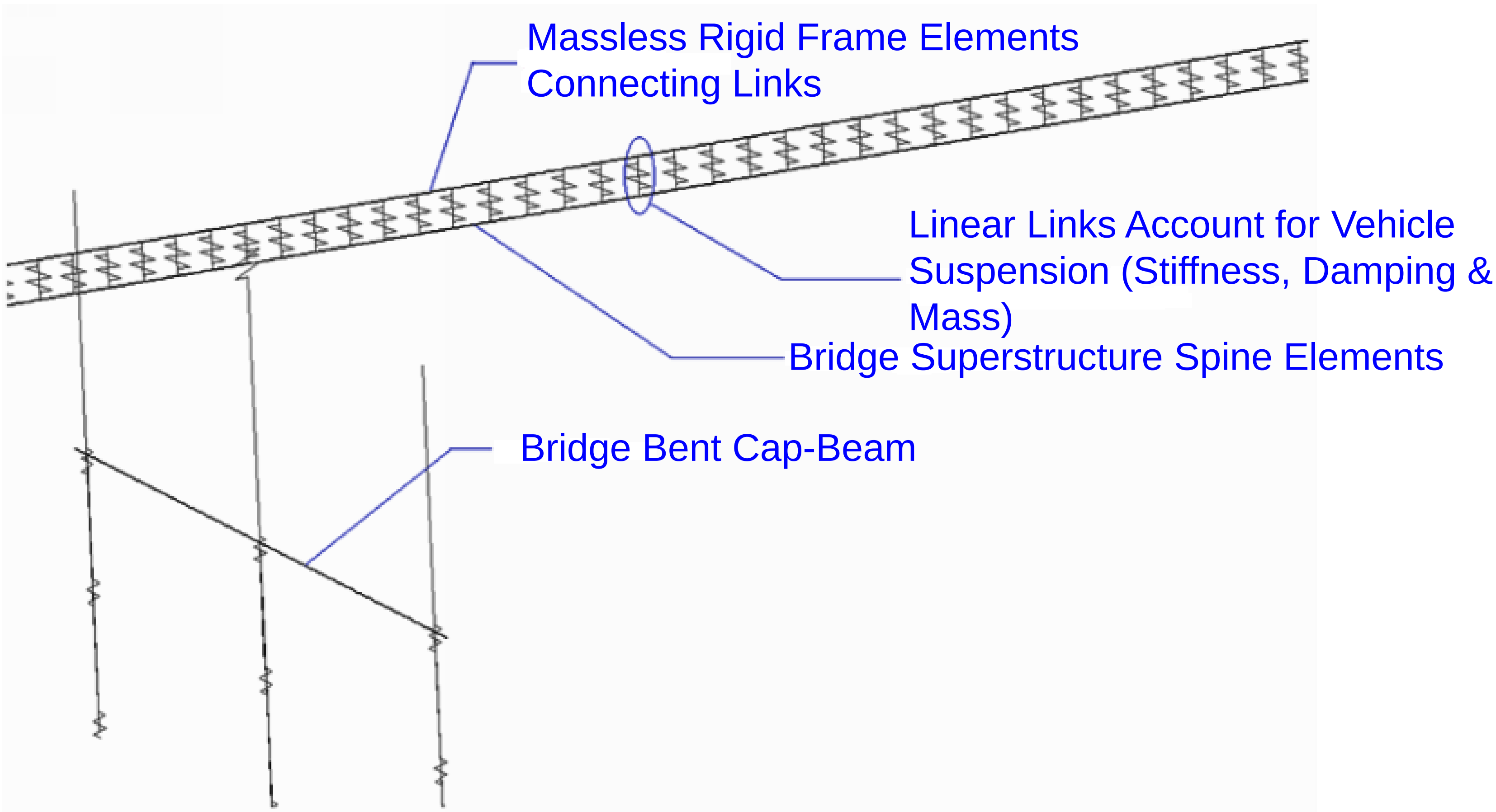
I-405 UNDERPASS BRIDGE
3-D BRIDGE SPINE MODEL (CSI BRIDGE/SAP 2000)

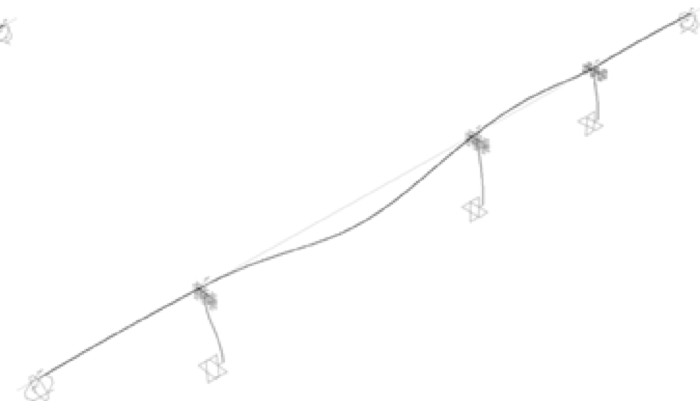


INTEGRATE VEHICLE SUSPENSION TO SUPERSTRUCTURE

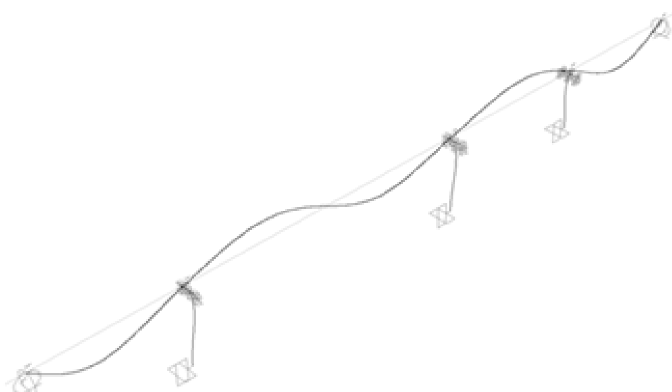


DEFORMED SHAPE OF FIRST 4 VIBRATION MODES

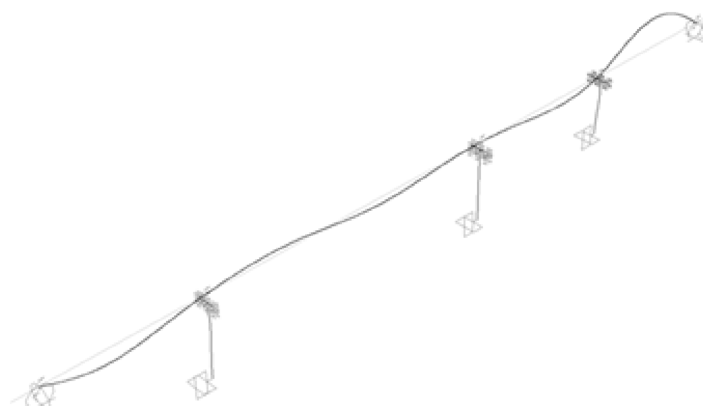
a) Mode Shape 1 (f=1.09 Hz)



b) Mode Shape 2 (f=1.13 Hz)



c) Mode Shape 3 (f=2.51 Hz)



d) Mode Shape 4 (f=2.76 Hz)

VEHICLE LOAD ANALYSIS METHOD (CSI BRIDGE/SAP 2000)

- Transient Static Analysis (assigned as "Linear Multi-step Static" load case in CSiBridge/SAP2000), to get U_{STATIC}

- Transient Dynamic Analysis (assigned as "Linear Direct Integration History" load case in CSiBridge/SAP2000) to get U_{DYNA}

DYNAMIC AMPLIFICATION FACTOR (DAF)

$$DAF = 1 + \frac{u_{DYNA} - u_{STATIC}}{u_{STATIC}} = \frac{u_{DYNA}}{u_{STATIC}}$$

	Deflection Comparison (AW3, 1-car)							
Location	Span 1		Span 2		Span 3		Span 4	
Enveloped maximum downward deflection in the Span	u_{STATIC}	u_{DYNA}	u_{STATIC}	u_{DYNA}	u_{STATIC}	u_{DYNA}	u_{STATIC}	u_{DYNA}
	0.16	0.18	0.57	0.60	0.14	0.15	0.25	0.27
DAF	1.14		1.05		1.08		1.08	
	Deflection Comparison (AW3, 3-car)							
Location	Span 1		Span 2		Span 3		Span 4	
Enveloped maximum downward deflection in the Span	u_{STATIC}	u_{DYNA}	u_{STATIC}	u_{DYNA}	u_{STATIC}	u_{DYNA}	u_{STATIC}	u_{DYNA}
	0.20	0.20	1.11	1.13	0.14	0.15	0.31	0.32
DAF	1.02		1.02		1.03		1.03	

CONCLUSIONS

- The paper demonstrates an efficient and cost effective way to perform complex rolling-stock analysis on a Design-Build Project using CSI Bridge/SAP 2000.

- The first-mode natural frequency is less than 3 Hz, a condition that might lead to vibration amplification due to the dynamic interaction between the superstructure and the rail cars, so it is necessary to evaluate the Dynamic Amplification Factor (DAF) of the bridge using a refined analysis method per MRDC.

CONCLUSIONS

- Based on our analyses, the computed DAF is smaller than the AASHTO LRFD prescribed factor. Based on our analyses, the design of the bridge can be considered safe since the calculated DAF is less than the DAF used in the design of this bridge.

QUESTIONS

Thank you

Q & A

Email: adurrani@hntb.com for Additional Questions

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