Bridge Deck Placement under Traffic-Induced Vibrations

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Western Bridge Engineers' Seminar
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Hwy 1 over Fairview Industrial Drive

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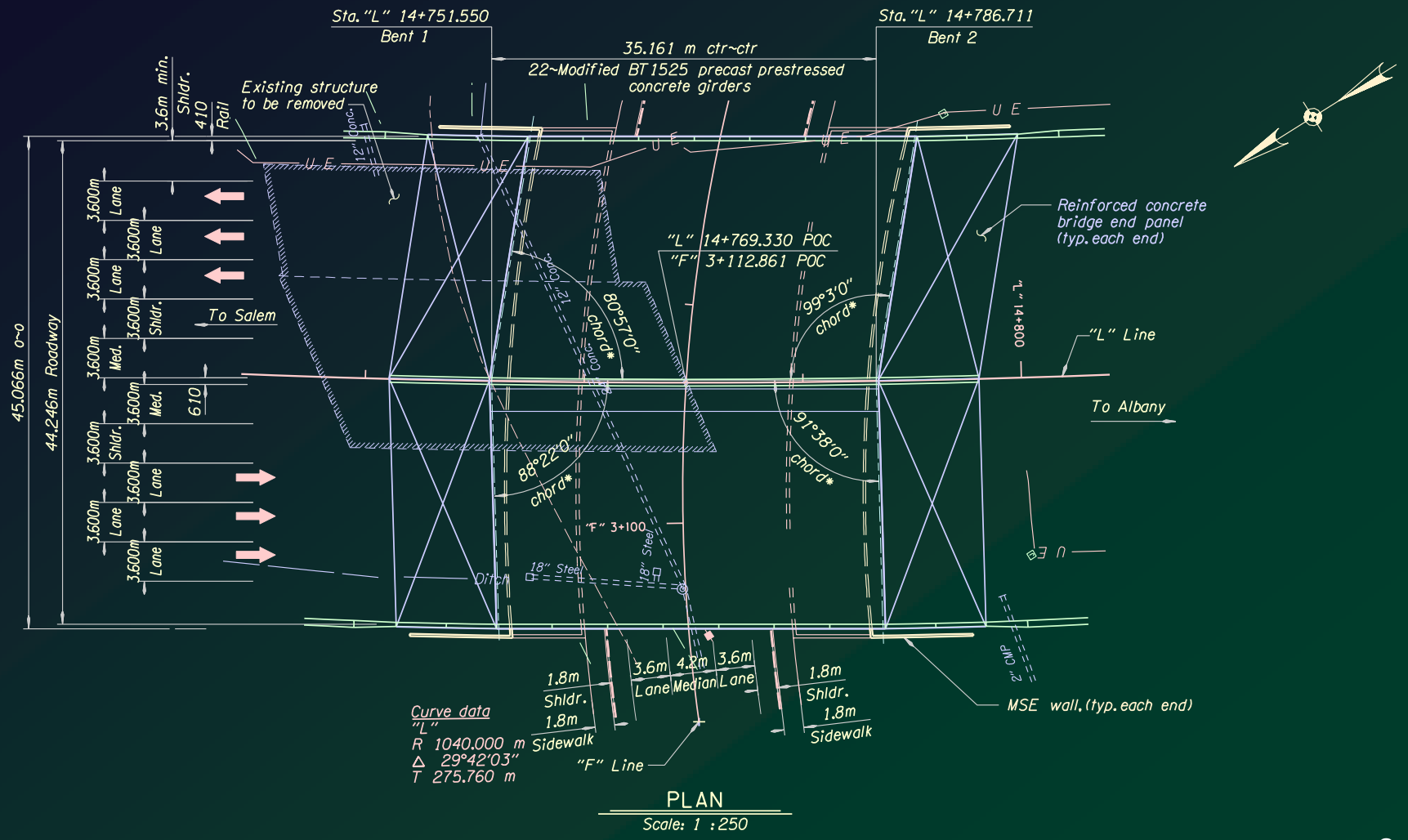
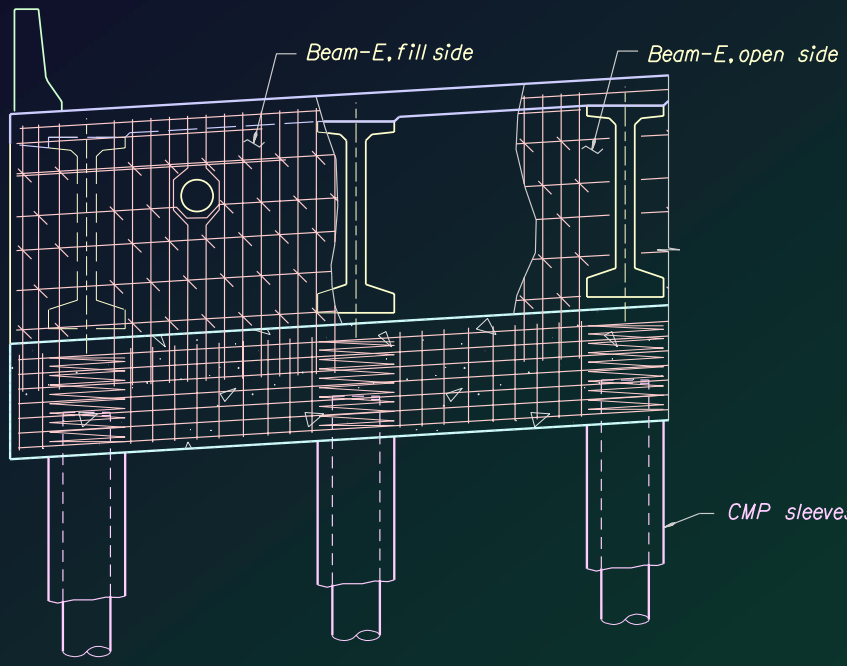
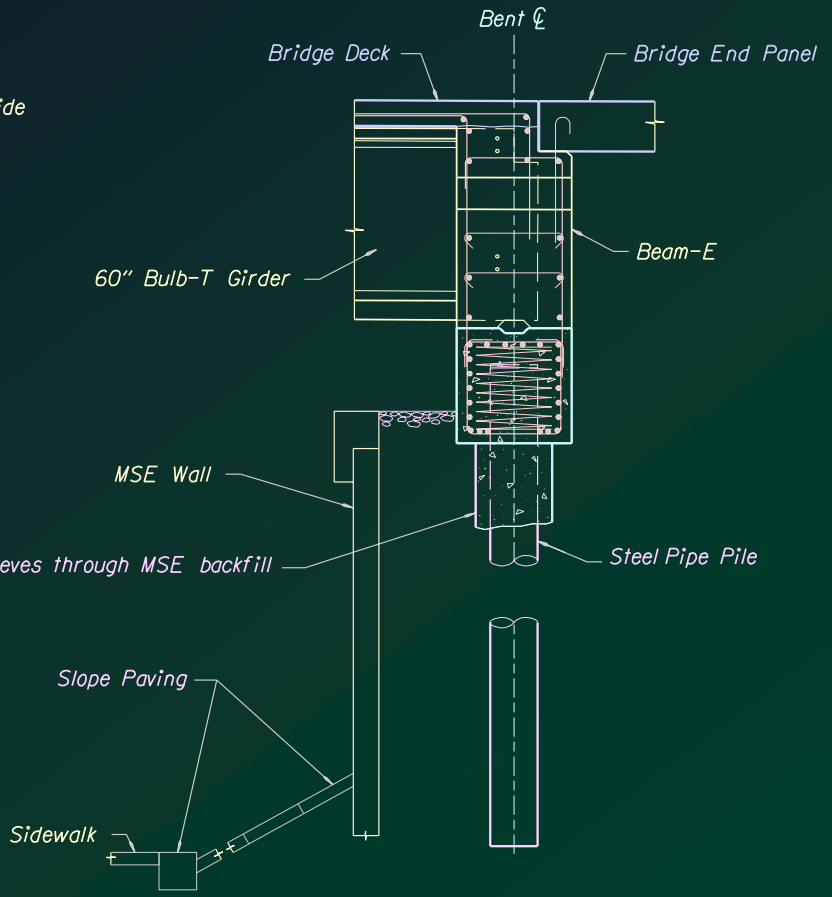


Abutment Details



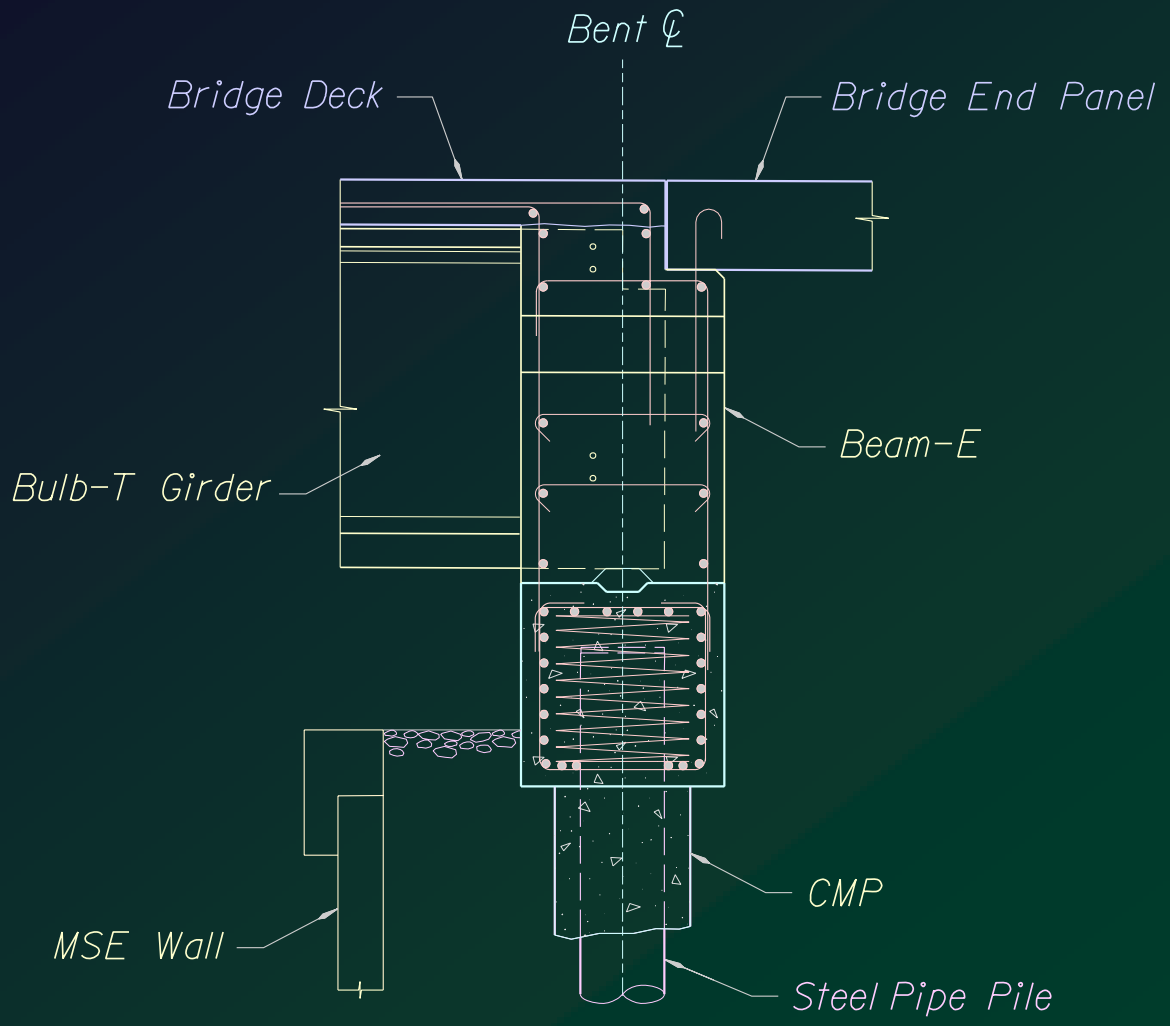
PARTIAL BENT 2 ELEVATION
(BENT 1 SIMILAR)
Scale: 1 :20



BENT 2 SECTION (BENT 1 SIMILAR)
Scale: 1 :20

Stage 2 Abutment Construction

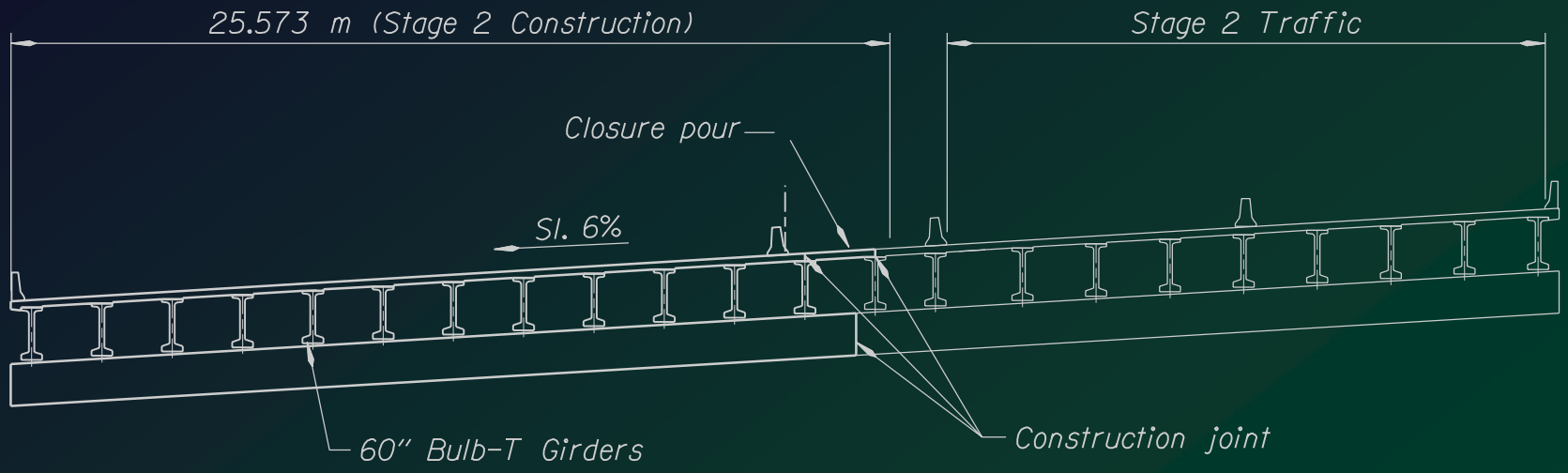
Abutment Section



Stage 2 Deck Section

Stage 2: 12 girders

Stage 1: 10 girders



STAGE 2

Stage 2 Deck Construction

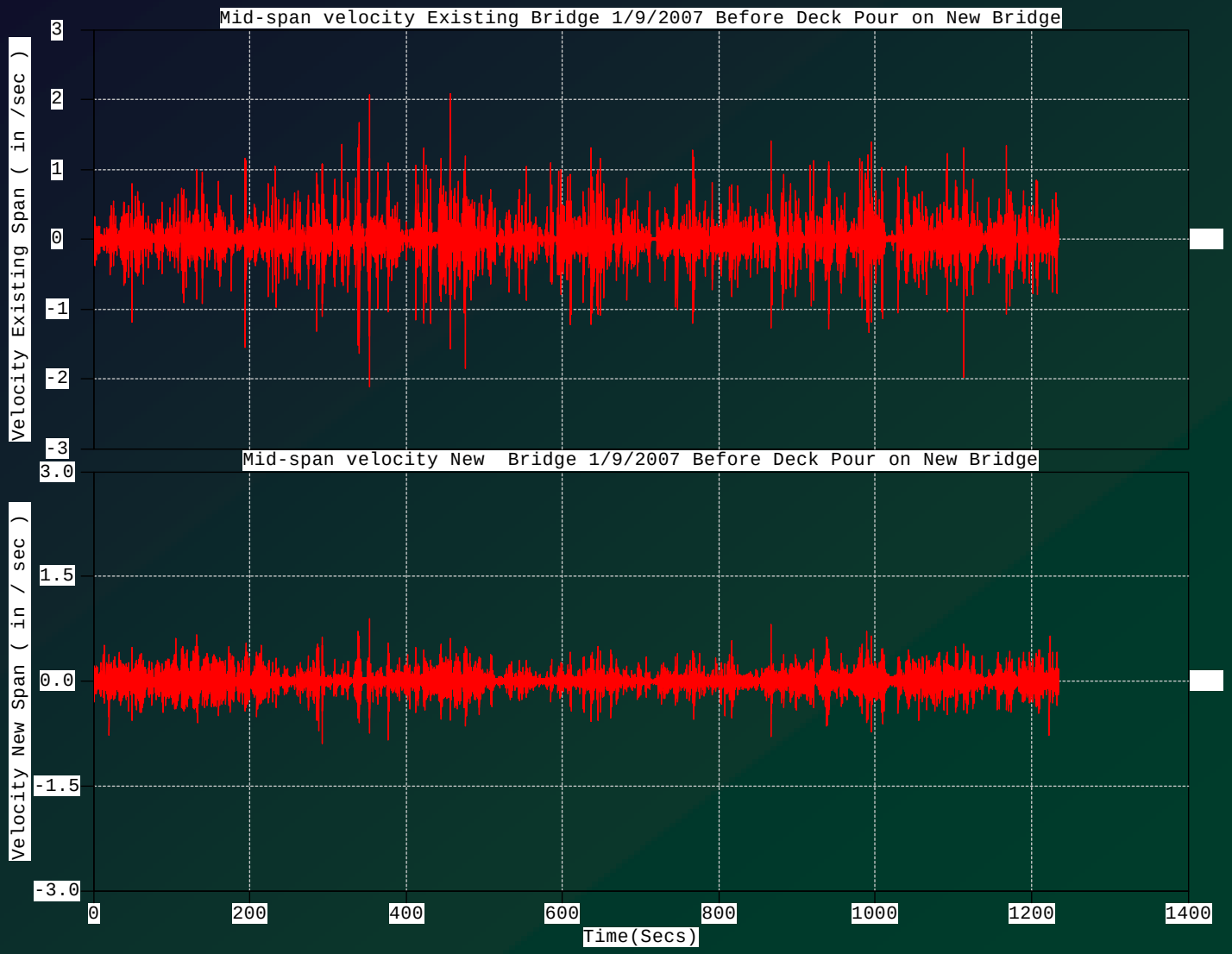
Initial Vibration Measurements

Initial Vibration Measurements

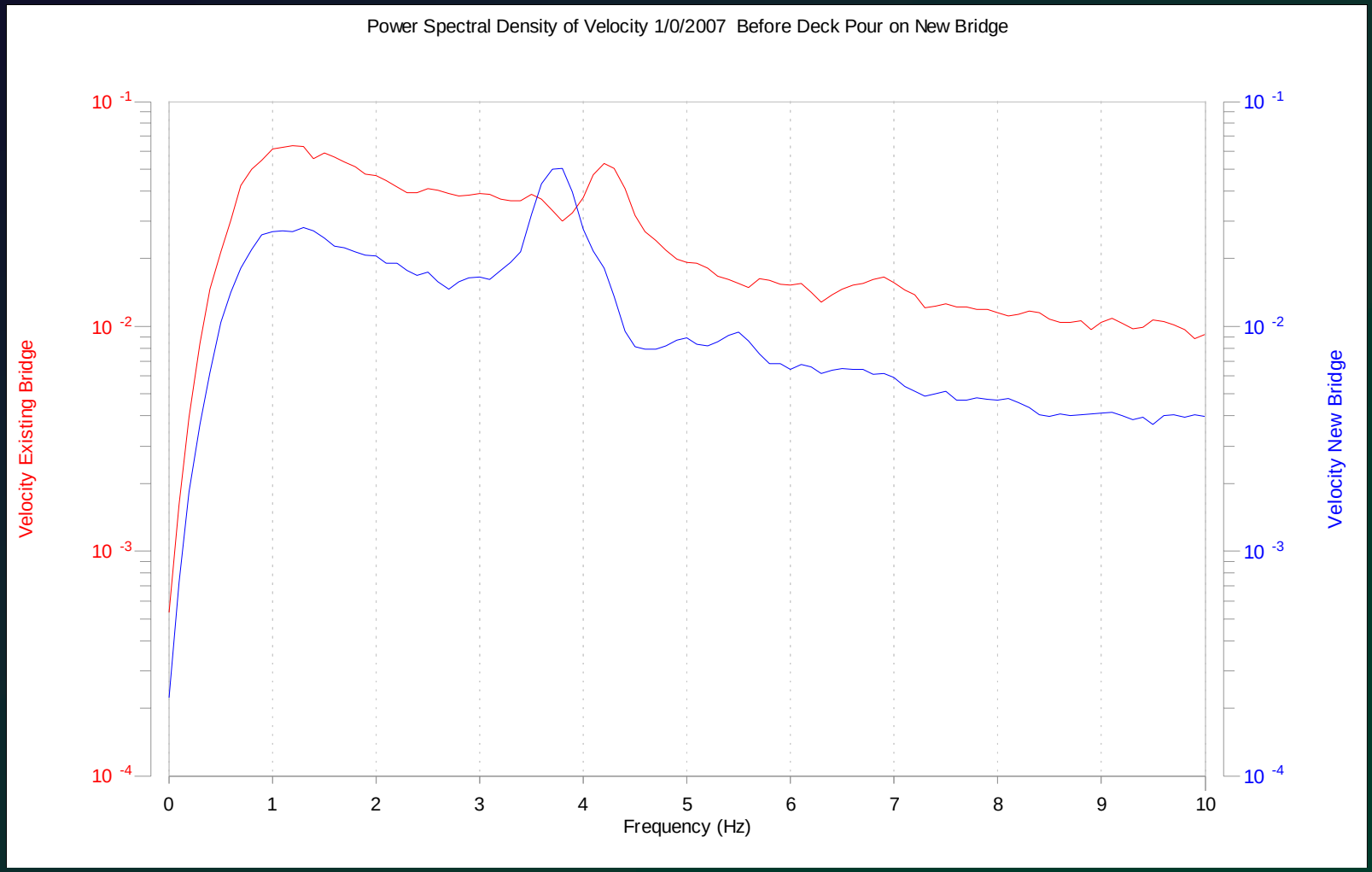
- Simultaneous mid-span measurements
  - In-service structure (Stage 1)
  - New structure (Stage 2)
- 20-minute period

	Stage 1	Stage 2
Peak Accelerations	0.23 g's	0.10 g's
Peak Velocity	2.0 in/sec	0.8 in/sec
Primary Frequency of Vibration	4.2 Hz	3.7 Hz

Initial Vibration Measurements

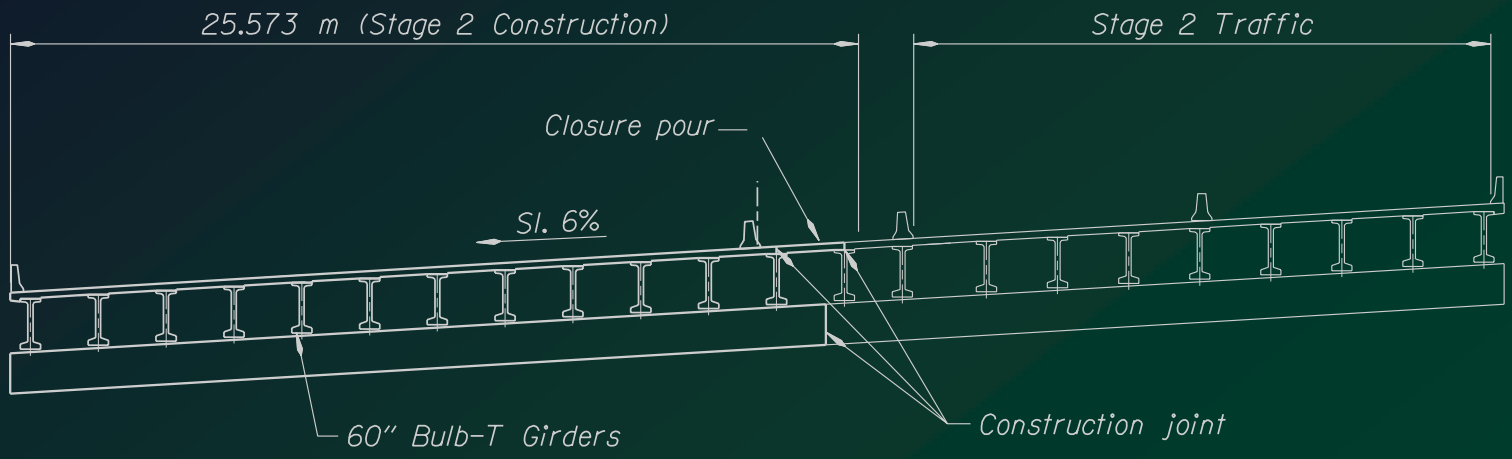


Initial Vibration Measurements



Cause of Vibrations

- Rotation of the pile caps due to truck live loading
- Pile cap for both stages were connected
  (Short end-bearing piles into a basalt layer)



STAGE 2

Cause of Vibrations

- Rotation of the pile caps due to truck live loading
- Pile cap for both stages were connected
  (Short end-bearing piles into a basalt layer)
- A proportional rotation was transmitted from Stage 1 resulting in a reduced, but similar vibratory movements in Stage 2
- Arrival time of peak acceleration and velocity was nearly simultaneous at Stage 1 and 2 locations

What do we do?

- Cut the pile cap?
- Remove concrete, but keep rebar continuous?
- Reduce traffic speed?
- Modify concrete mix?

Survey of Industry Recommendations

- ACI 345.2R *Guide for Widening Highway Bridges*, Carrato et al., ACI Journal, July-August 1992
- NCHRP Report 86 *Effects of Traffic-Induced Vibrations on Bridge-Deck Repairs*, David G. Manning, December 1981
- *Design Manual For Roads and Bridges*, The Highways Agency, Northern Ireland, November 2000
- *Bridge Construction Manual*, Minnesota DOT, November 2005
- *Protection of Fresh Concrete from Harmful Construction Related Vibrations*, Sheikhizadeh & Schettler, 2005 Western Bridge Engineers' Seminar

ACI 345.2R: Key Statements

- Damage from traffic-induced vibrations "… *is relatively rare and can be eliminated by the use of a proper construction sequence and correct design details*." [Section 1.2.6]

- Vibrations due to highway traffic "… *may actually be beneficial*." [Section 3.4]

- Damage from traffic-induced vibrations is rare when "… *fresh concrete reinforcement and forms are in synchronous movement*." [Section 3.4]

ACI 345.2R: Recommendations

- Use Low-slump concrete (≤ 4”). [Section 3.4.a]
- Use only straight bars between old and new concrete. [Section 3.4.b]
- Vehicle speed and weight restrictions are not necessary. [Section 3.4]

NCHRP Report 86: Key Statements

- "*Well-proportioned concrete is very tolerant of low-amplitude, low frequency vibrations during the period of setting and early strength development.*" [Summary]
- "*… traffic-induced vibrations do not cause relative movement between fresh concrete and embedded reinforcing steel.*" [Summary]
- Peak particle velocity provides an indication of the risk of damage. [Chapter 2]

NCHRP Report 86

Human Perception of Peak Particle Velocity

PPV (in/sec)	Human Reaction
0 – 0.006	Imperceptible
0.006 – 0.012	Threshold of perception
0.08	Vibrations perceptible
0.1	Continuous vibrations annoy people
0.2	Short-term vibrations annoy people
0.4 – 0.6	Unacceptable to people walking on bridges

From Table 2, Chapter 2, NCHRP Report 86, December 1981

The Highways Agency, Northern Ireland

- "*For concrete less than 24 hours old, it has been suggested that vibrations during construction should be limited to a peak particle velocity of 5 mm per second.*" [Section 2.4] {5 mm/sec = 0.2 in/sec}
- Use well-proportioned, low-lump concrete [Sections 2.9 & 2.10]
- Do not use hooked reinforcement. [Section 2.13]
- The connection of the reinforcement between the two segments should be as rigid as possible. [Section 2.14]

Mn/DOT Bridge Construction Manual

- "*The human body can detect a vibration velocity of 0.5 mm/sec. But damage does not usually result until vibration velocity reaches 50 mm/sec.*" [Section 5-393.362] {50 mm/sec = 2 in/sec}

Safe Peak Particle Velocities (newly placed concrete)

Concrete Age (hrs)	Allowable Max PPV (in/sec)
0 – 3	N/A
3 – 12	1.0 in/sec
12 – 24	1.5 in/sec
24 – 48	2.5 in/sec
> 48	4.0 in/sec

From Mn/DOT Bridge Construction Manual, Section 5-393.362, Nov. 2005

Sheikhizadeh & Schettler

Recommendations for WSDOT

Minimum Compressive Strength	Maximum PPV
1000 psi	0.10 in/sec
< 1000 psi to 1400 psi	1.0 in/sec
< 1400 psi to 2000 psi	2.0 in/sec

From 2005 Western Bridge Engineers' Seminar

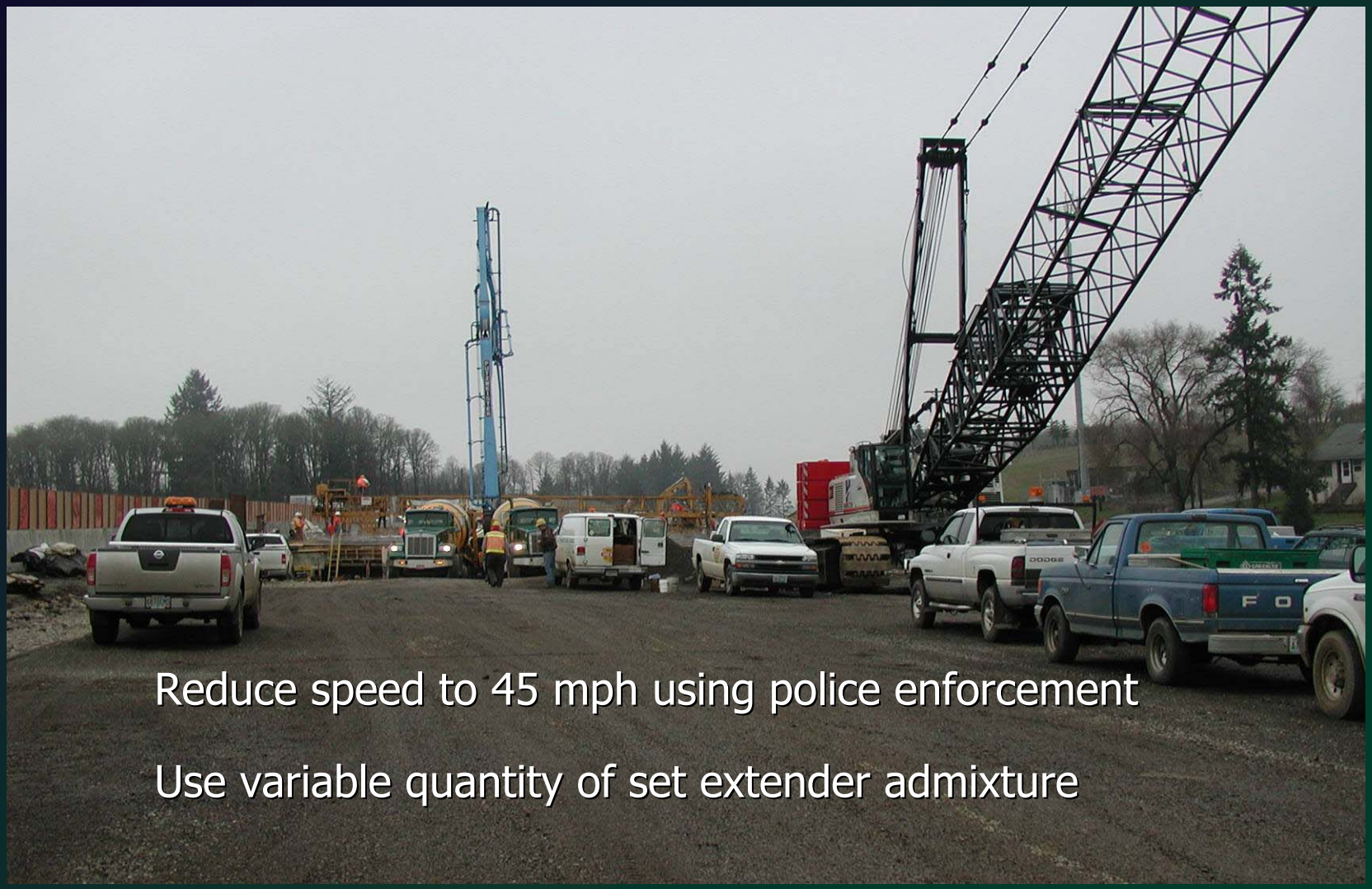
What do we do?

- Cut the pile cap? Possible & could be effective.
- Remove concrete, but keep rebar continuous? Possible & could be effective, but expensive.
- Reduce traffic speed? Significant speed reduction not practical, some reduction will not cause any harm.
- Modify concrete mix? Variable amount of set extender admixture might minimize exposure time.

Additional Considerations

- Documents researched did not provide a definitive answer whether problems would develop or not.
- Cost of sealing any cracks may be less than cost of cutting the pile cap.
- Rebar detailing and high performance concrete mix conform to recommendations.
- The additional mass from the deck concrete would likely reduce the PPV.
- Past performance of deck closures has been satisfactory.

Deck Placement



Reduce speed to 45 mph using police enforcement

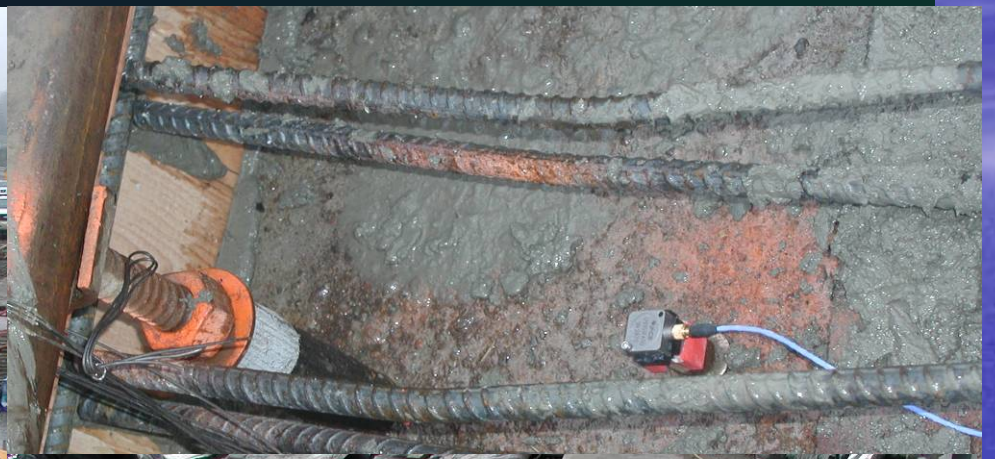
Use variable quantity of set extender admixture

Deck Placement

Deck Placement

Deck Placement

Vibration Measurements

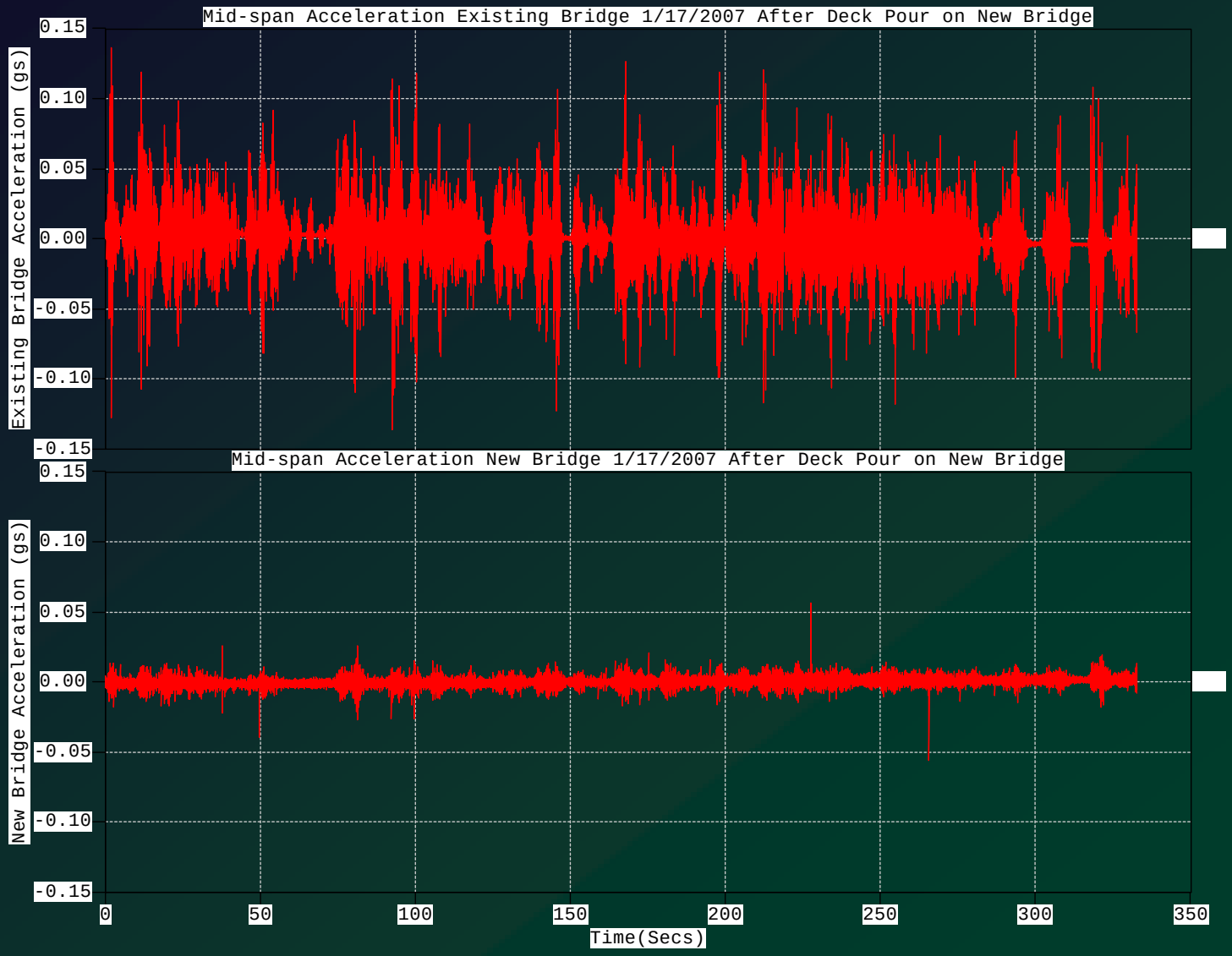


Deck Pour Vibration Measurements

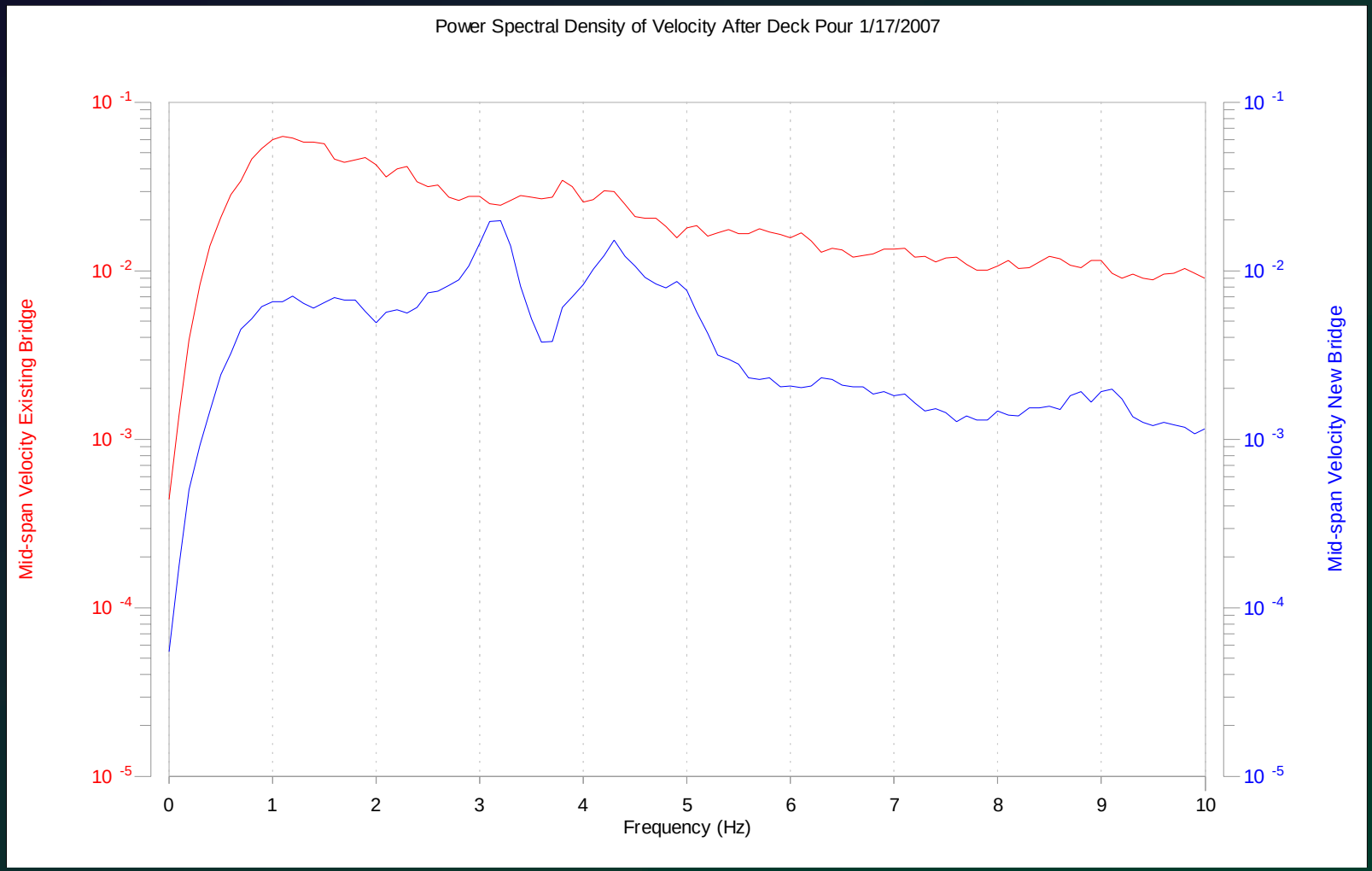
- Simultaneous mid-span measurements
  - In-service structure (Stage 1)
  - New structure (Stage 2)
- 15-minute period

	Stage 1	Stage 2
Peak Accelerations	0.18 g's	0.03 g's
Peak Velocity	1.8 in/sec	0.6 in/sec
Two Primary Frequencies	3.9 & 4.3 Hz	3.2 & 4.4 Hz

Vibration Measurements



Vibration Measurements



Comparison of Vibration Measurements

- Peak velocity of Stage 2 reduced from 0.8 to 0.6 in/sec (25% reduction)
- Peak velocity of Stage 1 reduced from 2.0 to 1.8 in/sec (10% reduction)
- Stage 2 (with wet concrete) vibrated at a peak velocity that was 33% of Stage 1 (with hardened concrete)

Deck Cracking?

Deck Cracking?

Cracks Under Deck

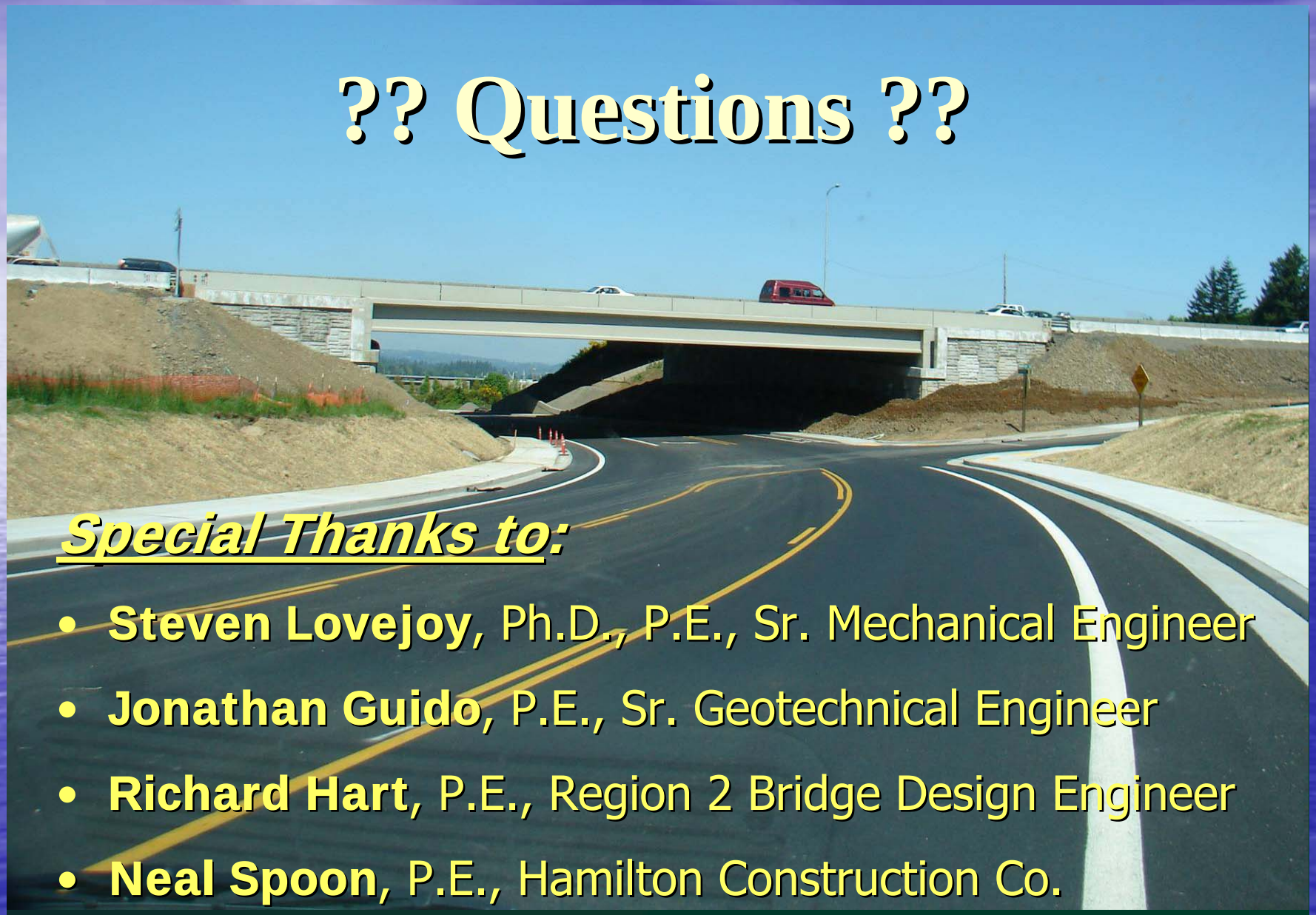
Cracks Under Deck

Cracks Under Deck

Conclusions

- 0.6 in/sec PPV can cause deck cracking.
- Consequences of cracking must be weighed against the cost of avoiding them.
- Avoid unnecessary vibrations.
  - Consider joints between substructure stages.
  - Place concrete when traffic volume is low.

?? Questions ??



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