Field Evaluation of the Rt. 601 Bridge: A Bridge Utilizing Strongwell 36 in. Fiber-Reinforced Polymer Double Web Beams

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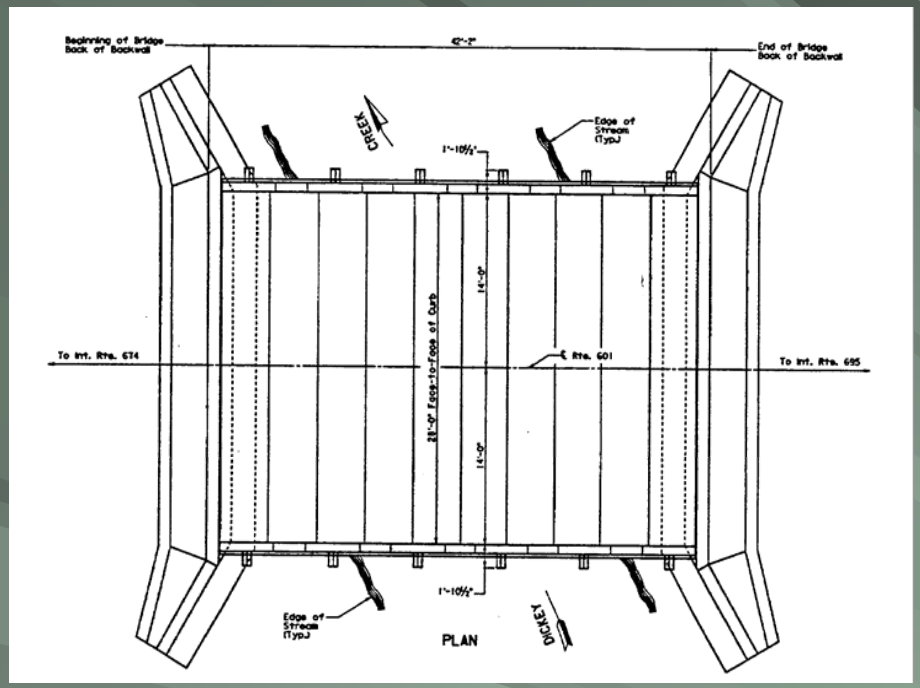
VDOT/FHWA Showcase on Fiber Reinforced Polymer Composites: Materials, Design, and Construction

Bristol, VA Sept. 20, 2006

Virginia Tech

Overview

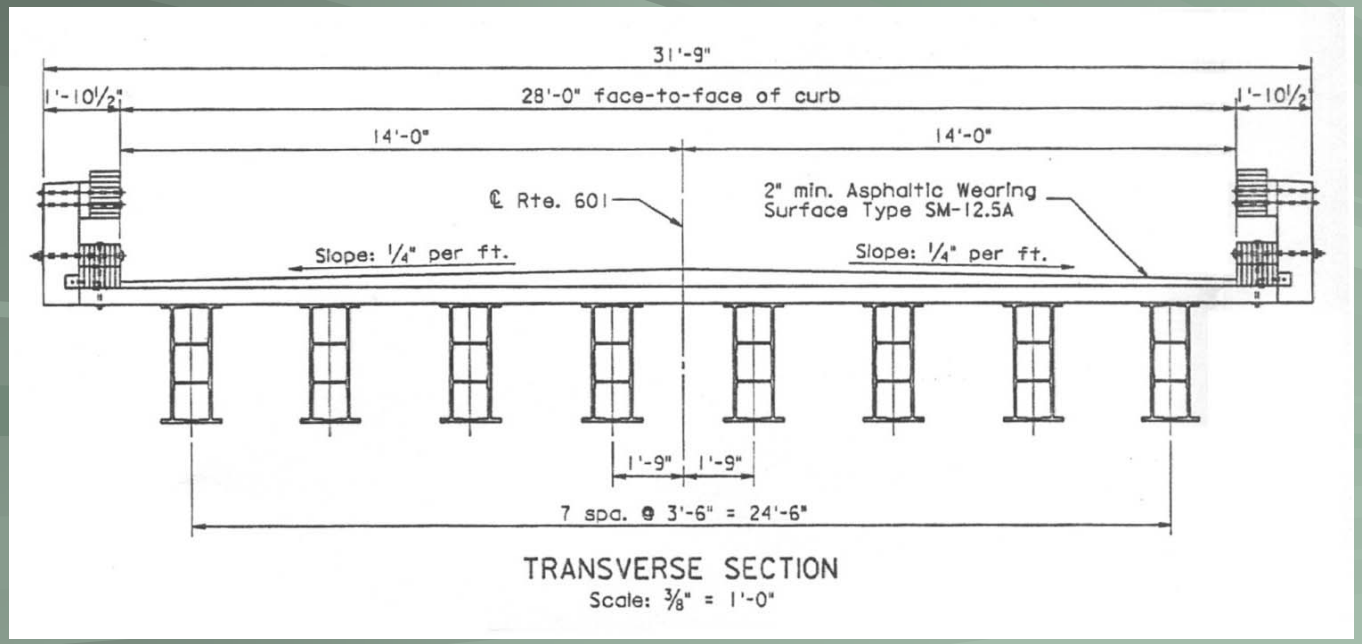
- Research Objectives
- Experimental Procedures
- Results of Primary Objectives
- Results of Secondary Objectives
- Conclusions and Recommendations



Rt. 601 Bridge

Sugar Grove, VA

- Installed Oct. 2001
- 36 in. Strongwell FRP Double Web Beam (DWB)
- Field Tested Oct. 2001 and June 2002



Research Objectives

- **Primary Objectives: Determination of AASHTO Parameters**
  - Wheel Load Distribution Factor "g"
  - Dynamic Load Allowance "IM"
  - Maximum Deflection
- **Secondary Objectives: Additional Bridge Behavior Characteristics**
  - Effect of Diaphragms
  - Axial and Torsion Effects
  - Symmetry Response

Wheel Load Distribution Factor, *g*

- **Method to Reduce Complexity of Bridge Analysis from Two Dimensional Loading Case to One Dimensional Girder Line Analysis**

- **Accounts for a Fraction of Load Distributed from Bridge System to Particular Component**

- **Expressed as Function of Spacing per Wheel Line of Truck Load**

$$g = \frac{S}{D}$$

"S" = Girder Spacing (ft)

"D" Varies with Deck and Girder materials, Type, Amount of Traffics Lanes loaded

Dynamic Load Allowance, *IM*

- **Takes Into Account Dynamic Effects of Wheel Loads on Bridges**
  - **Wheel Assembly Riding on Surface Discontinuities (Pot Holes, Deck Joints, Cracks)**
  - **Resonant Excitations from Similar Frequency of Vibration Between Bridge and Vehicle**

- **Dynamic Load Allowance (or Impact Factor) Only Applied to Truck Loads**
  - **AASHTO Standard Spec. Allows *IM* of 30 %**
  - **AASHTO LRFD Spec. Allows *IM* of 33%**

Deflection Control

- Employed for several reasons
  - Prevent Damage to Nonstructural Components (Wearing Surface Cracking)
  - Aesthetical Reasons: Appearance
  - Rider Comfort
  - Deflections Control Design
- AASHTO Criteria for Highway Bridges: *L/800*

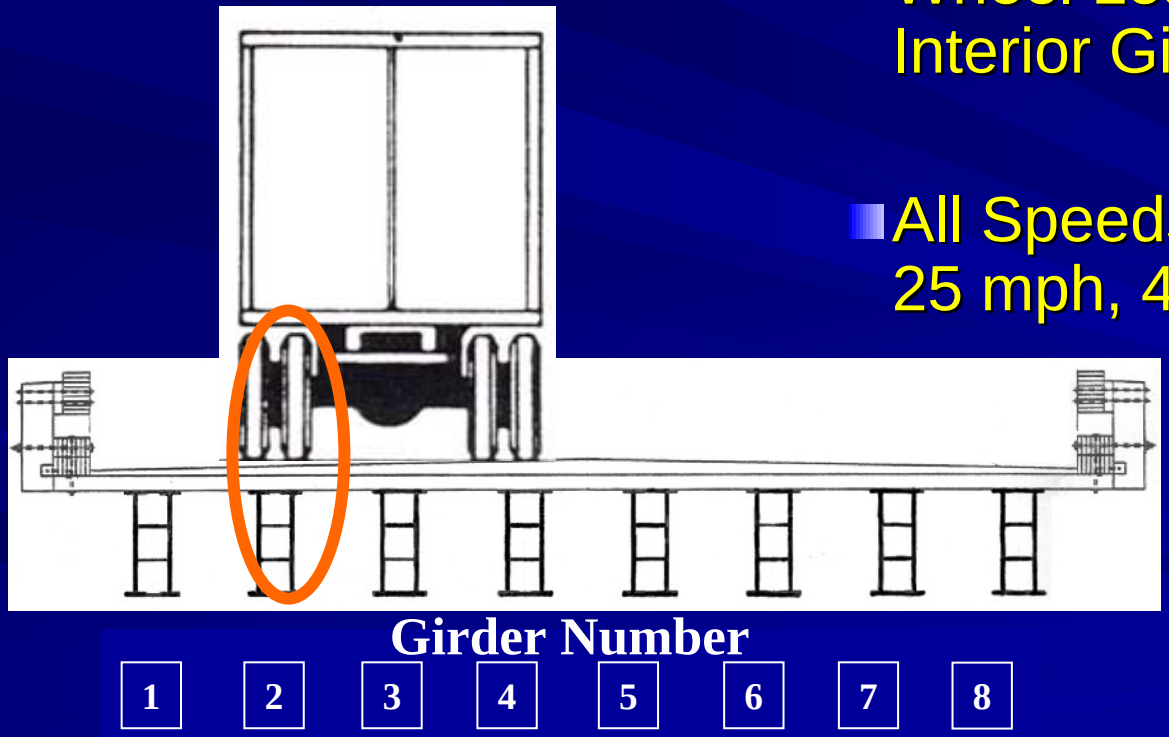
Experimental Procedures

Experimental Procedures

- Instrumentation for Primary Objectives (*IM*, *g*, Max Deflection)
  - Midspan Strains
  - Midspan Deflection
- Additional Instrumentation for Secondary Objectives
  - Bottom Flange Local FRP Strains at Location of Diaphragm
  - Strain Gages on Web for Neutral Axis Shift
  - Strain Gages at Interior Flanges of Exterior girders
    - **Torsion**
    - **Neutral Axis Shift**

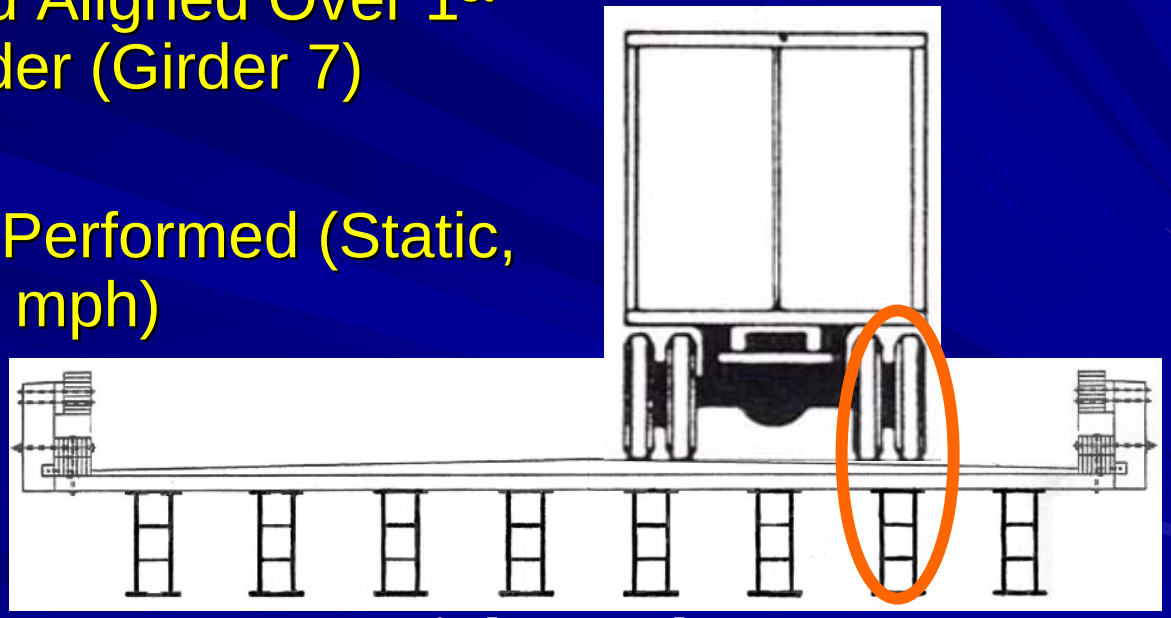
October 2001 Truck Axle Orientations

- West Interior Lane Pass
  - Wheel Load Aligned Over 1st Interior Girder (Girder 2)
  - All Speeds Performed (Static, 25 mph, 40 mph)



October 2001 Truck Axle Orientations

- East Interior Lane Pass
  - Wheel Load Aligned Over 1st Interior Girder (Girder 7)
  - All Speeds Performed (Static, 25 mph, 40 mph)

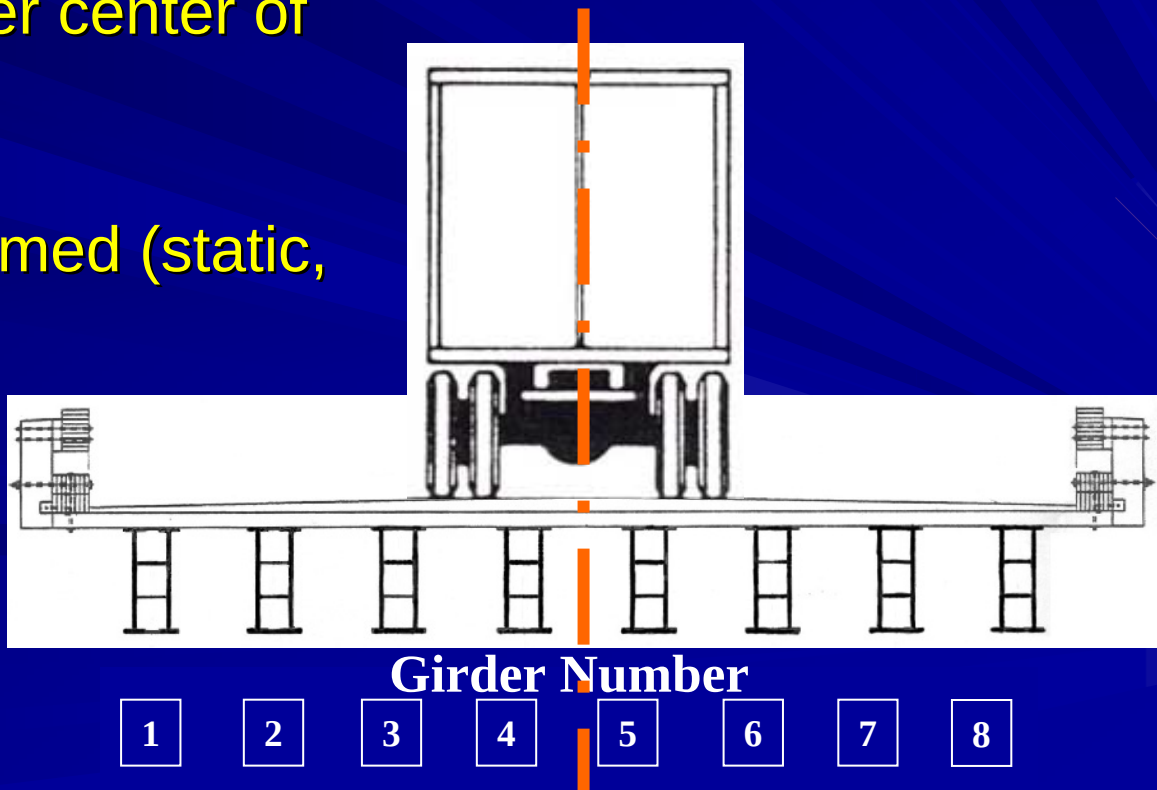


Girder Number

1 2 3 4 5 6 7 8

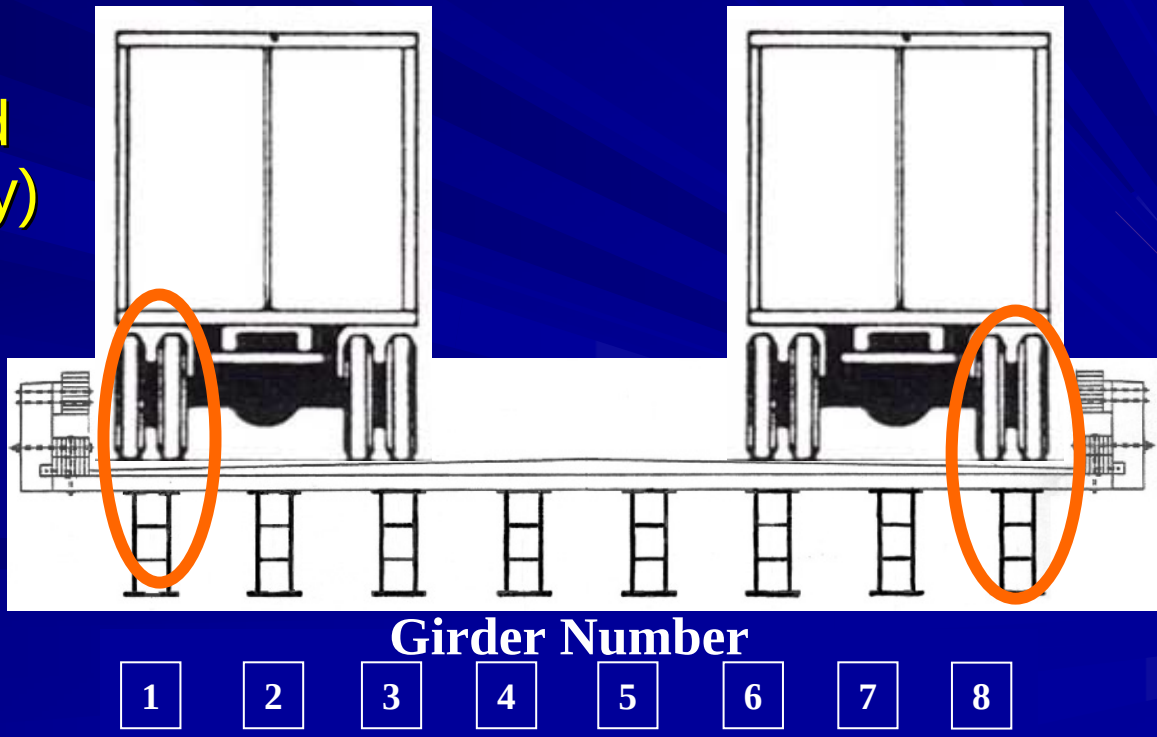
October 2001 Truck Axle Orientations

- Center Lane Pass
  - Wheel Load Aligned Symmetrically over center of bridge
  - All Speeds Performed (static, 25 mph, 40 mph)



October 2001 Truck Axle Orientations

- Multiple Lane Pass
  - Wheel Load Aligned Over Exterior Girders (Girder 1 & 8)
  - Only Static Speed Performed (Safety)



Field Test Breakdown

- **October 2001**
  - 4 Axle Orientations
  - 5 Repetitions per Orientation per Speed
    - 0, 25, & 40 mph for West int., East int., and Center
    - 0 mph for Multiple
  - ***50*** Total Passes

- **June 2002**
  - 6 Axle Orientations – (Single Lane Exterior East and West Included)
  - 5 Repetitions per Orientation per Speed
    - 0, 15, 25, & 40 mph for West int., East int., and Center
    - 0 mph for Multiple, East ext., and West ext.
    - 0 mph for Diaphragm Removal for East Ext. and East int.
  - *85* Total Passes

Experimental Results

Primary Objectives

- I) Wheel Load Distribution Factor
- II) Dynamic Load Allowance
- III) Maximum Deflections

- **When all girders of same section modulus used:**

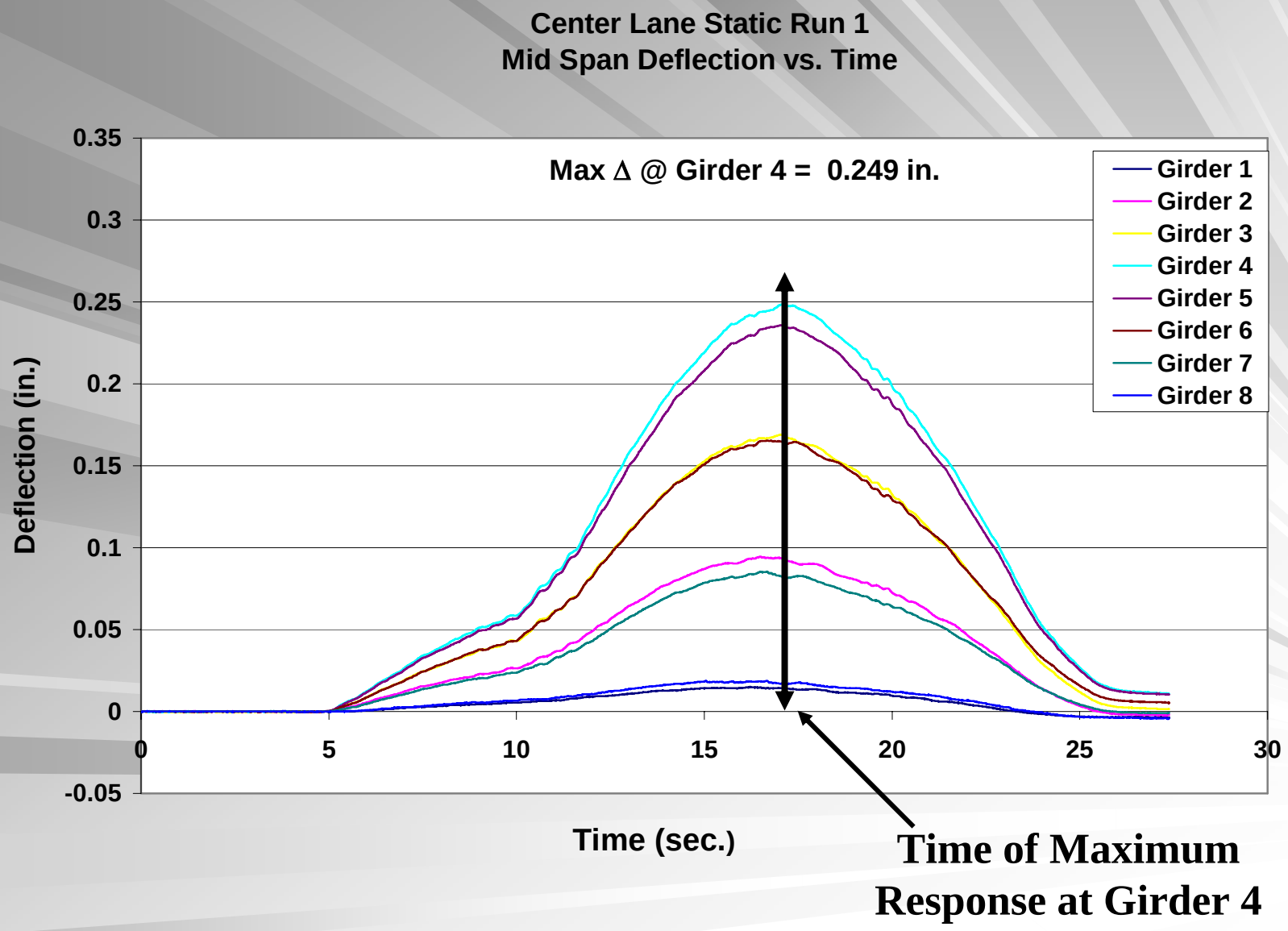
$$GDF_i = \frac{\varepsilon_i}{\sum_{j=1}^{k} \varepsilon_j}$$

- **If Deflection and Strain Data both included in study:**

$$GDF_i = \frac{R_i}{\sum_{j=1}^{k} R_j}$$

Where R_i is the response of the *i*th girder in strain or deflection

Sample Deflection vs. Time Plot

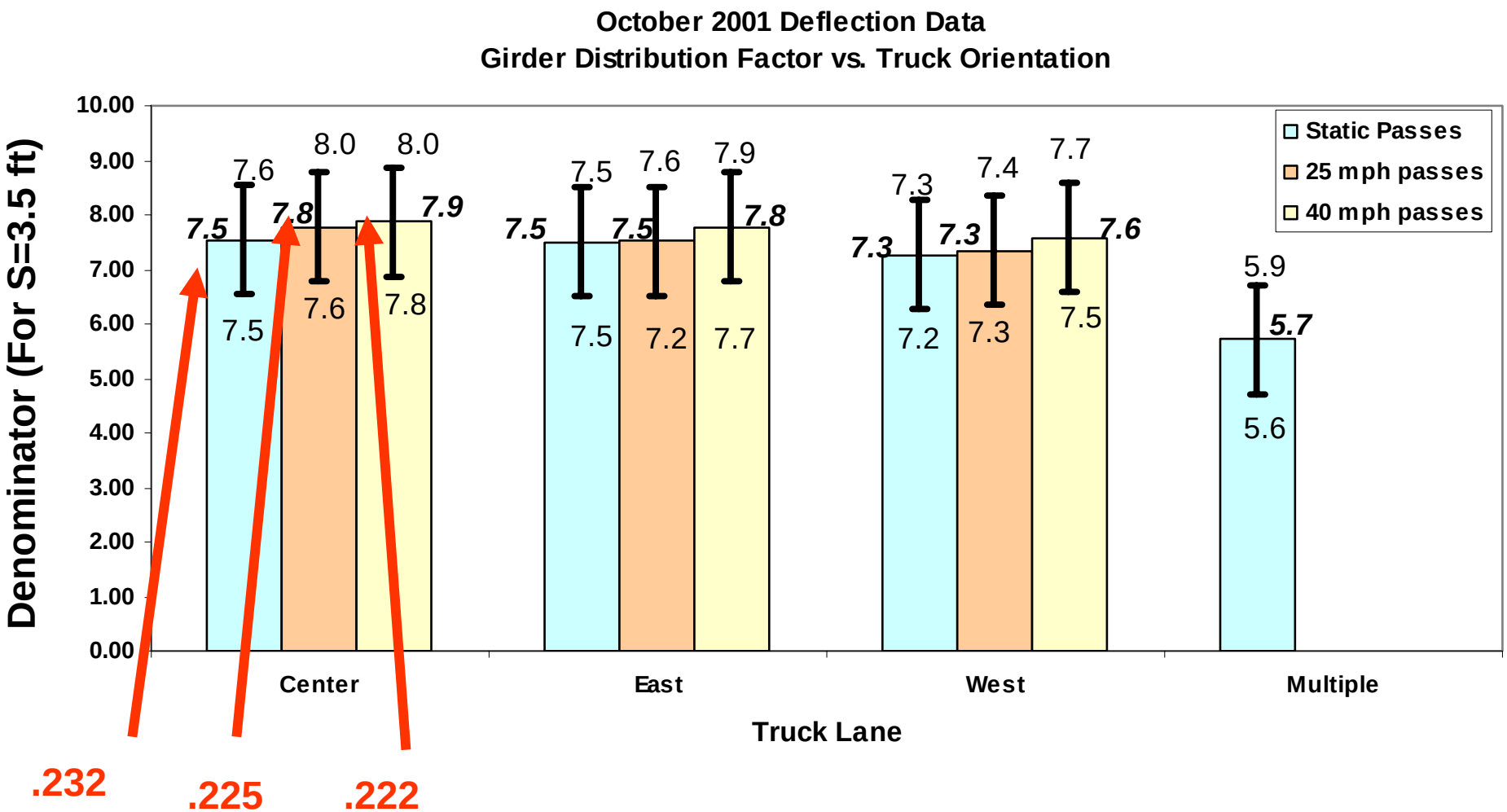


Sample Data Based on Series of 5 Passes at Each Speed

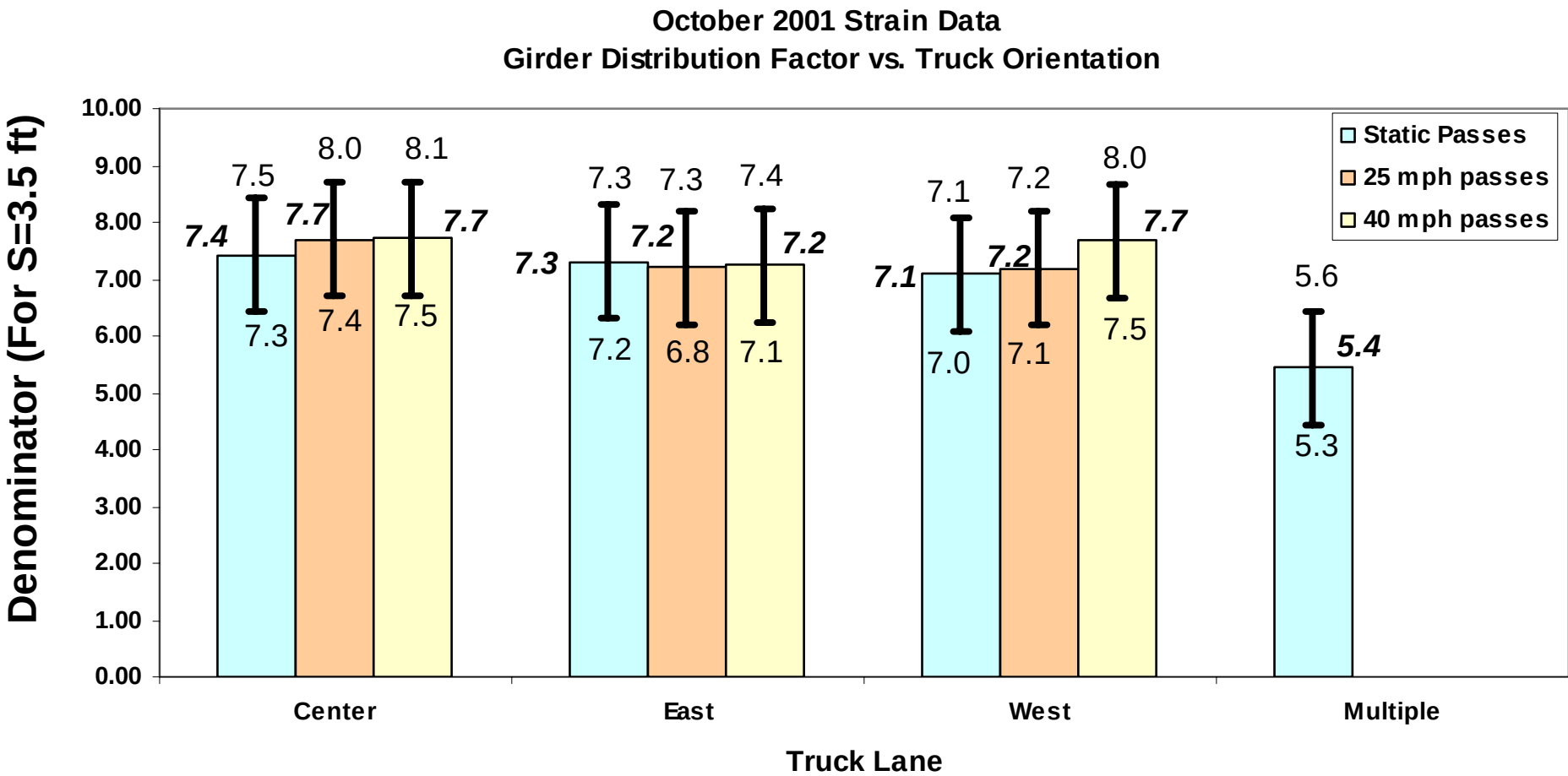
October 2001 Center Lane Pass (Deflection Data)

Girder #	Static Data				25 mph Data				40 mph Data			
	Avg Defl. (in.)	MAX GDF	MIN GDF	Avg. GDF	Avg Defl. (in.)	MAX GDF	MIN GDF	Avg. GDF	Avg Defl. (in.)	MAX GDF	MIN GDF	Avg. GDF
G1	0.019	0.027	0.018	0.021	0.028	0.038	0.020	0.031	0.028	0.040	0.026	0.032
G2	0.084	0.102	0.089	0.092	0.093	0.119	0.083	0.104	0.095	0.116	0.101	0.106
G3	0.162	0.188	0.174	0.179	0.167	0.204	0.161	0.186	0.165	0.195	0.179	0.186
G4	0.211	0.233	0.230	0.232	0.203	0.231	0.218	0.225	0.197	0.225	0.220	0.222
G5	0.179	0.198	0.192	0.197	0.170	0.197	0.183	0.189	0.166	0.190	0.182	0.187
G6	0.147	0.166	0.152	0.161	0.138	0.177	0.135	0.152	0.135	0.158	0.141	0.152
G7	0.077	0.087	0.077	0.084	0.073	0.099	0.067	0.080	0.072	0.088	0.075	0.081
G8	0.031	0.036	0.030	0.034	0.030	0.045	0.023	0.033	0.029	0.038	0.029	0.033
				Σ = 1.00				Σ = 1.00				Σ = 1.00

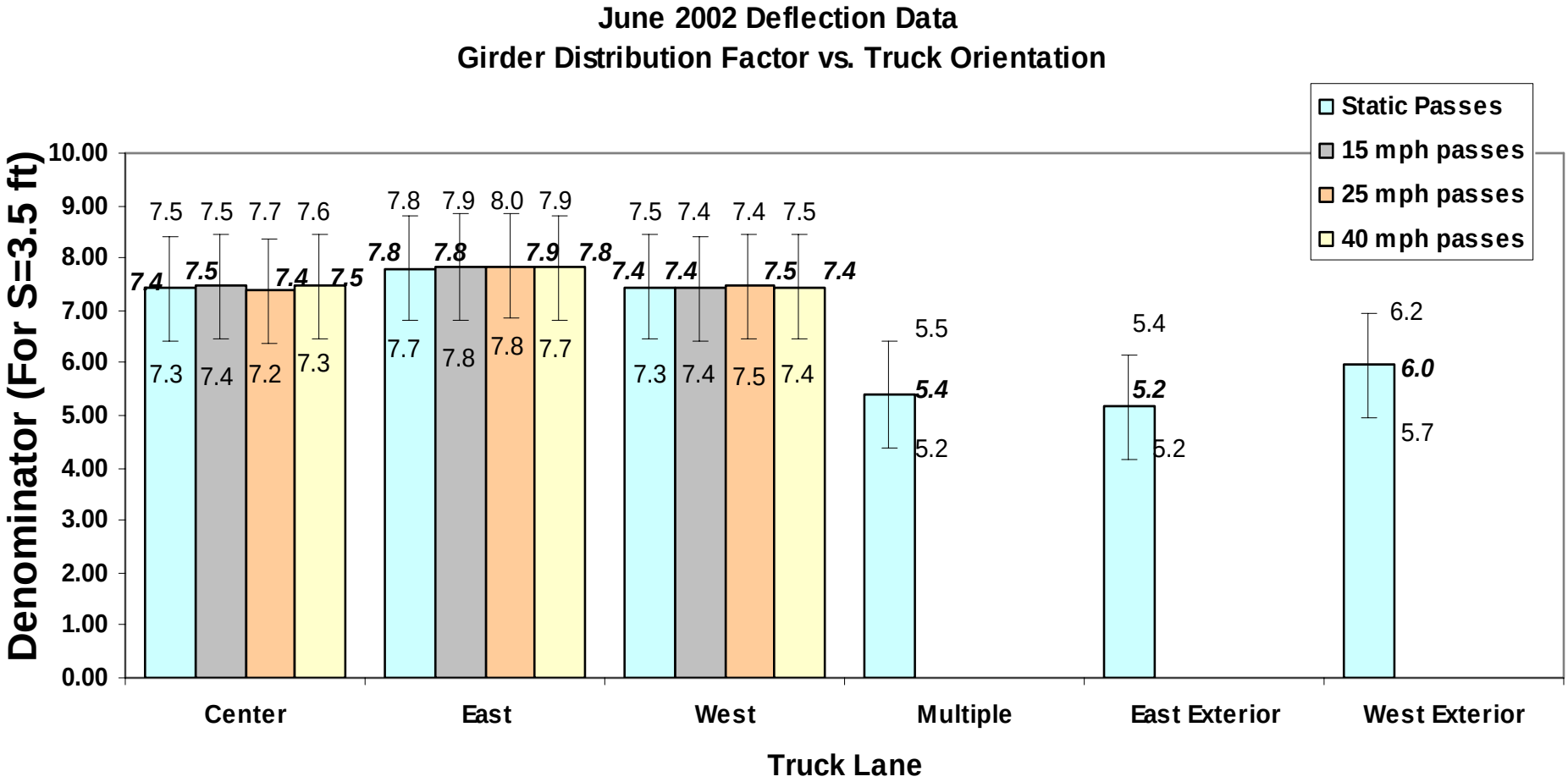
October 2001 Deflection Results (based on average of 5 truck passes)



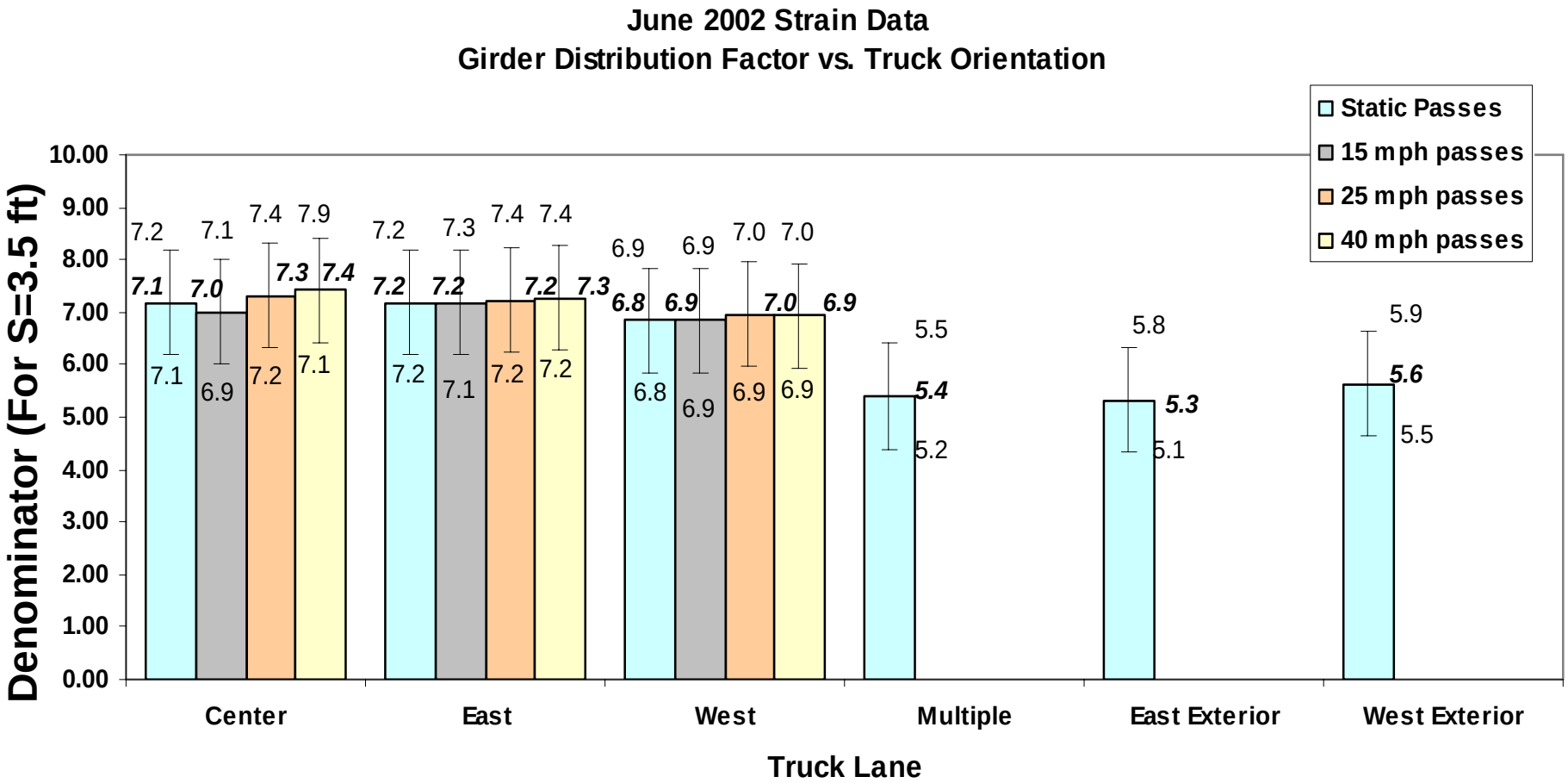
October 2001 Strain Results (Based on Average of 5 Truck Passes)



June 2002 Deflection Results (Based on Average of 5 Truck Passes)



June 2002 Strain Results
(Based on Average of 5 Truck Passes)



Wheel Load Distribution Comparison to AASHTO code

Calculation of Dynamic Load Allowance

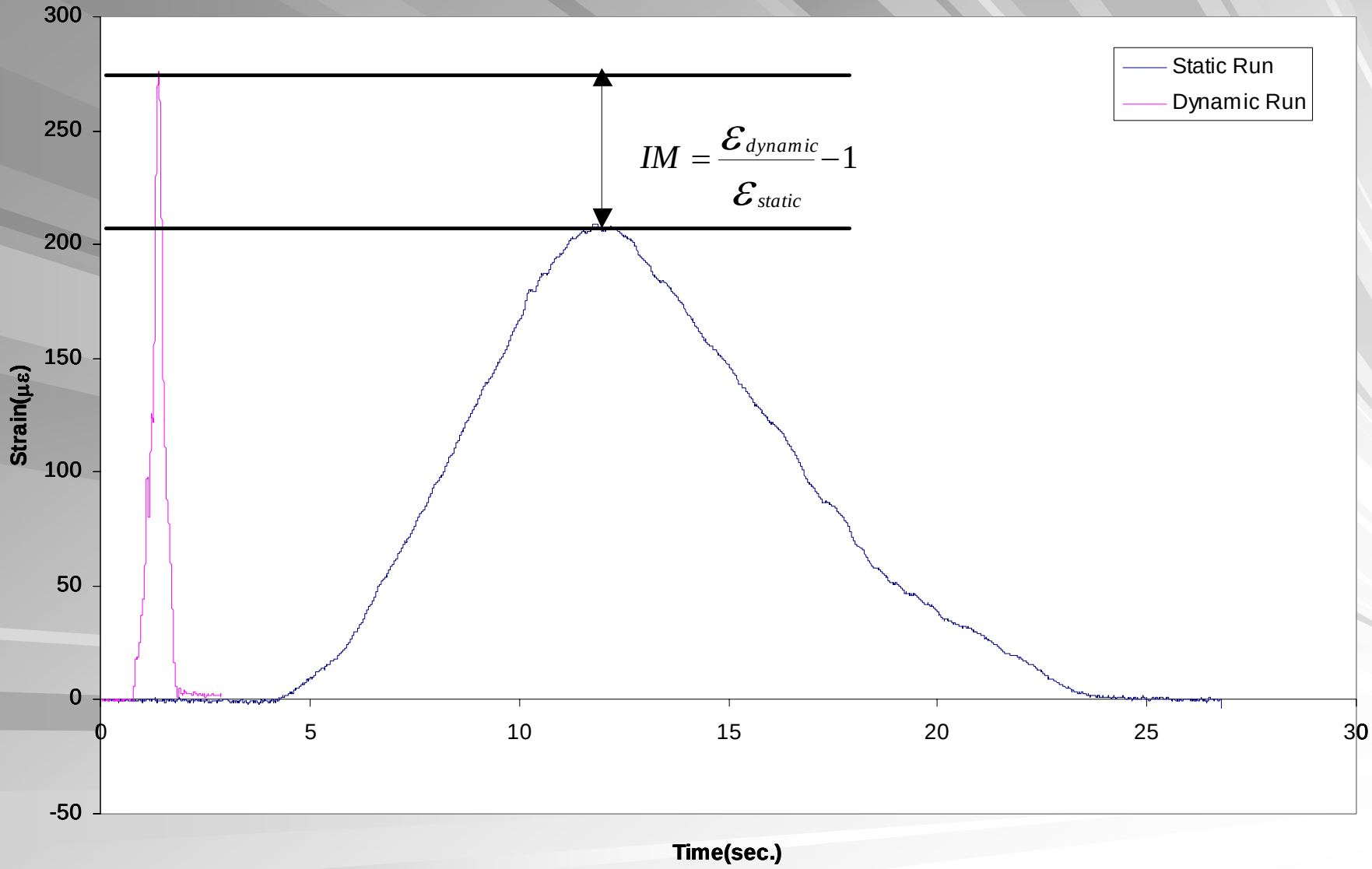
$$IM = \frac{R_{dyn}}{R_{stat}} - 1$$

Where R_{dyn} = Maximum Dynamic Response of Bridge (strain or deflection)

R_{sta} = Maximum Static Response of Bridge (strain or deflection)

IM = Dynamic Load Allowance

Dynamic Bridge Behavior



Dynamic Load Allowance Summary
Strain Data

Truck Axle Orientation	Speed (mph)	No. of passes	Oct. 2001 strain data			June 2002 strain data		
			Max *IM*	Avg *IM*	Girder Location	Max *IM*	Avg *IM*	Girder Location
Center	15	5			-----	0.083	0.068	-----
	25	5	0.117	-0.005	5	0.080	0.077	5
	40	5	-0.034	-0.076	5	0.357	0.230	5
East Interior	15	5			-----	0.098	0.078	-----
	25	5	0.138	**0.101**	6	0.041	0.038	6
	40	5	0.067	0.043	6	0.071	-0.006	6
West Interior	15	5			-----	0.066	0.039	-----
	25	5	0.135	0.072	3	0.097	0.087	3
	40	5	0.018	-0.026	3	0.316	**0.294**	3
			MAX	**0.101**		**MAX**	**0.294**	

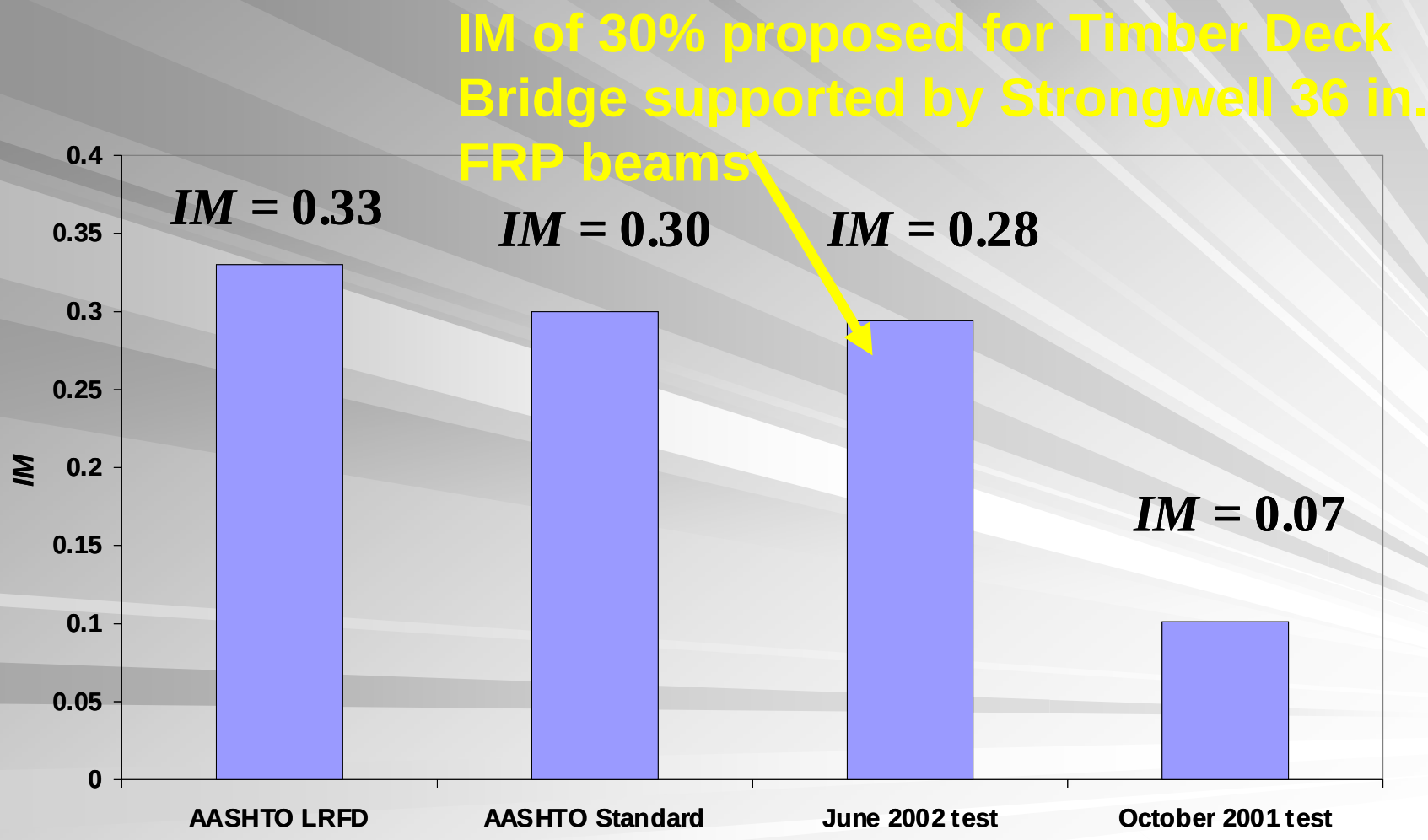
****Note:** **test not performed**

Dynamic Load Allowance Summary
Deflection Data

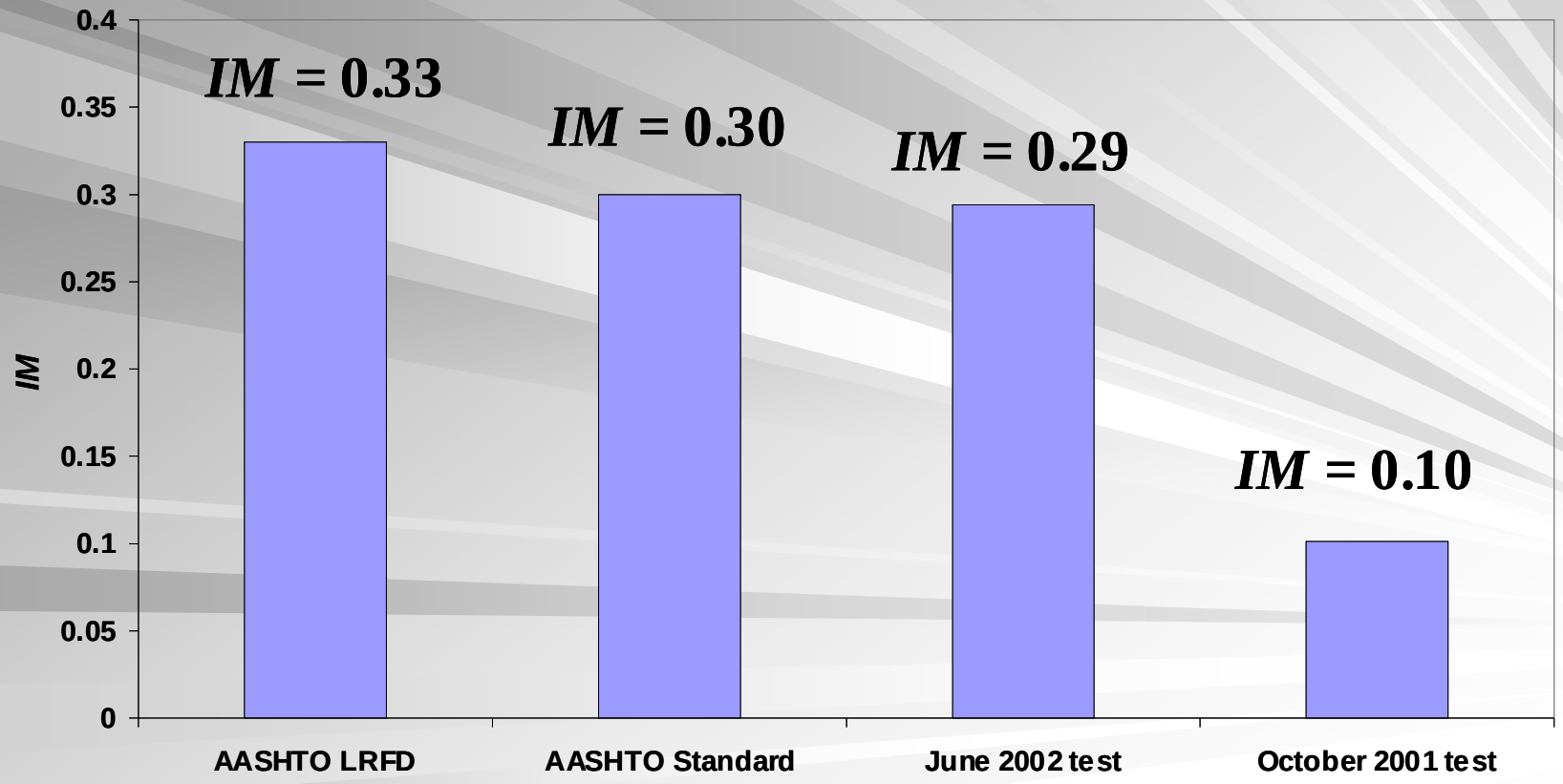
Truck Axle Orientation	Speed (mph)	No. of passes	Oct. 2001 defl. data			June 2002 defl. data		
			Max *IM*	Avg *IM*	Girder Location	Max *IM*	Avg *IM*	Girder Location
Center	15	5			-----	0.017	-0.005	-----
	25	5	0.003	-0.040	5	0.071	0.054	5
	40	5	-0.038	-0.066	5	0.271	0.216	5
East Interior	15	5			-----	0.065	0.046	-----
	25	5	0.089	**0.065**	6	0.032	0.026	6
	40	5	0.044	0.006	6	0.128	0.057	6
West Interior	15	5			-----	0.030	0.023	-----
	25	5	0.093	0.060	3	0.082	0.074	3
	40	5	0.038	0.015	3	0.304	**0.284**	3
			MAX	**0.065**		**MAX**	**0.284**	

****Note:** test not performed

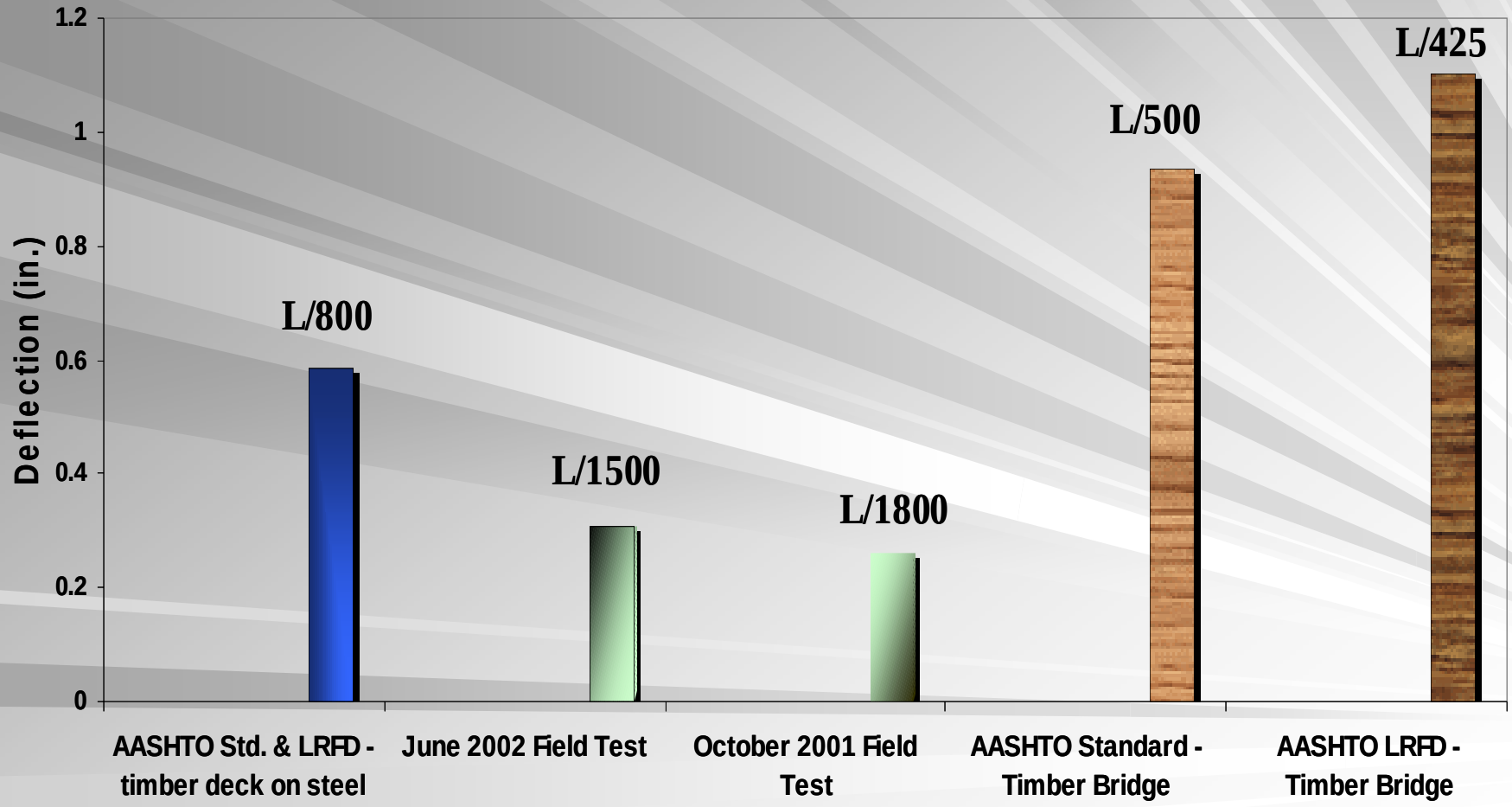
Dynamic Load Allowance Comparison to AASHTO specs (field based on deflection data)



Dynamic Load Allowance Comparison to AASHTO specs (field based on strain data)



Deflection Comparison to AASHTO Code



Deflection Discrepancy with L/800

- Reserve Stiffness from secondary bridge elements
  - Partial Composite Action
  - Restraint forces from Bearings
  - Guard Rails

Deflections

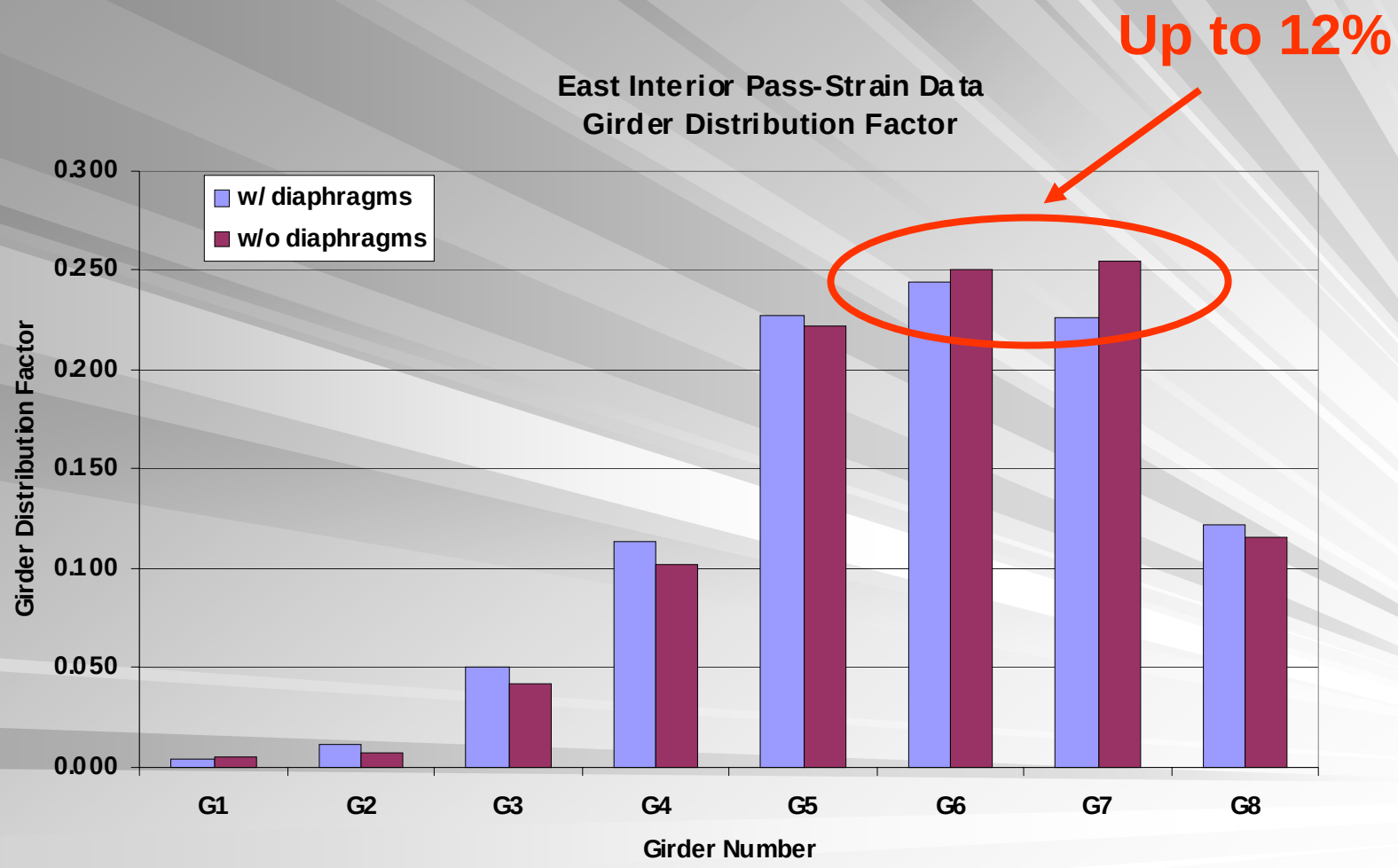
- Determined From Average of Five Truck Passes
- October 2001- 0.261 in. (L/1800)
  - Location of Girder One
  - Multiple Lane Pass
- June 2002 – 0.309 in. (L/1500)
  - Location of Girder Eight
  - East Exterior Pass

Secondary Objectives

- Effect of Diaphragm Removal
- Torsion and Axial Effects
- Response to Symmetry

Diaphragm bolts removed

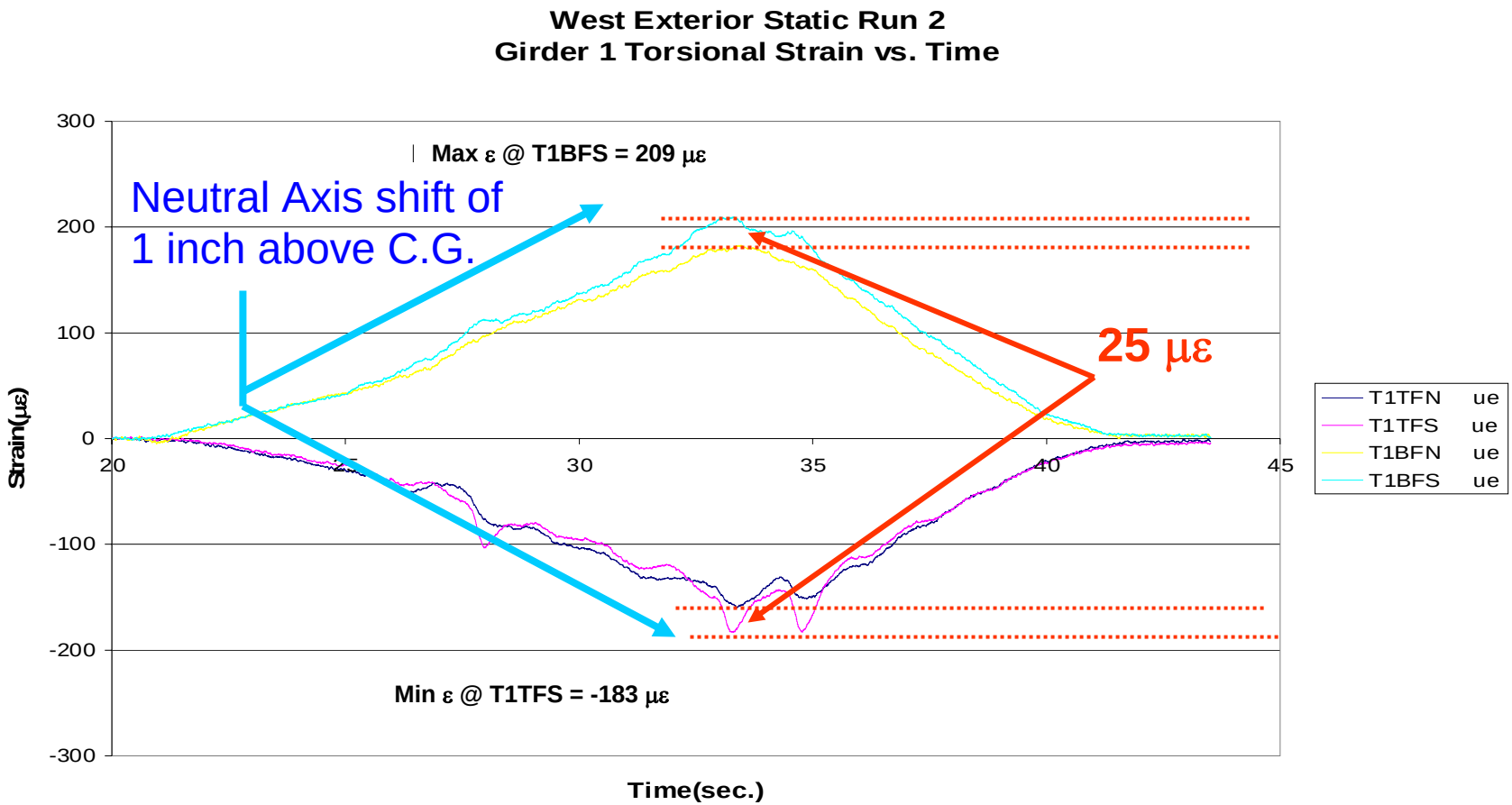
Effect on Girder Distribution



Effect of Diaphragms

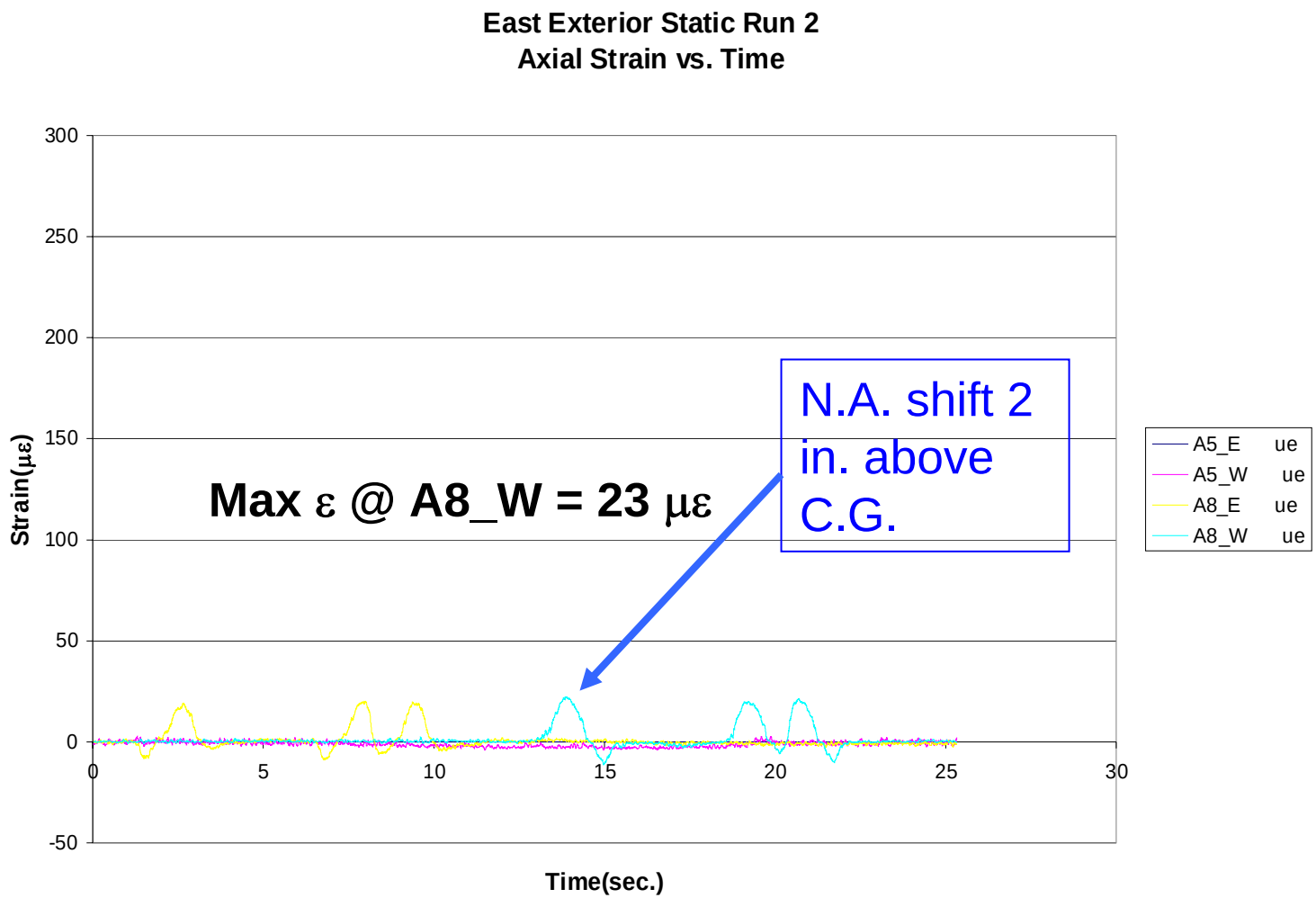
- Slight Increases in GDF and Response Along Loaded Region
- Does not Control Proposed Girder Distribution Factor of S/5

Torsion and Axial Effects

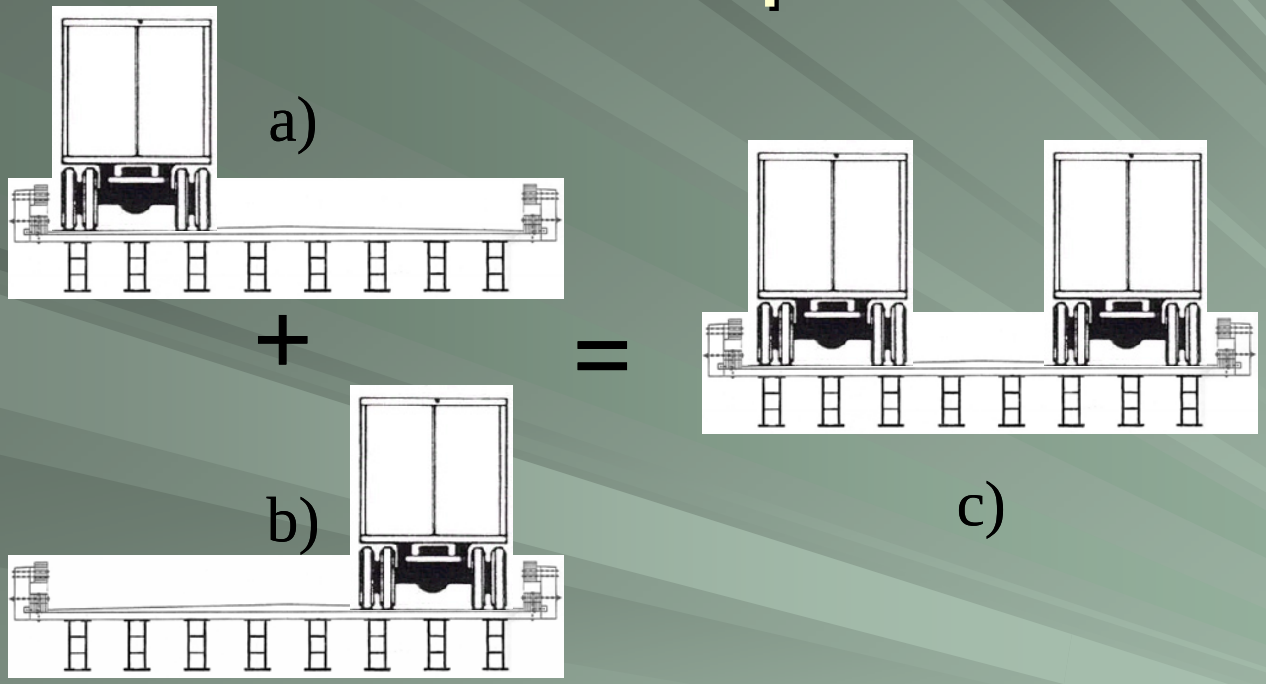


Axial Gages

- **Interior lane passes – 1 in. shift above C.G. of FRP beam**
- **Exterior lane passes – 2 in. shift above C.G. of FRP beam**



Superposition & Symmetry Response



- **Superimposed single lane exterior runs and compared with multiple lane runs**
- **% difference of Girder Distribution Factor and Deflection < 6%**

Conclusions

- Wheel Load Distribution Factor, *g*, has been determined
  - **Proposed at S/5.0 per wheel line**
  - **0.70 or 70% of an axle load**
  - **Wheel Load Distribution not a Function of speed**
- Dynamic Load Allowance *IM* has been determined
  - **Dynamic Load allowance of 30% proposed**
  - **From Fall 2001 test, *IM* was affected by settled approached. Improved approaches enhanced dynamic effects of bridge, suggesting dynamic load allowance is a time dependent quantity.**

Conclusions (cont'd)

- Maximum Deflection was determined to be L/1500, which is conservative to the L/800 value from the AASHTO specs.
- Reasons for deflection discrepancy
  - **Bearing Restraint at Supports**
  - **Partial Composite Action**
  - **Stiffness Provided by Guard Rails**

Conclusions (cont'd)

- Diaphragm removal did not greatly affect girder distribution factors
- Rt. 601 Bridge exhibited linear behavior, superimposed single lane loads were within 6% of multiple lane loads
- Some neutral axis shift experienced during field testing
  - **1 inch at midspan**
  - **2 inches at supports**

Recommendations

- Future testing should be done from six month to one year intervals to monitor any change in performance of bridge w/ regards to IM, g, and deflections
- Girder Distribution Factor a function of a number of bridge characteristics (span, skew, girder spacing, etc.). Efforts should be made to incorporate some variety in future FRP composite bridge design for future field testing purposes.

Questions?