# Nondestructive Load Testing of Bridges: An Oregon Perspective

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# Overview: Keeping good bridges in service

- Oregon DOT has been performing in-house live load testing since the mid 1990's.
- Load testing has been used to provide an alternative evaluation methodology to analytically computed load ratings.
- 2 case studies will be presented to highlight the variety of load testing and results.

# Load Testing Overview

- Load Testing is performed according to Section 8 of the AASHTO Bridge Evaluation Manual.

- Load testing by both diagnostic testing and proof load testing are done depending on the bridge type, load deficiency, bridge component configuration and availability of design information such as reinforcement layout, materials strengths, etc.

# Proof Load Testing:

- Typically only considered when the following conditions are true:
  - Unknown details of the bridge prevent an analytical rating.
  - A diagnostic load test can’t be utilized.
  - A final restriction of loads above legal levels is considered acceptable.
- Proof testing requires the load testing engineer to intentionally impart load effects that are likely higher than it has seen during its service life.

# Diagnostic Load Testing:

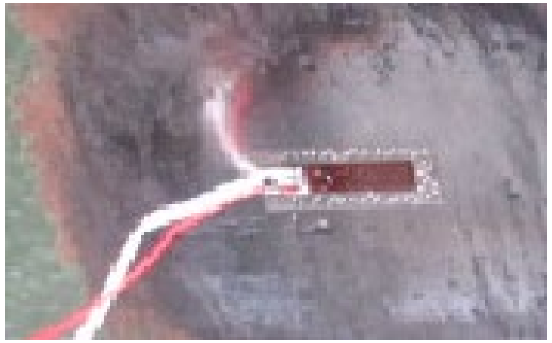
- Diagnostic load testing should be considered when the following conditions are true:
  - The details of the structure are known and an analytical load rating can be performed.
  - There aren’t signs of significant live load distress.
  - A refined analysis isn’t sufficient to achieve desired level of restriction.

# When not to load test (MBE 8.6)

- The cost of testing exceeds the cost of strengthening.
- Pretest evaluation shows that the load test in unlikely to improve the load rating.
- According to calculations, the bridge cannot sustain even the lowest level of load and the bridge doesn’t have a history of supporting loads in it’s current condition.
- There is a possibility of sudden failure (shear or facture)
- Access or traffic difficulties make testing impractical.

# Instrumentation

- EdaQ-lite by Somat
  - 16 channel data acquisition system
- Weld-on uniaxial strain gages (Steel)



- BDI Strain gage (Conc/Steel)
- Displacement Transducers

# Bridge of the Gods: Proof Test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# B of G: Description

- The Oregon approach span consists of 1-80’, 1-86’, and 1-80’ continuous steel plate girder spans.
- The interior span has a 44’ suspended span supported by pin and hangers.
- Mechanical fasteners (shear studs) were not detailed to ensure composite action between the plate girder and the reinforced concrete deck.
- A load and resistance factored rating was performed assuming non-composite action.
- Positive flexure controlled the rating with a recommend posting of **6 tons**.

# Bridge of the Gods:

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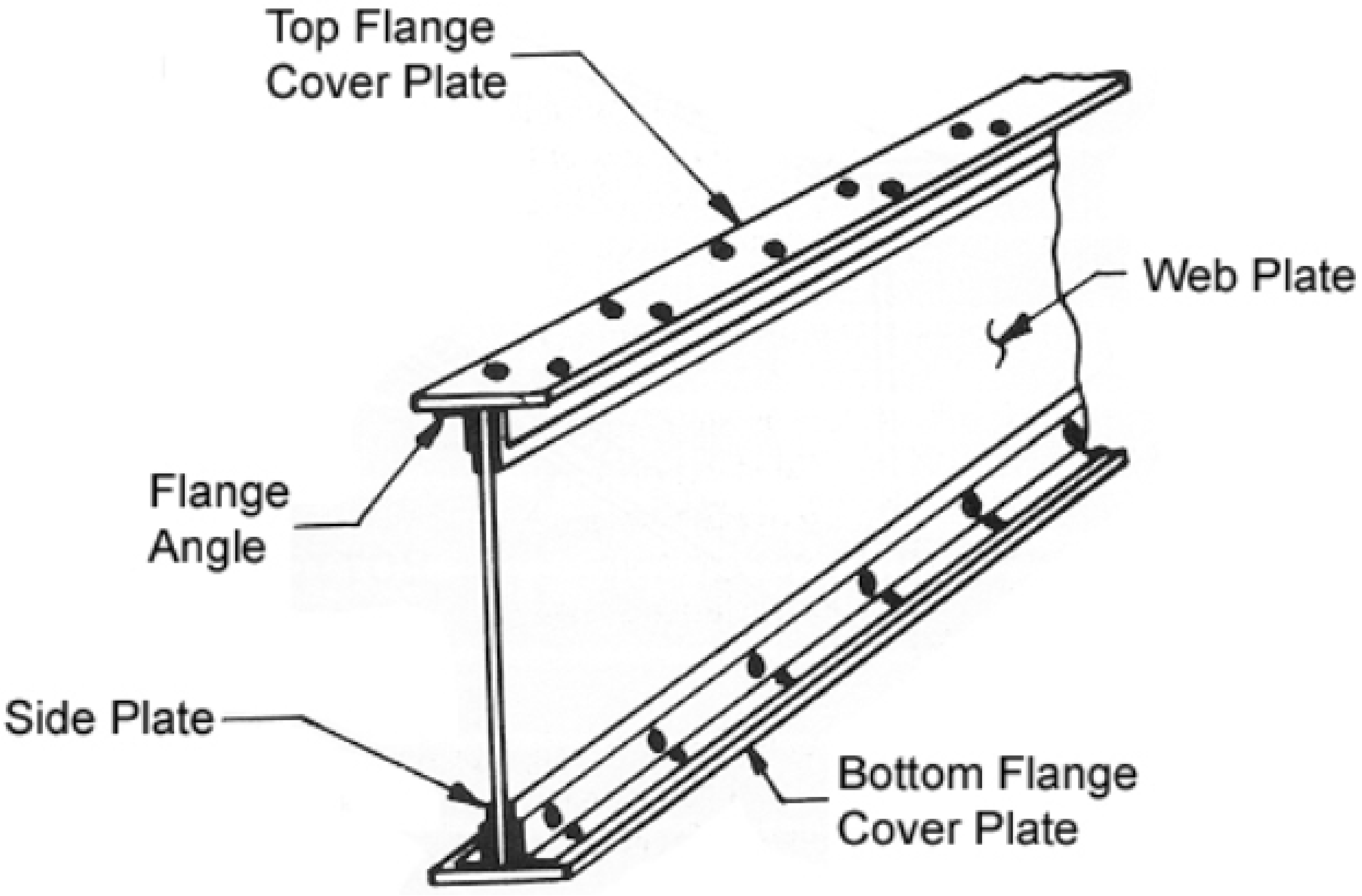
- Unintended composite action was identified as a possible explanation for the long history of successful performance.



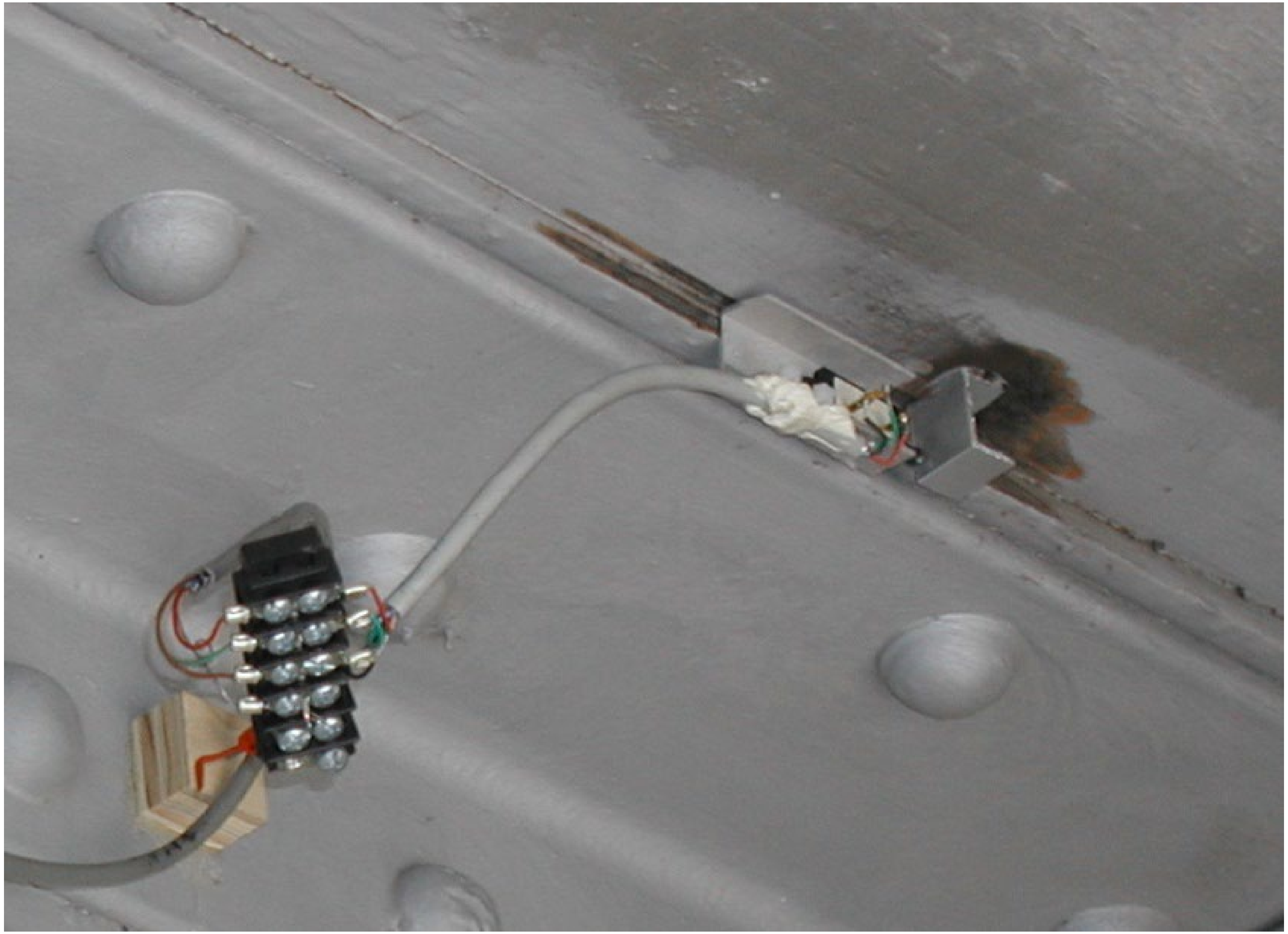
# B of G: Proof Testing Plan

- Composite action is expected up to some level short of ultimate loading.
- Performing a proof load test is a method for establishing a maximum safe working load capacity.
- Test is conducted by incrementally increasing the test loading until the target load is reached or signs of nonlinear behavior is observed.

# B of G: Instrumentation

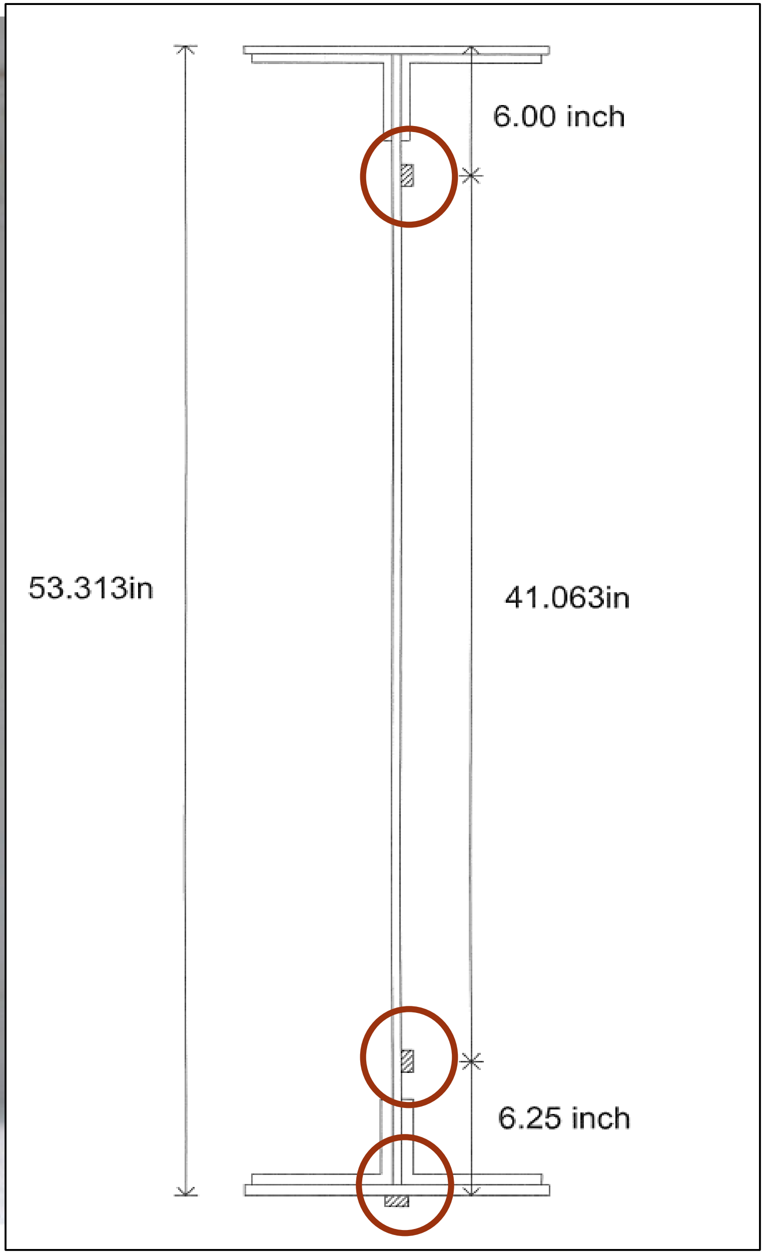
- Displacement transducers installed at ¼ and end span locations to monitor for slip between the top flange and reinforced concrete deck.

# B of G: Displacement Transducer



# B of G: Instrumentation

- Weld-on uniaxial strain gages installed on the top and bottom of the web plate and to the lower cover plate.


6.00 inch
53.313in
41.063in
6.25 inch

# B of G: Instrumentation

- Typical lower web plate strain gage installation:

# B of G: Selecting Target Proof Load

- The goal of proof tests is typically to have a final load rating of 1.0 for LEGAL vehicles .
- Including heavier permit loads can require very high proof loading targets.
- A target live-load factor magnifies the desired legal load to determine the required proof loading.

# B of G: Site Condition Factors

- Per MBE 8.8.3.3.1-1

| Consideration | Adjustment |
|---|---|
| One-Lane Load Controls | +15% |
| Nonredundant Structure | +10% |
| Fracture-Critical Details Present | +10% |
| Bridges in Poor Condition | +10% |
| In-Depth Inspection Performed | –5% |
| Rateable, Existing $RF \geq 1.0$ | –5% |
| $ADTT \leq 1000$ | –10% |
| $ADTT \leq 100$ | –15% |

# B of G: Target Test Load

$$X_{pA} = X_p\left(1 + \frac{\Sigma\%}{100}\right)$$ (MBE Eqt. 8.8.3.3.2-1)

$$X_{pA} = 1.40\left(1 + \frac{10\% - 5\% - 10\%}{100}\right)$$

$X_{pA} = 1.33$ Check: Greater than 1.3 and Less Than 2.2

# B of G: Target Test Load

Target Proof Load: Flexure at mid-span

$$L_T = X_{pA} {}^{*} L_R(1 + IM) \qquad \text{(MBE Eqt. 8.8.3.3.2-2)}$$

$$L_T = 1.33{}^{*}(1004.6\text{k-ft}){}^{*}(1 + 0.10)$$

$$L_T = 1469.7 \text{ k-ft}$$

# Test Vehicle(s): Two 10 yard dump trucks

# B of G: Loading

- Used 9 loading scenarios to increment loading until target was reached.
- Monitored for non-linear behavior during all testing.

# B of G: Final Target Loading

# B of G: Target Loading

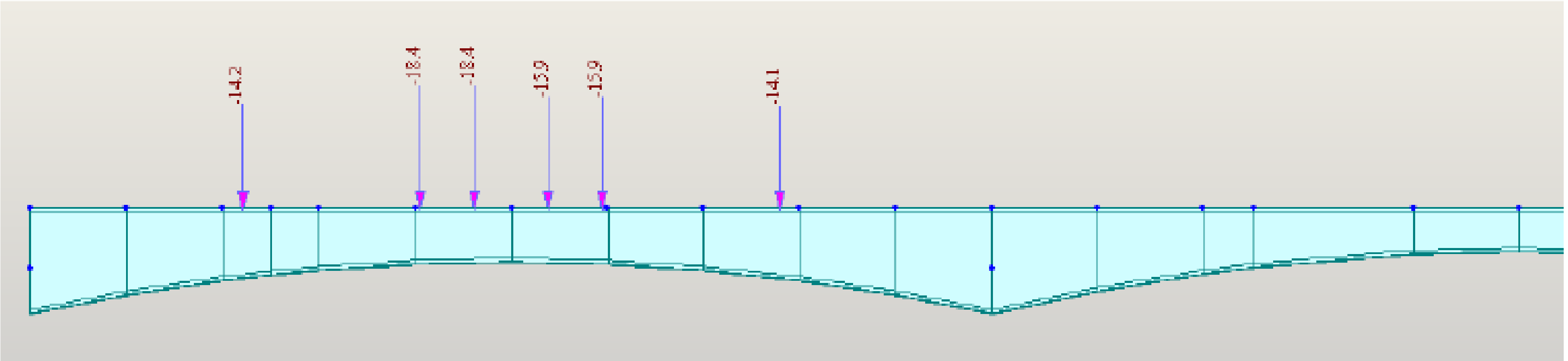
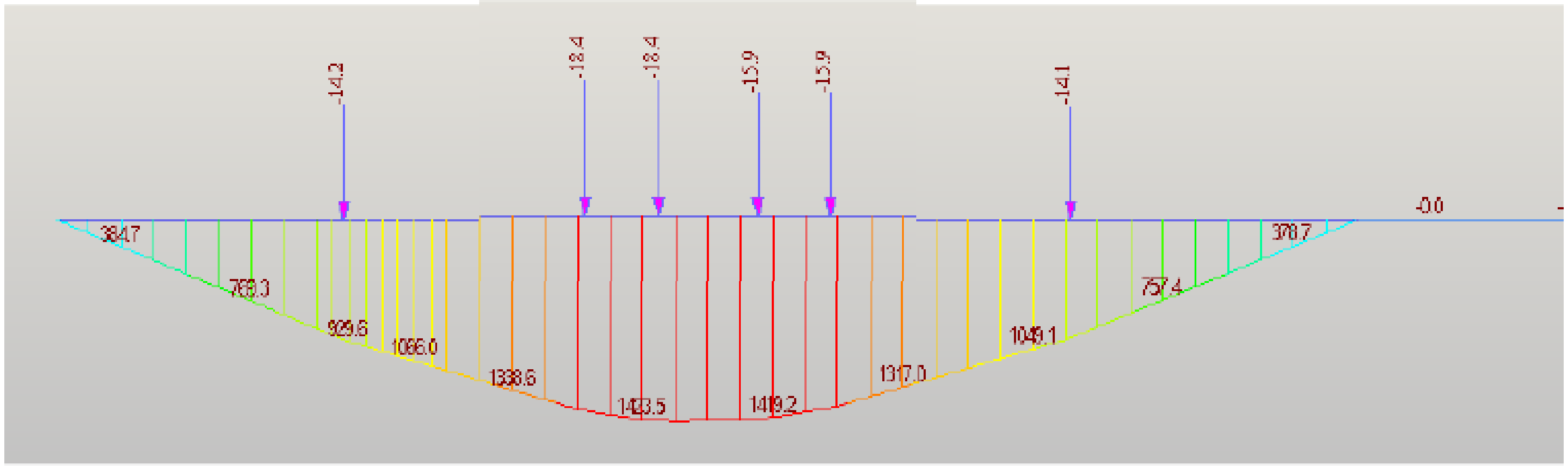



**Figure 12: Load Case 9 Moment Distribution**



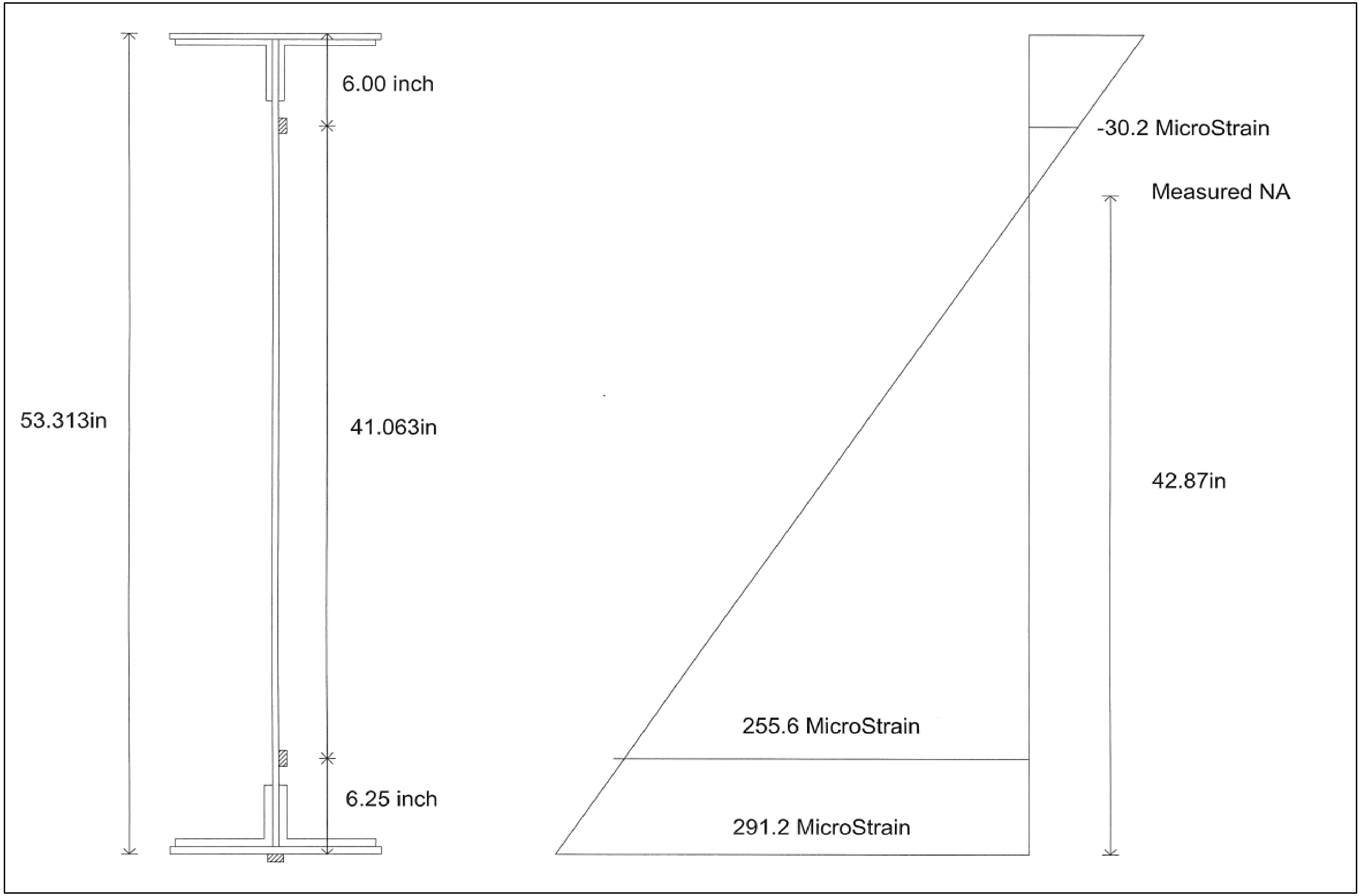
# B of G: Target Loading

- 2 – fully loaded 10 yard dump trucks parked back to back.
- Total GVW = 121,300 lbs.
- 2 sets of tandems = 85,900 lbs. over just 15ft.
- Midspan test load moment = 1,423 kip-ft
- No slippage or inelastic deformation was observed.

# B of G: Results

- Midspan Neutral Axis Comparison:
  - Measured Neutral Axis = 42.7”
  - Theoretical Neutral Axis = 46.7” (Composite)

    = 24.6 “ (Non-Composite)
  - The measured neutral axis was repeated in all 9 load cases with minimal variation.
  - The measured neutral axis is in close agreement with the theoretical composite neutral axis.


6.00 inch
53.313in
41.063in
6.25 inch
-30.2 MicroStrain
Measured NA
42.87in
255.6 MicroStrain
291.2 MicroStrain

# B of G: Operating Capacity

$$OP = \frac{k_O L_p}{X_{pA}} \qquad (8.8.3.3.3\text{-}1)$$

- $k_O$ = Factor for how the test was terminated (did you reach your target)
- $L_p$ = Proof Loading
- $X_{pA}$ = Target LL Factor

# B of G: Operating Capacity

Operating Level Capacity: Flexure at mid-span

$$OP = \frac{k_O * L_p}{X_{pA}} \qquad \text{(MBE Eqt. 8.8.3.3.3-1)}$$

$K_O$ = 1.00 (Target Load was reached before bridge showed sign of distress)

$L_p$ = 1470k-ft

$$OP = \frac{(1.0)*(1470k-ft)}{1.33} = 1105\ k - ft\ (Operating\ Capacity)$$

$X_{pA}$ = 1.33

# B of G: Rating factor calculation

$$RF_O = \frac{OP}{L_r * (1+IM)}$$

$$RF_O = \frac{1105k-ft}{(1004.7k-ft)*(1+0.10)} = 1.00$$

# B of G: Rating Factor Conclusion

| Truck Loading | Lane Moment (k-ft) | DF Multi-Lane | Lr (k-ft) | RFo |
|---|---|---|---|---|
| HL93 | 1819.2 | 1.10 | 2001.1 | 0.50 |
| ORLEG3 | 829.3 | 1.10 | 912.3 | 1.10 |
| ORLEG3S2 | 860.3 | 1.10 | 946.4 | 1.06 |
| ORLEG3-3 | 913.3 | 1.10 | 1004.7 | 1.00 |
| SU4 Truck | 928.0 | 1.10 | 1020.8 | 0.98 |
| SU5 Truck | 1029.3 | 1.10 | 1132.3 | 0.89 |
| SU6 Truck | 1149.3 | 1.10 | 1264.3 | 0.79 |
| SU7 Truck | 1258.7 | 1.10 | 1384.5 | 0.73 |
| OR-CTP-2A | 1005.1 | 1.10 | 1105.6 | 0.91 |
| OR-CTP-2B | 1069.2 | 1.10 | 1176.1 | 0.85 |
| OR-CTP-3 | 1235.3 | 1.10 | 1358.9 | 0.74 |
| OR-STP-3 | 1233.0 | 1.10 | 1356.3 | 0.74 |
| OR-STP-4A | 1326.0 | 1.10 | 1458.6 | 0.69 |
| OR-STP-4B | 1653.2 | 1.10 | 1818.5 | 0.55 |
| OR-STP-4C | 1472.4 | 1.10 | 1619.7 | 0.62 |
| OR-STP-4D | 1757.8 | 1.10 | 1933.6 | 0.52 |
| OR-STP-4E | 1984.3 | 1.10 | 2182.8 | 0.46 |
| OR-STP-5BW | 1827.7 | 1.10 | 2010.4 | 0.50 |

# B of G: Conclusions

- The girders were verified as composite with the deck up to the target test loading.
- Rating factors were calculated following Chapter 8 of the AASHTO Manual for Bridge Evaluation.
- The recommend posting of 6 tons was rescinded and replaced with a recommendation to restrict vehicles greater than legal loads.
- Note that the proof loading induced load effects higher than the permit loads, but to provide an appropriate level of reliability they are restricted from the bridge.

# Powder River (Bridge St): Diagnostic Test

# Powder River (Bridge St): Background

- Single span rolled steel girders with a composite reinforced concrete deck.
- Bridge Geometry: Length = 27'-0", Width = 56'-0"
- Original construction 1933 and widened in 1960.
- Supported by 28 girder lines with a c-c spacing of 2'.
- Widening project caused 2 longitudinal joints in the deck.
- LRFR was performed and mid-span flexure of the original steel girders controlled.
- Recommended the restriction of all vehicles greater than the standard legal loads.

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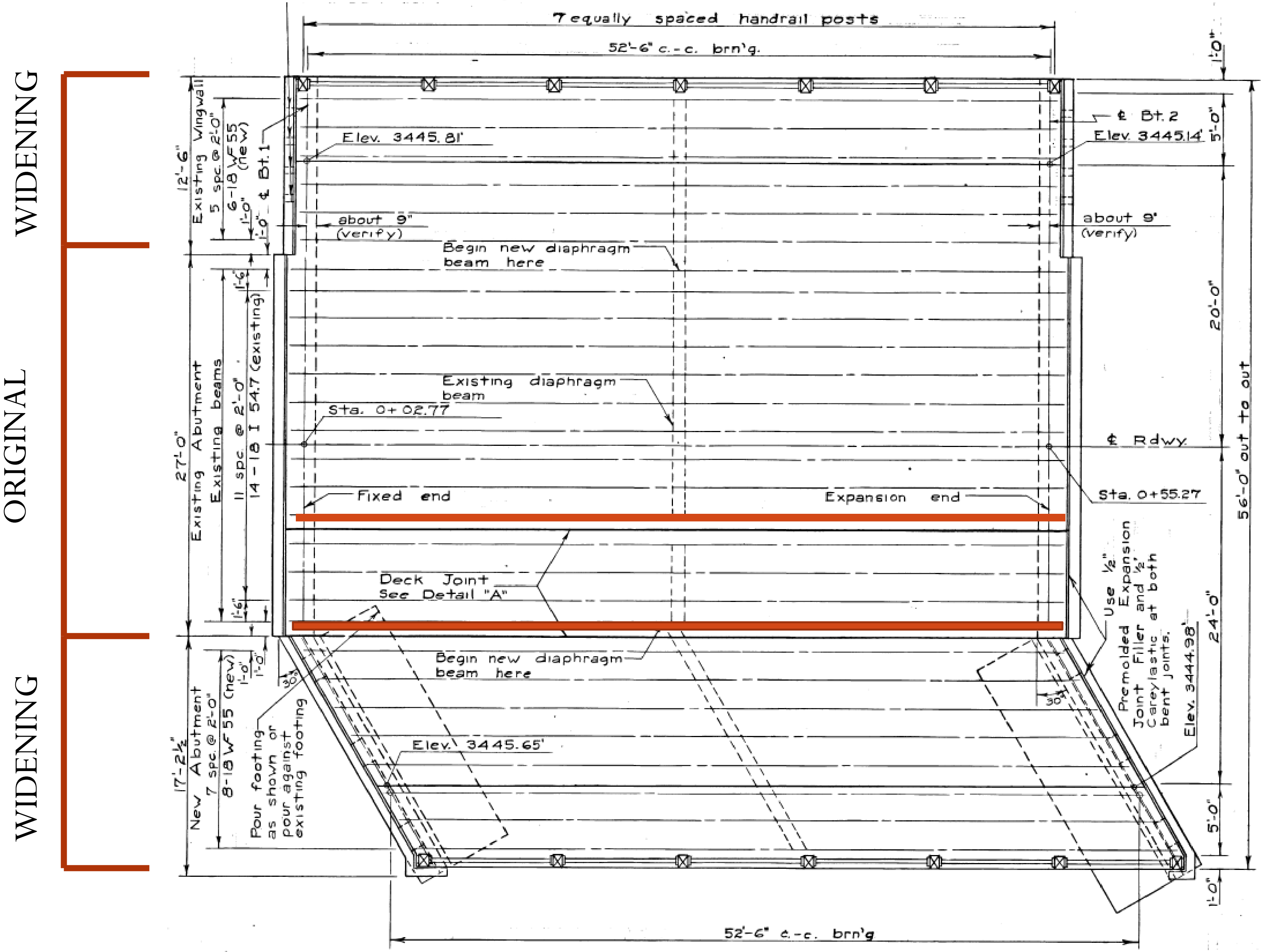
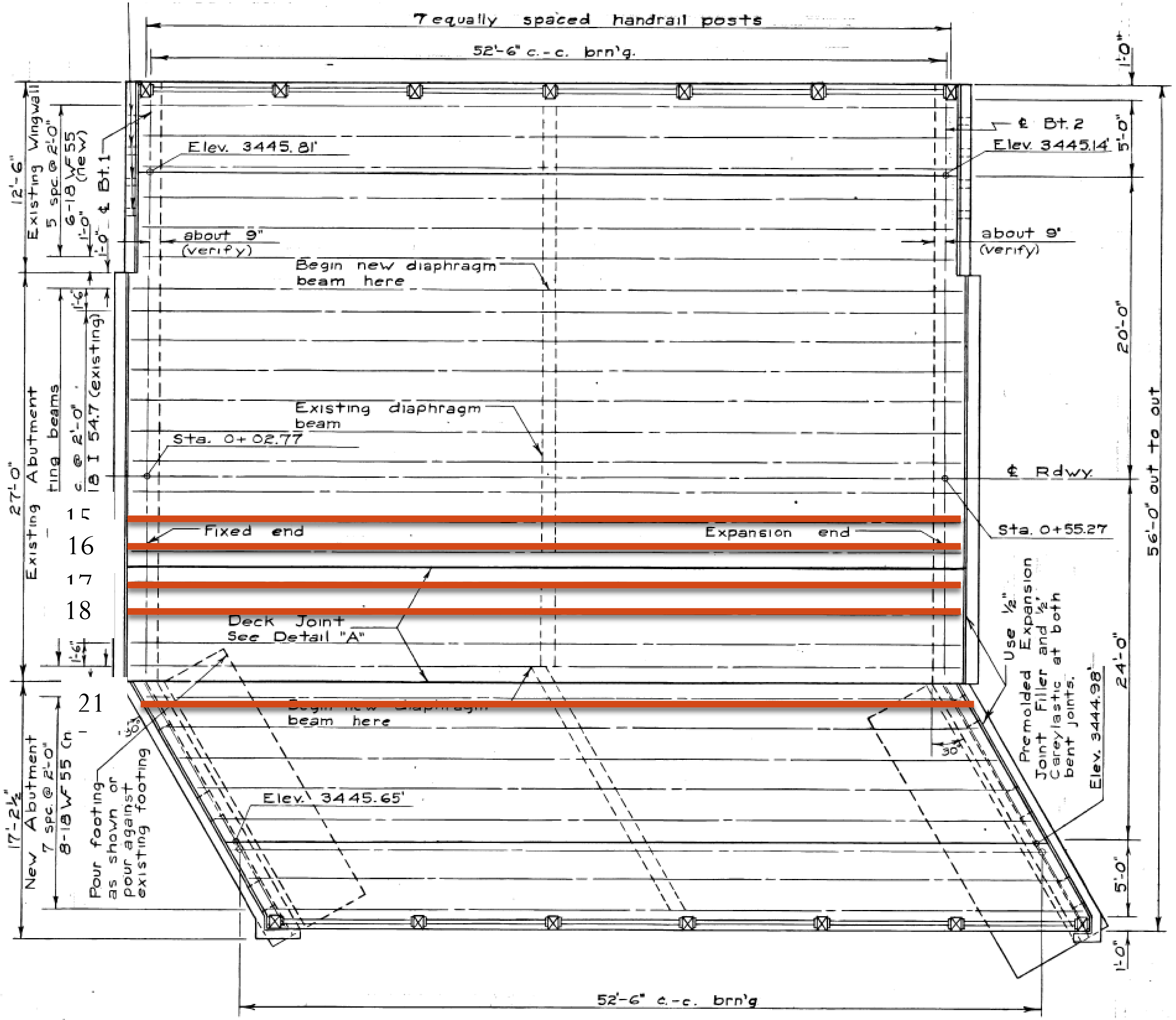


# Powder River (Bridge St): Load Testing Plan

- LRFR analysis assumed no load sharing between longitudinal joints.
- Load rating used lever rule for calculating live load distribution factors for exterior girders (0.600) and AASHTO LRFD equations for interior girders (0.568)
- Girders adjacent to longitudinal joints were treated as exterior girders.
- Due to the tight girder spacing, the live load sharing is expected to be higher than assumed during the analytical analysis.

# Powder River (bridge St): Girders of Interest



# Powder River (Bridge St): Load Testing Plan

- Performed a diagnostic load test to improve understanding of live load sharing.
- Uniaxial weld on strain gages were installed on the bottom flange of girders at midspan.
- 4 static load configurations were used to ensure maximum load effects were imparted on the girders of interest.
- Load rating was updated following the methodology outlined in Section 8.8.2 of the AASHTO Manual for Bridge Evaluation.

# Powder River (Bridge St): Typical Strain Gage Installation

# Powder River (Bridge St): Loading

- Test Vehicle: Fully loaded state owned dump truck.
  - (GVW 50,280 lbs)
  - Representative of Type 3 load case.
  - Magnitude of test load high enough to utilize the full benefit of the calibration for most legal and permitted loads.
  - The remaining live load models received a reduced calibration.

# Powder River (Bridge St): Loading

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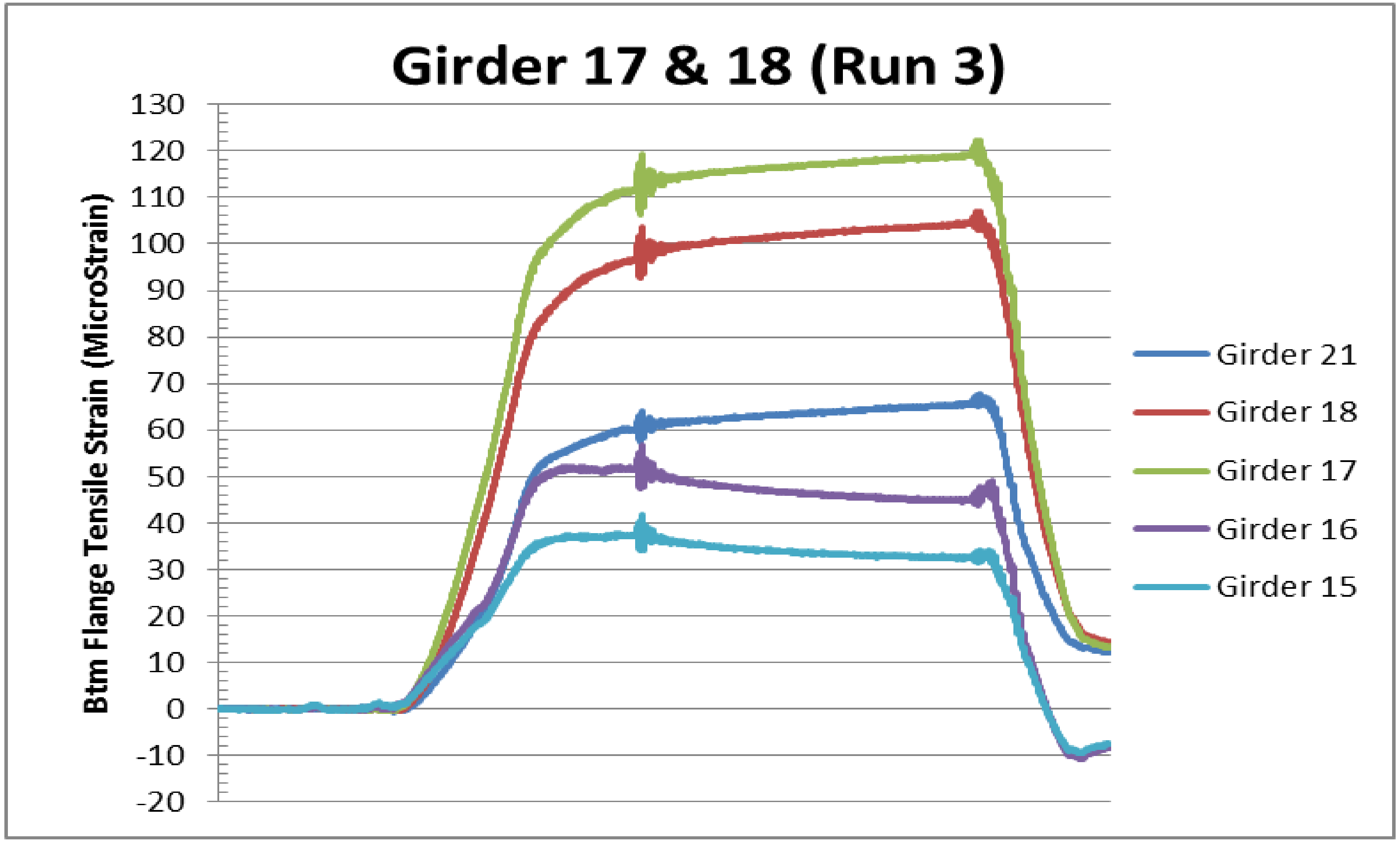
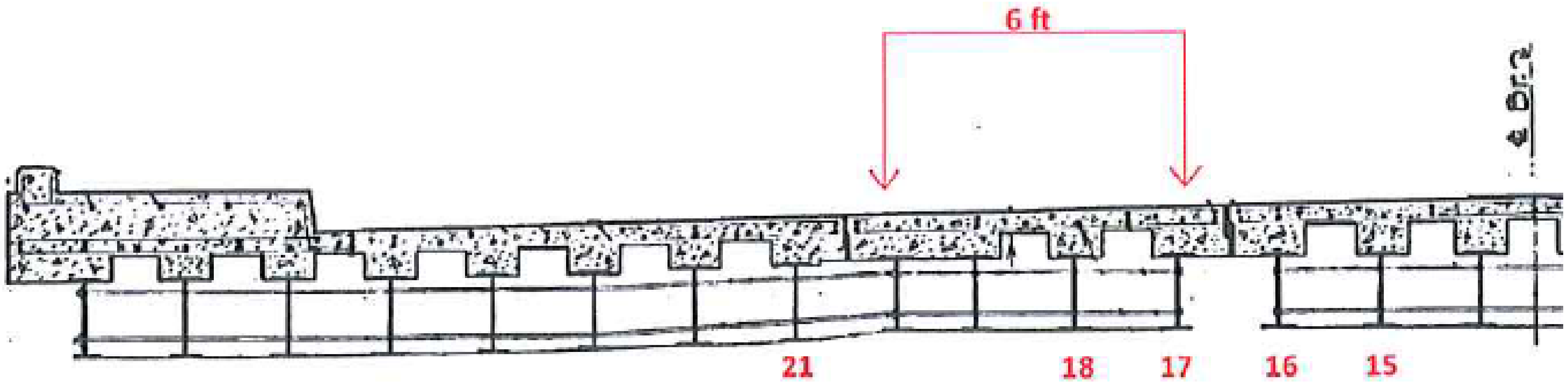
# Powder River (Bridge St):

- Measured strains for Load Case 3 (Max. measured strain)



# Power River (Bridge St): Load case 3

Figure 7: Girder 17 and 18 Truck Placement



# Powder River: Rating Factor Calculation

$$RF_T = RF_C * K \qquad \text{(MBE 8.8.2.3-1)}$$

$$K = 1 + K_a * K_b \qquad \text{(MBE 8.8.2.3.1-1)}$$

# Powder River: Rating Factor Calculation

$$K_a = \frac{\varepsilon_c}{\varepsilon_T} - 1 \qquad \text{(MBE 8.8.2.3.1-2)}$$

| Girder Line | Measured Btm Flg Strain: $\varepsilon_T$ (Max) | Theoretical Btm Flg Strain: $\varepsilon_c$ (Max) | $K_a$ |
|---|---|---|---|
| Orig Interior (18) | 103.7 | 365.4 | 2.52 |
| Orig Exterior (17) | 118.3 | 593.6 | 4.02 |
| New Exterior (21) | 65.2 | 576.5 | 7.85 |
| New Interior (22) | 65.2 | 425.4 | 5.53 |

# Powder River (Bridge St): Results

**Original Interior Girder Line Calibration for positive mid-span flexure**

| Truck | Kb | Ka | K | RF (Uncalibrated) | RF (Calibrated) |
|---|---|---|---|---|---|
| HL93(max) | 0.80 | 2.52 | 3.016 | 0.41 | 1.24 |
| ORLEG3(max) | 1.00 | 2.52 | 3.52 | 1.12 | 3.94 |
| ORLEG3S2(max) | 1.00 | 2.52 | 3.52 | 1.10 | 3.87 |
| ORLEG3-3(max) | 1.00 | 2.52 | 3.52 | 1.28 | 4.51 |
| SU4 Truck(max) | 1.00 | 2.52 | 3.52 | 0.97 | 3.41 |
| SU5 Truck(max) | 1.00 | 2.52 | 3.52 | 0.90 | 3.17 |
| SU6 Truck(max) | 1.00 | 2.52 | 3.52 | 0.81 | 2.85 |
| SU7 Truck(max) | 0.80 | 2.52 | 3.016 | 0.74 | 2.23 |
| OR-CTP-2A(max) | 1.00 | 2.52 | 3.52 | 1.13 | 3.98 |
| OR-CTP-2B(max) | 1.00 | 2.52 | 3.52 | 1.05 | 3.70 |
| OR-CTP-3(max) | 1.00 | 2.52 | 3.52 | 0.91 | 3.20 |
| OR-STP-3(max) | 1.00 | 2.52 | 3.52 | 1.04 | 3.66 |
| OR-STP-4A(max) | 1.00 | 2.52 | 3.52 | 0.86 | 3.03 |
| OR-STP-4B(max) | 0.80 | 2.52 | 3.016 | 0.96 | 2.90 |
| OR-STP-4C(max) | 0.80 | 2.52 | 3.016 | 0.90 | 2.71 |
| OR-STP-4D(max) | 0.80 | 2.52 | 3.016 | 0.85 | 2.56 |
| OR-STP-4E(max) | 0.80 | 2.52 | 3.016 | 0.84 | 2.53 |
| OR-STP-5BW(max) | 0.80 | 2.52 | 3.016 | 0.87 | 2.62 |

# Powder River (Bridge St): Conclusions

- Lateral load distribution is significantly higher than modeled analytically.
- The longitudinal joints still allow for some level of lateral load distribution.
- The load restriction was recommendation was rescinded and the bridge remains open to all legal, continuous trip permit, and single trip permit loads.

# Is load testing preservation?

- Depends on who you ask…
- FHWA doesn't consider LL testing as a method of preservation.
- However, it can be a valuable tool for owners to keep GOOD structures in service.
- Preserving a structure doesn't benefit the public if we turn around and knock it down due to load restrictions.
- There are multiple companies at this conference that can help with load testing needs.

# Contact Information

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All case studies presented have complete write-ups that are available upon request.