2011Western Bridge Engineers' Seminar

September 25-28, 2011

Portland-Milwaukie Light Rail Bridge: First Transit-Only Cable-Stayed Bridge Offers Unique Capacity for Shared Use

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ACKNOWLEDGEMENTS

Tri-County Metropolitan Transportation District of Oregon (TriMet)

Bridge Owner and Lead Development Agency

HNTB Corporation

Engineering Consultant to TriMet

HNTB

PROJECT OVERVIEW

- Extend light rail service 7.3 miles from South Waterfront in Portland to City of Milwaukie
- Achieve key project component – 1,720-ft bridge spanning the Willamette River
- Design bridge for transit-only use – first cable-stayed transit-only bridge in the United States
- Provide shared use between light-rail, buses, pedestrians, and cyclist

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CRITERIA FOR NEW BRIDGE

- Remain economical
- Provide signature structure
- Ensure good seismic resistance
- Design tower height not to exceed elevation of 200.0 ft
- Offer low maintenance
- Provide required navigational clearance
- Minimize impact to Willamette River
- Use prescriptive design-build approach

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SPAN REQUIREMENTS

- **Navigational clearance requirements:**

  Assume mean water at elevation 12.04 ft

  Provide 150-ft width to elevation 82.91 ft

  Provide 600-ft width to elevation 70.39 ft

- **Final span selection:**

  Main span of 780 ft

  Back span of 390 ft; place end bents on land

BRIDGE SITE PLAN

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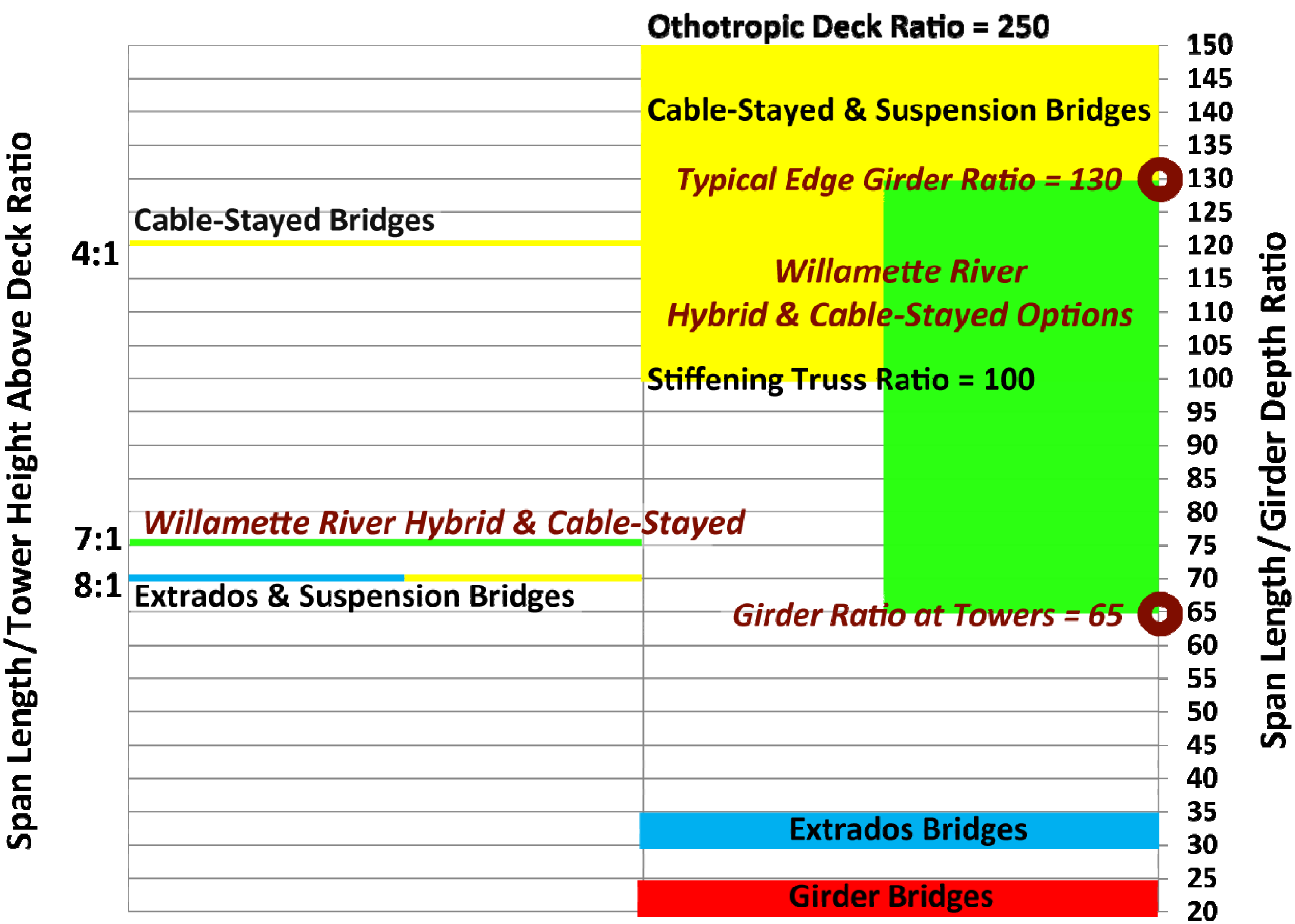
FINAL BRIDGE TYPES STUDIED

- Cable-stayed H-tower bridge
- Hybrid suspension/cable-stayed H-tower bridge
- Wave-frame bridge

BRIDGE DEPTH MATRIX



CABLE-STAYED OPTION

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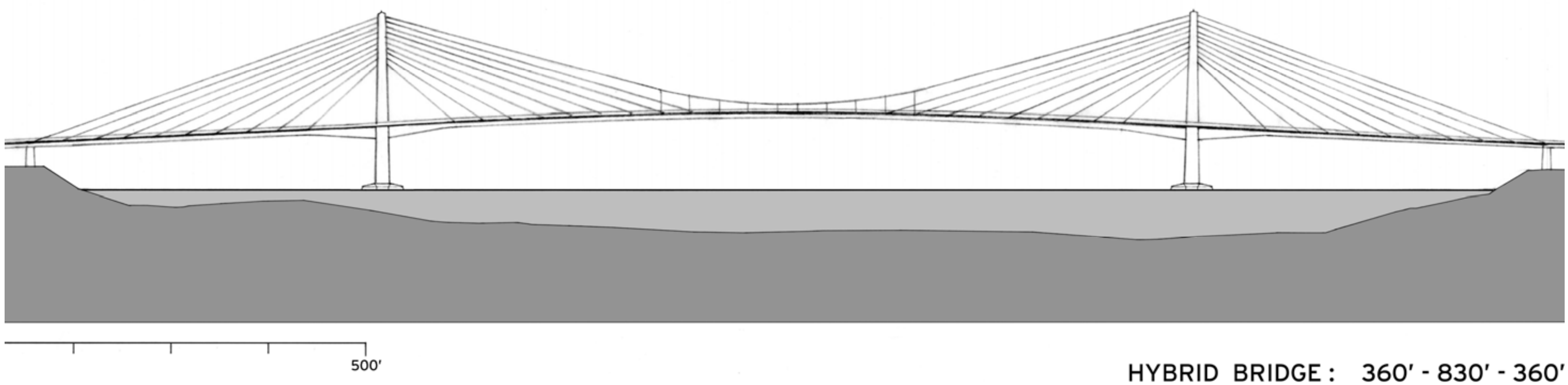
HYBRID OPTION

HYBRID ELEVATION



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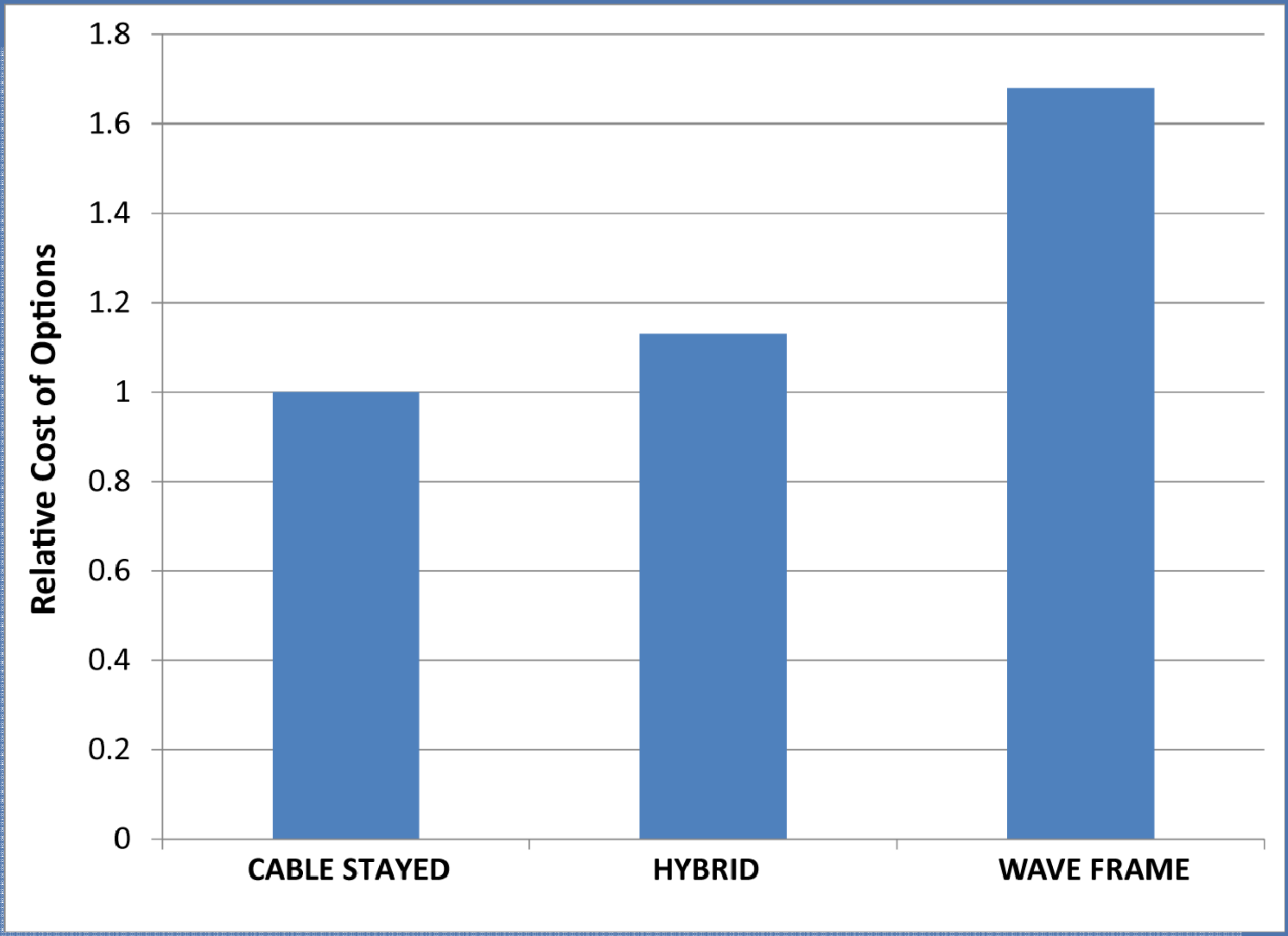
WAVE-FRAME OPTION

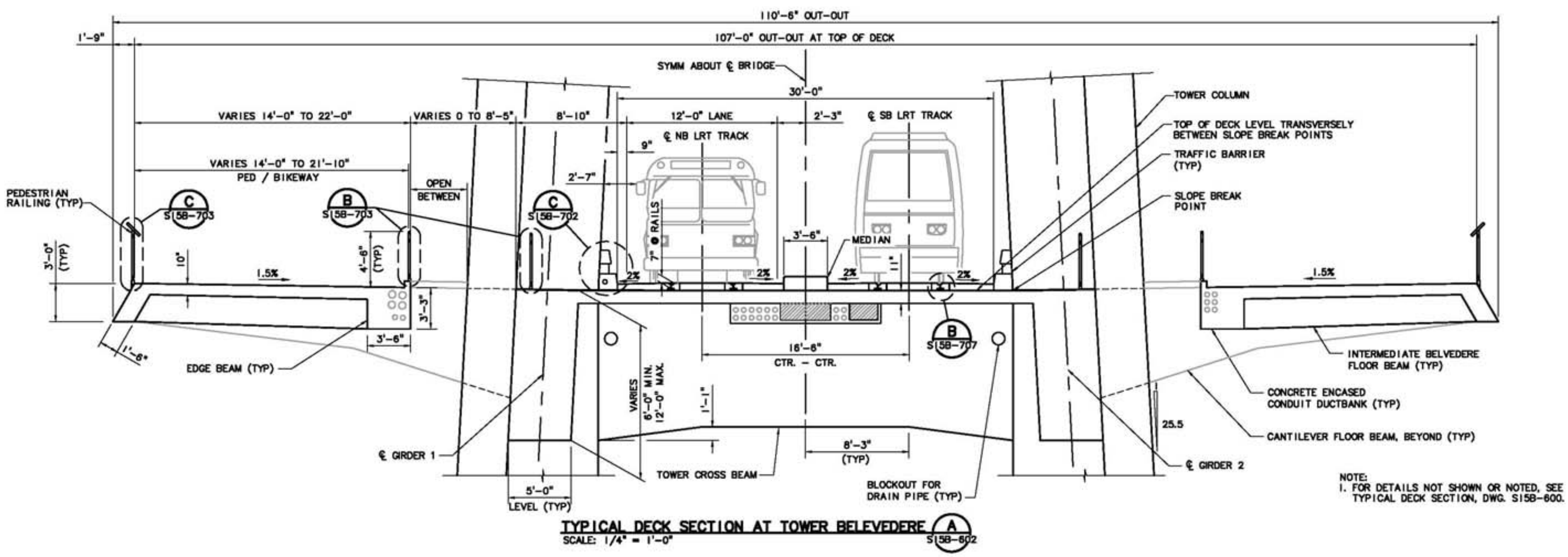
OPTION COST COMPARISON



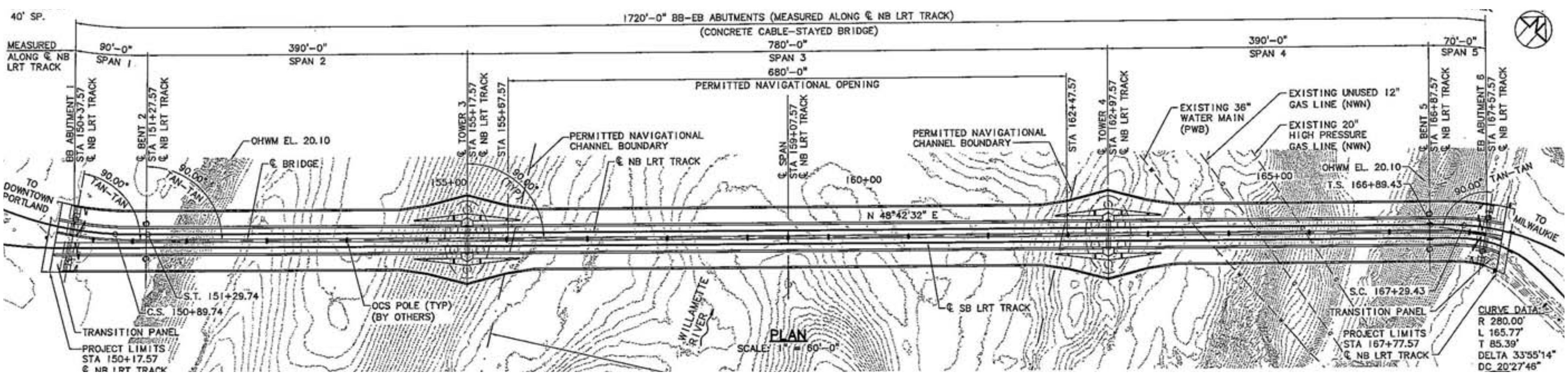
ADDITIONAL HYBRID COST

Bridge Component	Cost Differential
Concrete-Superstructure	-$1459000
Epoxy-Reinforcing Steel Superstructure	-$206,950
Stay Cables	-$649,300
Main-Suspension Cable	$3,383,700
Suspenders	$163,200
Structural Steel-Furnish	$1,777,000
Structural Steel-Erect	$3,949,000
Structural Steel-Clean/Paint	$222,800
Total Additional Cost	**$7,180,450**

SIGNIFICANT PEDESTRIAN USE



DECK PLAN


1720'-0" BB-EB ABUTMENTS (MEASURED ALONG ℄ NB LRT TRACK)
(CONCRETE CABLE-STAYED BRIDGE)
40' SP.
MEASURED ALONG ℄ NB LRT TRACK
90'-0" SPAN 1
390'-0" SPAN 2
780'-0" SPAN 3
680'-0" PERMITTED NAVIGATIONAL OPENING
390'-0" SPAN 4
70'-0" SPAN 5
BB ABUTMENT 1 STA 150+37.57 ℄ NB LRT TRACK
℄ BENT 2 STA 151+27.57 ℄ NB LRT TRACK
℄ TOWER 3 STA 155+17.57 ℄ NB LRT TRACK
STA 155+67.57
℄ SPAN STA 159+07.57 ℄ NB LRT TRACK
STA 162+47.57
℄ TOWER 4 STA 162+97.57 ℄ NB LRT TRACK
℄ BENT 5 STA 166+87.57 ℄ NB LRT TRACK
EB ABUTMENT 6 STA 167+57.57 ℄ NB LRT TRACK
OHWM EL. 20.10
℄ BRIDGE
PERMITTED NAVIGATIONAL CHANNEL BOUNDARY
℄ NB LRT TRACK
EXISTING 36" WATER MAIN (PWB)
EXISTING UNUSED 12" GAS LINE (NWN)
EXISTING 20" HIGH PRESSURE GAS LINE (NWN)
TO DOWNTOWN PORTLAND
TO MILWAUKIE
90.00° TAN-TAN
155+00
160+00
165+00
N 48°42'32" E
T.S. 166+89.43
S.T. 151+29.74
C.S. 150+89.74
OCS POLE (TYP) (BY OTHERS)
℄ SB LRT TRACK
WILLAMETTE RIVER
PLAN
SCALE: 1" = 60'-0"
TRANSITION PANEL
PROJECT LIMITS STA 150+17.57 ℄ NB LRT TRACK
S.C. 167+29.43
PROJECT LIMITS STA 167+77.57 ℄ NB LRT TRACK
CURVE DATA:
R 280.00'
L 165.77'
T 85.39'
DELTA 33°55'14"
DC 20°27'46"

PEDESTRIAN COMFORT

- **Transit vehicle-induced vibrations**

  Rolling Stock Analysis

- **Pedestrian-induced vibrations**

  Synchronous Lateral Excitation Analysis

ROLLING STOCK ANALYSIS

- **Design criteria**

  Combine vehicle- and wind-induced vibration

  Operation speed of 25 mph

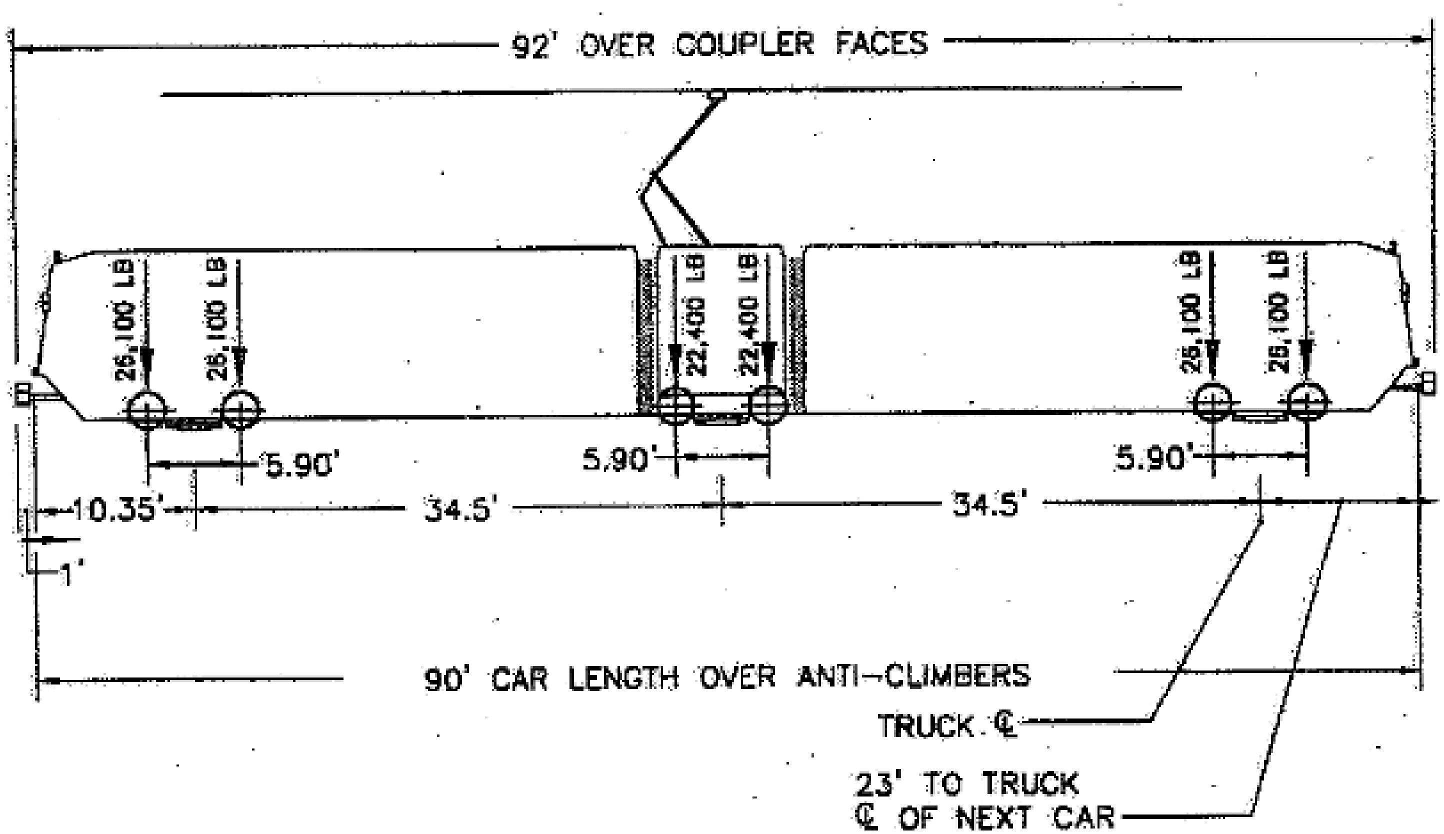
  Wind speed of 30 mph

- **Vibration limits:**

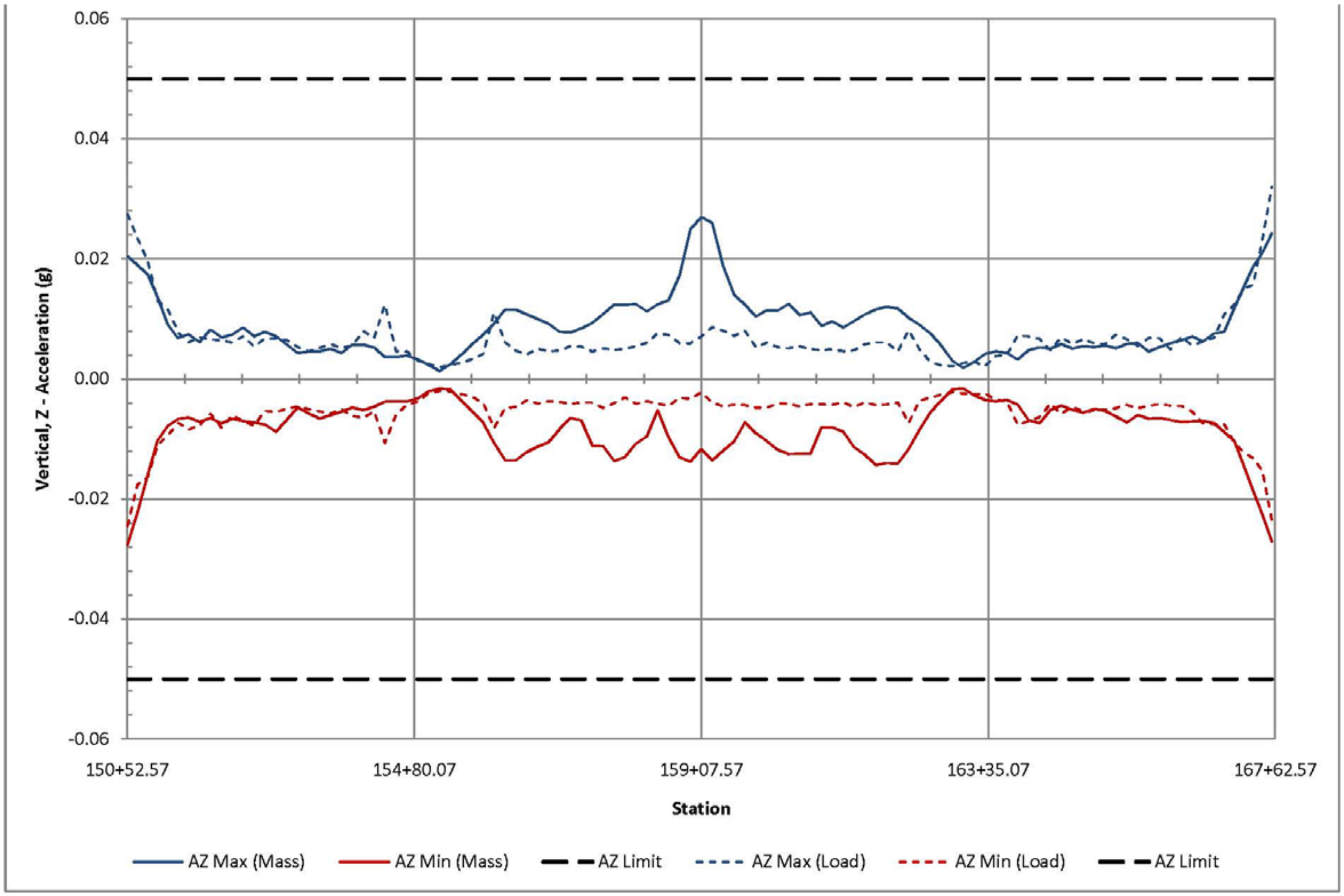
  0.05g vertical acceleration

  0.025g horizontal acceleration

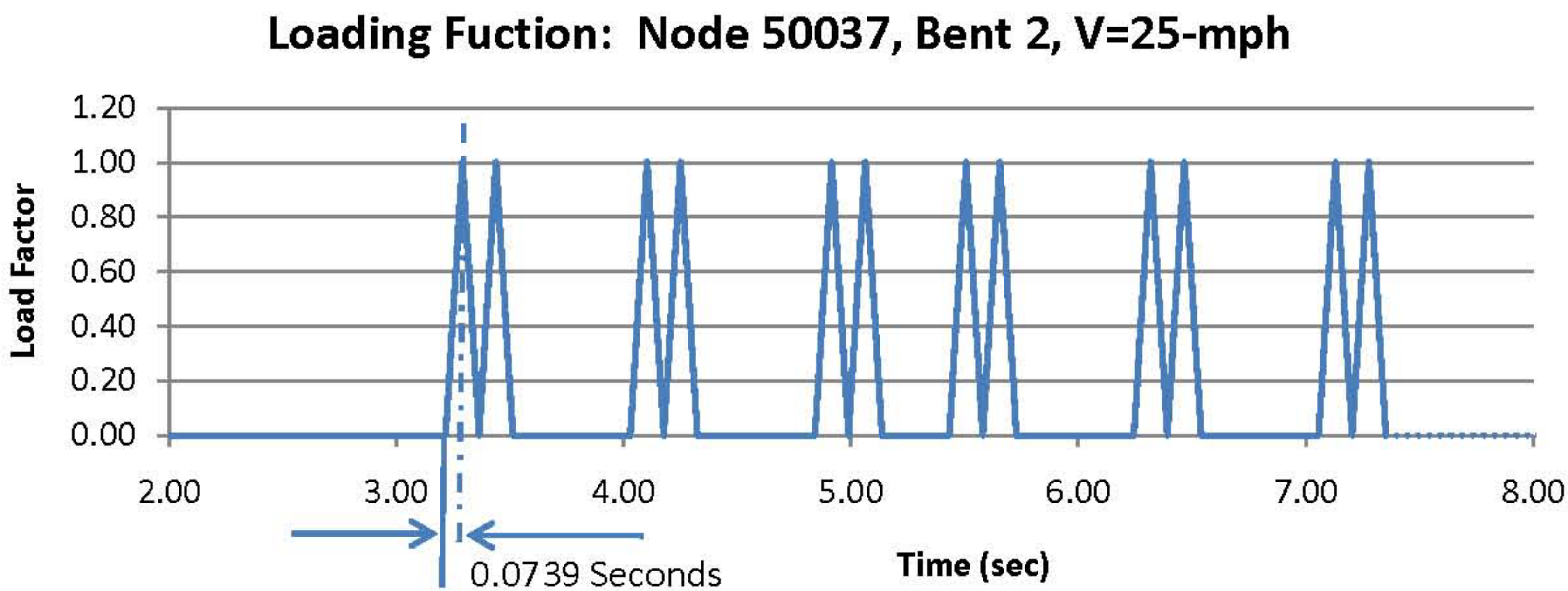
TRANSIT VEHICLE



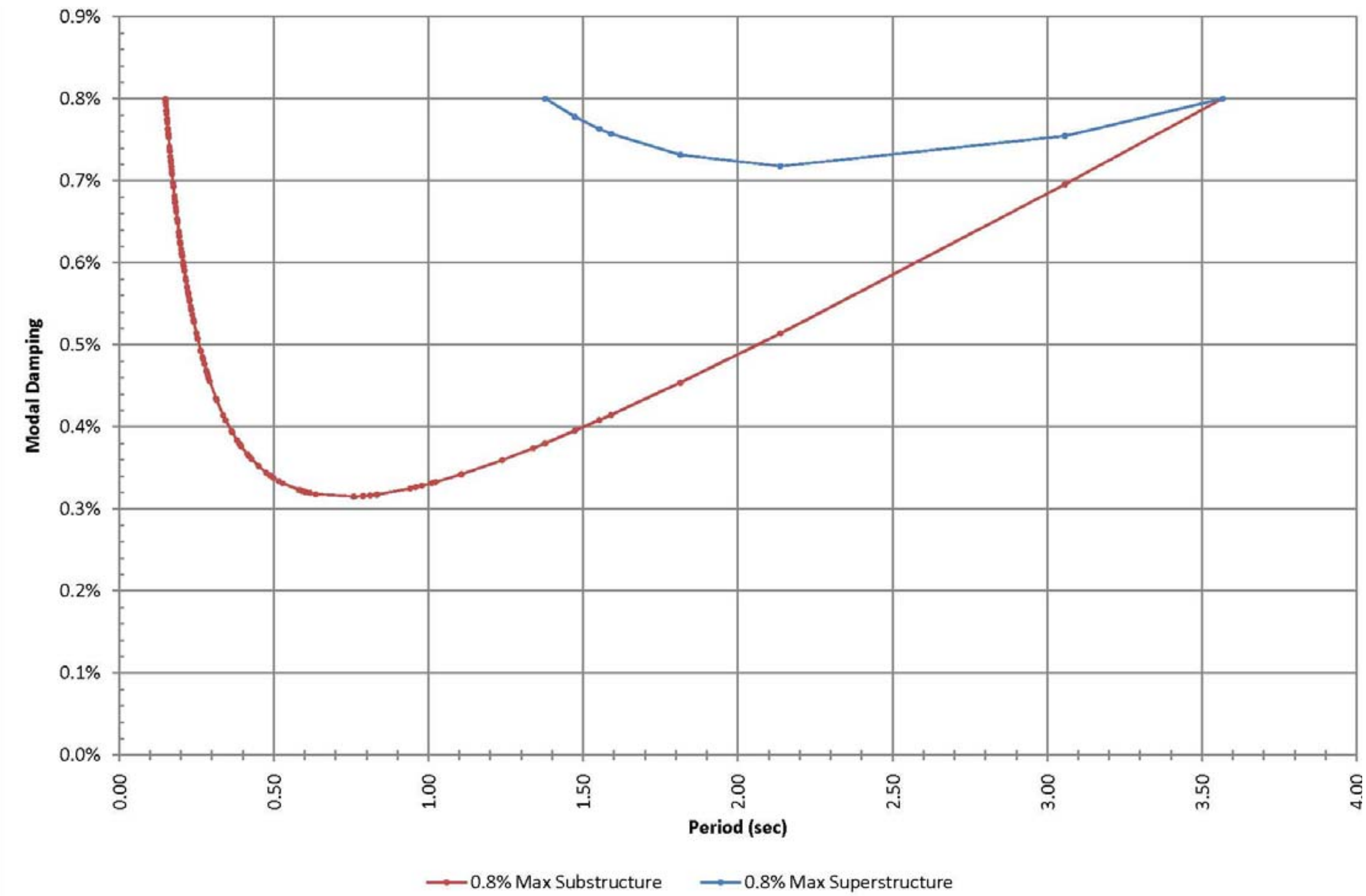
VEHICLE CONSIDERED AS MASS



AXLE-LOADING FUNCTION

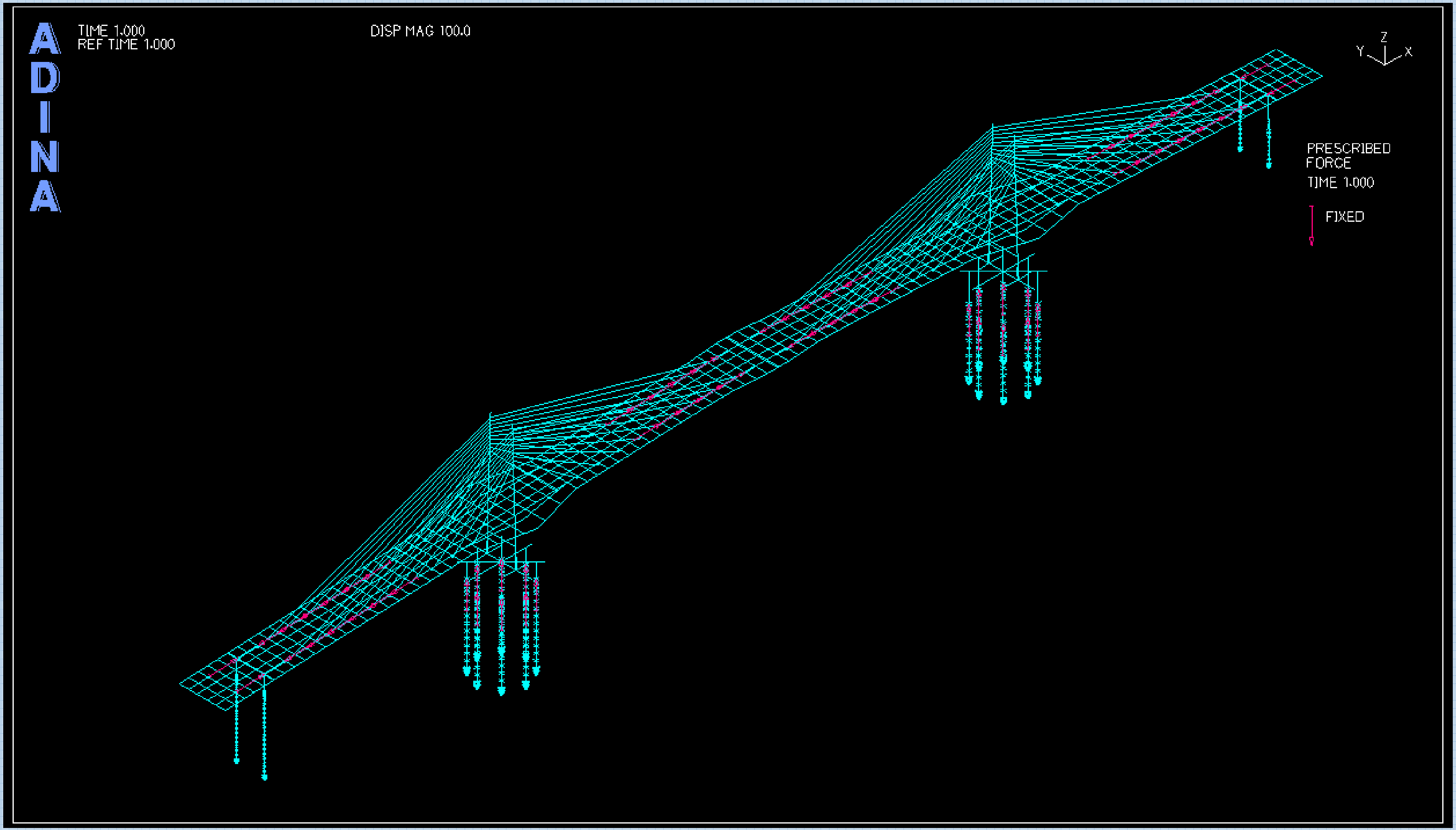


DAMPING

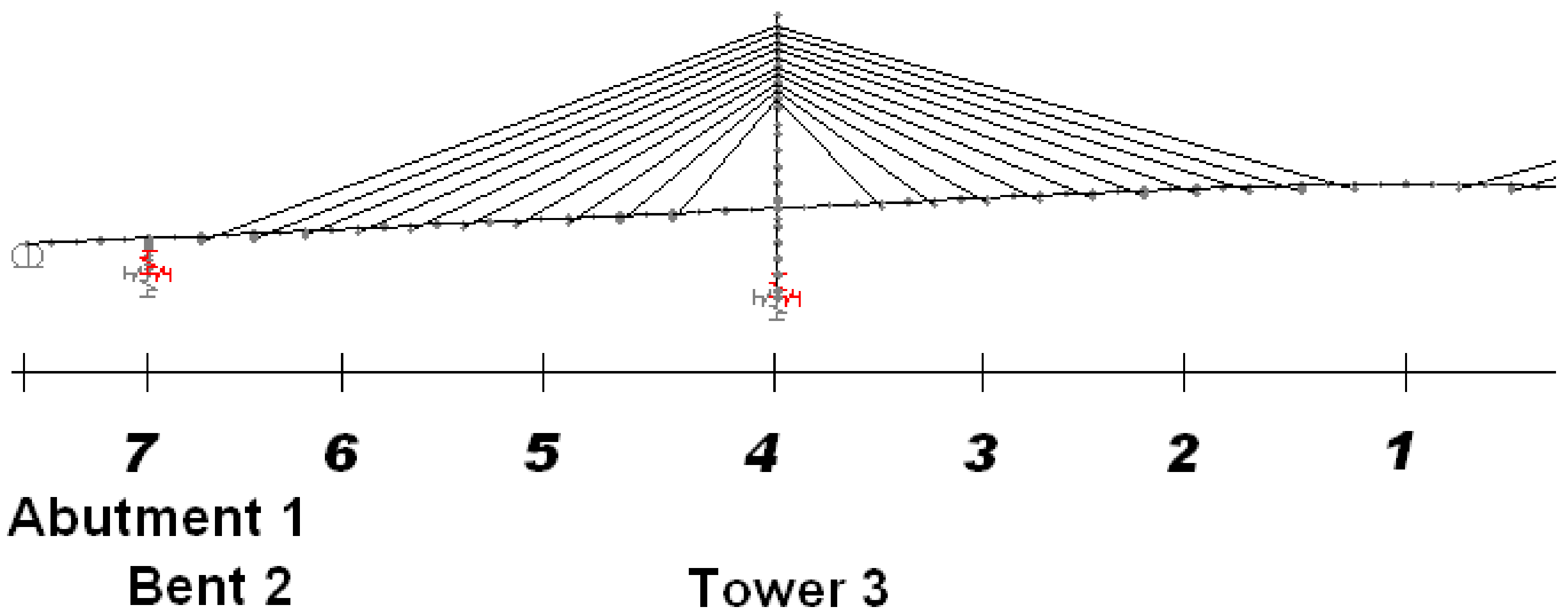


0.9%
0.8%
0.7%
0.6%
0.5%
0.4%
0.3%
0.2%
0.1%
0.0%
Modal Damping
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
Period (sec)
0.8% Max Substructure
0.8% Max Superstructure

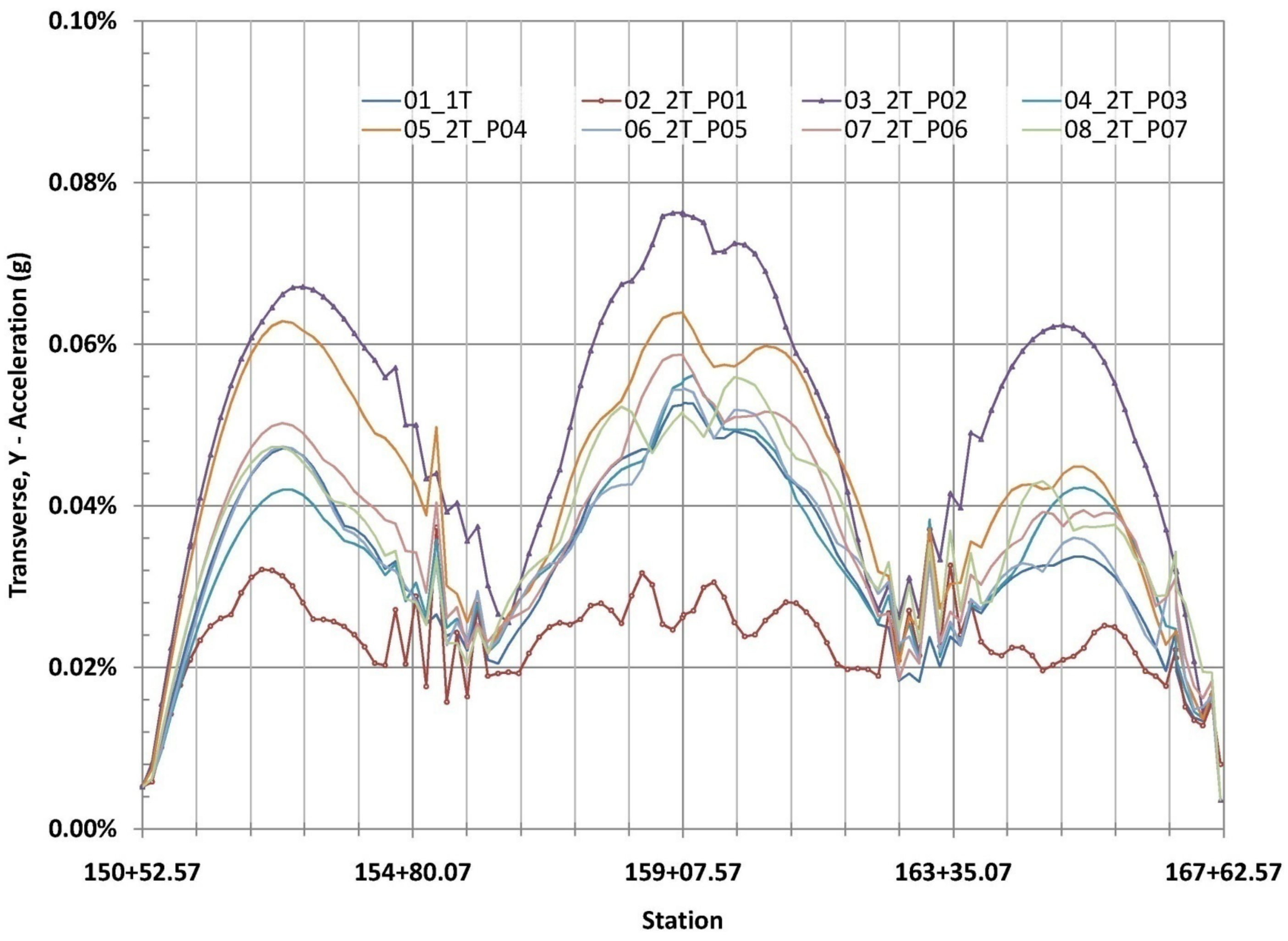
DYNAMIC RESPONSE



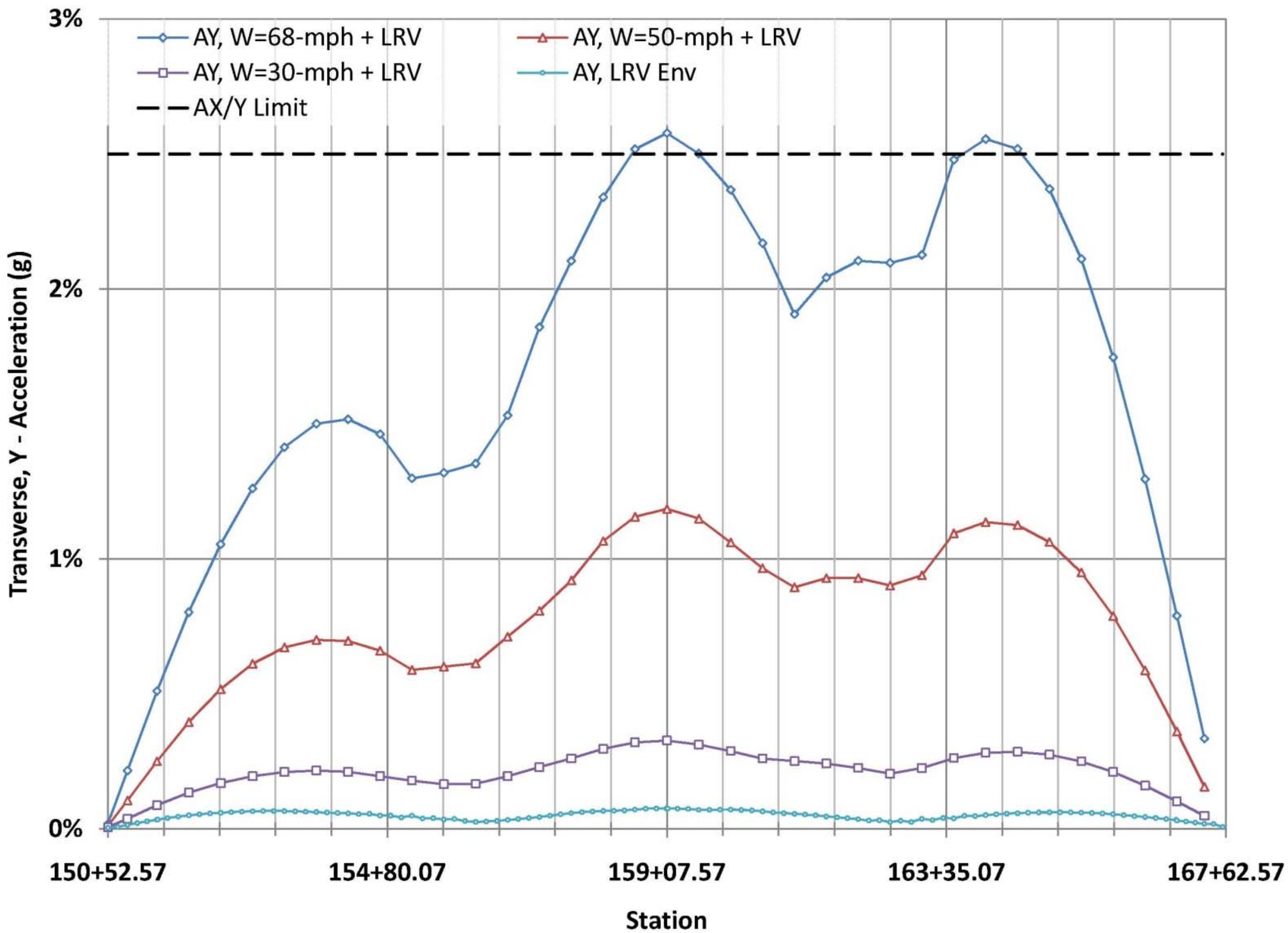
ALTERNATE TRAIN PASS LOCATIONS



ROLLING STOCK ANALYSIS RESULTS – WITHOUT WIND



ROLLING STOCK ANALYSIS RESULTS – WITH WIND



SYNCHRONOUS LATERAL EXCITATION

- **Design criteria**

  Pedestrian loading across entire bridge

  Sétra – French Ministry of Transport and Infrastructure

- **Vibration limits:**

  0.05g vertical acceleration

  0.01g horizontal acceleration

SYNCHRONOUS LATERAL EXCITATION – BASIC CONCEPT

- A percentage of pedestrians will randomly synchronize walking frequencies
- Statistical studies establish this percentage
- Pedestrian synchronized walking frequencies must match bridge frequencies for synchronous lateral excitation
- Bridge will resonate dynamically
- If bridge response is sufficient, other pedestrians adjust walking frequency to match and then synchronous lateral excitation occurs

SETRA PROCEDURE

- **Determine footbridge class**

  Class I – Urban Footbridge: very heavy traffic; frequently fully loaded
- **Define comfort level**

  Maximum comfort range 1: 0.05g vertical acceleration; 0.01g horizontal acceleration
- **Develop analytical model**
- **Determine natural frequencies of bridge**

  Lower bound mass: mass of structure alone

  Upper bound mass: 14.6 psf pedestrian mass

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IDENTIFY FREQUENCIES OF CONCERN

Veritical and Longitudinal Vibration						
Frequency (Hz)	0	1	1.7	2.1	2.6	5
Range 1			M26- 1.64			
Range 2				M33- 2.0		
Range 3						
Range 4						

Transverse Horizontal Vibration						
Frequency (Hz)	0	0.3	0.5	1.1	1.3	2.5
Range 1			M6 - 0.62 M11- 0.89 M14- 1.0			
Range 2		M3- 0.46				
Range 3						
Range 4						

Risk of Resonance

Range 1: Maximum

Range 2: Medium

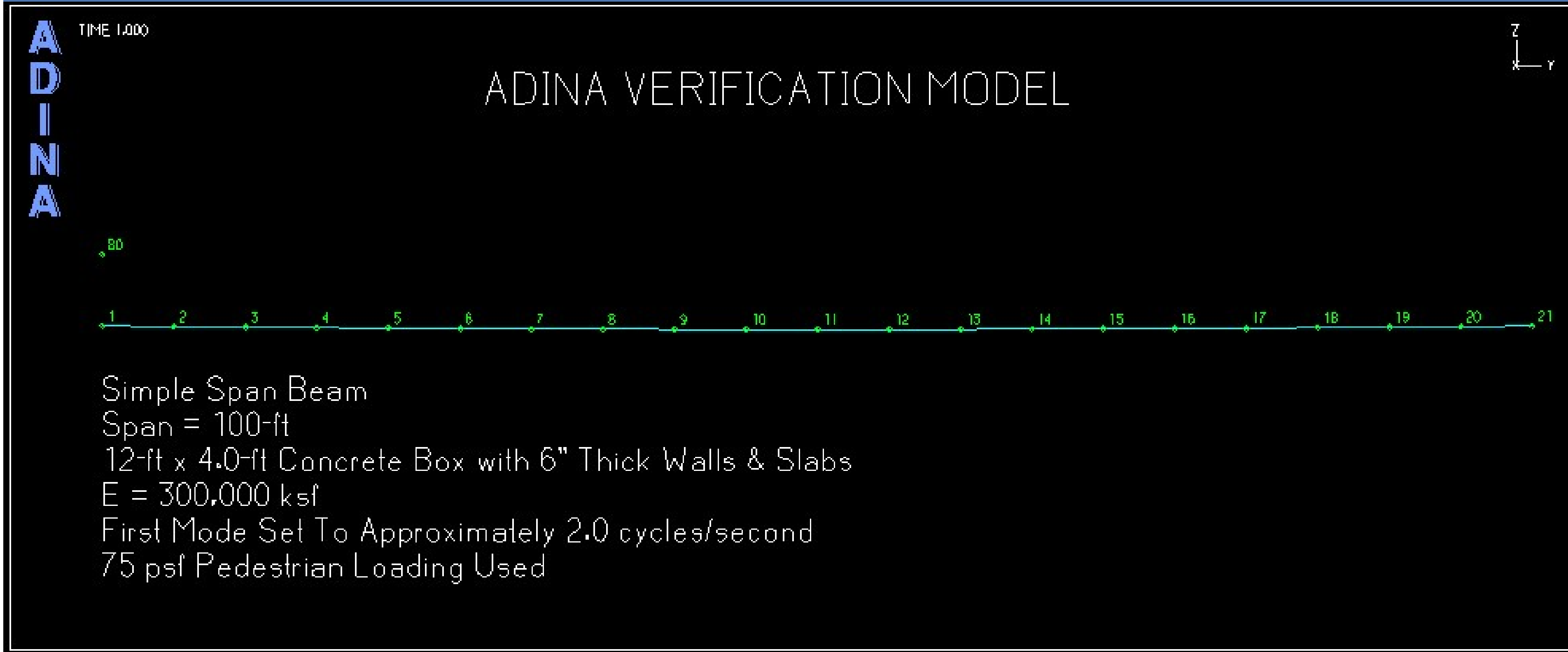
Range 3: Low for Standard Loading

Rabge 4: Negligible

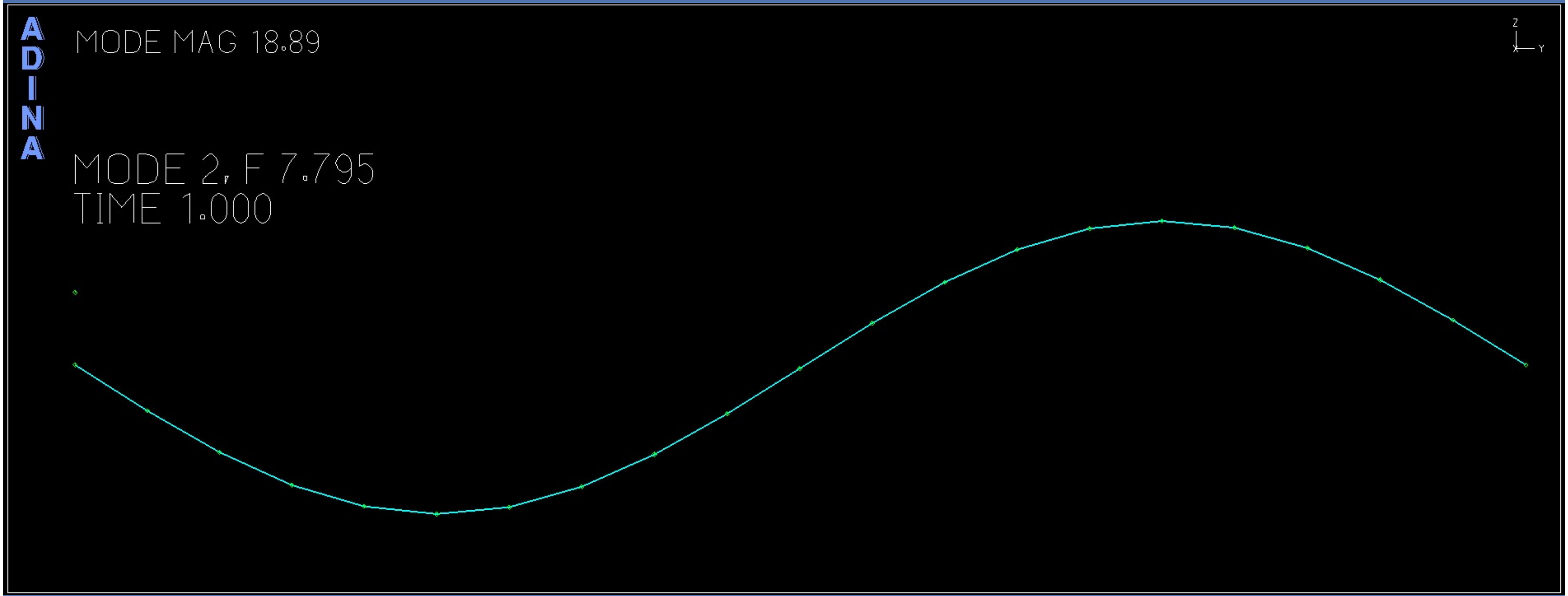
DEVELOP LOAD PATTERNS AND FUNCTIONS

- Develop load intensities
- Apply to entire deck in direction under investigation
- Sign of load to match mode shape
- Use sinusoidal-loading function

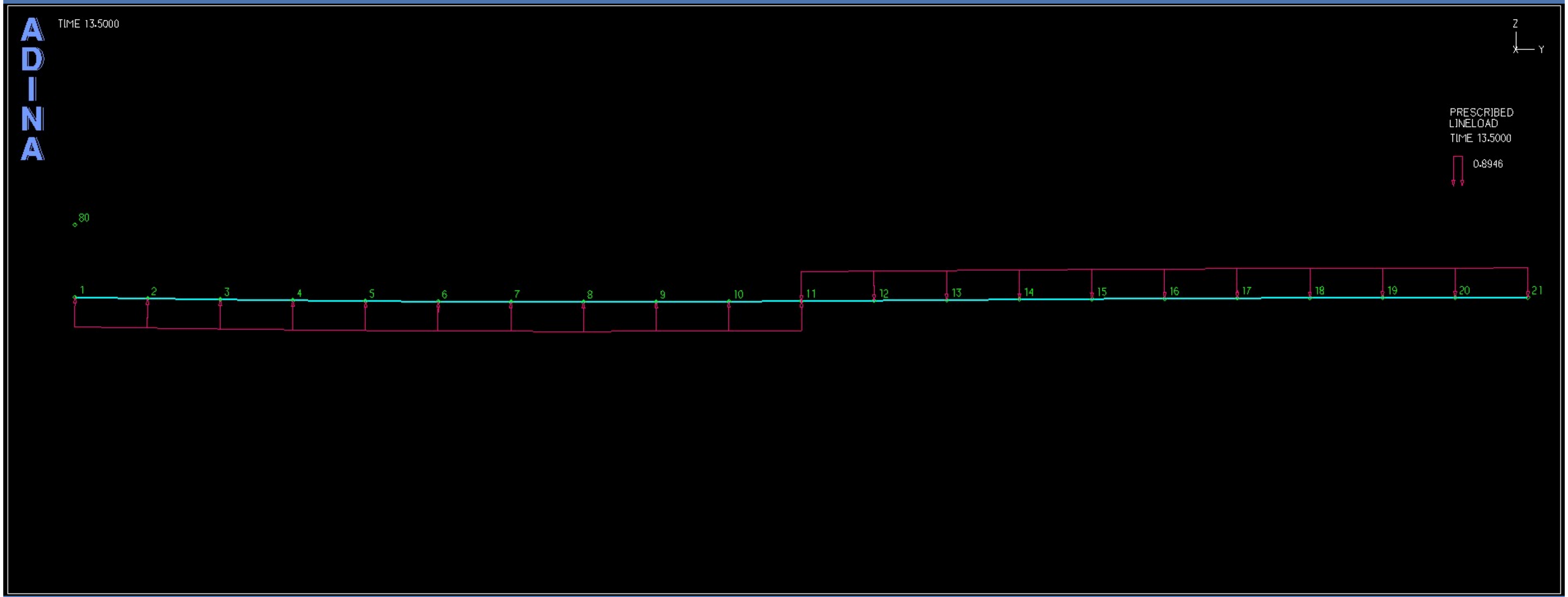
EXAMPLE – SIMPLE-SPAN BRIDGE



MODE 2



PEDESTRIAN LOADING



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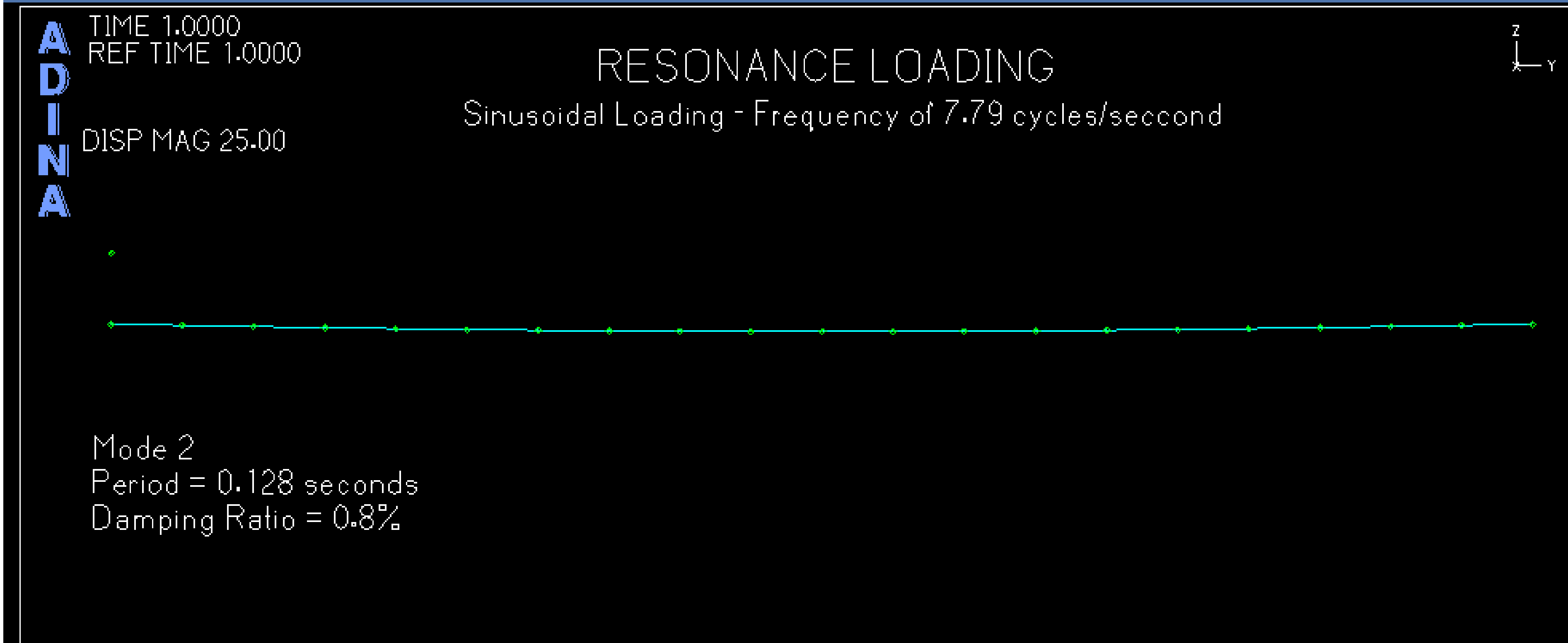
RESONANCE RESPONSE



SYNCHRONOUS LATERAL EXCITATION RESULTS

- Portland-Milwaukie Light Rail Bridge not subject to synchronous lateral excitation
- Maximum horizontal acceleration of 0.005g at Mode 3
- Maximum vertical acceleration of 0.015g at Mode 3

CONCLUSIONS

- Through prescriptive design-build, the owner maintains control of important aspects when using design-build
- To accomplish this, the owner should perform adequate preliminary engineering studies prior to issuing Request for Proposals
- Synchronous Lateral Excitation and Rolling Stock analyses important with large pedestrian use