

*Simplified Live Load Distribution
Formula
NCHRP 12-62 with Specification
Discussion*

Research Team

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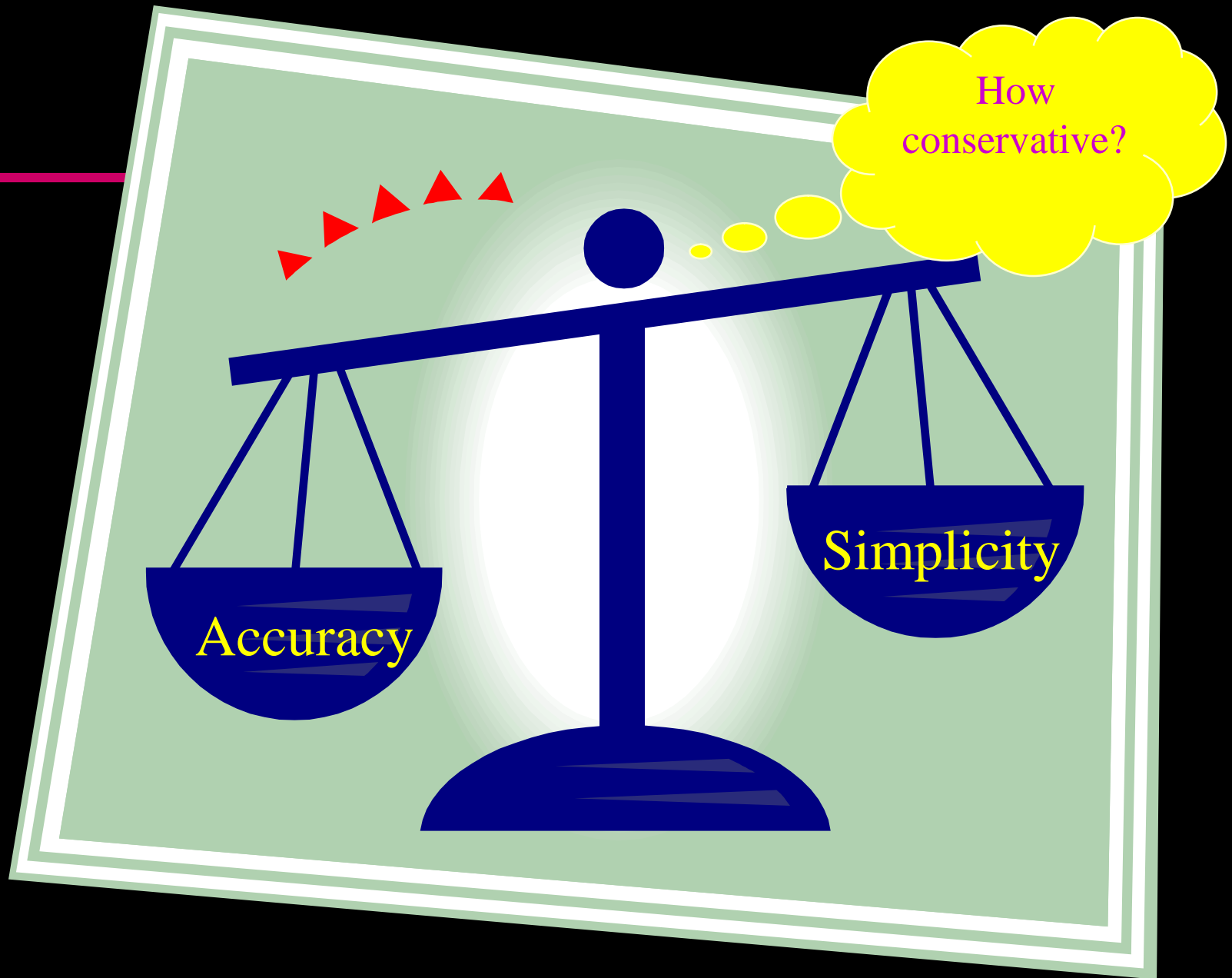
NCHRP Manager: David Beal, P.E.

Introductory Comments

- Large step
- Address all questions
- Next step

Objective

- Develop **new** recommended LRFD live-load distribution-factor design equations for shear and moment that are *simpler* to apply and have a *wider range of applicability* than those in the current LRFD. The need for refined methods of analysis should be minimized.



Advantages

- Consistent approach for bridge types
- Based upon lever rule (shear and one-lane moment) – and adjusted
- Based uniform distribution (multiple-lanes loaded – and adjusted
- Independently accounts for multiple presence
- Eliminates many limits on application

Advantages

- Independently accounts for variability of simple analysis with respect to rigorous
- Independent of cross section and span lengths
- Same for positive and negative moment areas

Advantages

- Many pages shorter
- Many variables, definitions, and computations are eliminated
- Once transformations are understood the adjustments from lever/uniform are readily seen
- Well documented

Advantages

- Extensible within proposed framework
 - Different coefficients
 - Analysis variability is quantified
 - Recalibration
 - LRFR
 - Multiple presence
 - Safety net
 - Lower bound for rigorous analysis

Disadvantages

- New and Different
- Minor programming required
- Minor training
- Empirically based
- Rigorous analysis as standard practice will be discouraged

Status

- Good input from T-05 and T-10
- Need time to revise and relax some simplification and improve accuracy
- Community to re-review
- Mid Year meeting to provide modifications
- Re review and response/revisions

Message today

Is not ...



The Framework

NCHRP 12-62

*More than
Simplification*

Three Separate Components

Structural Analysis

$$mg = m\gamma_s \left[a_m \left(LR \text{ or } uniform \right) + b_m \right]$$

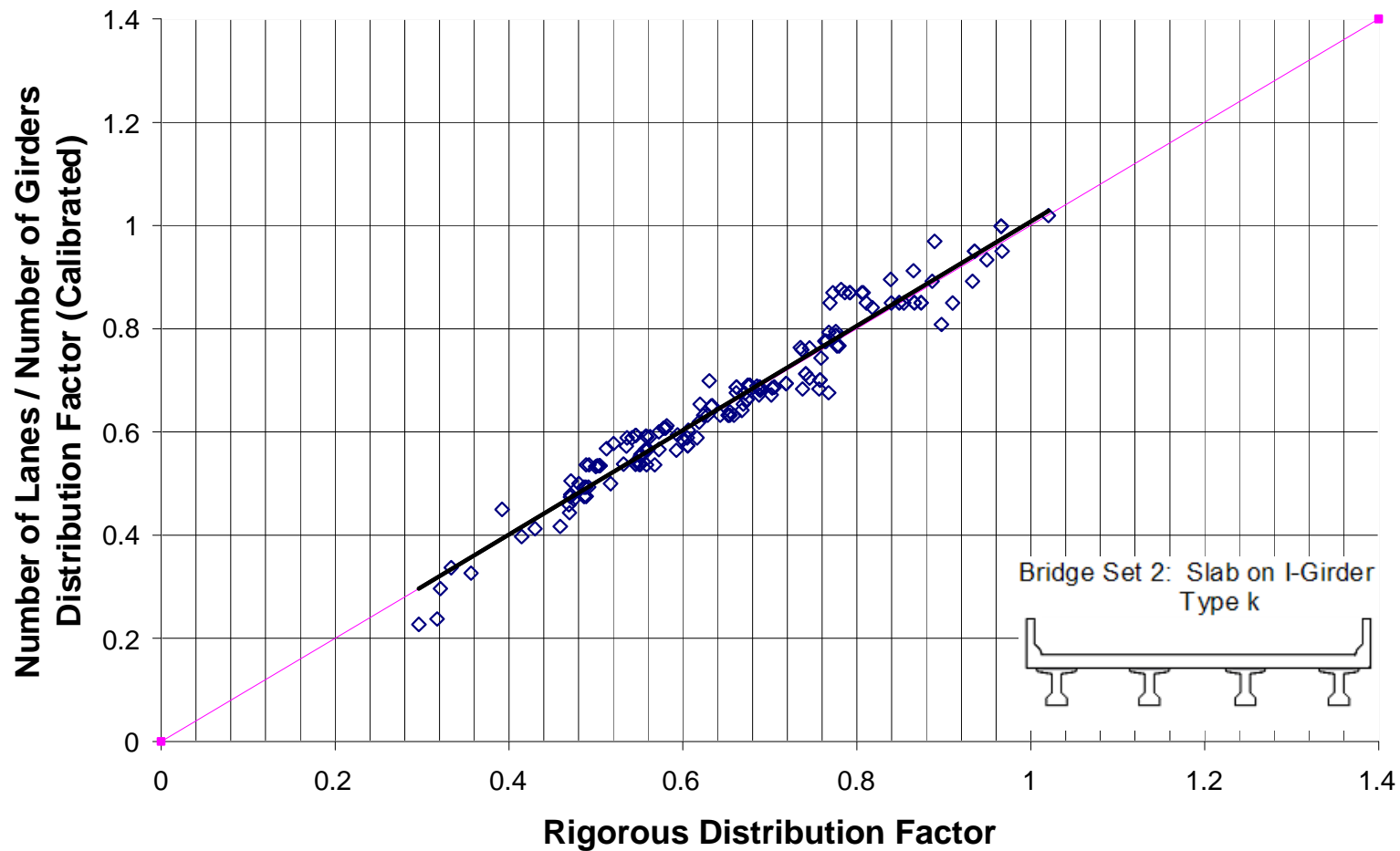
Uncertainty associated with analysis

Multiple Presence

Analysis Component

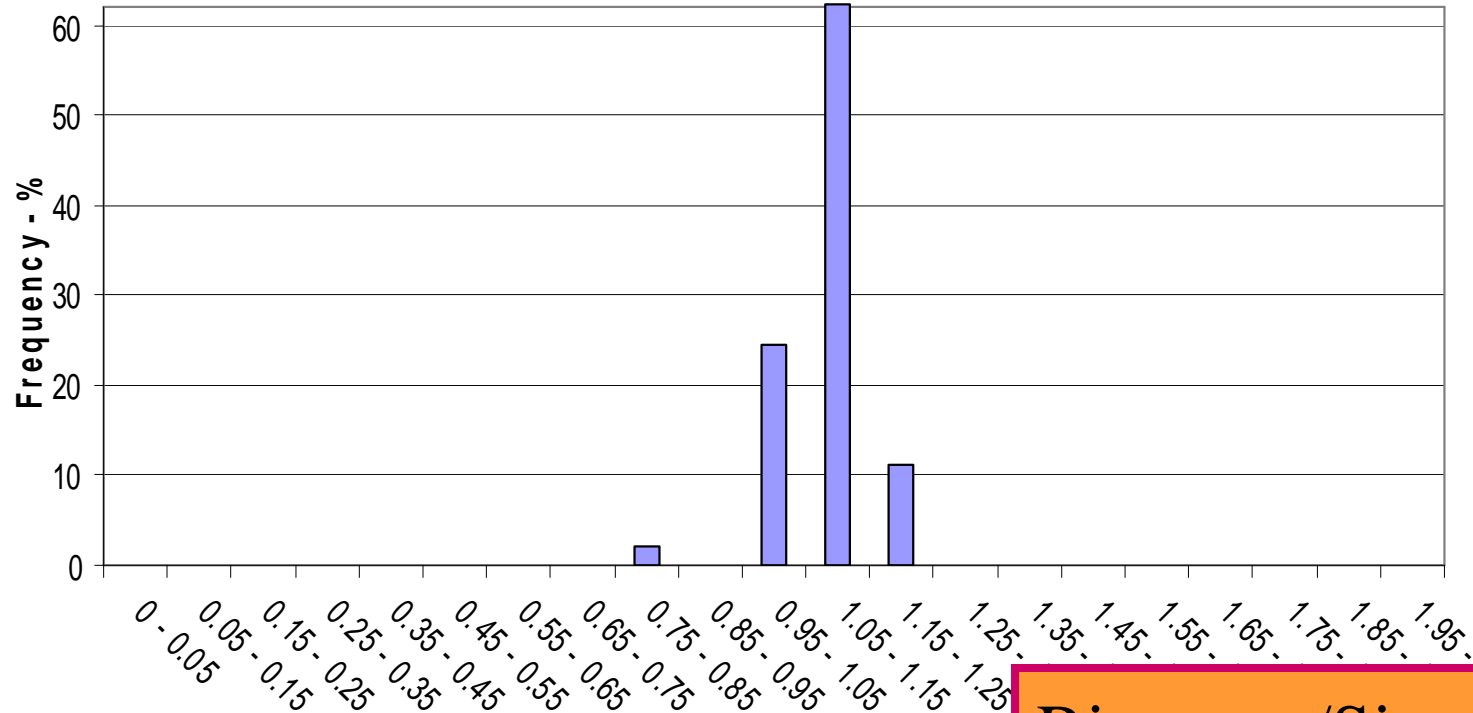
$$y = 1.0105x - 0.003$$
$$R^2 = 0.9509$$

Moment in the Interior Girder, 2 - 4 Lanes Loaded, Location 104.00



Uncertainty Component

Moment in the Interior Girder, 4 Lanes Loaded, Location 104.00. 3 & 4 lanes not critical.



Ratio - Spec Dist Factor (Calibration, Multiple Presence, and Distribution)
Rigorous Distribution Factor w/ m

Rigorous/Simple

Multiple Presence Component

$$mg = m\gamma_s \left[a_m (LR \text{ or } uniform) + b_m \right]$$

Multiple Presence

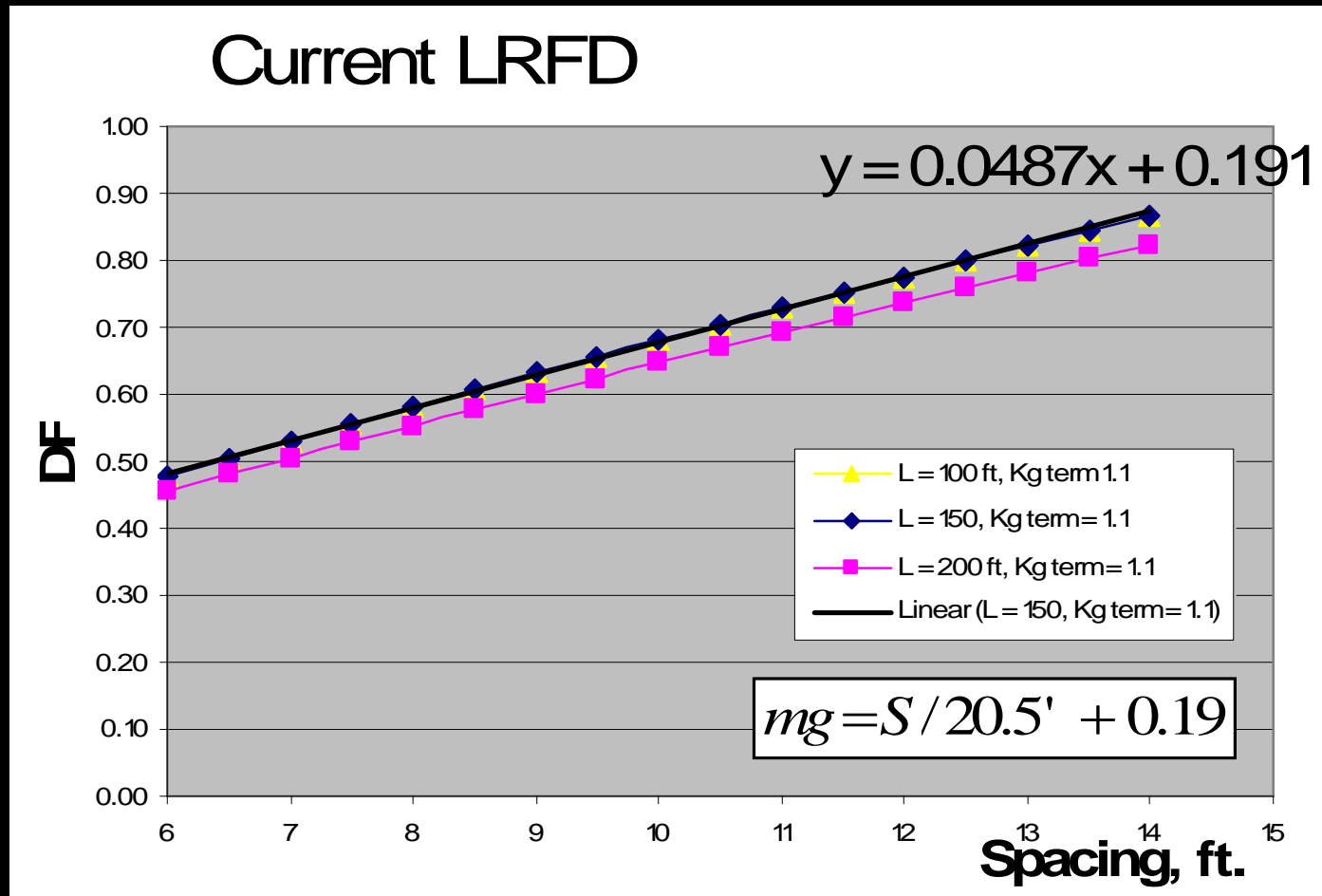
Current

$$mg = 0.075 + \left(\frac{S}{9.5} \right)^{0.4} \left(\frac{S}{L} \right)^{0.2} \left(\frac{K_g}{12.0 L t_s^3} \right)^{0.1}$$

Back out variability (12-26)?
Multiple presence - no



Example



$$mg = 0.075 + \left(\frac{S}{9.5}\right)^{0.4} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_g}{12.0Lt_s^3}\right)^{0.1}$$

“Simplification is more than
just simple computations”

Dr. Mertz

Perspective

- History
- Trends
- New work

Example

➤ 12-26 Std Specification

$$m = 1.0, 0.90, 0.75$$

➤ 12-26 LRFD

$$m = 1.2, 1.0, 0.85, 0.65$$

Three Separate Components

Structural Analysis

$$mg = m\gamma_s \left[a_m \left(LR \text{ or } uniform \right) + b_m \right]$$

Uncertainty associated with analysis

Multiple Presence

Questions

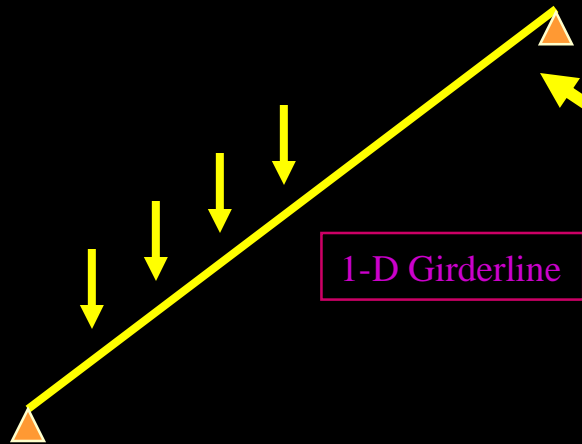
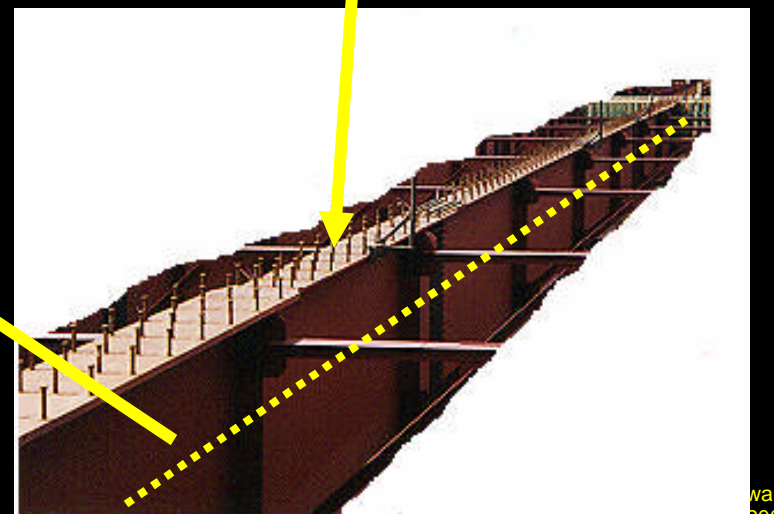
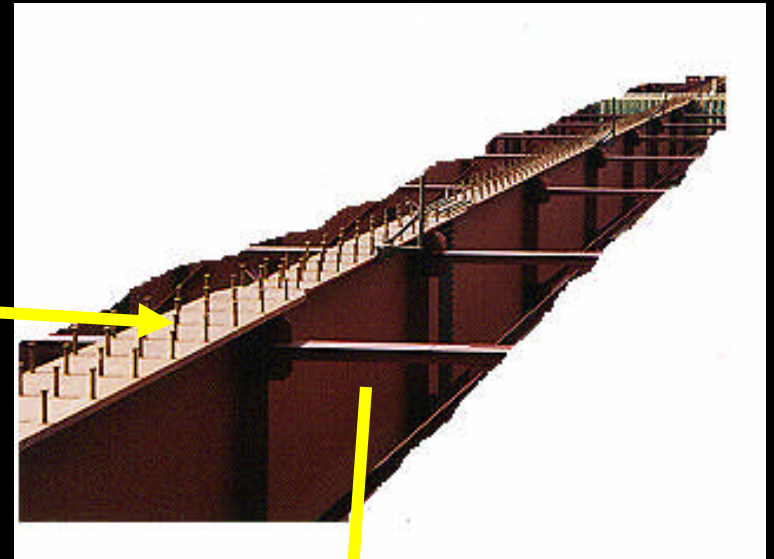
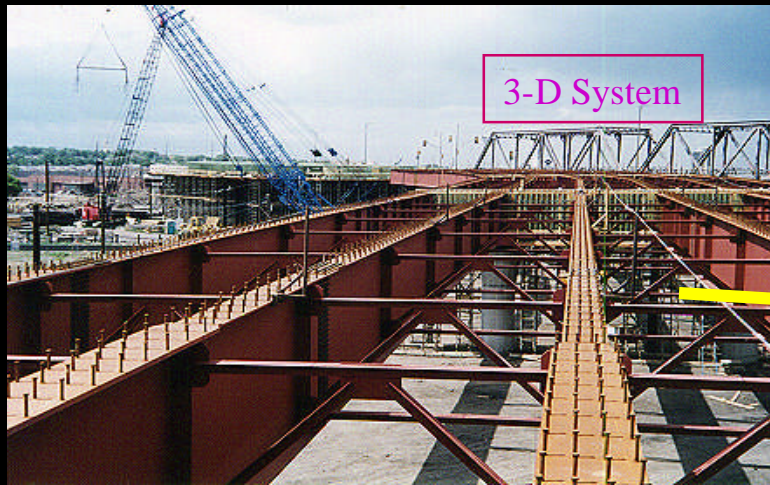
End of talk

Possible Questions/Issues

- Different coefficients for number of lanes?
- Change from unified approach to *best* approach for each type, i.e., LR, Uniform adjusted
- Three girders
 - Boxes
 - Open sections
- Skew adjustment for moment – stiffness?
- Combine slab on girder bridge types

Let's begin

The Challenge



Literature Review

- Current Specifications & Simplified Approach
- Modeling Techniques
- Field Testing
- Parametric Effects
- Bridge Type
- Nonlinear effects

~146 References

Summary Table (NBI Data)

Bridge Percentages by Type		
Type	1990-present	Total Inventory
Steel Beam	30.0%	42.8%
Concrete I	29.8%	15.1%
Precast Concrete Boxes with Shear Keys	11.2%	5.0%
Slabs	14.3%	15.8%
	85.3%	78.7%

Data Source		Reference	Total No. Bridges	Bridge Types	Number of Bridges	Aspect Ratio (L/W)			
						θ (deg)	min	max	
Data Source	Ref	NCHRP 12-26	1	809	Conc. T-Beam	71			
					Steel I-Beam	183			
					Prestressed I-Beam	94	max	min	max
					Prestressed Conc. Box	112	52.98	0.32	3.26
					R/C Box	121	66.1	0.4	4.53
					Slab	127	47.7	0.31	3.12
					Multi-Box	66	n/a	0.52	8.13
					Conc. Spread Box	35	n/a	0.53	5.5
					Steel Spread Box	20	70	0.21	2.56
							55.8	0.22	5.96
	Data Source	TN Tech Set 1	2	24	Precast Conc. Spread Box	4	26.70	1.43	4.97
					Precast Conc. Bulb-Tee	4	33.50	1.45	1.53
					Precast Conc. I-Beam	3	31.56	1.91	2.74
					CIP Conc. T-Beam	3	26.23	2.24	3.05
					CIP Conc. Multicell	4	50.16	1.60	5.11
					Steel I-Beam	4	31.95	3.28	7.00
					Steel Open Box	2	N/A	0.38	5.22
							N/A	1.40	8.00
							N/A	1.13	9.60
Data Source	LRFR	3	653	Slab on RC, Prest., and Steel Girders	653	N/A	2.76	6.82	
						70.00	0.21	9.60	
Data Source	Parametric Bridges	N/A	74	Spread Box Beams	27				
				Adjacent Box Beams	23				
				Slab on Steel I-Beam	24				
Summary:					1560				

Data Sources

1. NCHRP 12-26 Bridge Database

800 + Bridges can be used in an automated process to generate simplified and rigorous analyses.

2. Tenn. Tech. Database

Detailed descriptions and rigorous analysis are available from a recent TT study for TN DOT. Results, structural models, etc., are readily available.

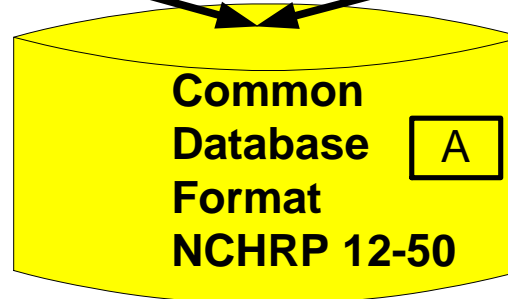
3. Virtis/Opis Database Bridges

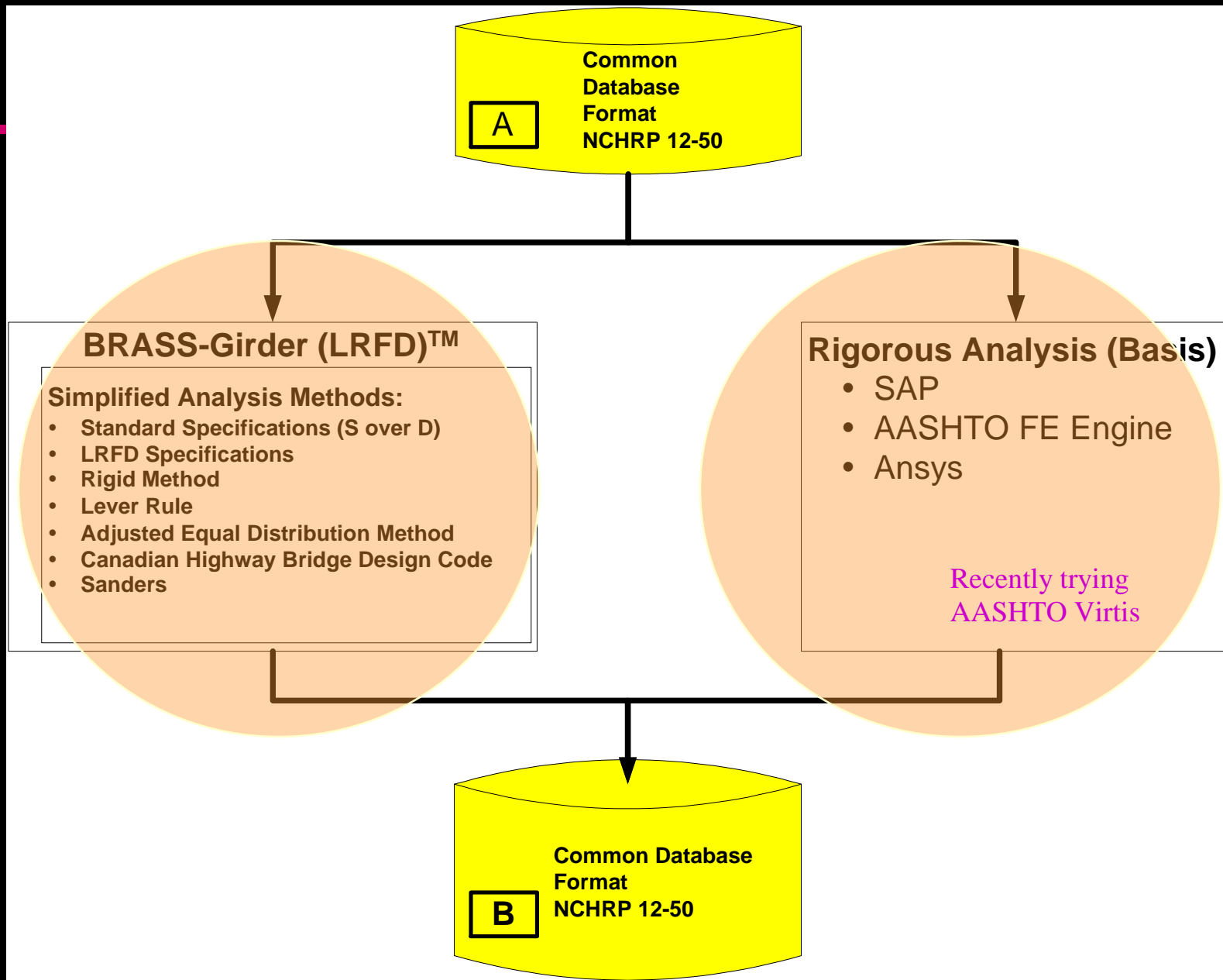
650+ bridges may be exported from Virtis/Opis to supply real bridges to both simplified and rigorous methods.

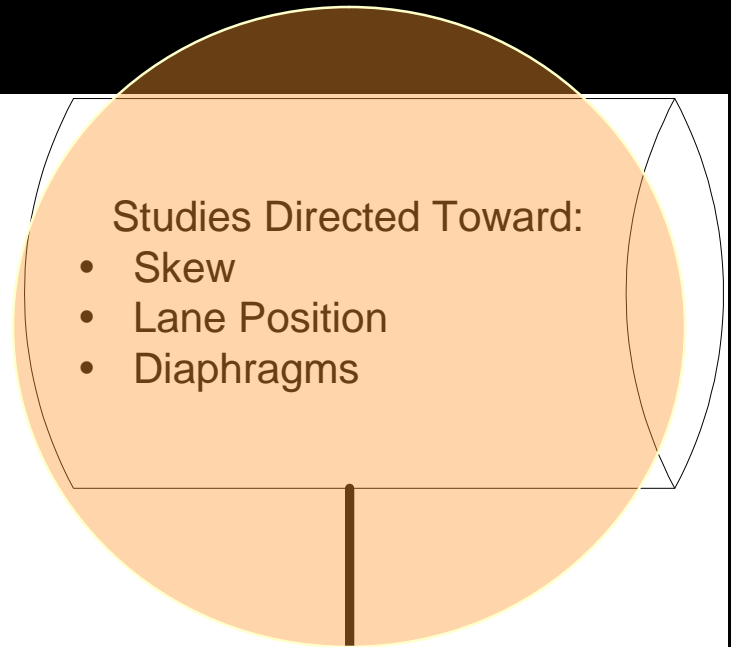
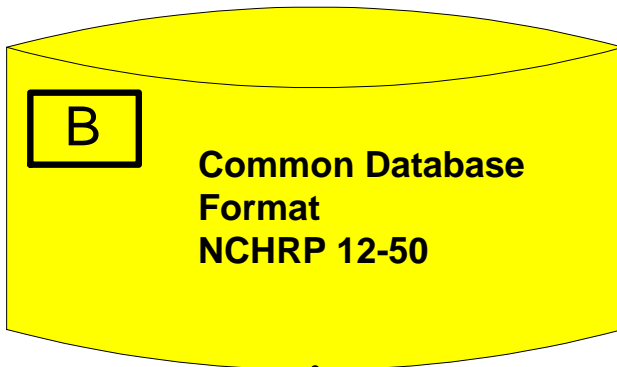
4. Parametrically Generated Bridges

74 Bridges were developed to test the limits of applicability of the proposed method.

Condense to a
Common Database







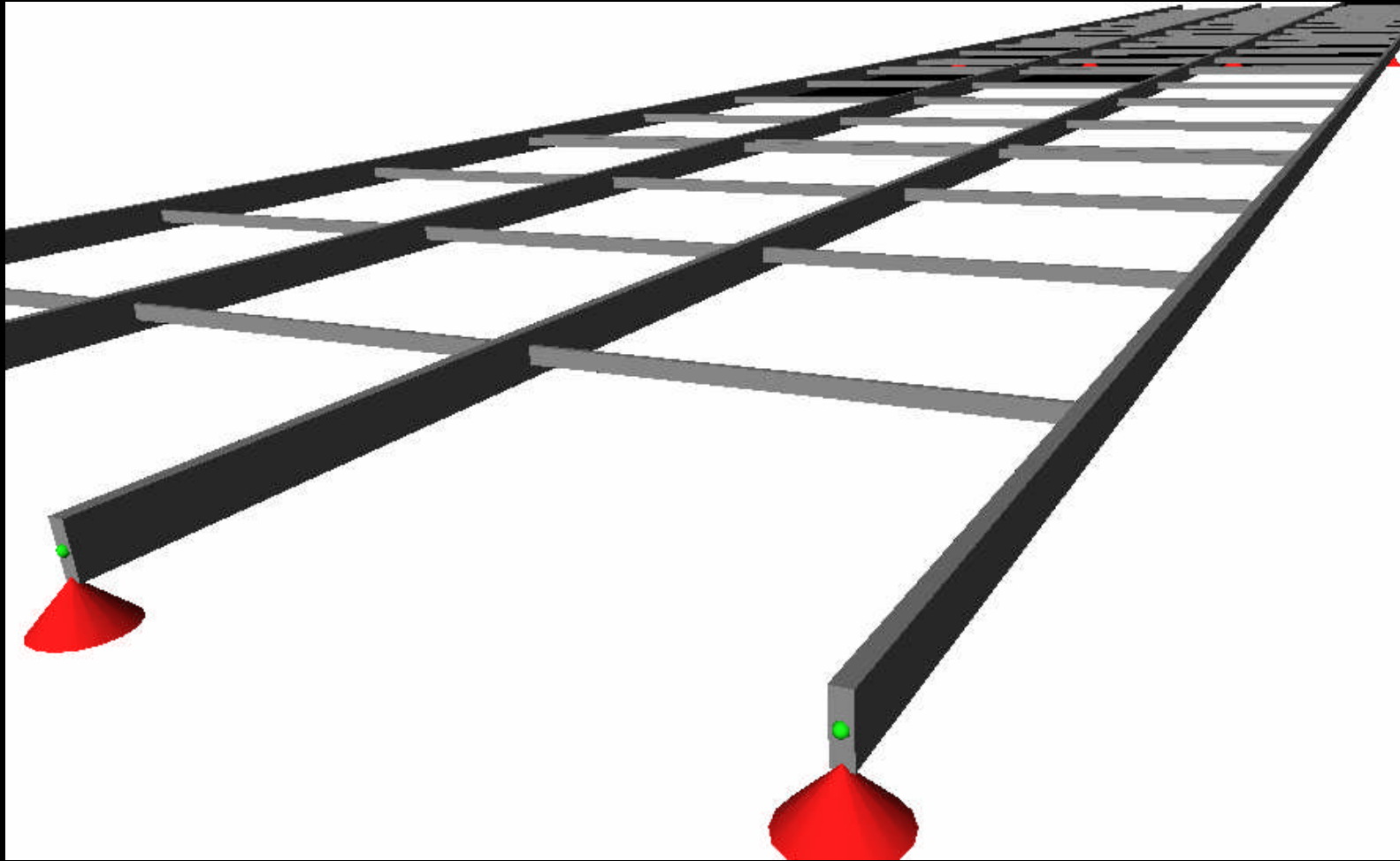
Simplified Moment and Shear Distribution Factor Equations

- Specification and Commentary Language
 - Design Examples
 - Final Report
- Iterative Process Involving Tasks 7,8, and 9 through 12.

Comparisons and Regression Testing (NCHRP 12- 50 Process)

Tasks 6 & 9
Regression testing on “real” bridges (Virtis/Opis database, NCHRP 12-26 database)
(compare proposed method to current LRFD method)
Comparisons from parametric bridges and rigorous analysis

Grillage Method (structural model)

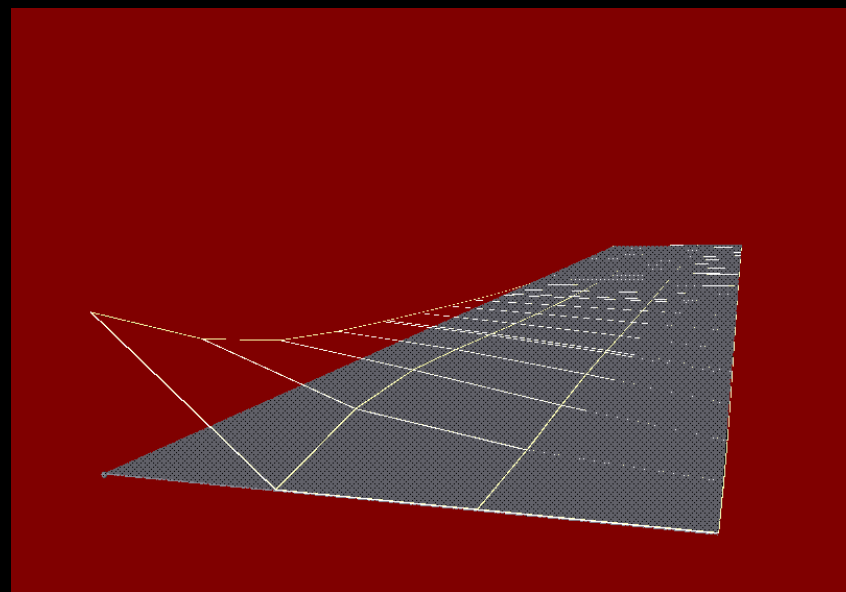
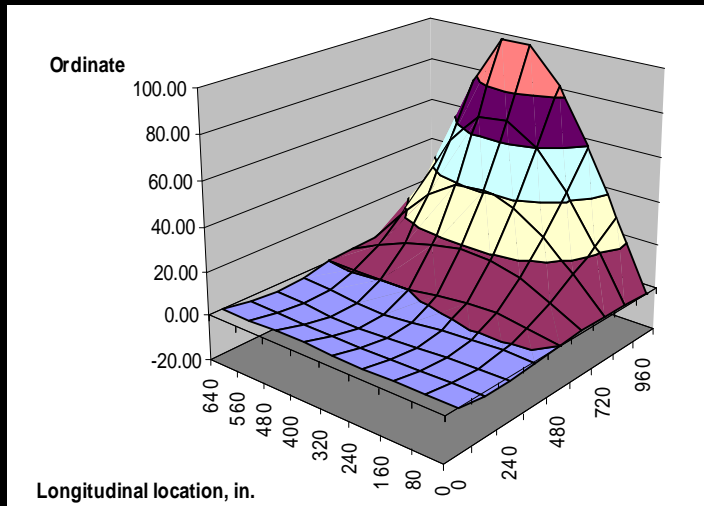


Proposed Implementation

- Two simple methods for types
 - Uniform
 - Lever rule
- One set of coefficients (for number of lanes)
- Multiple presence based upon lanes loaded in simple analysis
- Simplification factor adjusts for variability

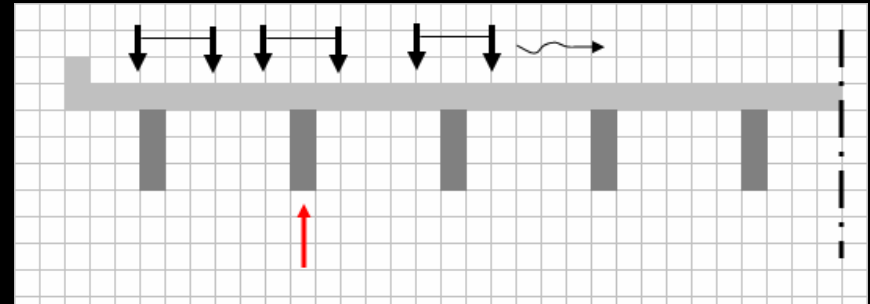
$$mg = m\gamma_s \left[a_m \left(LR \text{ or } uniform \right) + b_m \right]$$

Influence Surfaces (structural model)



Automated Live Load Positioning

- Critical live load placement
- Actions (shear, moment, reaction, translation)
- Single and multiple lanes loaded
- Critical longitudinal position
- Accounts for barrier, etc.
- 4-ft truck transverse truck spacing
- POI at least tenth points



Computation of Distribution Factor

$$\text{Distribution Factor} = g = \frac{[\text{Rigorous Action}]/[\text{Number Lanes}]}{\left[\begin{array}{l} \text{Action from Beamline} \\ \text{for same Longitudinal Position} \end{array} \right]}$$

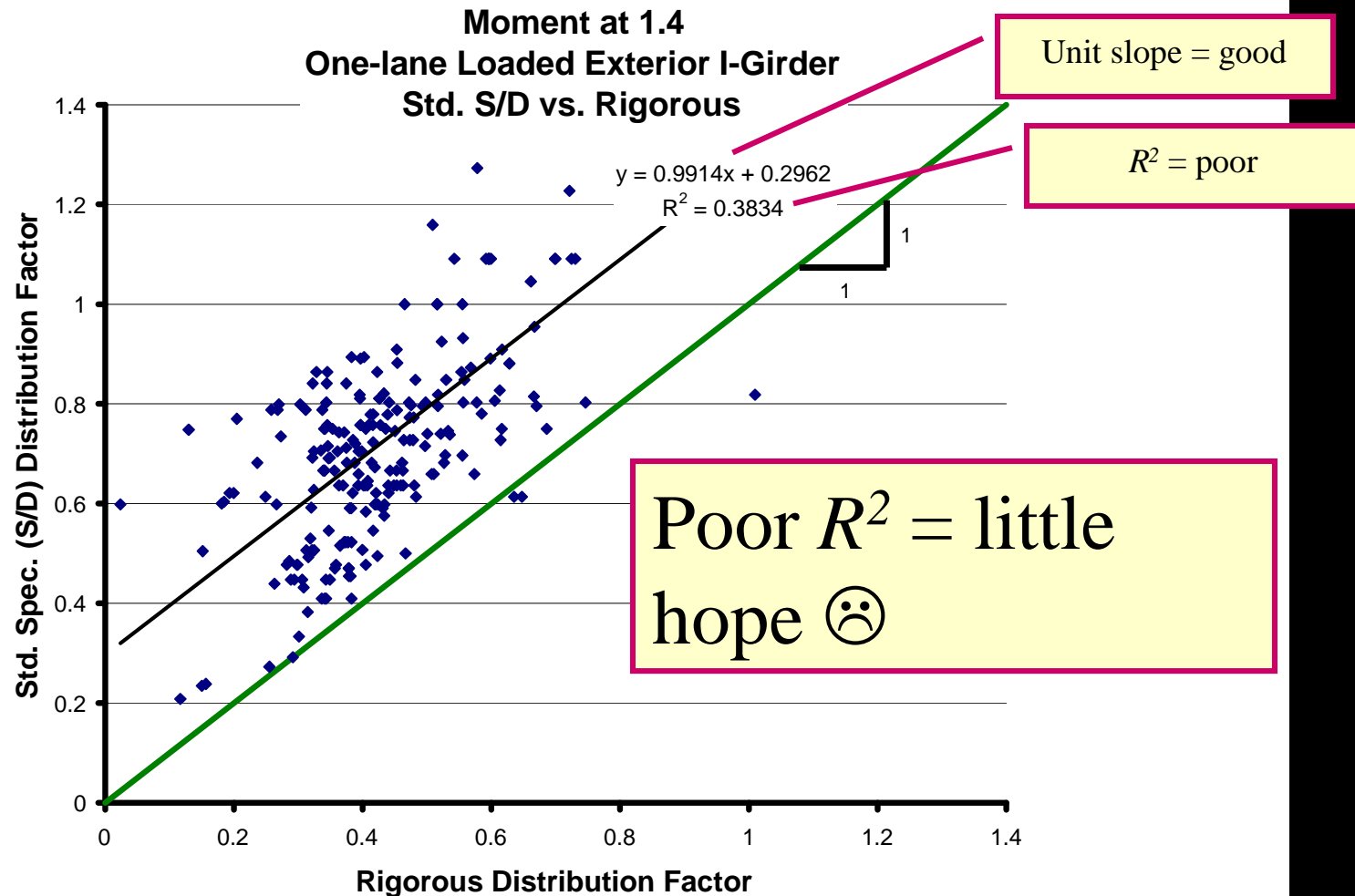
$$g = \frac{M_{\text{rigorous}}}{M_{\text{beam}}}$$

Research: 3-D to 1-D
spatial reduction

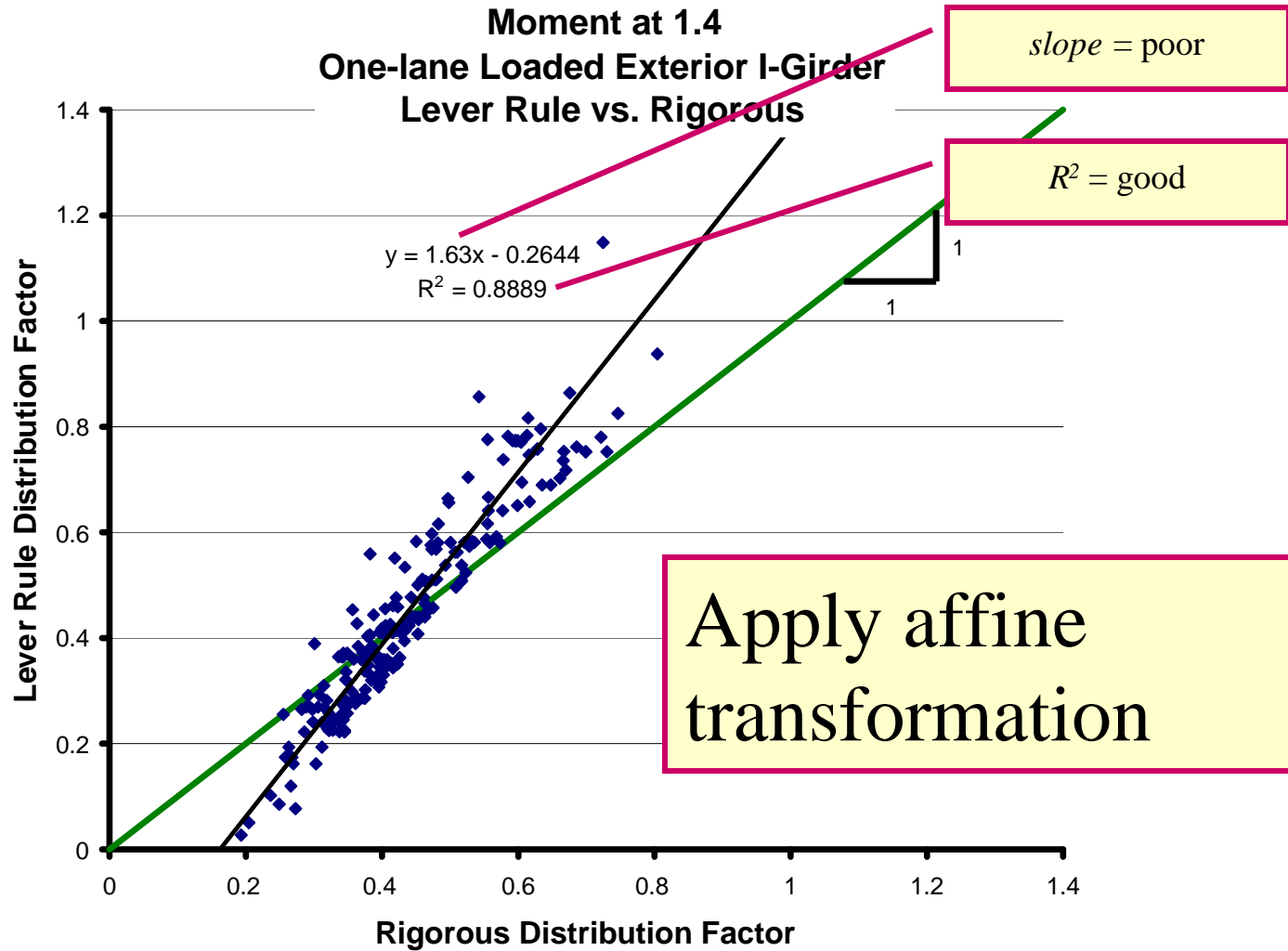
$$M_{\text{design}(\text{rigorous estimate})} = M_{\text{beam}} g$$

Application: 1-D to 3-D
spatial reduction

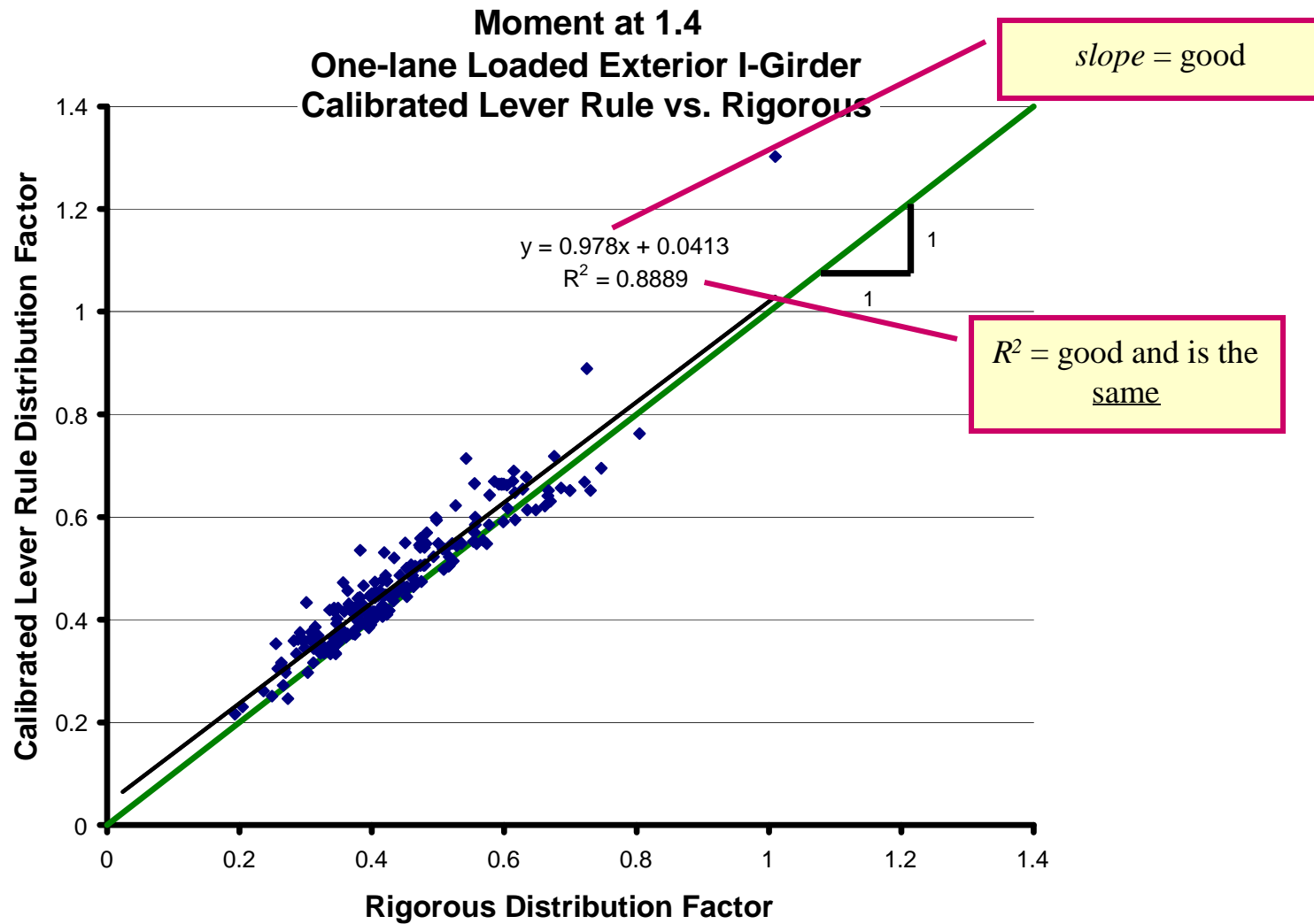
Example of Standard Specification Results



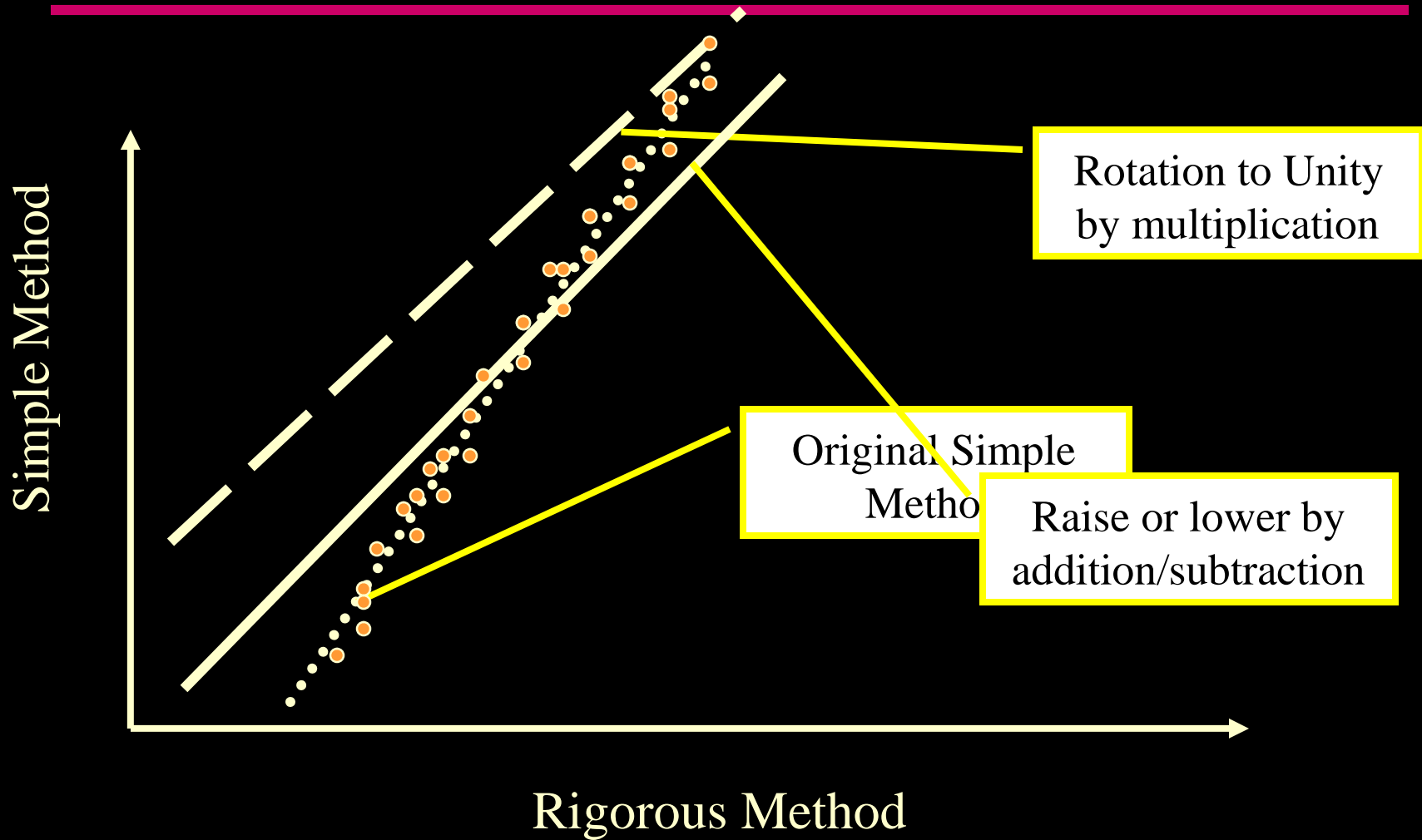
Lever Rule Results



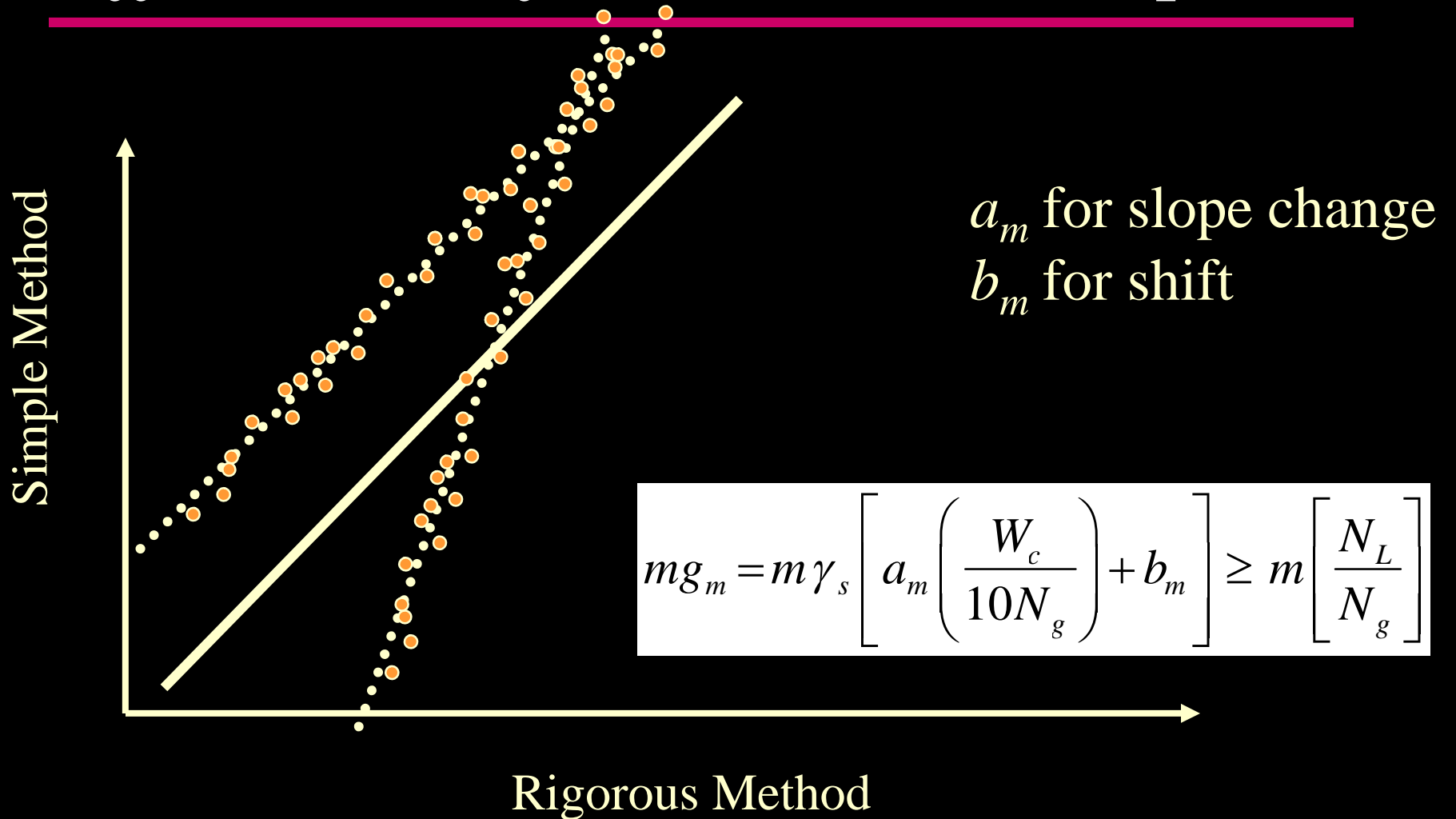
Calibrated Lever Rule Results



Affine Transformation Concept



Affine Transformation Concept



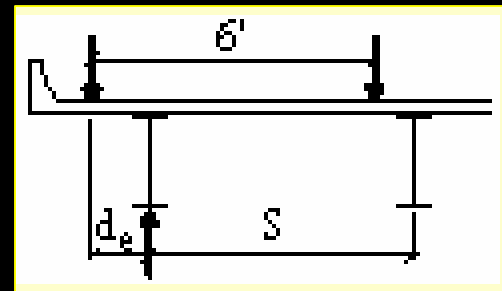
Moment Distribution Factor Computation

Number of Loaded Lanes	Girder	Distribution Factor	Multiple Presence Factor
One	Interior and Exterior	$mg_m = m\gamma_s \left[a_m (g_{leverrule}) + b_m \right] \geq m \left[\frac{N_{lanes}}{N_g} \right]$	$m = 1.2$
Two or more Loaded Lanes	Interior and Exterior	$mg_m = m\gamma_s \left[a_m \left(\frac{W_c}{10N_g} \right) + b_m \right] \geq m \left[\frac{N_L}{N_g} \right]$	Use integer part of $\frac{W_c}{12}$ to determine number of loaded lanes N_L for multiple presence.

Removed m
limit of 0.85

Multiple Presences

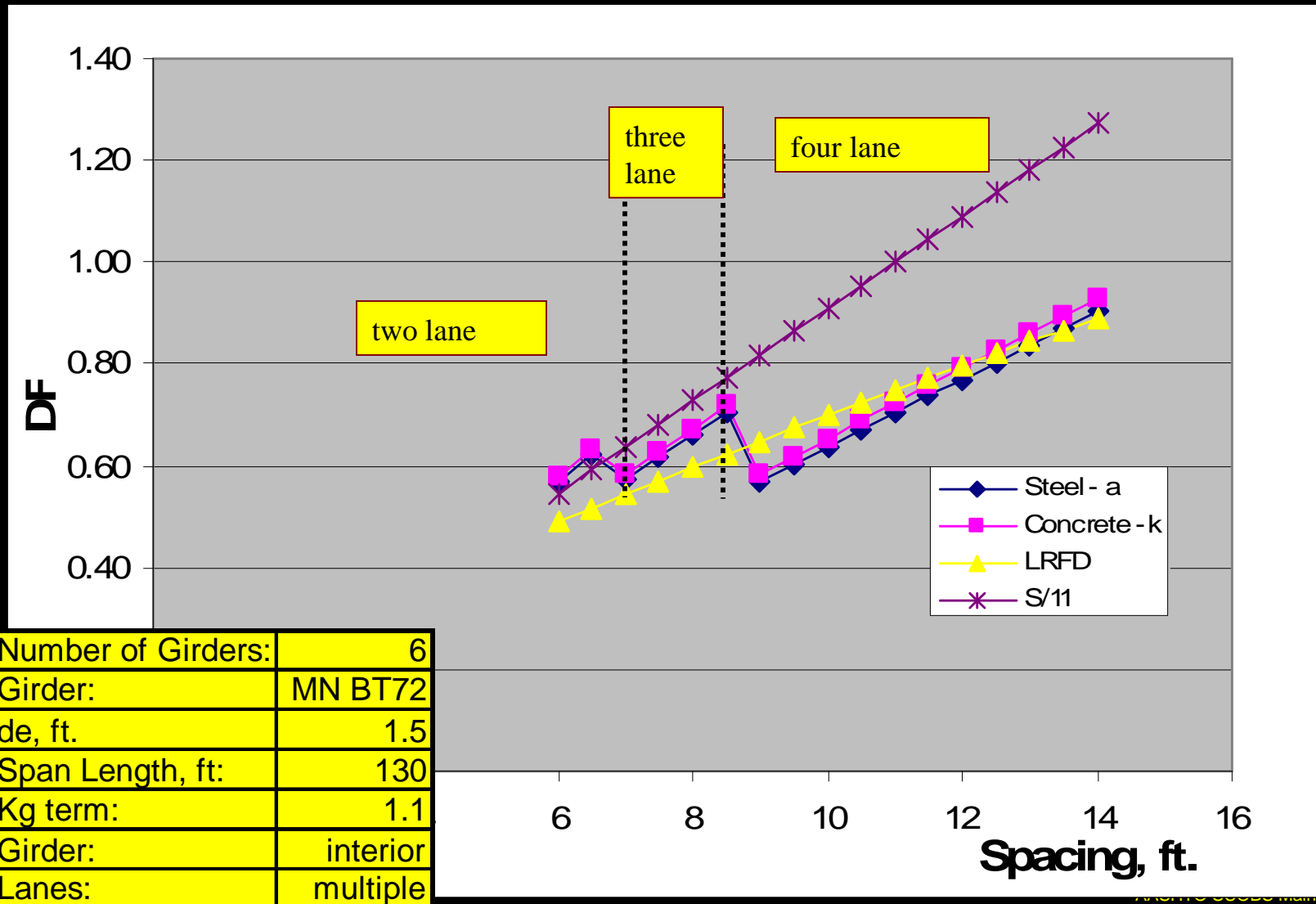
Number of Loaded Lanes	Multiple Presence Factor "m"
1	1.20
2	1.00
3	0.85
4 or more	0.65



Basic method: Lever or Uniform

$$mg_m = m \gamma_s \left[a_m \left(\frac{W_c}{10N_g} \right) + b_m \right] \geq m \left[\frac{N_L}{N_g} \right]$$

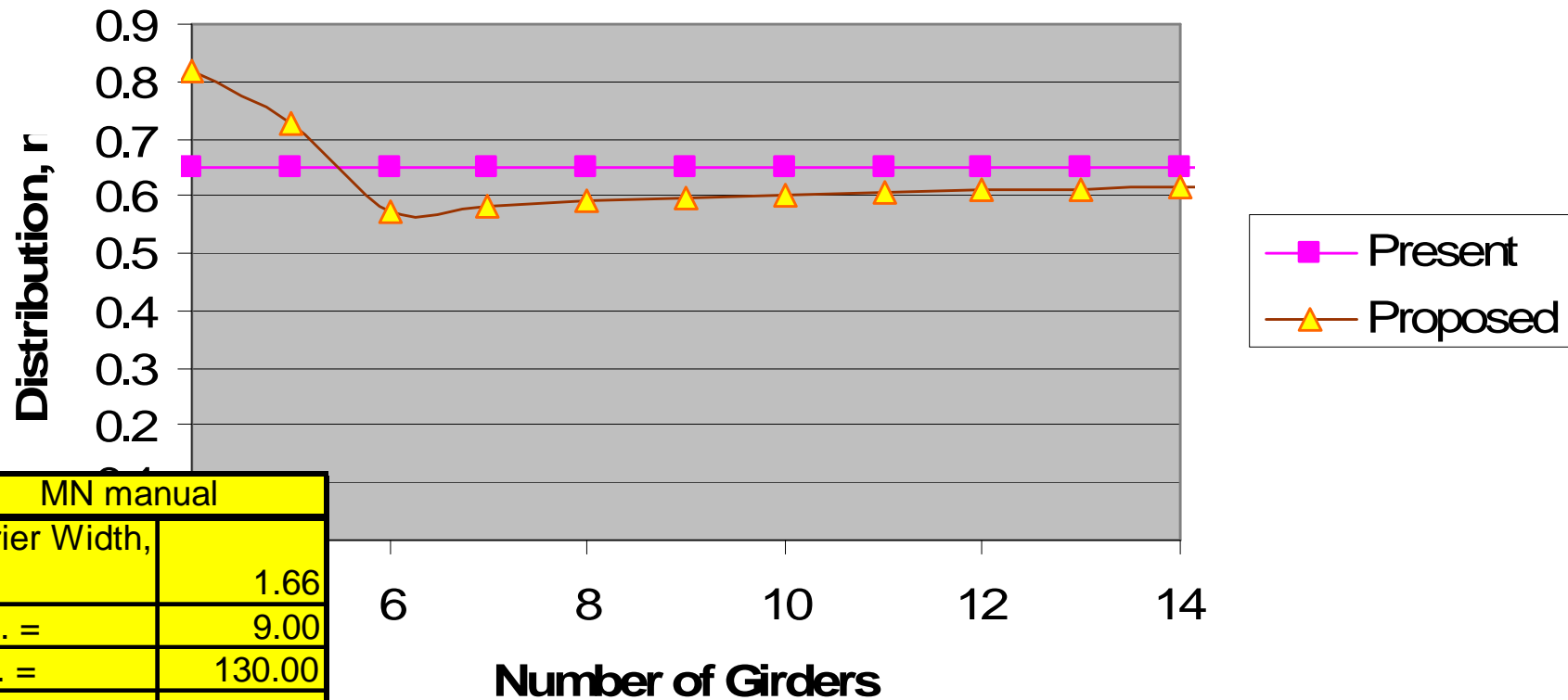
MN DOT Manual



Number of Girders:	6
Girder:	MN BT72
de, ft.	1.5
Span Length, ft:	130
Kg term:	1.1
Girder:	interior
Lanes:	multiple

MN Manual

MN Design Manual Bridge



MN manual	
Barrier Width, ft. =	1.66
S, ft. =	9.00
L, ft. =	130.00
$\gamma_s =$	1.01
$a_m =$	1.23
$b_m =$	-0.12

Issue of Loaded Lanes

$y = 0.9981x + 0.0023$ **Moment in the Interior Girder, 2 Lanes Loaded, Location 104.00**

$R^2 = 0.9268$

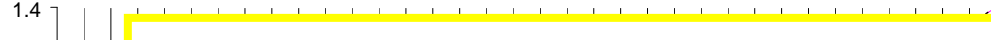
Proposed LRFD Specification Distribution Factor (Calibration Only)



$y = 1.0532x - 0.0227$ **Moment in the Interior Girder, 3 Lanes Loaded, Location 104.00**

$R^2 = 0.9182$

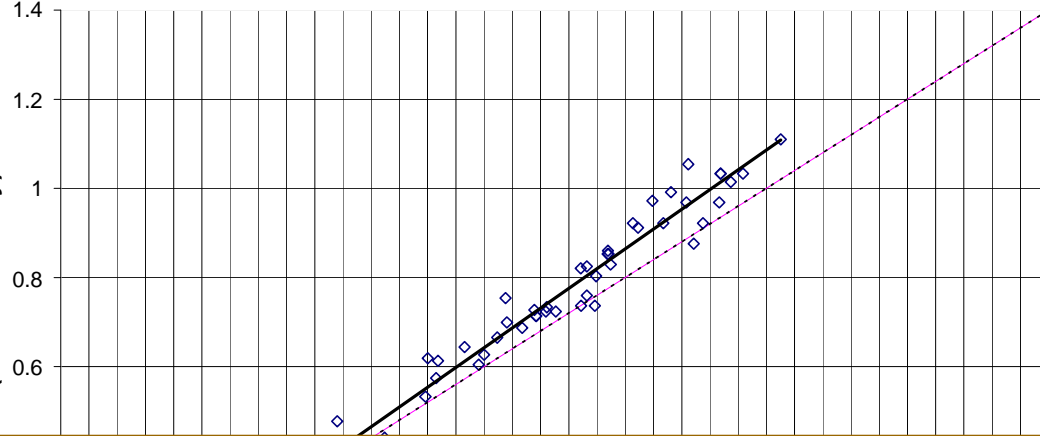
Proposed LRFD Specification Distribution Factor (Calibration Only)



$y = 1.1096x - 0.023$ **Moment in the Interior Girder, 4 Lanes Loaded, Location 104.00**

$R^2 = 0.9455$

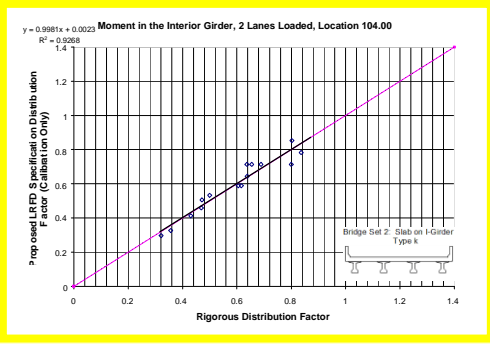

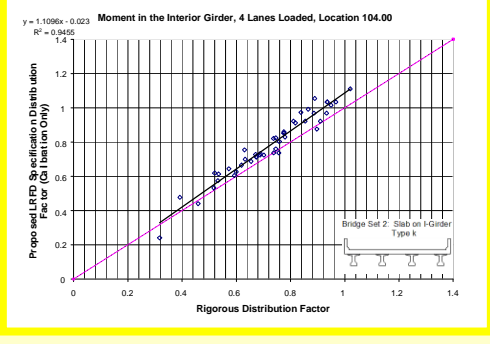
LRFD Specification Distribution Factor (Calibration Only)



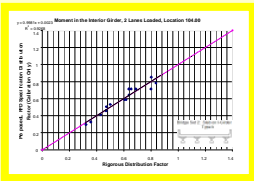
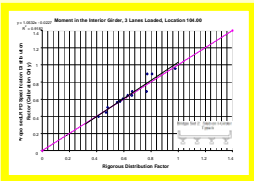
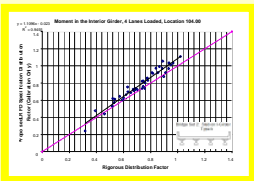
Issue: Do we have separate coefficients for number of lanes loaded?

Rigorous Distribution Factor

Implementation Decision

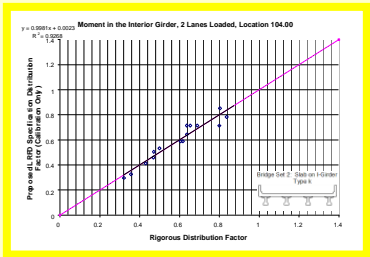
Lanes	Simple vs Rigorous	
2		a_m, b_m used in original calibration – was conservative and simple
3		a_m, b_m slightly different ~5%
4		a_m, b_m different ~10%

Implementation Decision

Lanes	Simple vs Rigorous	Coefs	m	mg	Critical
2		a_{m2}, b_{m2}	1.0	mg_2	} Max
3		a_{m3}, b_{m3}	0.85	mg_3	
4		a_{m4}, b_{m4}	0.65	mg_4	

$$mg = m\gamma_s \left[a_m (LR \text{ or } uniform) + b_m \right]$$

Implementation Decision

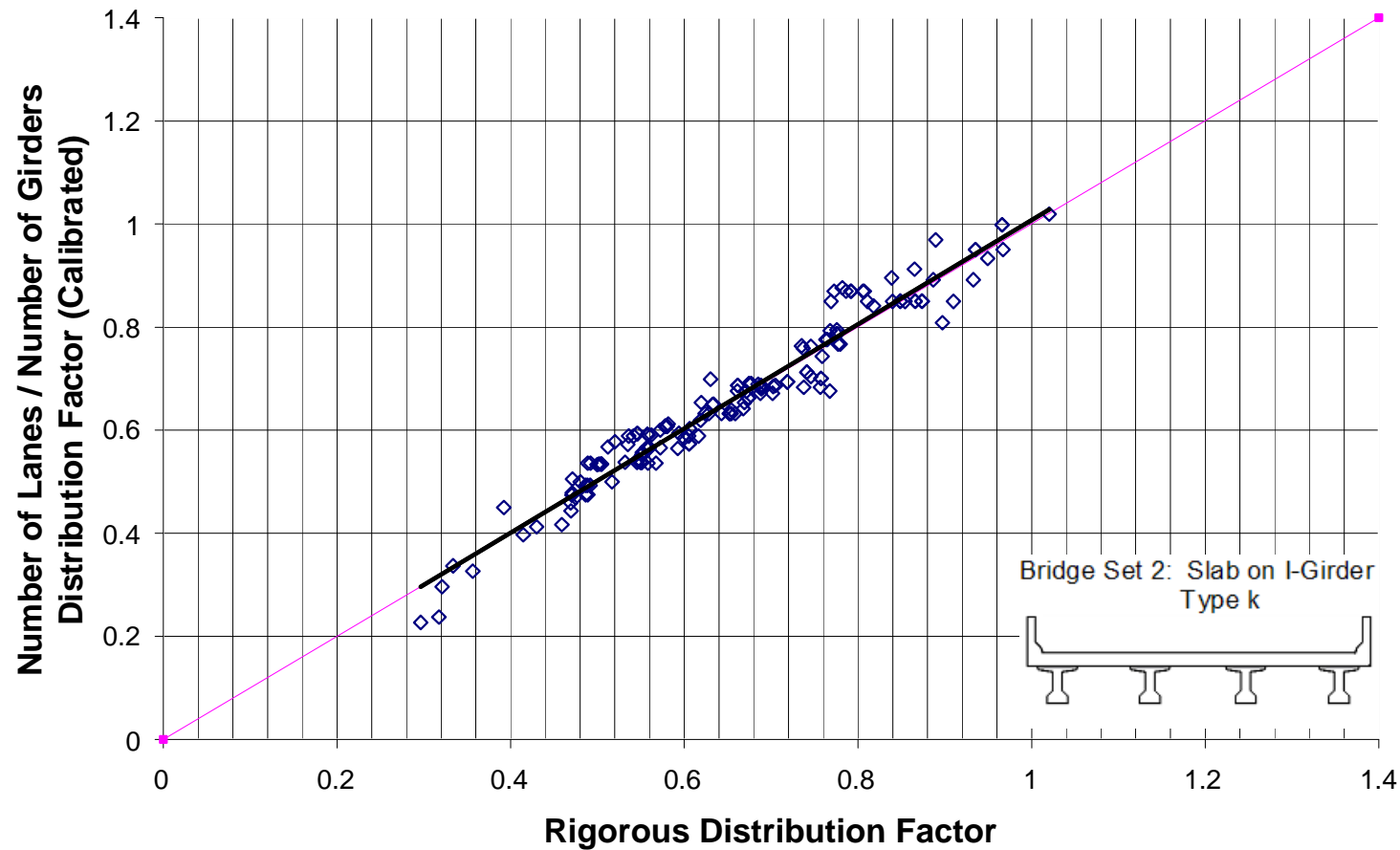
Lanes	Simple vs Rigorous	Coefs	m	mg	Critical
2, 3, 4		a_m, b_m	Determined in simply analysis	mg	

$$mg = m\gamma_s \left[a_m (LR \text{ or } uniform) + b_m \right]$$

Steel-I Moment Interior 2-4 Lanes

$$y = 1.0105x - 0.003$$
$$R^2 = 0.9509$$

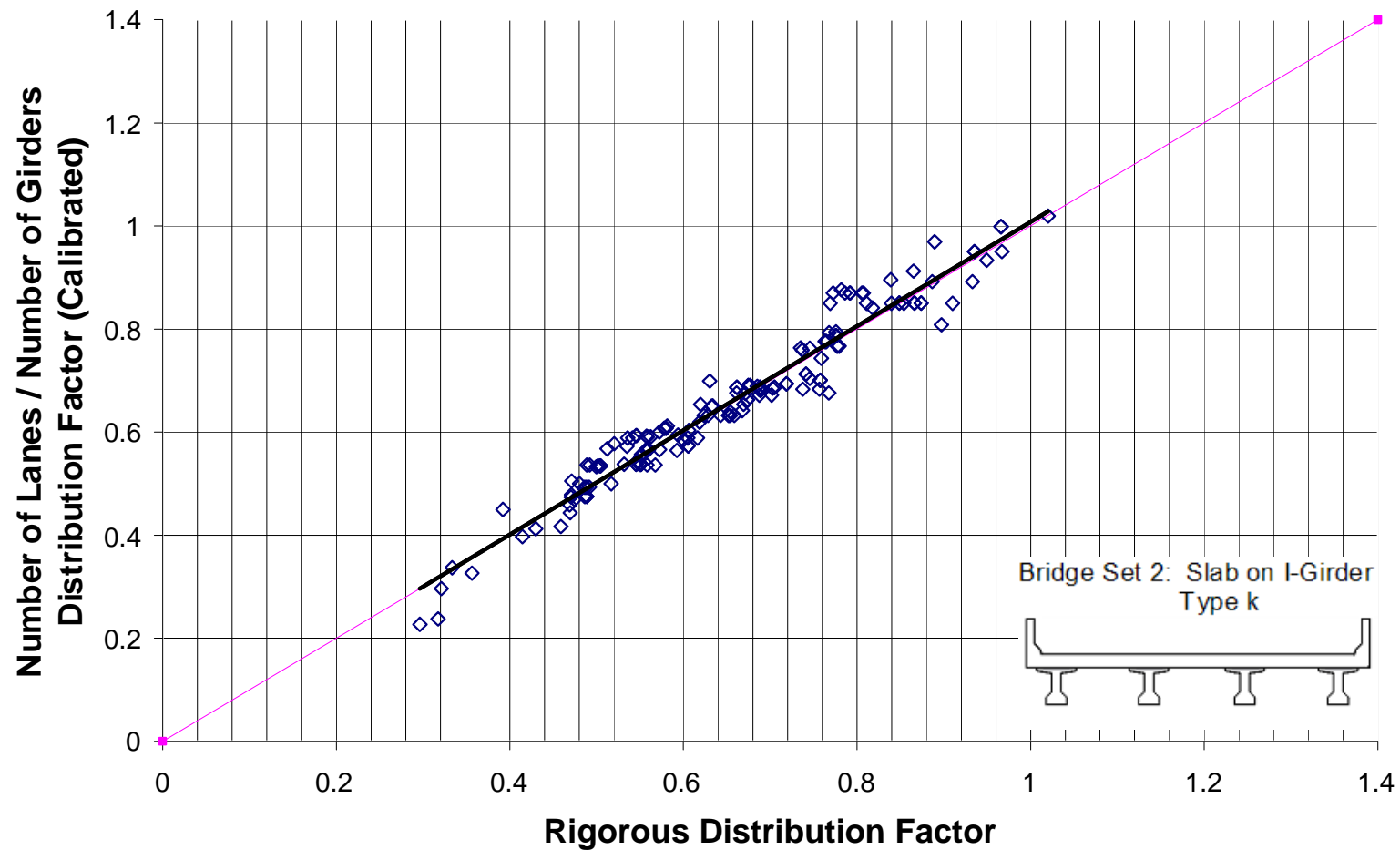
Moment in the Interior Girder, 2 - 4 Lanes Loaded, Location 104.00



Concrete I Moment Interior 2-4 Lanes

$$y = 1.0105x - 0.003$$
$$R^2 = 0.9509$$

Moment in the Interior Girder, 2 - 4 Lanes Loaded, Location 104.00

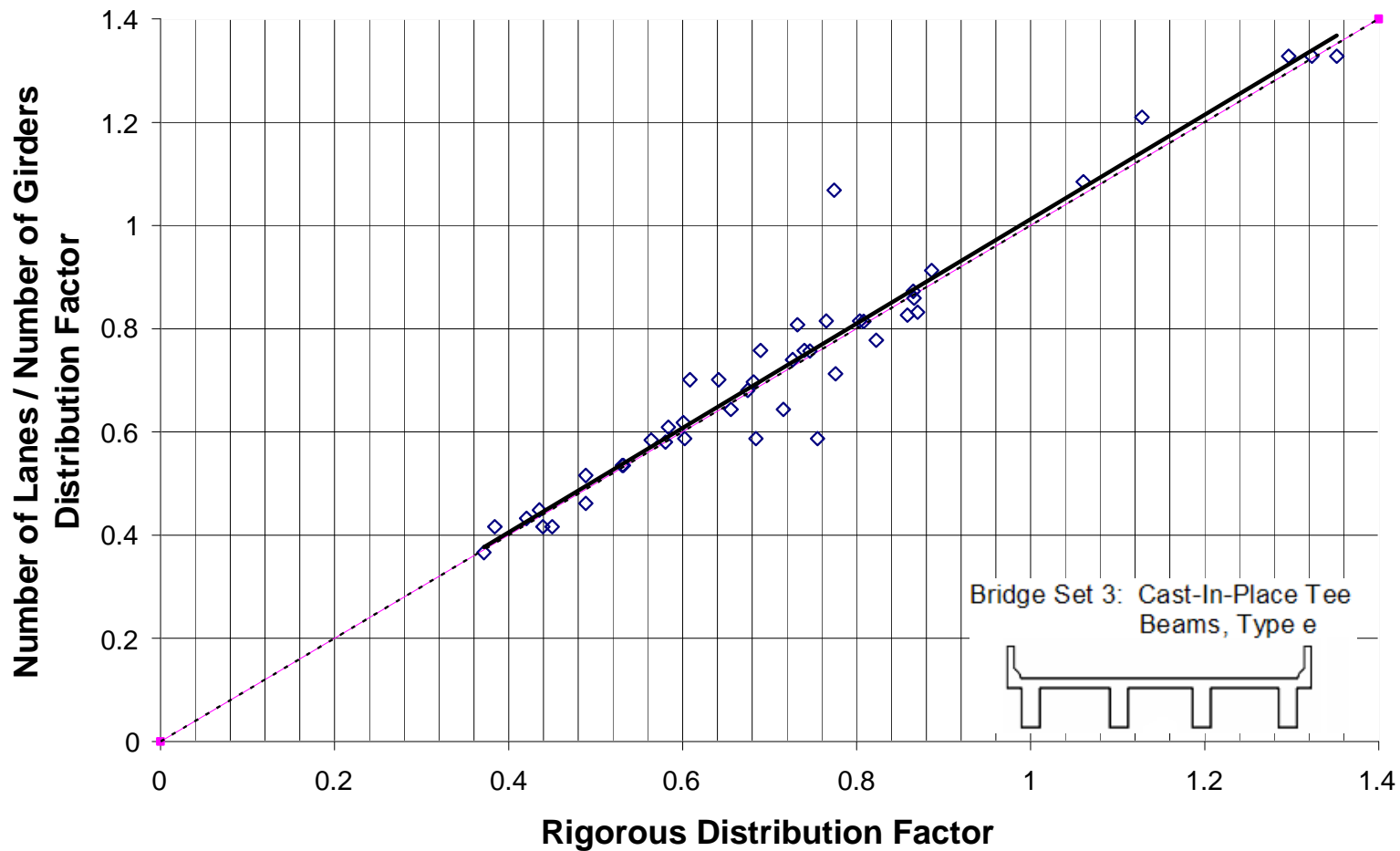


Concrete-T Moment Interior 2-4 Lanes

Moment in the Interior Girder, 2 - 4 Lanes Loaded, Location 104.00

$$y = 1.0111x + 0.0008$$

$$R^2 = 0.9324$$

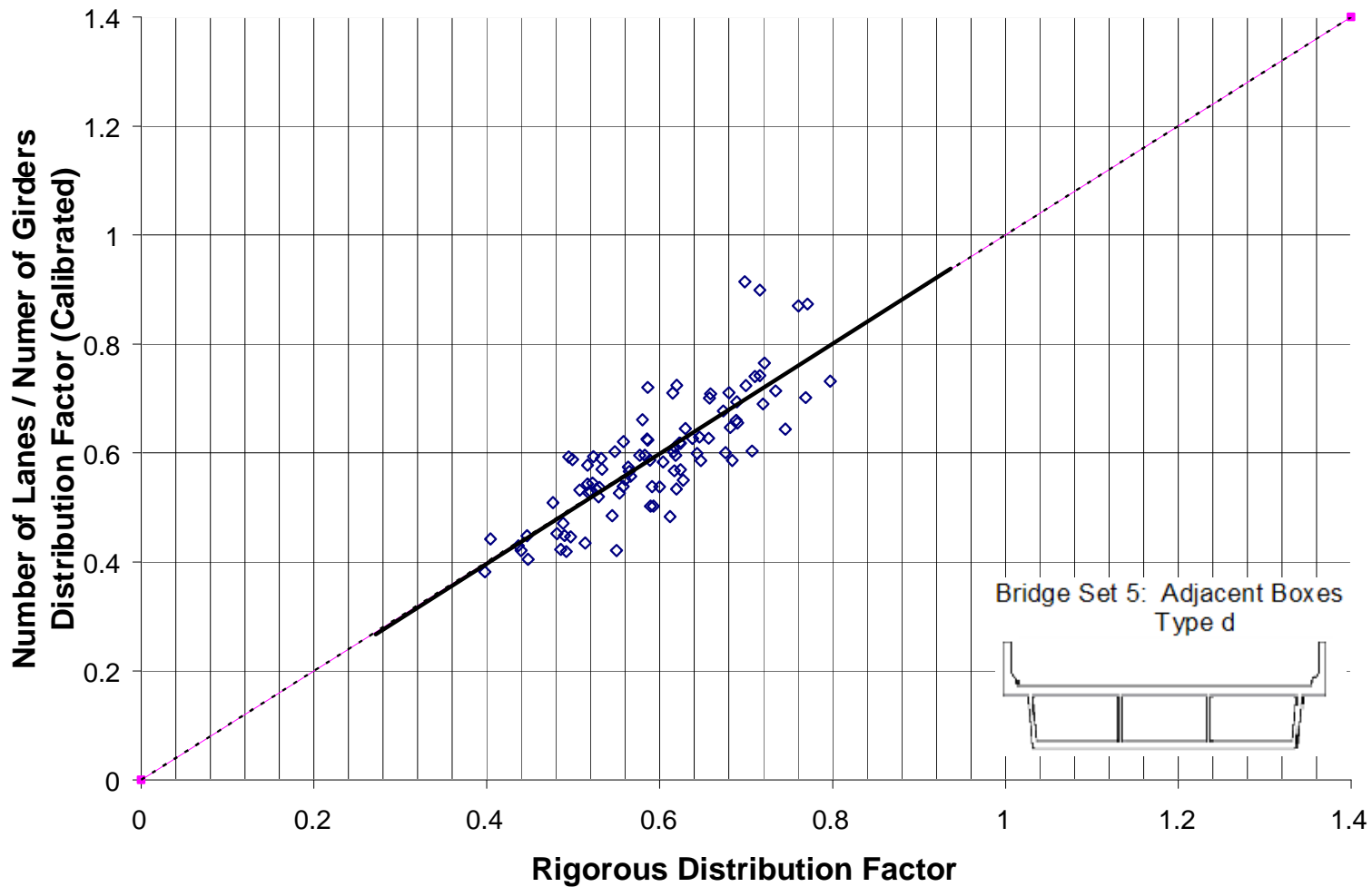


CIP Boxes Moment Interior 2-4 Lanes

$$y = 1.0092x - 0.0072$$

$$R^2 = 0.6711$$

Moment in the Interior Girder, 2 - 4 Lanes Loaded, Location 104.00

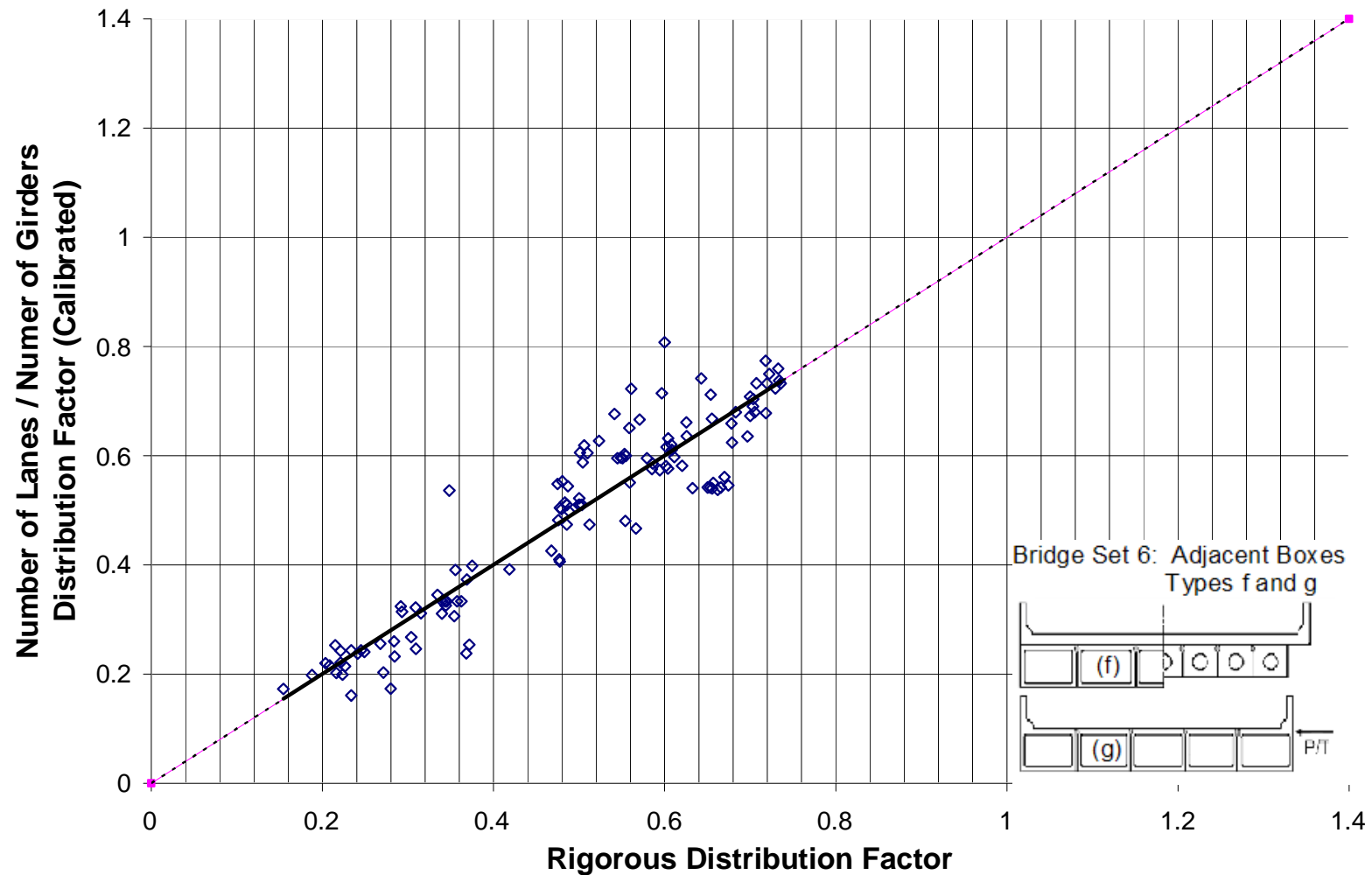


Adjacent Boxes Moment Interior 2-4 Lanes

$$y = 0.9994x + 0.0008$$

$$R^2 = 0.8717$$

Moment in the Interior Girder, 2 - 4 Lanes Loaded, Location 104.00



Canadian Approach



- Perform simple analysis (Lanes = 1, 2, 3, 4 ...)
- Apply multiple presence
- Select critical

Lever Rule Equations (aids)

Girder Location	Number of Loaded Lanes	Distribution Factor	Range of Application	Loading Diagram	Number of Wheels to Beam
Exterior	1	$\frac{1}{2} + \frac{d_e}{2S}$	$(d_e + S) \leq 6 \text{ ft}$ $ d_e < S$		1
		$1 + \frac{d_e}{S} - \frac{3}{S}$	$(d_e + S) > 6 \text{ ft}$		2
	2 or more	$1 + \frac{d_e}{S} - \frac{3}{S}$	$(d_e + S) \leq 10 \text{ ft}$		2
		$\frac{3}{2} + \frac{3d_e}{2S} - \frac{8}{S}$	$10 < (d_e + S) \leq 16 \text{ ft}$		3
		$2 + \frac{2d_e}{S} - \frac{16}{S}$	$16 < (d_e + S) \leq 20 \text{ ft}$		4

Remove Column, T05 felt it was confusing

Calibration Coefficients (Shear)

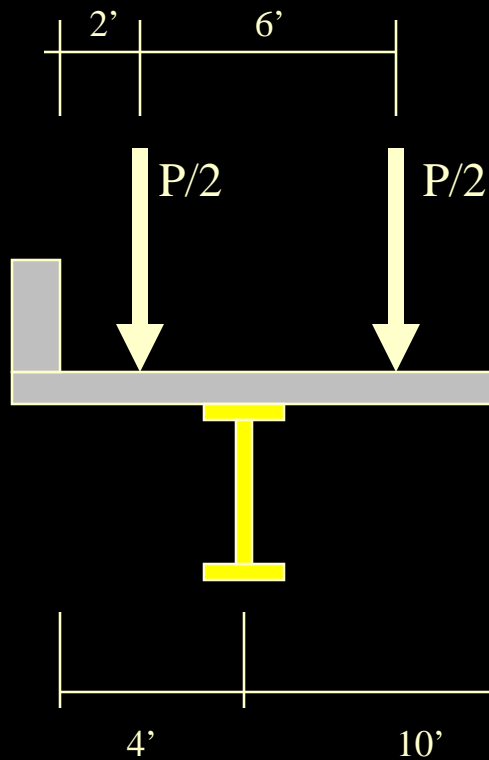
Structure Type	AASHTO LRFD Cross Section Type	Shear							
		Exterior				Interior			
		One Loaded Lane		Two or More Lanes		One Loaded Lane		Two or More Lanes	
		a_v	b_v	a_v	b_v	a_v	b_v	a_v	b_v
		Lever Rule							
Steel I-Beam	a	0.70	0.13	0.83	0.11	1.04	-0.12	0.99	0.01
Precast Concrete I-Beam, Precast Concrete Bulb-Tee Beam, Precast Concrete Tee Section with Shear Keys and with or without Transverse Post-Tensioning, Precast Concrete Double Tee with Shear Keys with or without Post-Tensioning, Precast Concrete Channel with Shear Keys	h, i, j, k	0.83	0.07	0.92	0.06	1.08	-0.13	0.94	0.03
Cast-in-Place Concrete Tee Beam	e	0.79	0.09	0.94	0.05	1.24	-0.22	1.21	-0.17
Cast-in-Place Concrete Multicell Box Beam	d	0.85	0.00	0.82	0.04	1.19	-0.20	0.71	0.23
Adjacent Box Beam with Cast-in-Place Concrete Overlay	f	0.87	0.03	0.91	0.03	1.05	-0.10	1.00	-0.05
Adjacent Box Beam with Integral Concrete	g								
Precast Concrete Spread Box Beam	b, c	0.61	0.15	0.78	0.12	1.00	-0.11	0.83	0.07
Open Steel Box Beam	c	Use Article 4.6.2.2.4							

Calibration Coefficients (Moment)

Structure Type	AASHTO LRFD Cross Section Type	Moment							
		Exterior				Interior			
		One Loaded Lane		Two or More Lanes		One Loaded Lane		Two or More Lanes	
		a_m	b_m	a_m	b_m	a_m	b_m	a_m	b_m
		Lever Rule		Uniform		Lever Rule		Uniform	
Steel I-Beam	a	0.53	0.19	1.14	-0.12	0.97	-0.24	1.18	-0.10
Precast Concrete I-Beam, Precast Concrete Bulb-Tee Beam, Precast Concrete Tee Section with Shear Keys and with or without Transverse Post-Tensioning, Precast Concrete Double Tee with Shear Keys with or without Post-Tensioning, Precast Concrete Channel with Shear Keys	h, i, j, k	0.68	0.14	1.25	-0.20	1.33	-0.41	1.23	-0.12
Cast-in-Place Concrete Tee Beam	e	0.65	0.15	1.11	-0.14	1.40	-0.41	1.14	-0.05
Cast-in-Place Concrete Multicell Box Beam								0.93	-0.10
Adjacent Box Beam with Concrete Overlay								0.83	-0.01
Adjacent Box Beam with Concrete									
Precast Concrete Spread Box Beam	b, c	0.62	-0.08	1.00	-0.06	0.77	-0.17	0.79	0.11
Open Steel Box Beam	c	Use Article 4.6.2.2.4							

$$M_g M_m = M \left[a_m (g_{\text{lever rule}}) + b_m \right] \geq M \left[\frac{N_I}{N_E} \right]$$

Example



$$R_{\text{exterior}} = \left(\frac{P}{2}\right)\left(\frac{6}{10}\right) + \left(\frac{P}{2}\right)\left(\frac{12}{10}\right) = 0.9P$$

$$g_{\text{Lever Rule}} = 0.9$$

$$g_{\text{Calibrated}} = a_m g_{\text{Lever Rule}} + b_m = 0.53(0.9) + 0.19$$

$$g_{\text{Calibrated}} = 0.67$$

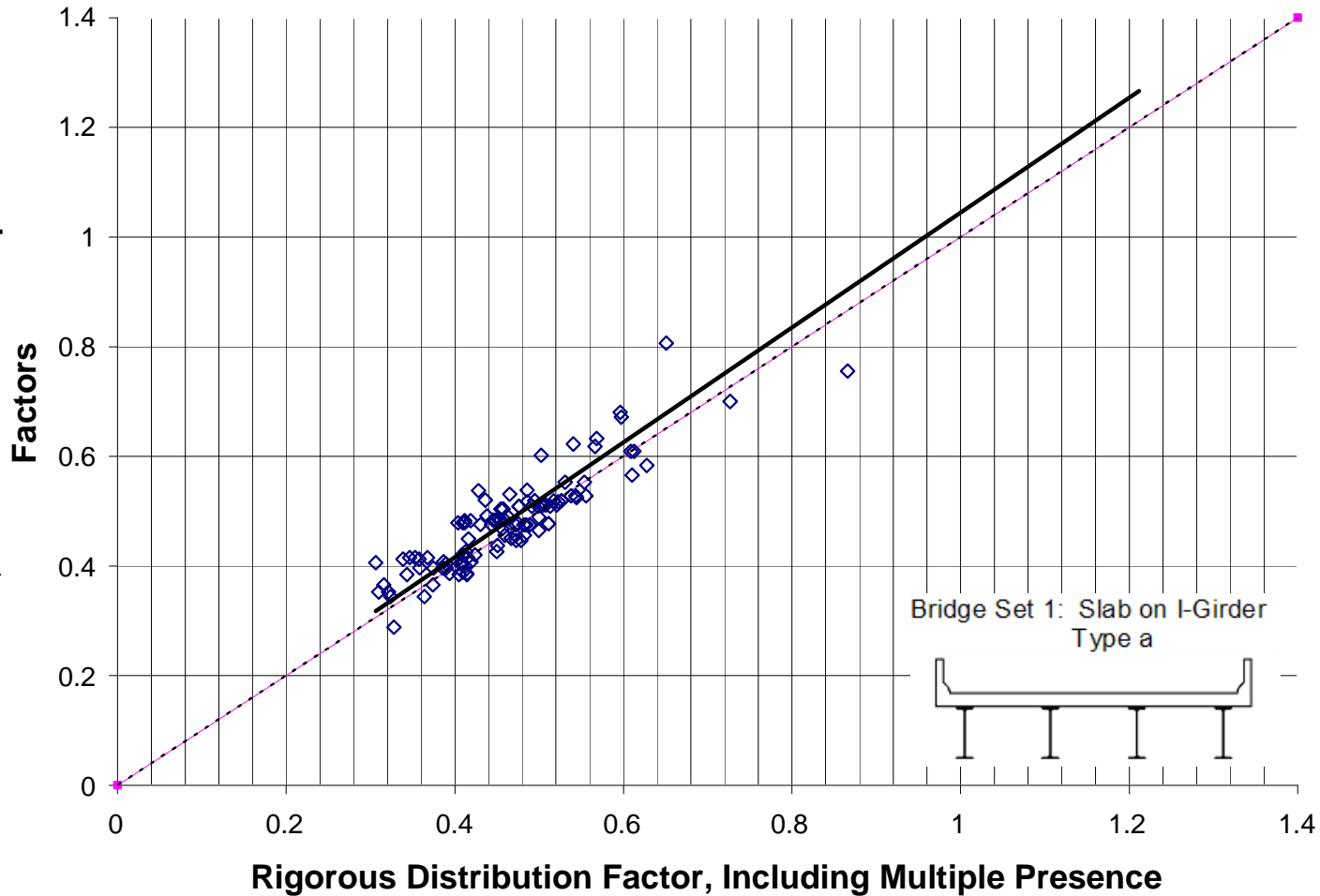
Exterior One-Lane Moment

$$y = 1.0477x - 0.0032$$

$$R^2 = 0.8727$$

Moment in the Exterior Girder, 1 Lane Loaded, Location 104.00

Proposed LRFD Specification Distribution Factor, Including Calibration, Multiple Presence, and Distribution Simplification

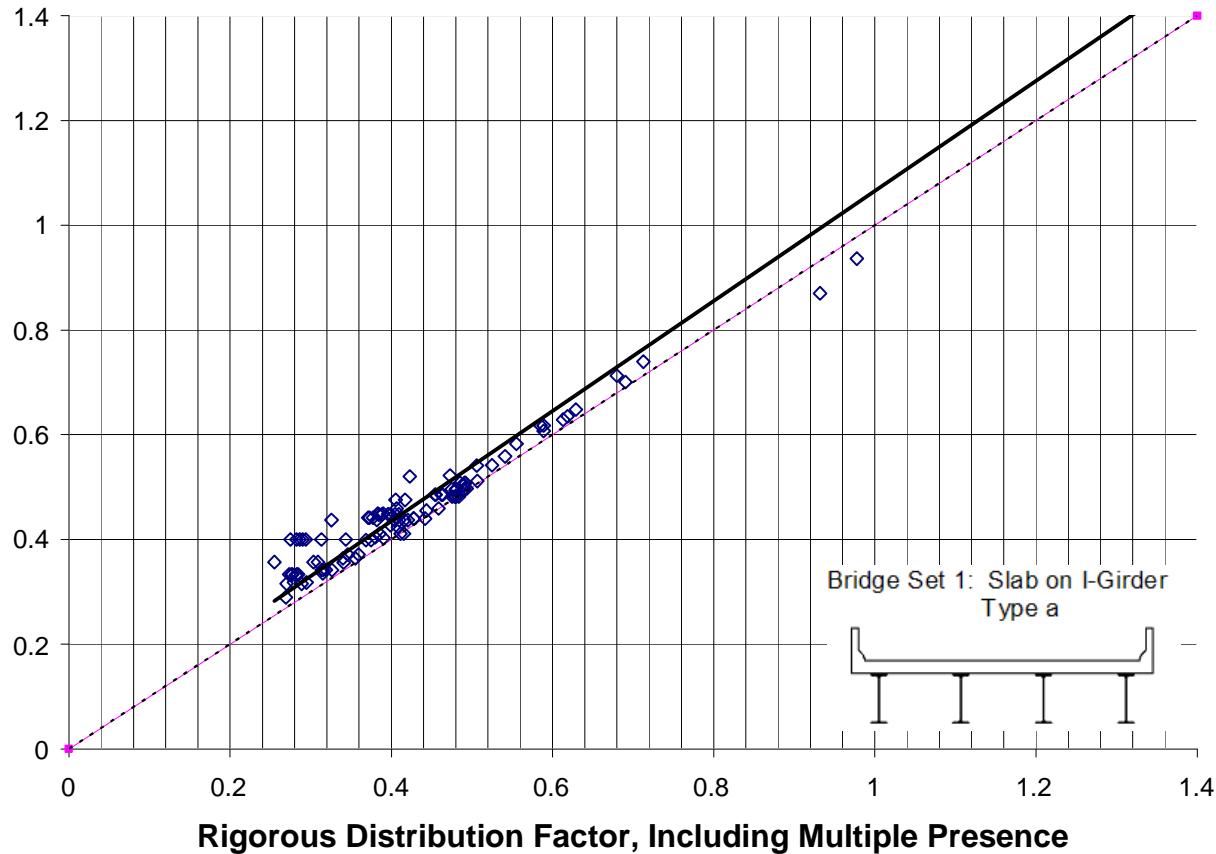


Shear Exterior Two Lanes

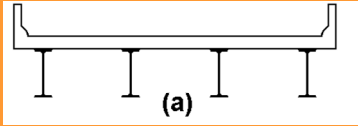
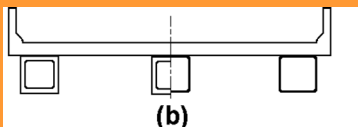
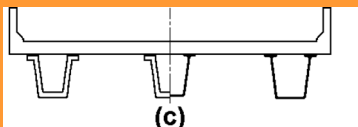
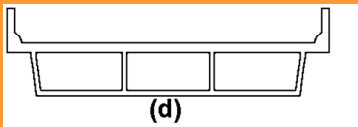
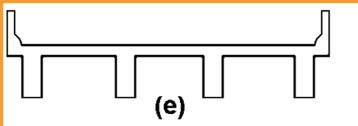
$$y = 1.051x + 0.0145$$
$$R^2 = 0.9581$$

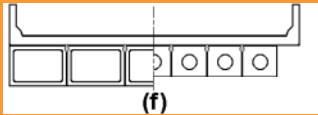
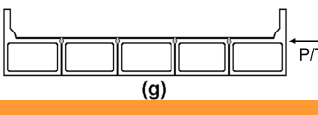
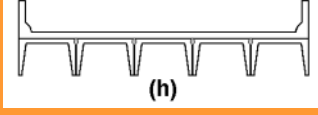
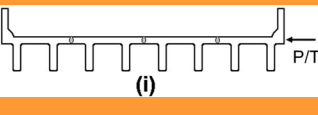
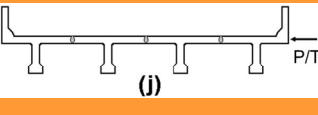
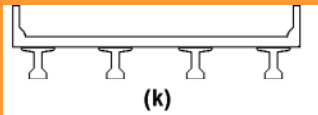
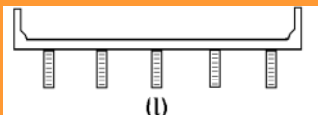
Shear in the Exterior Girder, 2 Lanes Loaded, Location 100.00

Proposed LRFD Specification Distribution Factor, Including Calibration, Multiple Presence, and Distribution Simplification Factors

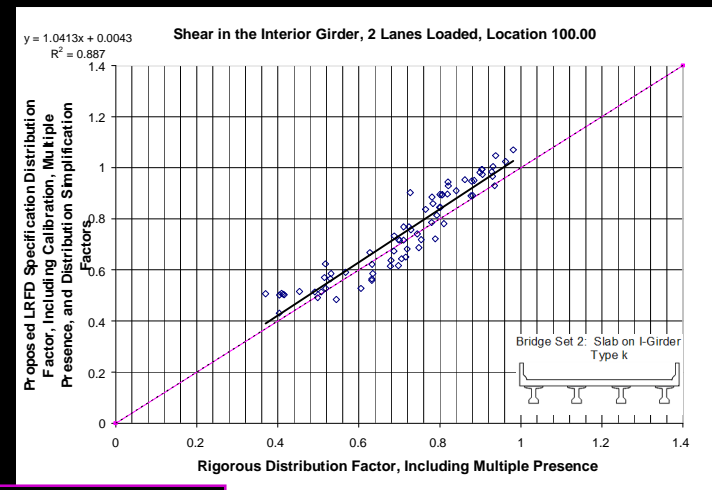
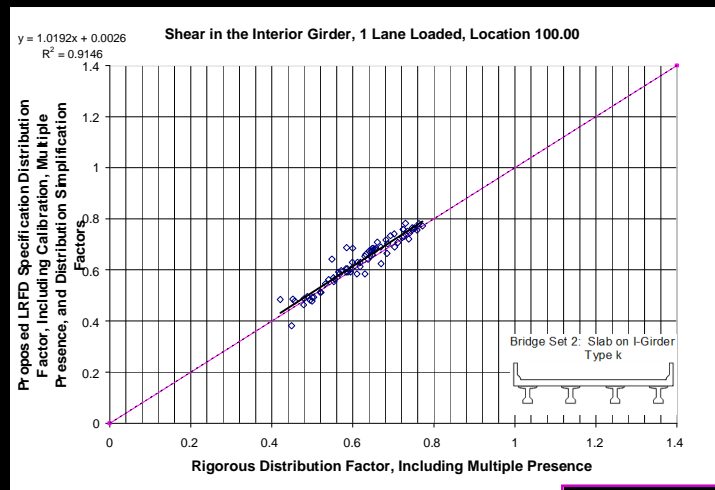


Different Bridge Types

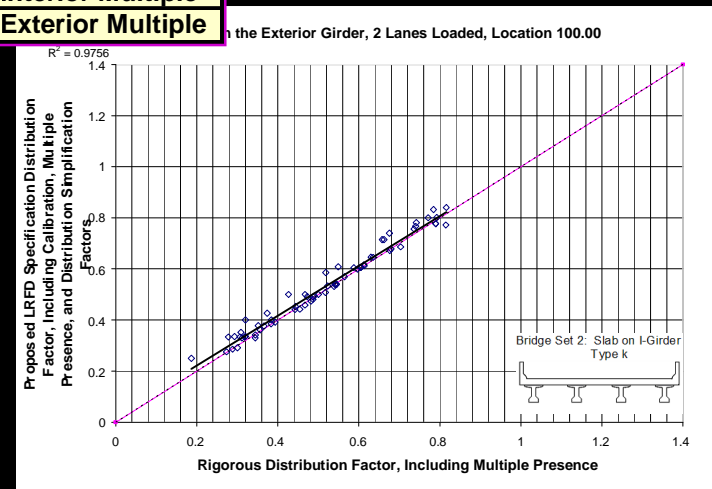
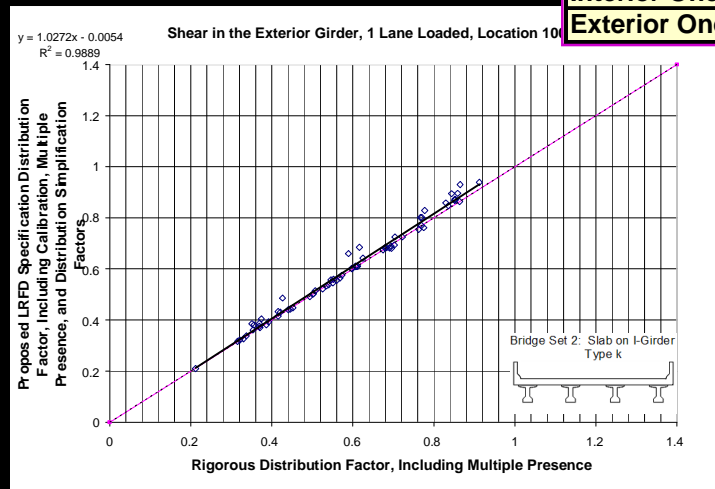
SUPPORTING COMPONENTS	TYPE OF DECK	TYPICAL CROSS-SECTION
Steel Beam	Cast-in-place concrete slab, precast concrete slab, steel grid, glued/spiked panels, stressed wood	
Closed Steel or Precast Concrete Boxes	Cast-in-place concrete slab	
Open Steel or Precast Concrete Boxes	Cast-in-place concrete slab, precast concrete deck slab	
Cast-in-Place Concrete Multicell Box	Monolithic concrete	
Cast-in-Place Concrete Tee Beam	Monolithic concrete	

Precast Solid, Voided or Cellular Concrete Boxes with Shear Keys	Cast-in-place structural concrete overlay	
Precast Solid, Voided, or Cellular Concrete Box with Shear Keys and with or without Transverse Post-Tensioning	Integral concrete	
Precast Concrete Channel Sections with Shear Keys	Cast-in-place structural concrete overlay	
Precast Concrete Double Tee Section with Shear Keys and with or without Transverse Post-Tensioning	Integral concrete	
Precast Concrete Tee Section with Shear Keys and with or without Transverse Post-Tensioning	Integral concrete	
Precast Concrete I or Bulb-Tee Sections	Cast-in-place concrete, precast concrete	
Wood Beams	Cast-in-place concrete or plank, glued/spiked panels or stressed wood	

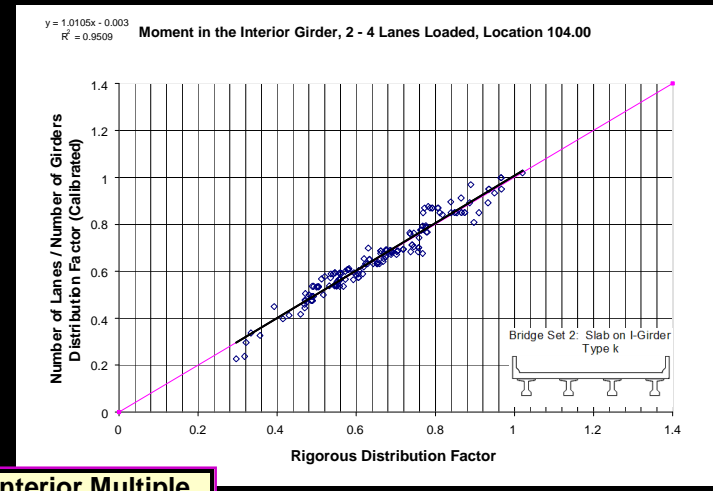
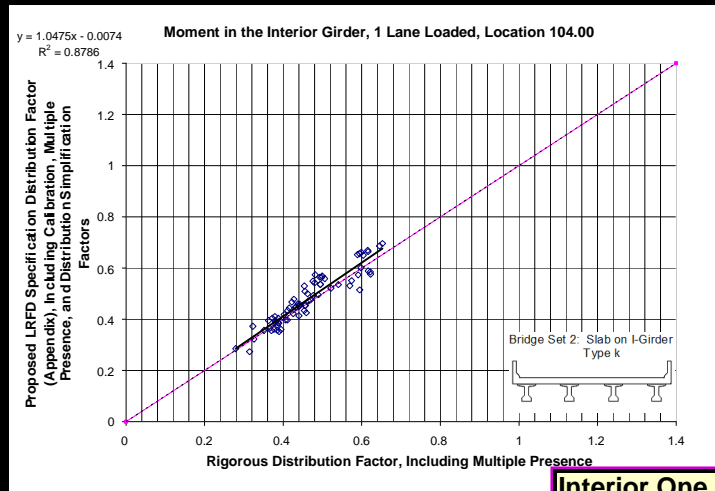
Concrete I Section Shear



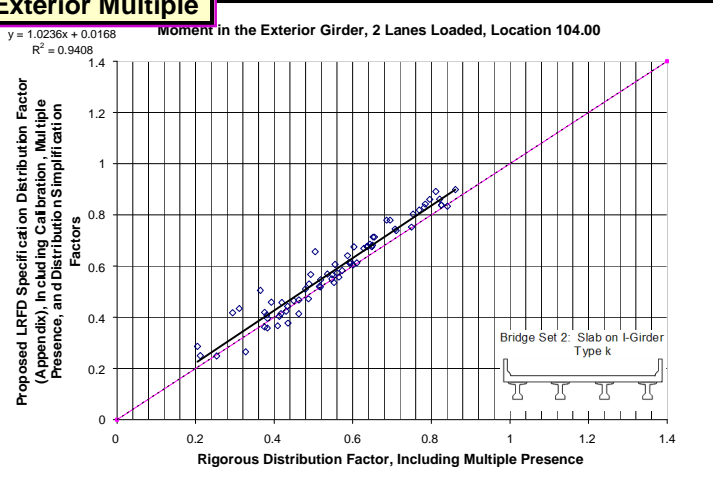
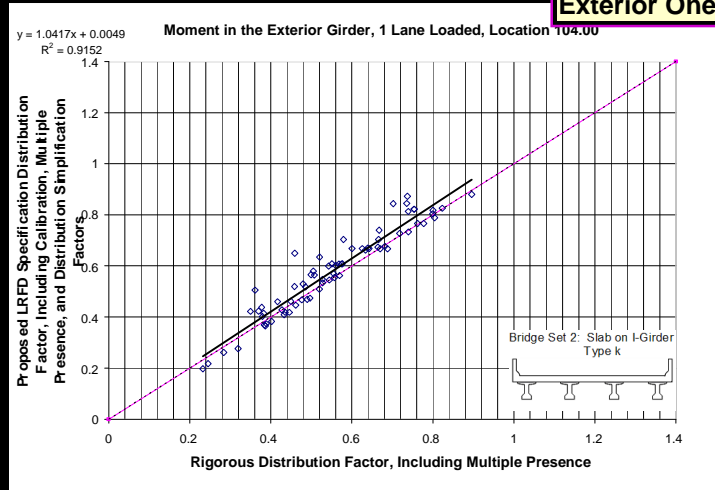
Interior One	Interior Multiple
Exterior One	Exterior Multiple



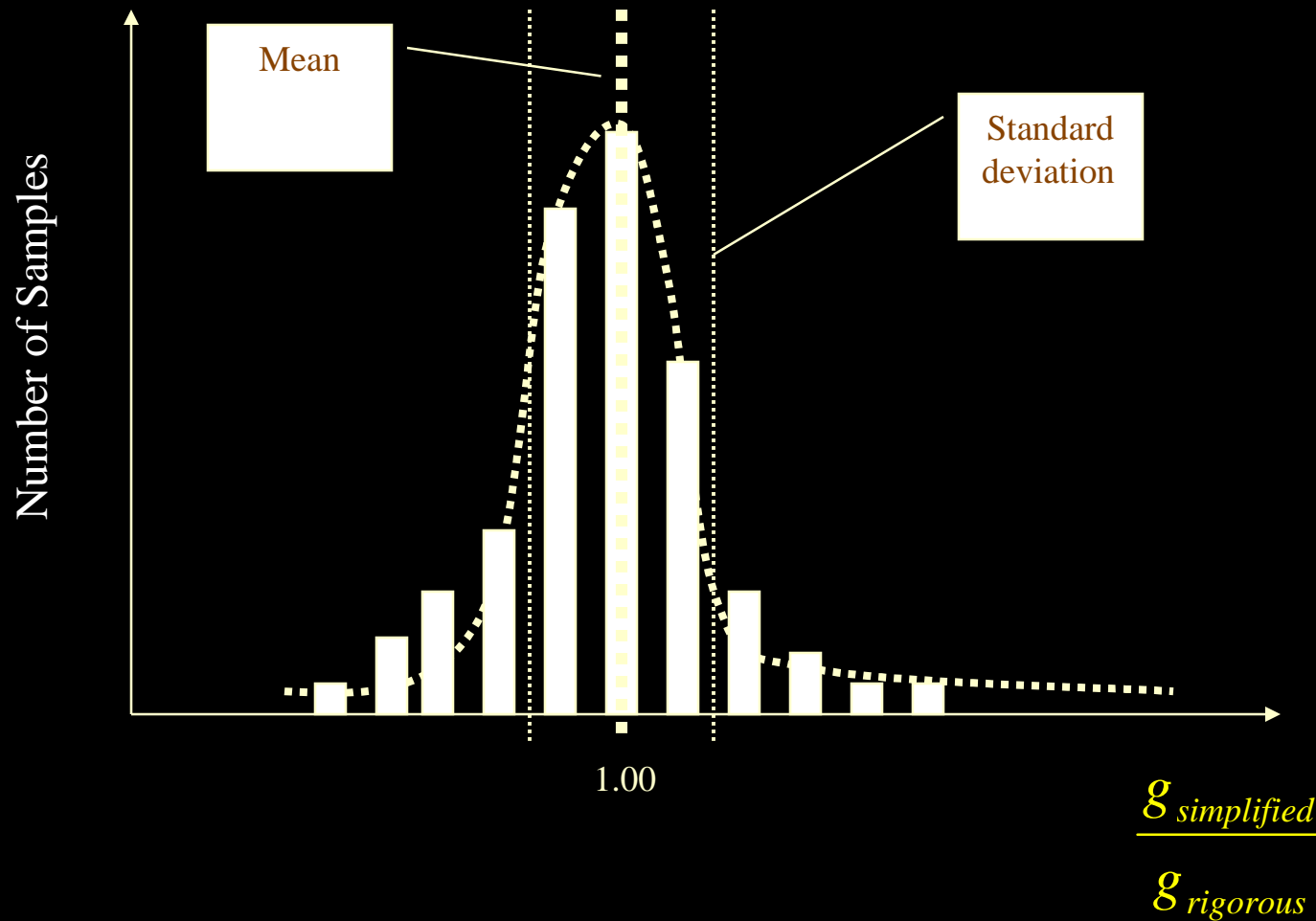
Concrete I Section Moment



Interior One
Interior Multiple
Exterior One
Exterior Multiple



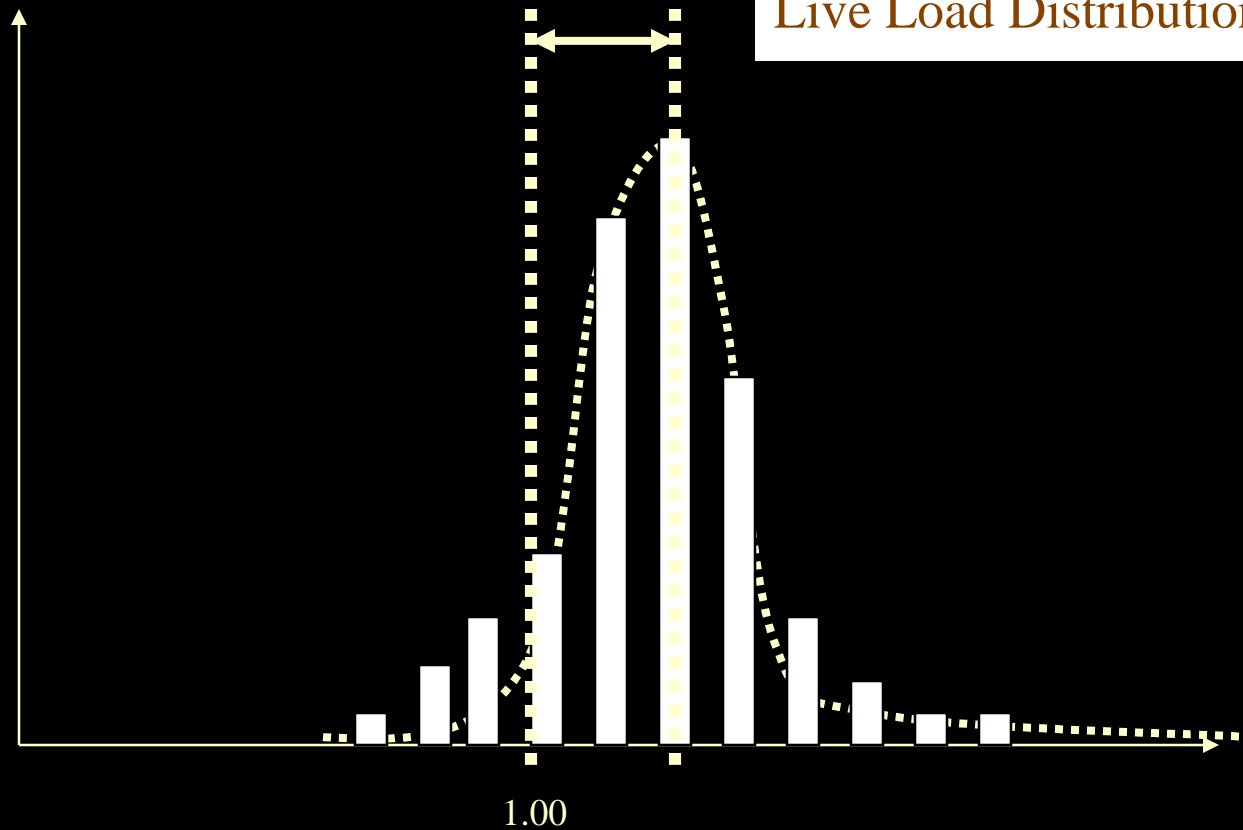
Statistical Comparison Conceptual



Shift Simple Upward by a factor

Increase by a factor that is related to the COV

Live Load Distribution Simplification = γ_s



Simple / Rigorous

Analysis Simplification Factors, γ_s

Structure Type	AASHTO LRFD Cross Section Type	Action	Exterior		Interior	
			One-lane	Two or more lanes	One-lane	Two or more lanes
Steel I-Beam	a	Shear	1.02	1.02	1.02	1.04
		Moment	1.04	1.07	1.11	1.05
Precast Concrete I-Beam, Precast Concrete Bulb-Tee Beam, Precast Concrete Tee Section with Shear Keys and with or without Transverse Post-Tensioning, Precast Concrete Double Tee with Shear Keys with or without Post-Tensioning, Precast Concrete Channel with Shear Keys	h, k, i, j	Shear	1.03	1.02	1.02	1.04
		Moment	1.04	1.10	1.08	1.01
Cast-in-Place Concrete Tee Beam	e	Shear	1.03	1.03	1.05	1.08
		Moment	1.02	1.05	1.13	1.05
Cast-in-Place Concrete Multicell Box	d	Shear	1.05	1.02	1.04	1.03
		Moment	1.17	1.04	1.18	1.06
Precast Concrete Spread Box Beam	b, c	Shear	1.02	1.03	1.03	1.03
		Moment	1.14	1.04	1.08	1.05
Adjacent Box Beam with Cast-in-Place Concrete Overlay, Adjacent Box Beam with Integral Concrete	f, g	Shear	1.03	1.06	1.15	1.10
		Moment	1.15	1.10	1.21	1.08
Open Steel Box Beam	c	Shear	1.00	1.00	1.00	1.00
		Moment	1.00	1.00	1.00	1.00

Example Continued

$$R_{\text{exterior}} = \left(\frac{P}{2}\right)\left(\frac{6}{10}\right) + \left(\frac{P}{2}\right)\left(\frac{12}{10}\right) = 0.9P$$

$$g_{\text{Lever Rule}} = 0.9$$

$$g_{\text{Calibrated}} = a_m g_{\text{Lever Rule}} + b_m = 0.53(0.9) + 0.19$$

$$g_{\text{Calibrated}} = 0.67$$

Previous
Example

$$g_{\text{Calibrated}} = g = 0.67$$

$$\gamma_a mg = 1.02(1.2)(0.67)$$

$$\gamma_a mg = 0.82$$

All effects are now separated and understandable

$$\gamma_s mg = 1.02 (1.2) (0.67)$$

$$\gamma_s mg = 0.82$$

Analysis

Effect of Multiple Presence

Variability in analysis

Skew Adjustment

- Load effect increases for shear
- Load effect decreases for moment

Skew

- Adjustments for shear
- No iteration
- Commentary M&M 20-07 Study (shear adjustment spatial variation)
- Neglect decrease for moment

Re-entered in Rev 1 of
Agenda

Skew Simplification (shear and reactions)

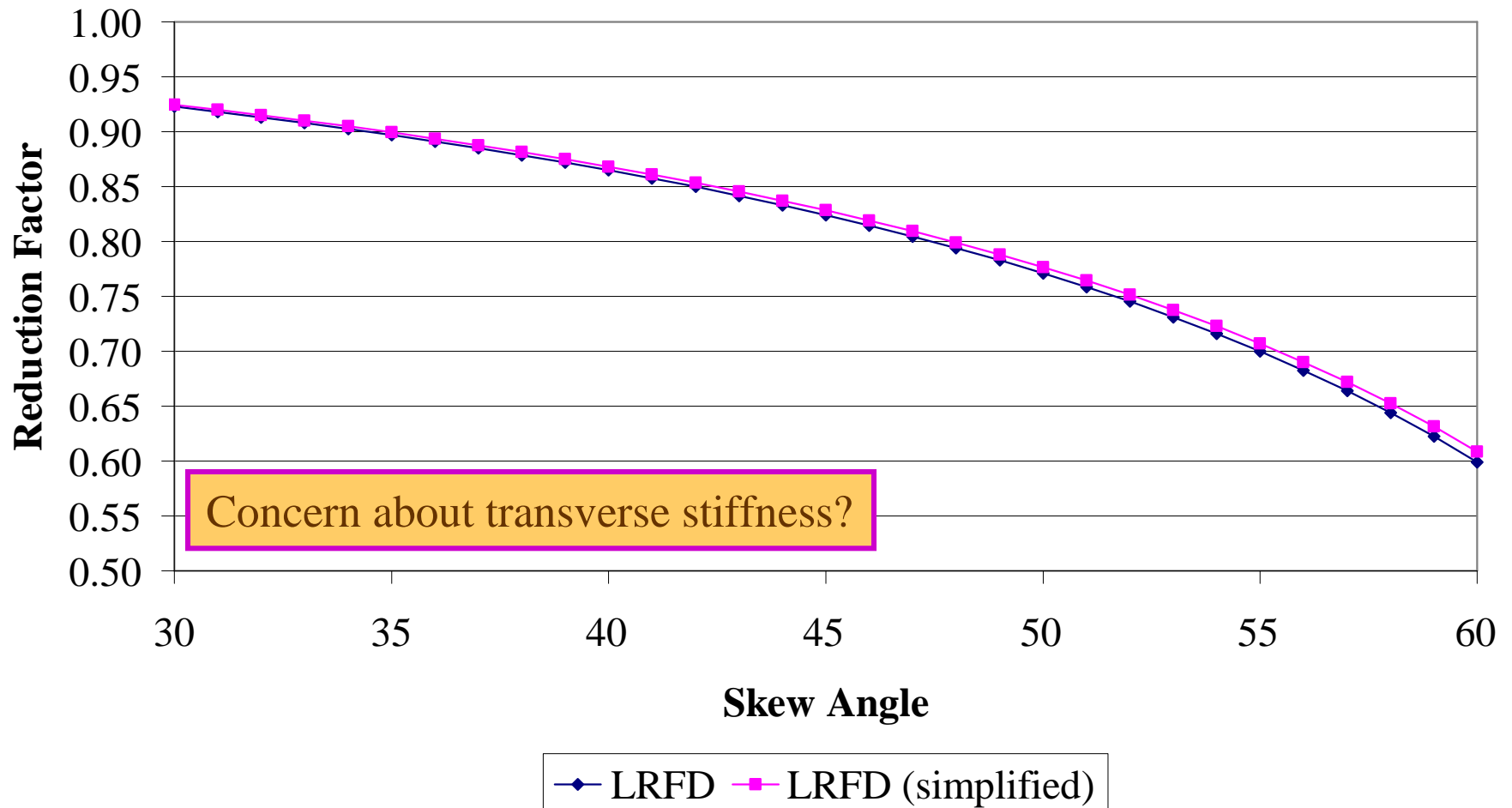
Type of Superstructure	Applicable Cross-Section from Table 4.6.2.2.1-1	Skew Adjustment Factor	Range of Applicability
Concrete Deck, Filled Grid, Partially Filled Grid, or Unfilled Grid Deck Composite with Reinforced Concrete Slab on Steel Beams; Concrete T-Beams, T- and Double T-Section	a, e, k and also i, j if sufficiently connected to act as a unit	$1.0 + 0.20 \tan \theta$	$0^\circ \leq \theta \leq 60^\circ$ $3.5 \leq S \leq 16.0$ $20 \leq L \leq 240$ $N_b \geq 4$
Precast Concrete I, Bulb Tee Beams, and Precast channel sections with Shear Keys	h, k	$1.0 + 0.09 \tan \theta$	$0^\circ \leq \theta \leq 60^\circ$ $3.5 \leq S \leq 16.0$ $20 \leq L \leq 240$ $N_b \geq 4$
Cast-in-Place Concrete Multicell Box	d	$1.0 + \left(0.25 + \frac{12.0L}{70d}\right) \tan \theta$	$0^\circ < \theta \leq 60^\circ$ $6.0 < S \leq 13.0$ $20 \leq L \leq 240$ $35 \leq d \leq 110$ $N_c \geq 3$
Concrete Deck on Spread Concrete Box Beams	b, c	$1.0 + \frac{\sqrt{\frac{Ld}{12.0}}}{6S} \tan \theta$	$0^\circ < \theta \leq 60^\circ$ $6.0 \leq S \leq 11.5$ $20 \leq L \leq 140$ $18 \leq d \leq 65$ $N_b \geq 3$
Concrete Box Beams Used in Multibeam Decks	f, g	$1.0 + \frac{12.0L}{90d} \sqrt{\tan \theta}$	$0^\circ < \theta \leq 60^\circ$ $20 \leq L \leq 120$ $17 \leq d \leq 60$ $35 \leq b \leq 60$ $5 \leq N_b \leq 20$

$$\left[\frac{K_g}{12Lt_s^3} \right]$$

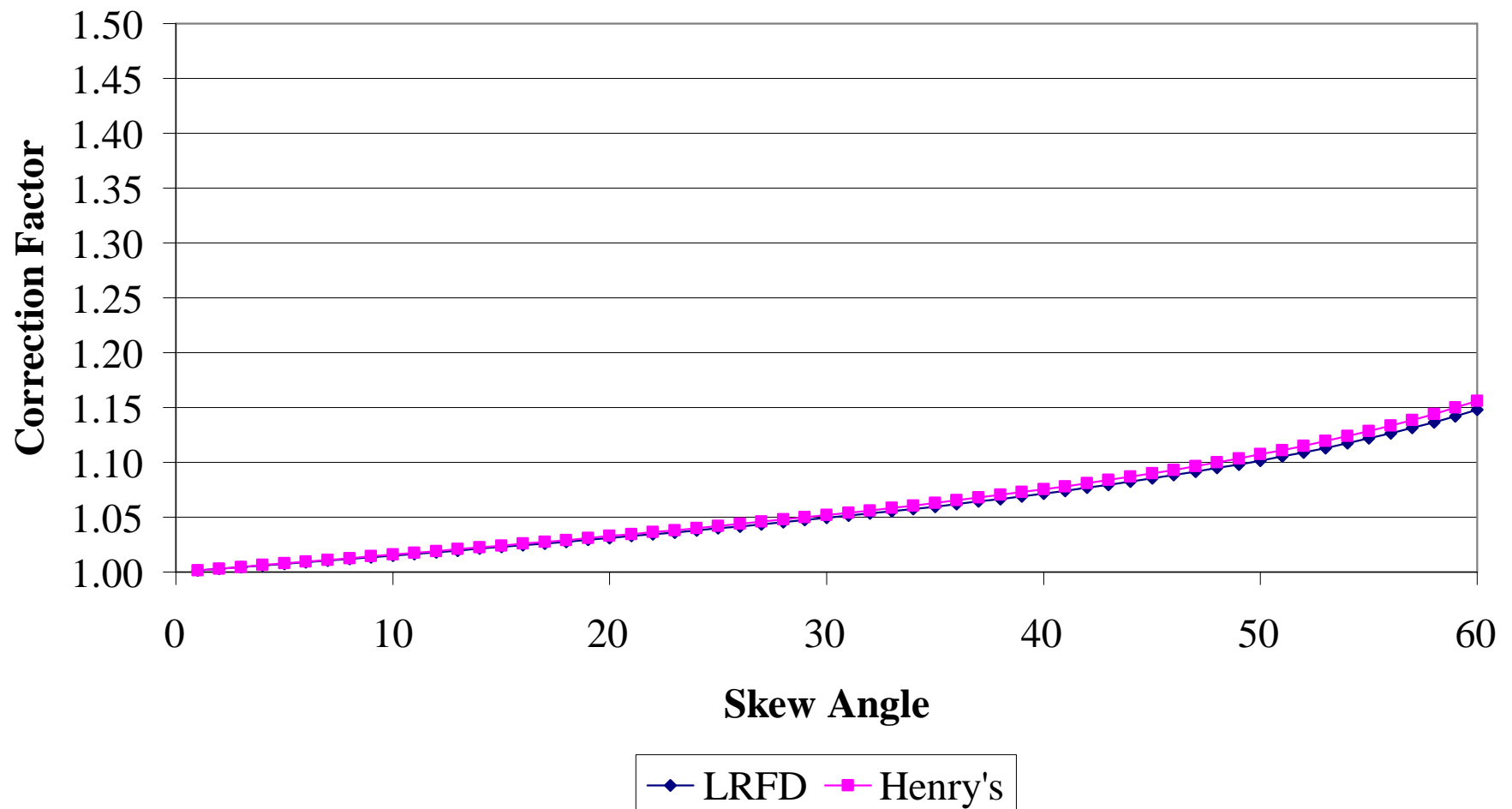
Skew Simplification (moment)

Type of Superstructure	Applicable Cross-Section from Table 4.6.2.2.1-1	Skew Adjustment Factor	Range of Applicability
Concrete Deck, Filled Grid, Partially Filled Grid, or Unfilled Grid Deck Composite with Reinforced Concrete Slab on Steel Beams; Concrete T-Beams, T- and Double T-Section	a, e, k and also i, j if sufficiently connected to act as a unit	$1 - c_1 (\tan \theta)^{1.5}$ $c_1 = 0.25 \left(\frac{S}{L} \right)^{0.5}$ <p>If $\theta < 30^\circ$ then $c_1 = 0.0$ If $\theta > 60^\circ$ use $\theta = 60^\circ$</p>	$30^\circ \leq \theta \leq 60^\circ$ $3.5 \leq S \leq 16.0$ $20 \leq L \leq 240$ $N_b \geq 4$
Precast Concrete I, Bulb Tee Beams, and Precast channel sections with Shear Keys	h, k	$1 - c_1 (\tan \theta)^{1.5}$ $c_1 = 0.50 \left(\frac{S}{L} \right)^{0.5}$ <p>If $\theta < 30^\circ$ then $c_1 = 0.0$ If $\theta > 60^\circ$ use $\theta = 60^\circ$</p>	$30^\circ \leq \theta \leq 60^\circ$ $3.5 \leq S \leq 16.0$ $20 \leq L \leq 240$ $N_b \geq 4$
Concrete Deck on Concrete Spread Box Beams, Cast-in-Place Multicell Box Concrete Box Beams and Double T-Sections used in Multibeam Decks	b, c, d, f, g	$1.05 - 0.25 \tan \theta \leq 1.0$ <p>If $\theta > 60^\circ$ use $\theta = 60^\circ$</p>	$0^\circ \leq \theta \leq 60^\circ$

Reduction of Load Distribution Factors for Moment (Type "k" bridges)



Correction Factors for Load Distribution Factors for Shear (Type "k" bridges)



Skew Adjustment

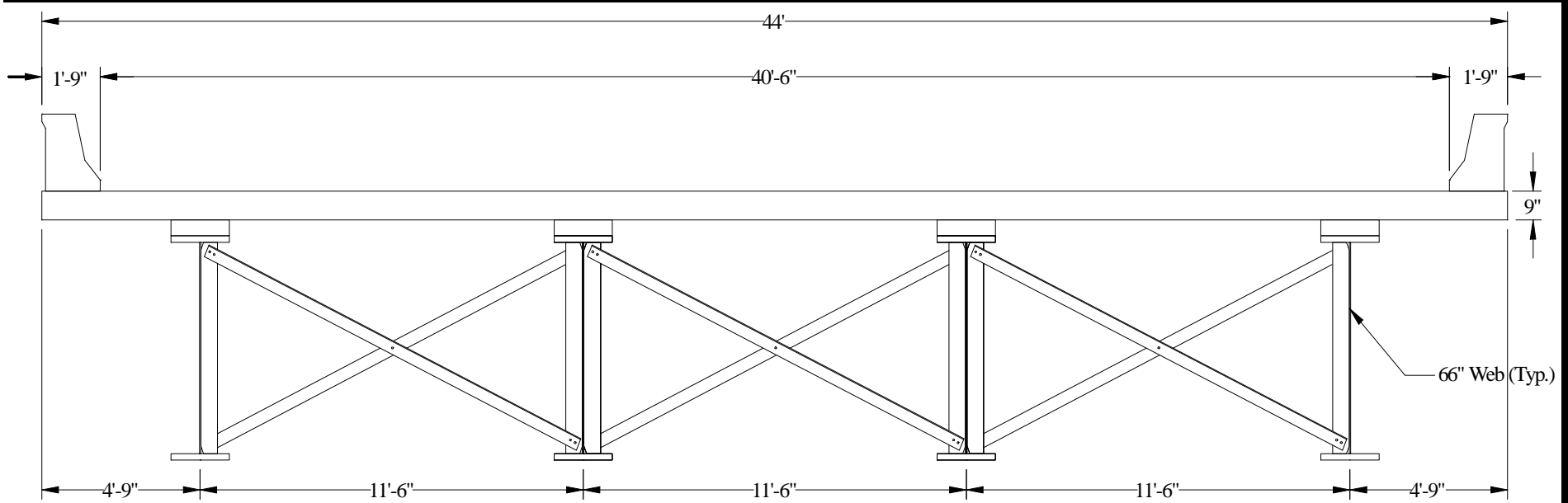
➤ Shear

- Increases load effect
- Intermediate diaphragms and cross frames are *necessary* to achieve behavior
- Must include this effect

➤ Moment

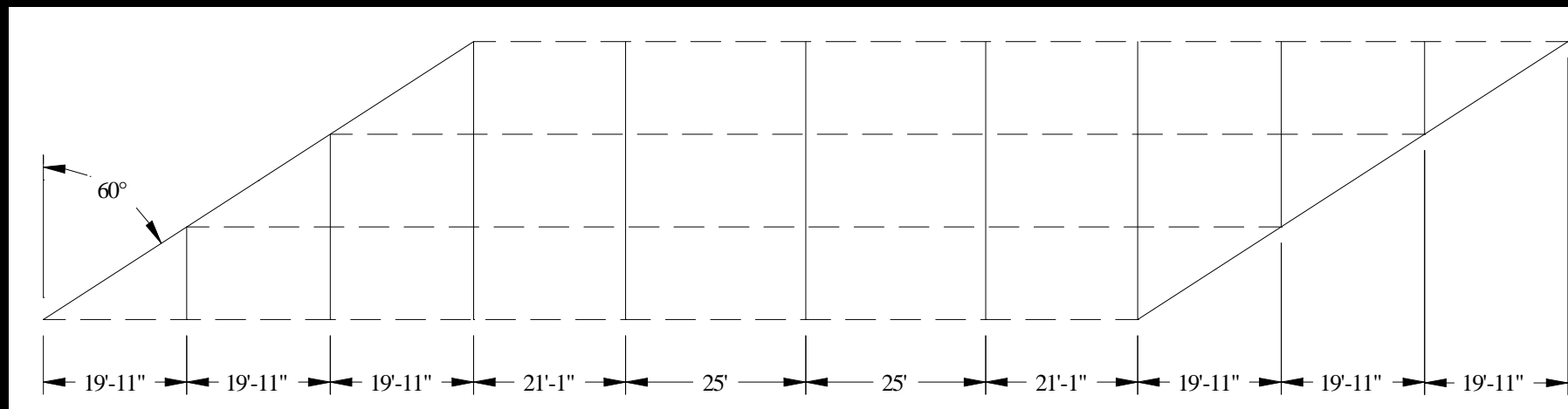
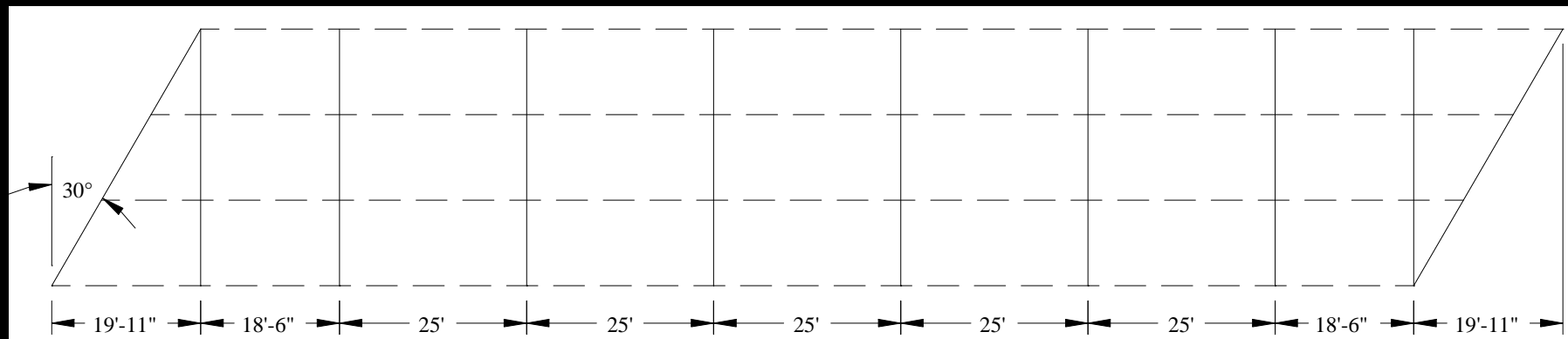
- Decreases load effect
- *Sufficient* transverse stiffness is required
- Initially removed from specification
- Included in rev. 1 (submitted last week)

Diaphragm Stiffness Study

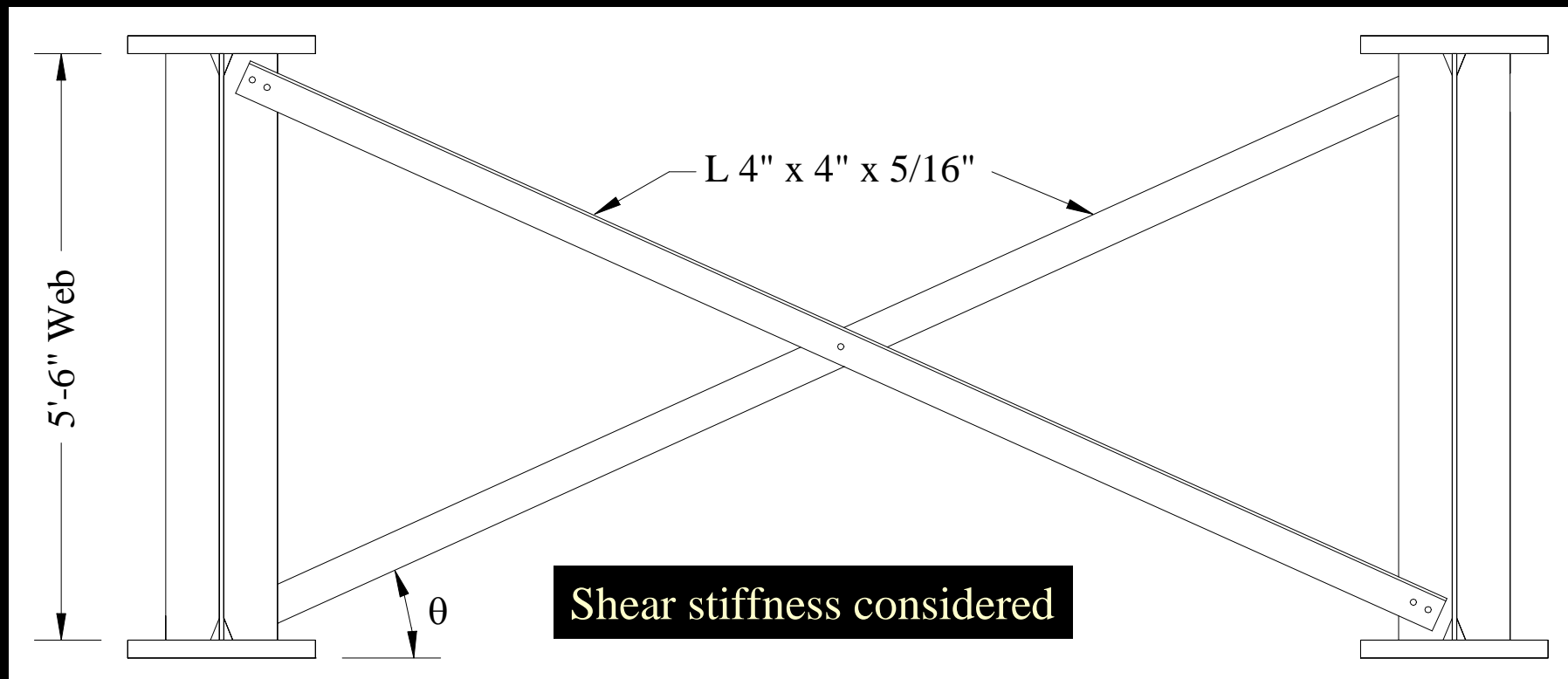


Span Length = 2 x 153

Typical Framing Plan



Stiffness of Cross Frame



$$k_e = 2 \left(\frac{AE}{L} \right) \sin^2 \theta$$

$$k_e = 2 \left(\frac{(2.4 \text{ in}^2)(29000 \text{ ksi})}{(12.75 \text{ ft}) \left(12 \frac{\text{in}}{\text{ft}} \right)} \right) \sin^2 (25.6^\circ) = 170 \frac{\text{k}}{\text{in}}$$

Skew Adjustment Results

Steel Plate Girder Bridge				
Four steel plate girders, two spans at 152 ft., spacing 11'-6"				
Skew, deg.	Diaphragm Stiffness	Moment	Ratio	Reference
0	Zero, no diaphragms	1213	1.00	Table L-18, Figure L-139
30		1185	0.98	
60		1117	0.92	
0	Actual Estimate K = 170 k/in	~ no change	1.00	Figure L-157
30			0.98	
60			0.92	
0	Rigid	1130	1.00	Figure L-175
30		885	0.78	
60		800	0.71	

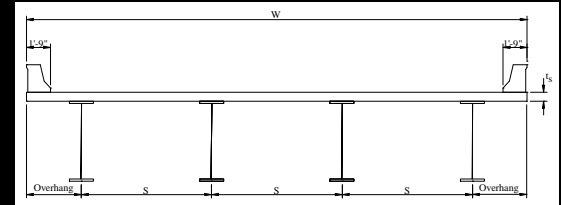
Findings

- Need *sufficient* transverse stiffness for moment decrease to be achieved
- Estimated frame stiffness was not sufficient
- Rigid is illustrates behavior
- More study is required on quantification of required stiffness
- Aside -- CSA suggested *appropriate* analysis

Curvature

- No change

Push-the-limits bridges



Bridge No.	Girder Spacing, S (ft)	Recommended minimum slab thickness (AASHTO STD Table 8.9.2)	Slab Thickness, t_s (in)	Span Length, L (ft)	Total Bridge Width, W (ft)	No. of girders	Overhang (ft)
1	12	8.80	9.00	240	44	4	4
2	12	8.80	9.00	260	44	4	4
3	12	8.80	9.00	280	44	4	4
4	12	8.80	9.00	300	44	4	4
5	12	8.80	9.00	200	44	4	4
6	14	9.60	9.75	200	48	4	3
7	16	10.40	10.50	200	54	4	3
8	18	11.20	11.25	200	60	4	3
9	20	12.00	12.00	200	68	4	4
10	12	8.80	9.00	160	58	5	5
11	12	8.80	9.00	160	53	4	8.5

Many Parameter Studies

➤ Skew

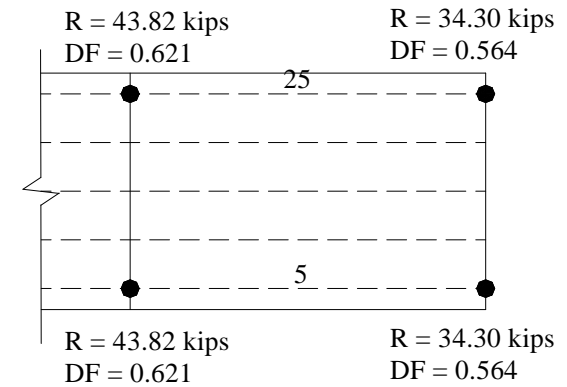
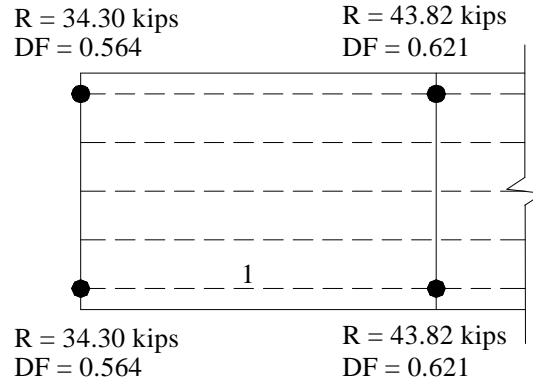
- Diaphragm Cross-frame Stiffness
- End Cross-frames
- Intermediate Cross-frames

➤ Typical Example

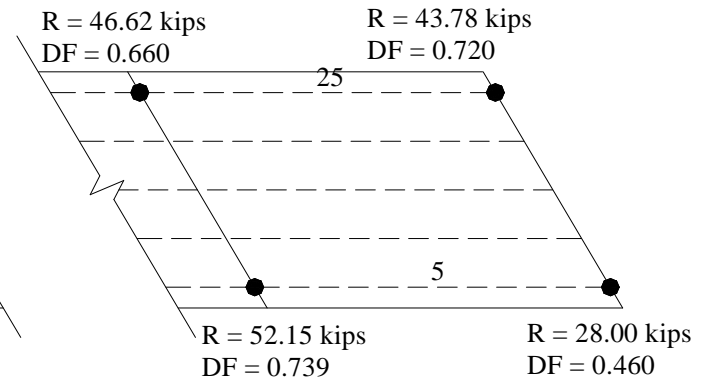
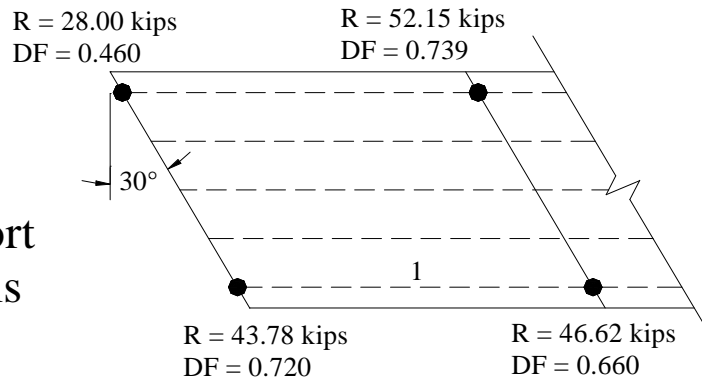
Span 1

Span 5

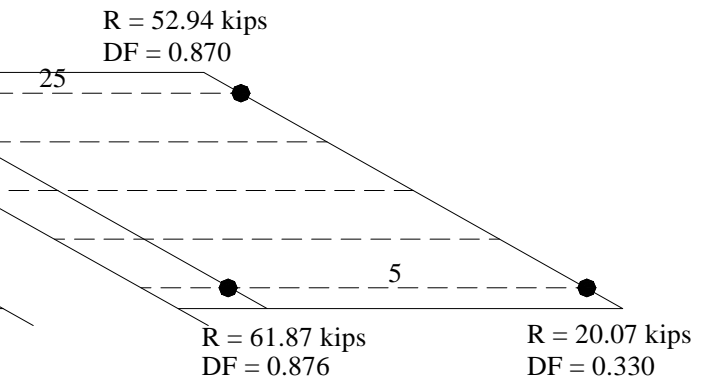
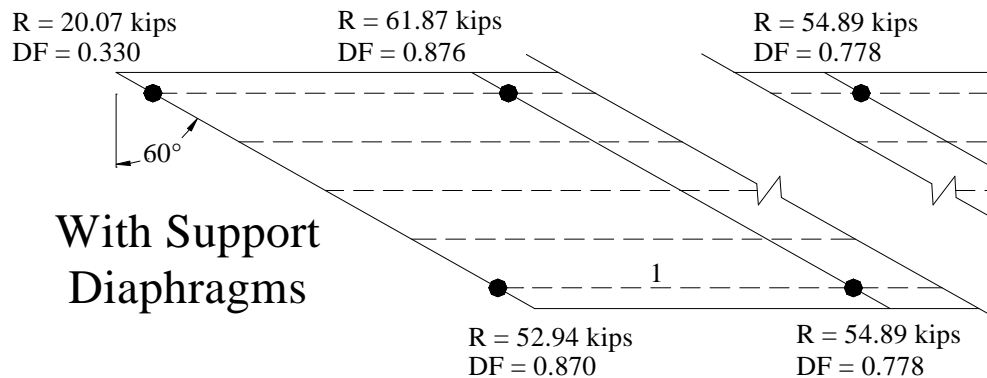
With Support Diaphragms



With Support Diaphragms



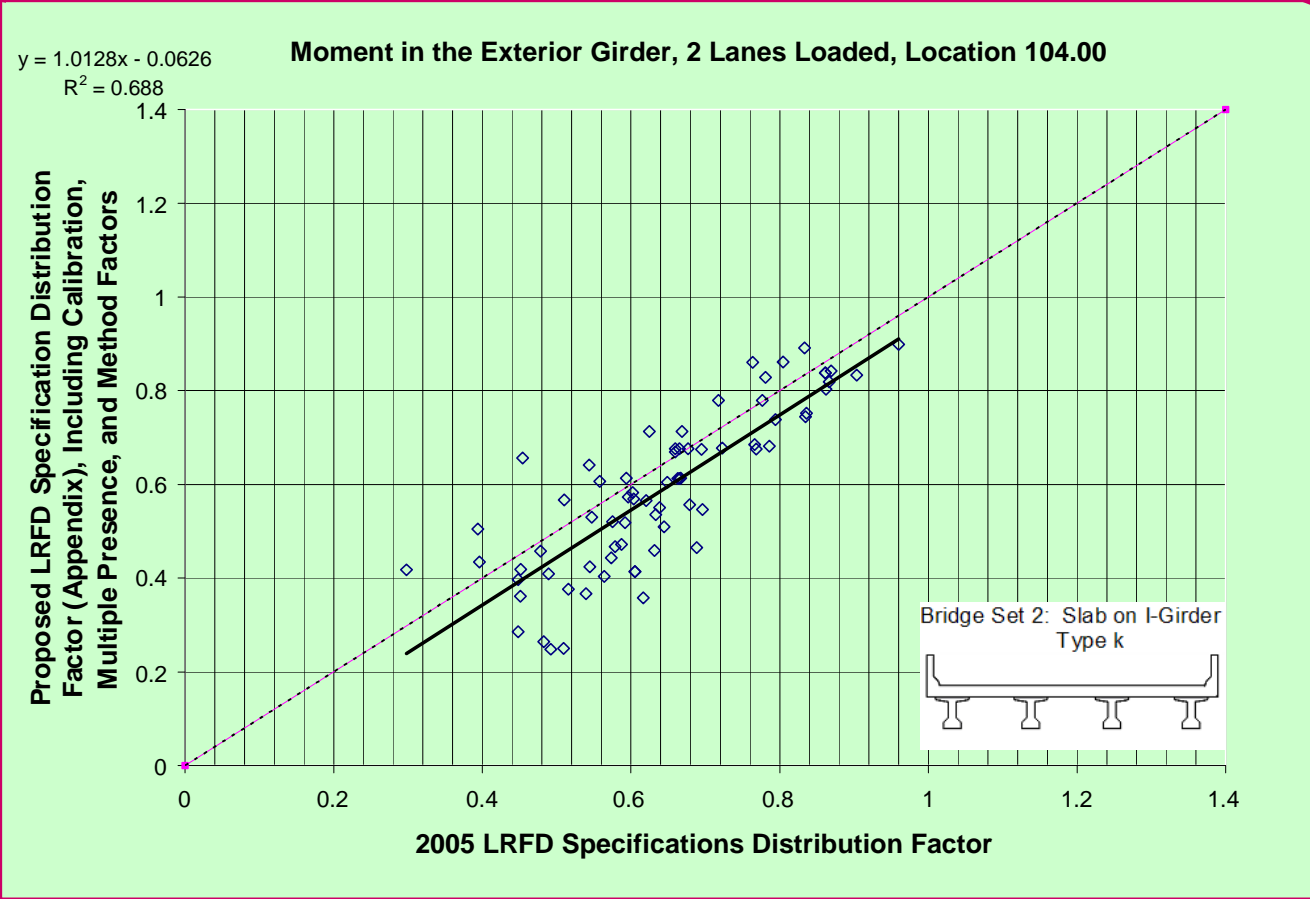
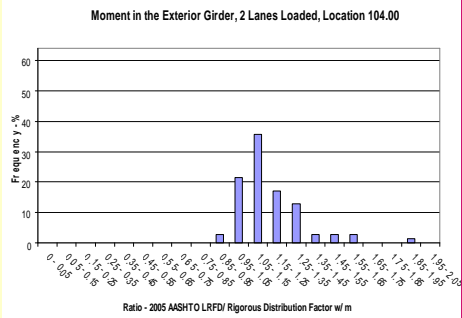
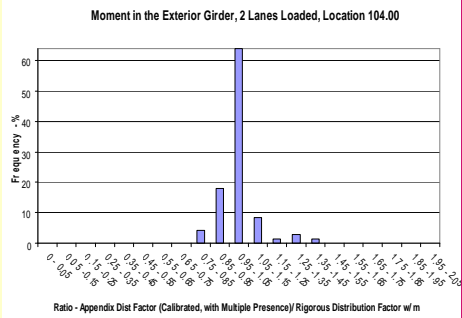
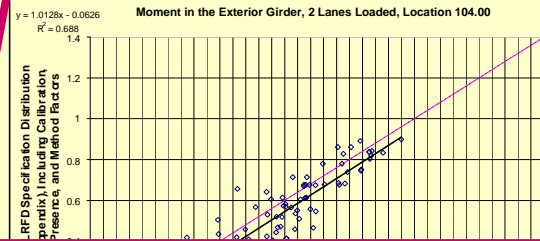
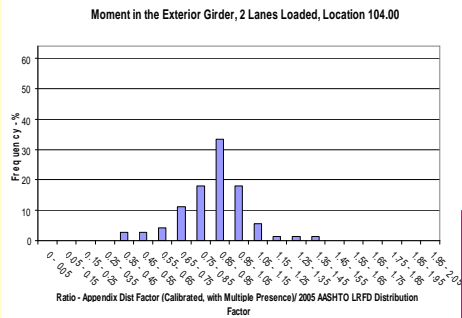
With Support Diaphragms



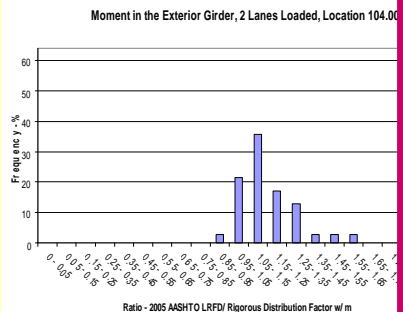
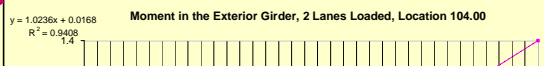
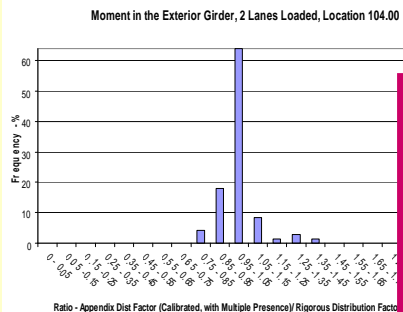
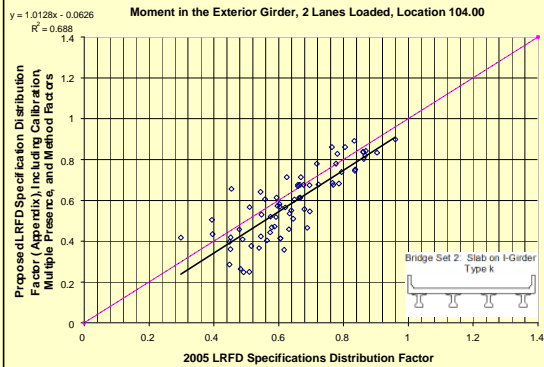
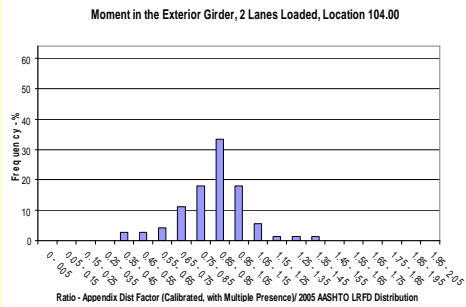
Regression Testing

Complete database used to compare:

- LRFD
- S/D
- Rigorous
- Again, used 12-50



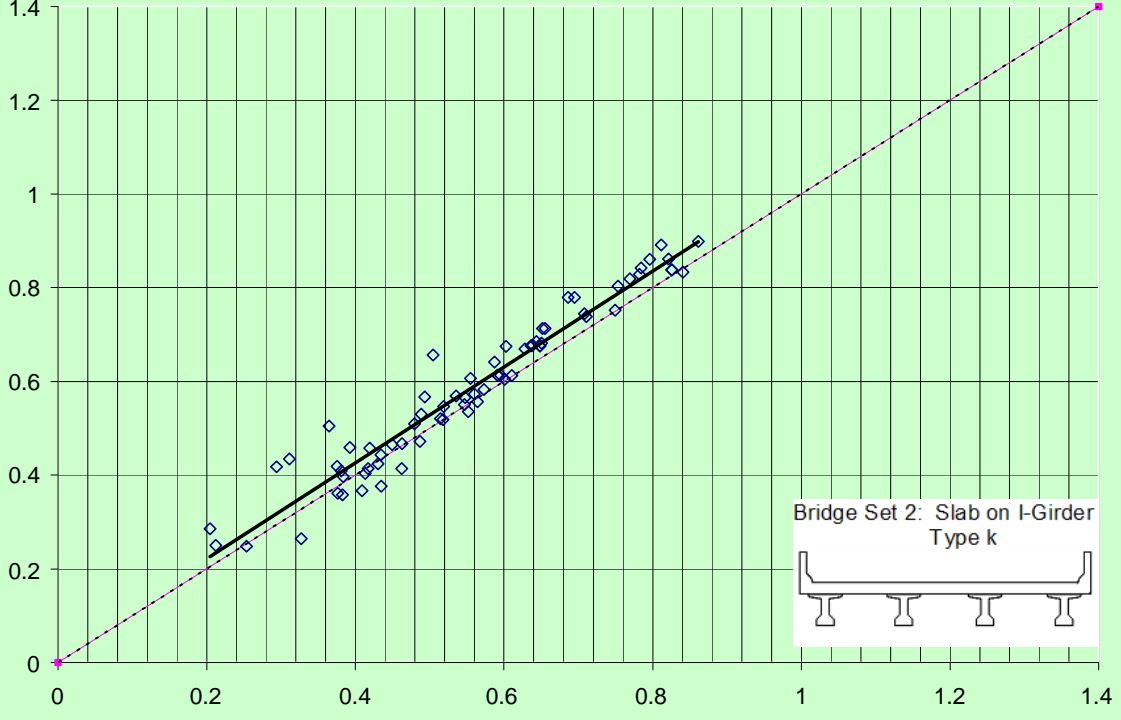
Statistic	Methods Compared		
	Appendix Dist Factor (Calibrated, with Multiple Presence)/2005 AASHTO LRFD	Appendix Dist Factor (Calibrated, with Multiple Presence)/Rigorous with multiple presence	2005 AASHTO LRFD/Rigorous with multiple presence
Average	0.87	1.00	1.20
Standard Deviation	0.18	0.10	0.26
Coefficient of Variation	20.77%	9.78%	21.29%
Count	72	72	72



$y = 1.0236x + 0.0168$
 $R^2 = 0.9408$

Moment in the Exterior Girder, 2 Lanes Loaded, Location 104.00

Proposed LRFD Specification Distribution Factor (Appendix), Including Calibration, Multiple Presence, and Method Factors



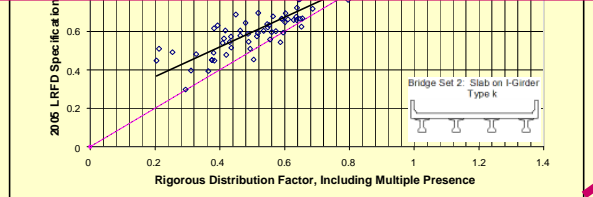
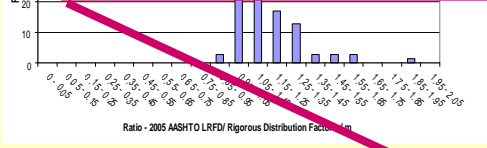
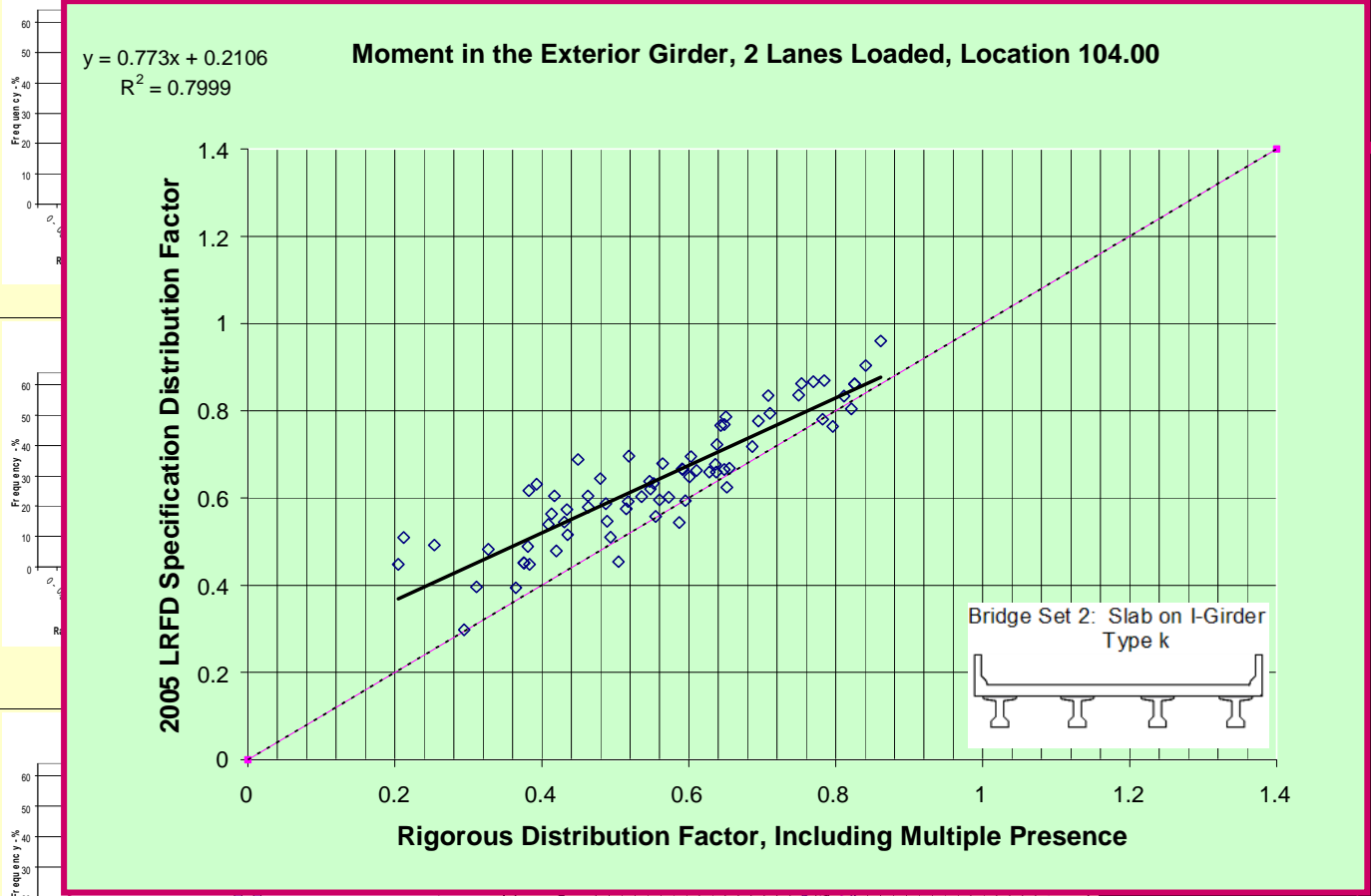
Statistic	Appendix Dist Factor (Calibrated, with Multiple Presence)/2005 AASHTO LRFD
Average	0.87
Standard Deviation	0.18
Coefficient of Variation	20.77%
Count	72

Moment in the Exterior Girder, 2 Lanes Loaded, Location 104.00

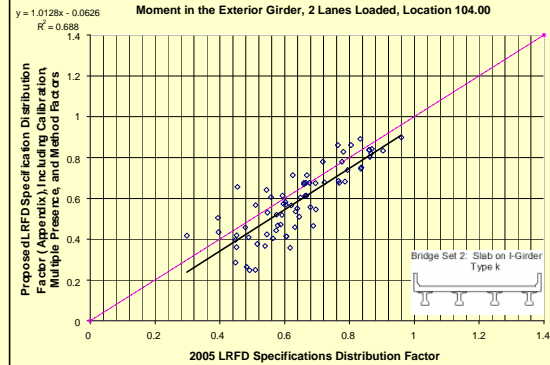
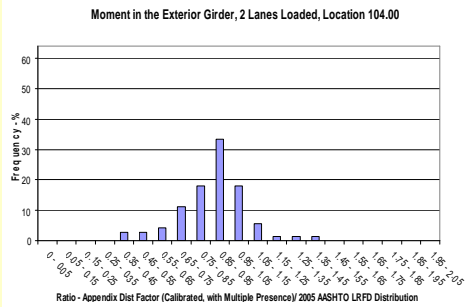
Moment in the Exterior Girder, 2 Lanes Loaded, Location 104.00
 $y = 1.0128x - 0.0626$
 $R^2 = 0.688$
 1.4

$y = 0.773x + 0.2106$
 $R^2 = 0.7999$

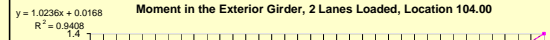
Moment in the Exterior Girder, 2 Lanes Loaded, Location 104.00



Statistic	Methods Compared		
	Appendix Dist Factor (Calibrated, with Multiple Presence)/2005 AASHTO LRFD	Appendix Dist Factor (Calibrated, with Multiple Presence)/Rigorous with multiple presence	2005 AASHTO LRFD/Rigorous with multiple presence
Average	0.87	1.00	1.20
Standard Deviation	0.18	0.10	0.26
Coefficient of Variation	20.77%	9.78%	21.29%
Count	72	72	72

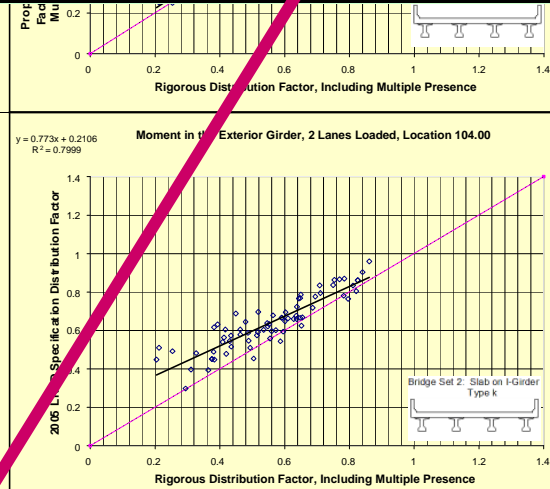
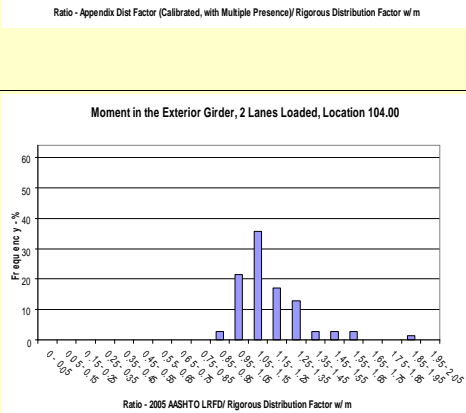


Moment in the Exterior Girder, 2 Lanes Loaded, Location 104.00



Methods Compared

Statistic	Appendix Dist Factor (Calibrated, with Multiple Presence)/2005 AASHTO LRFD	Appendix Dist Factor (Calibrated, with Multiple Presence)/Rigorous with multiple presence	2005 AASHTO LRFD/Rigorous with multiple presence
Average	0.87	1.00	1.20
Standard Deviation	0.18	0.10	0.26
Coefficient of Variation	20.77%	9.78%	21.29%
Count	72	72	72



Statistic	Appendix Dist Factor (Calibrated, with Multiple Presence)/2005 AASHTO LRFD	Appendix Dist Factor (Calibrated, with Multiple Presence)/Rigorous with multiple presence	2005 AASHTO LRFD/Rigorous with multiple presence
Average	0.87	1.00	1.20
Standard Deviation	0.18	0.10	0.26
Coefficient of Variation	20.77%	9.78%	21.29%
Count	72	72	72

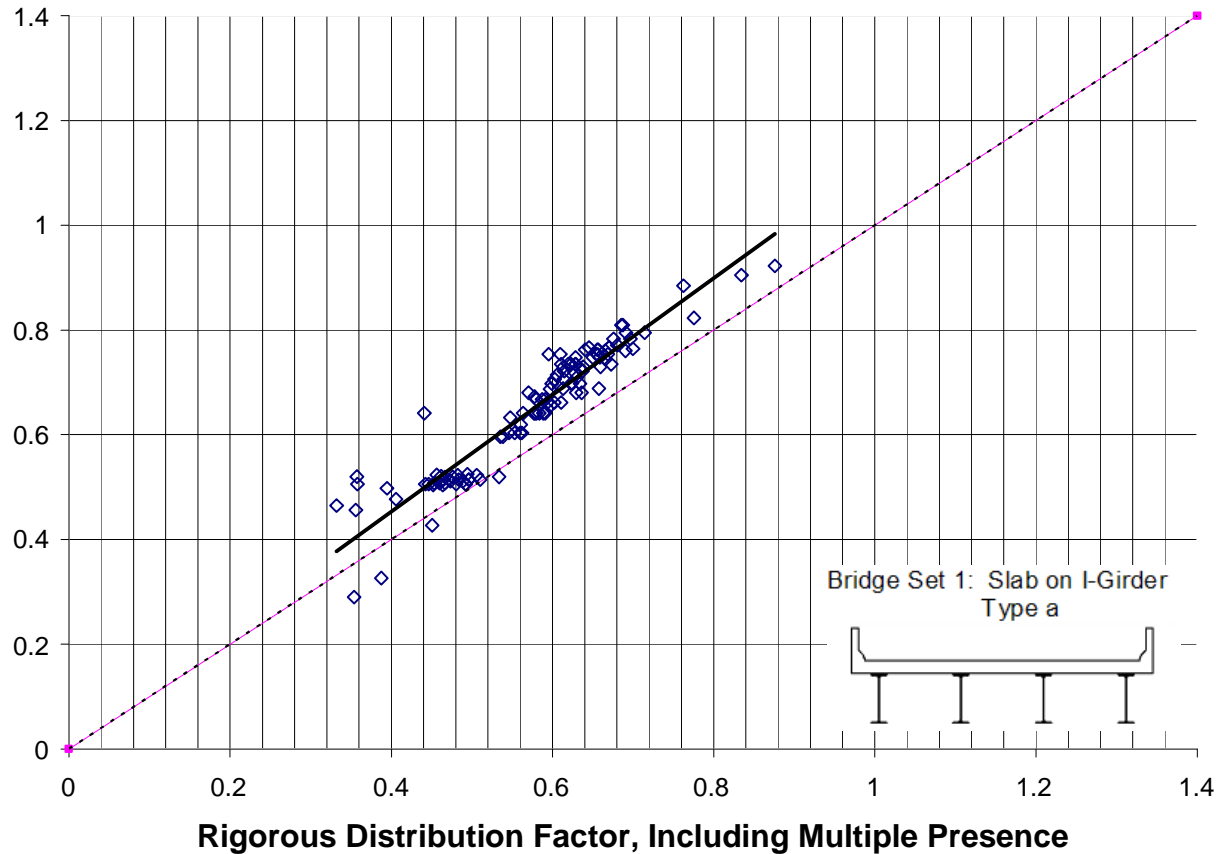
Shear Interior One Lane

$$y = 1.115x + 0.0066$$

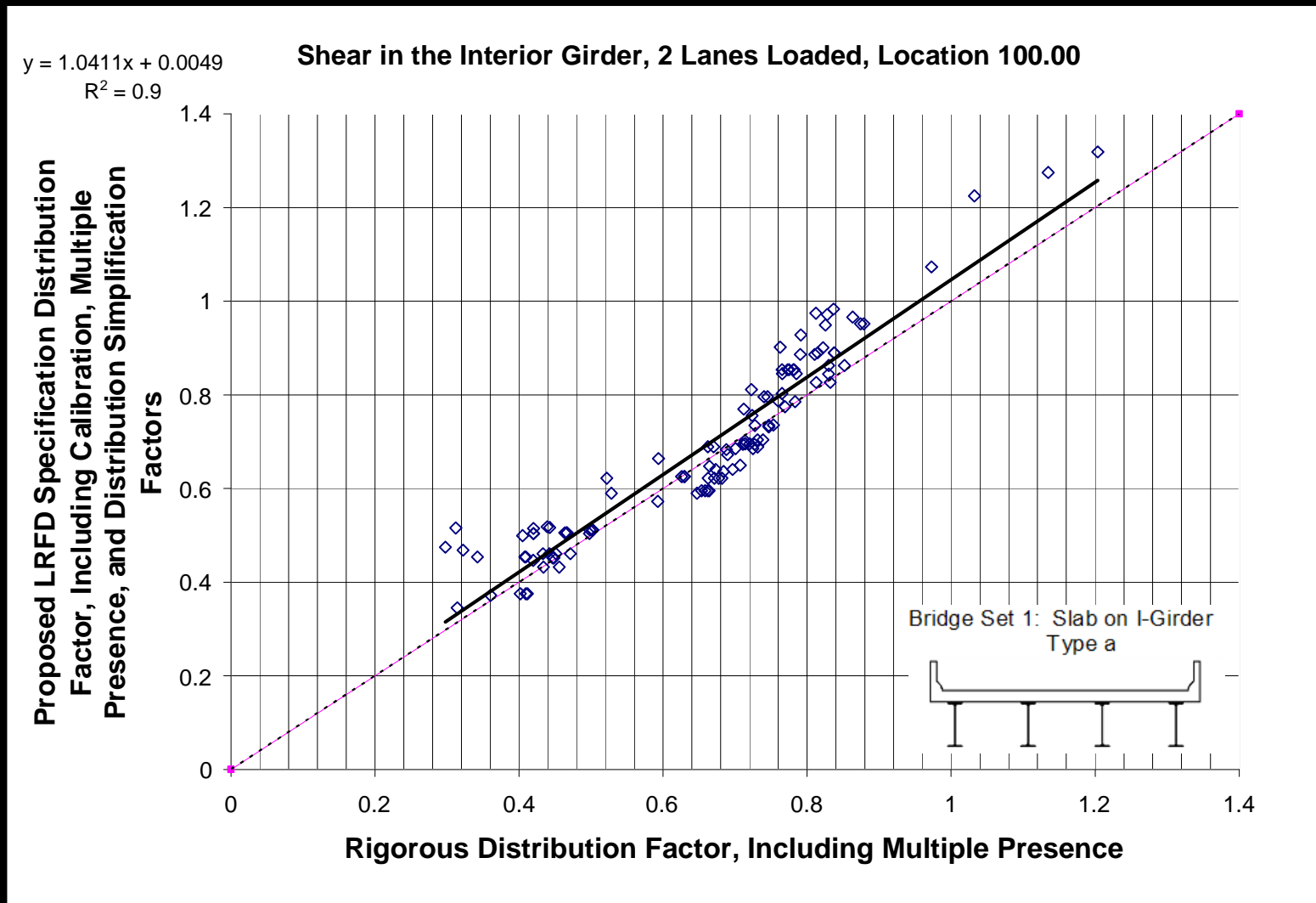
$$R^2 = 0.8934$$

Shear in the Interior Girder, 1 Lane Loaded, Location 100.00

Proposed LRFD Specification Distribution Factor, Including Calibration, Multiple Presence, and Distribution Simplification Factors



Shear Interior Two Lanes

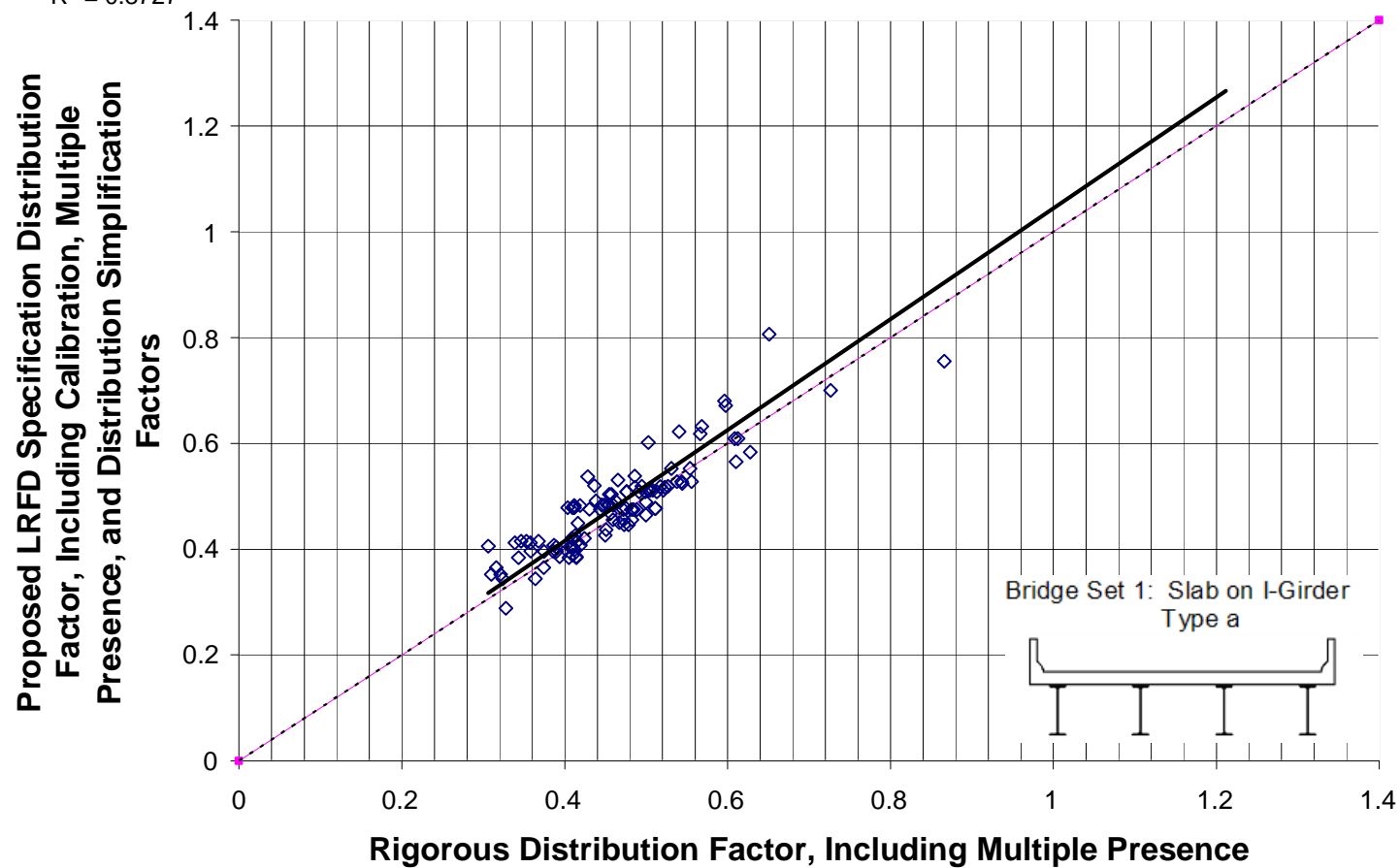


Moment Exterior One Lane

$$y = 1.0477x - 0.0032$$

$$R^2 = 0.8727$$

Moment in the Exterior Girder, 1 Lane Loaded, Location 104.00

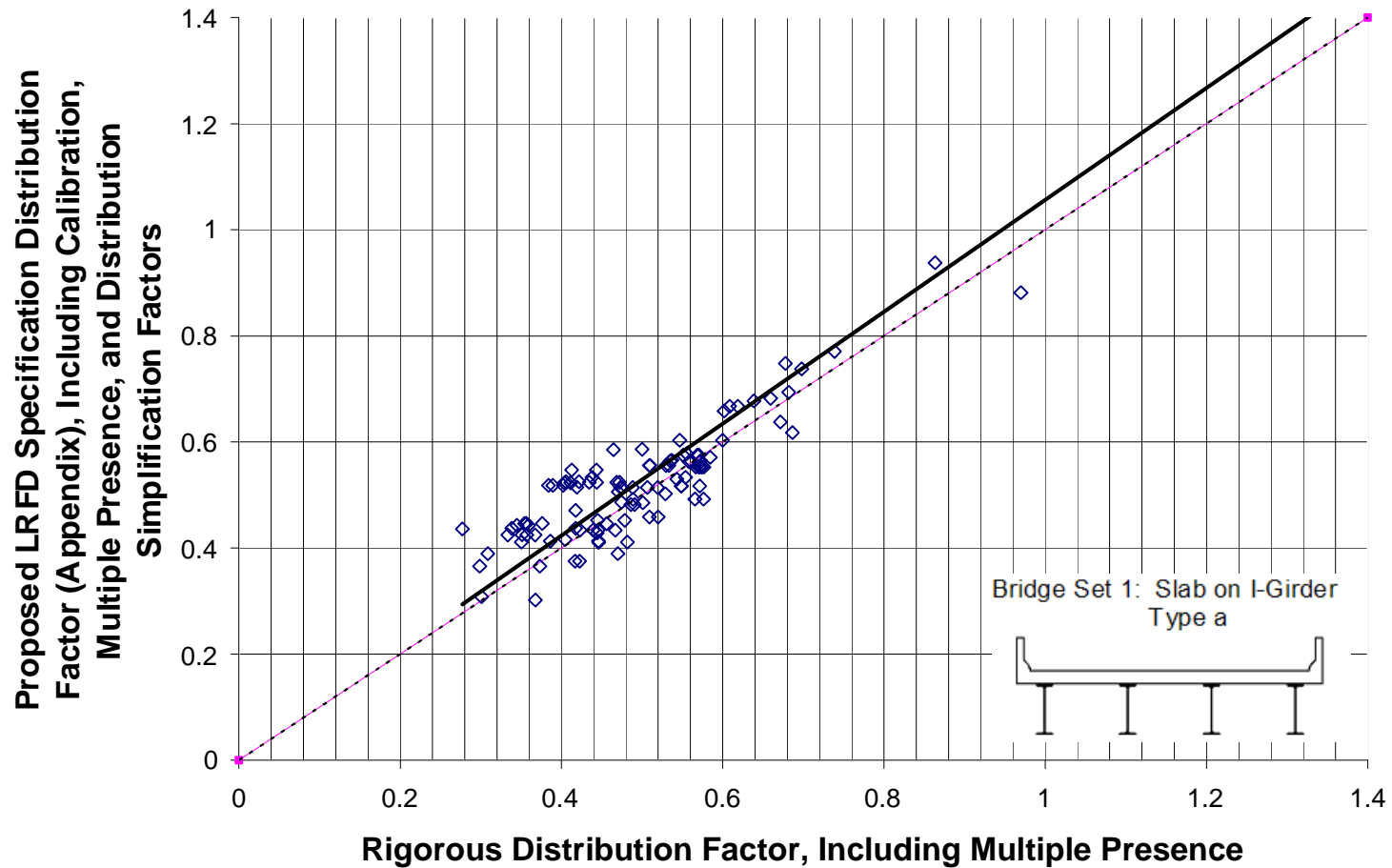


Moment Exterior Two Lanes

$$y = 1.0551x + 0.0013$$

$$R^2 = 0.8566$$

Moment in the Exterior Girder, 2 Lanes Loaded, Location 104.00

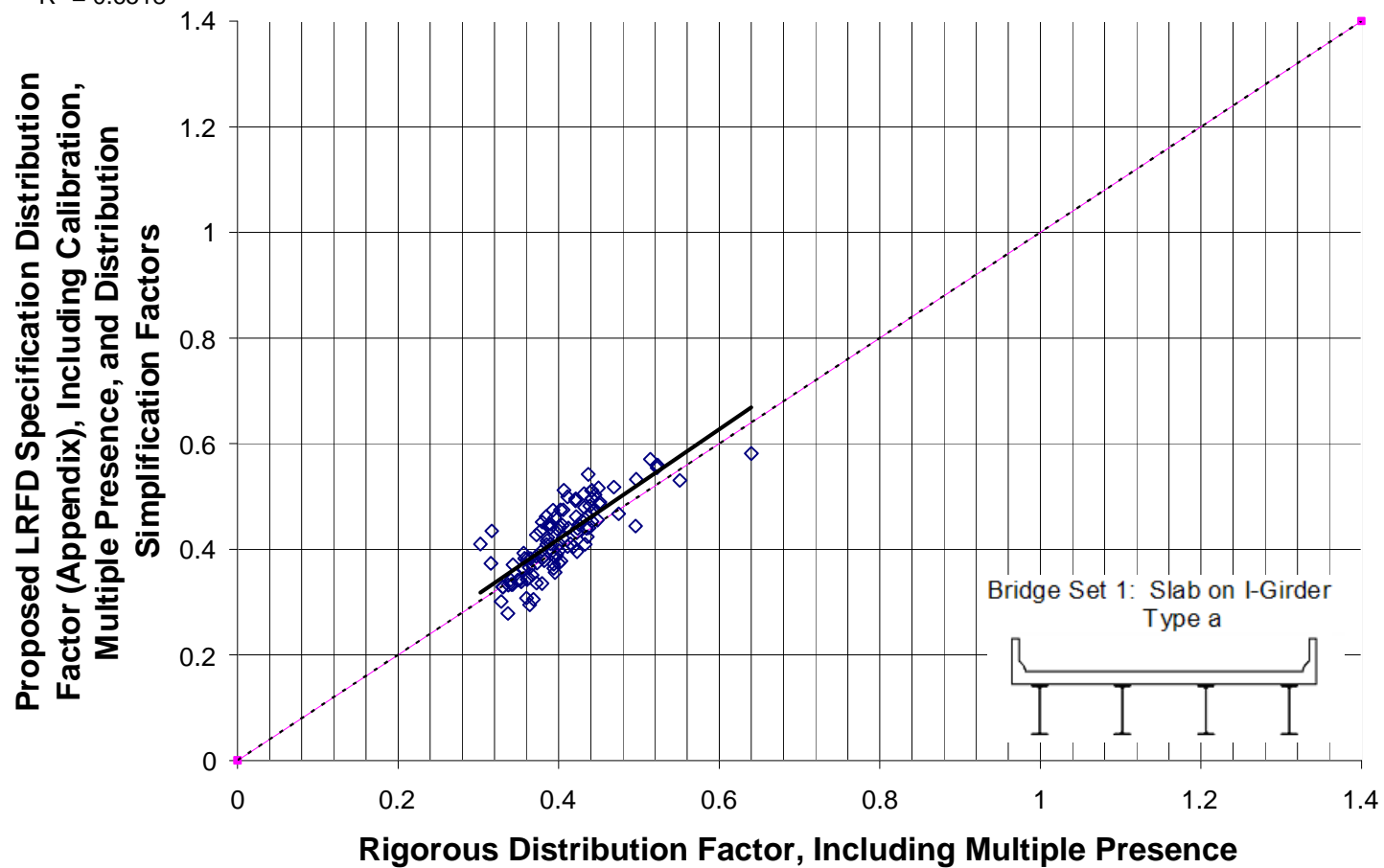


Moment Interior One Lane

$$y = 1.0391x + 0.0037$$

$$R^2 = 0.6518$$

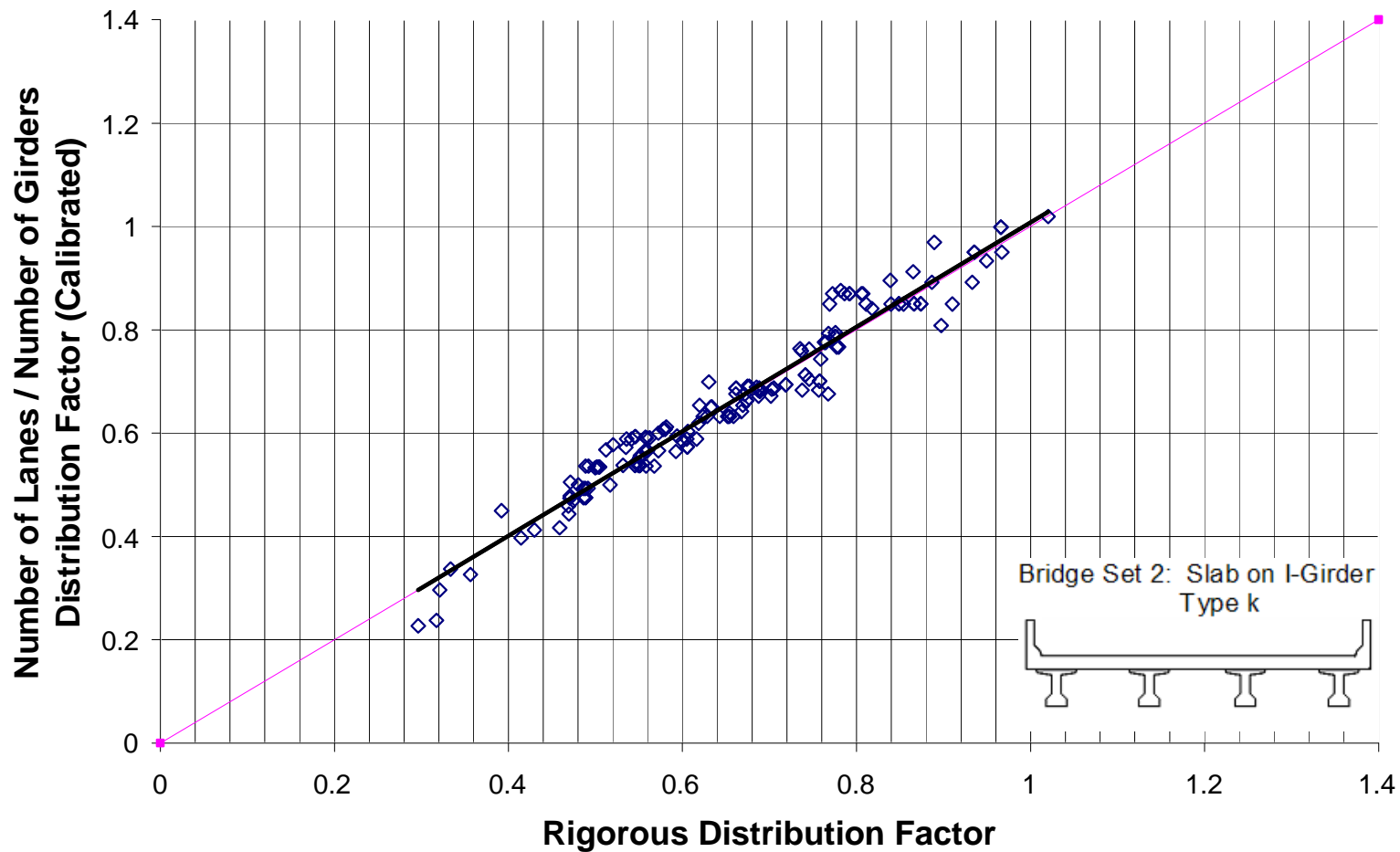
Moment in the Interior Girder, 1 Lane Loaded, Location 104.00



Moment Interior Multiple Lanes

$y = 1.0105x - 0.003$
 $R^2 = 0.9509$

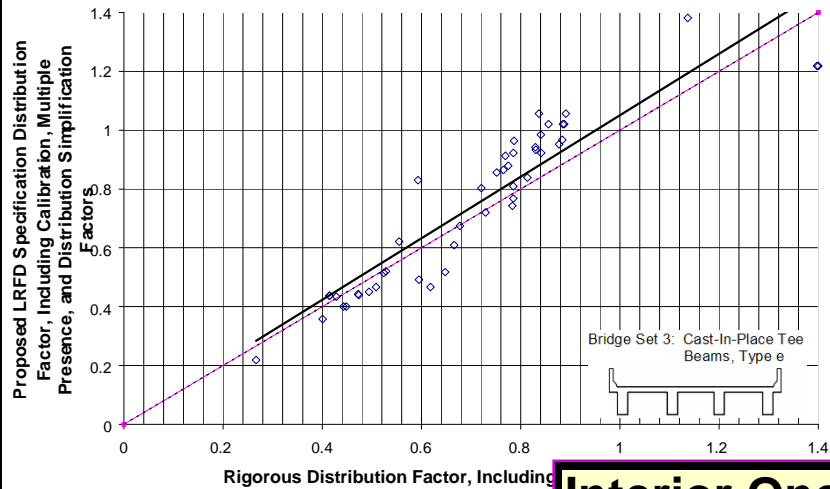
Moment in the Interior Girder, 2 - 4 Lanes Loaded, Location 104.00



Concrete Tee Beams Shear

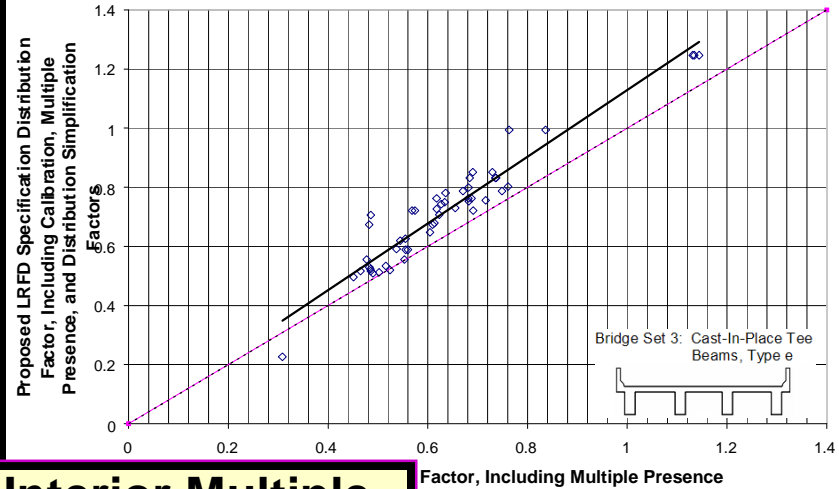
$y = 1.0457x + 0.0051$
 $R^2 = 0.8371$

Shear in the Interior Girder, 2 Lanes Loaded, Location 100.00



$y = 1.1279x + 0.0017$
 $R^2 = 0.9168$

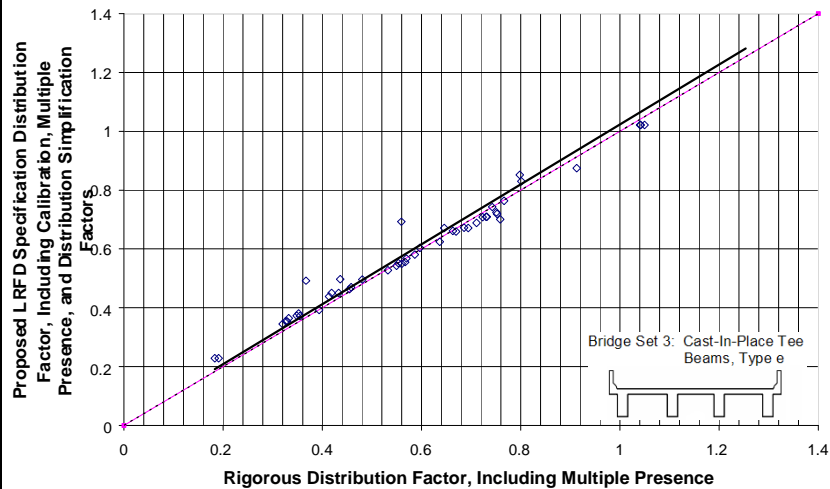
Shear in the Interior Girder, 1 Lane Loaded, Location 100.00



Interior One	Interior Multiple
Exterior One	Exterior Multiple

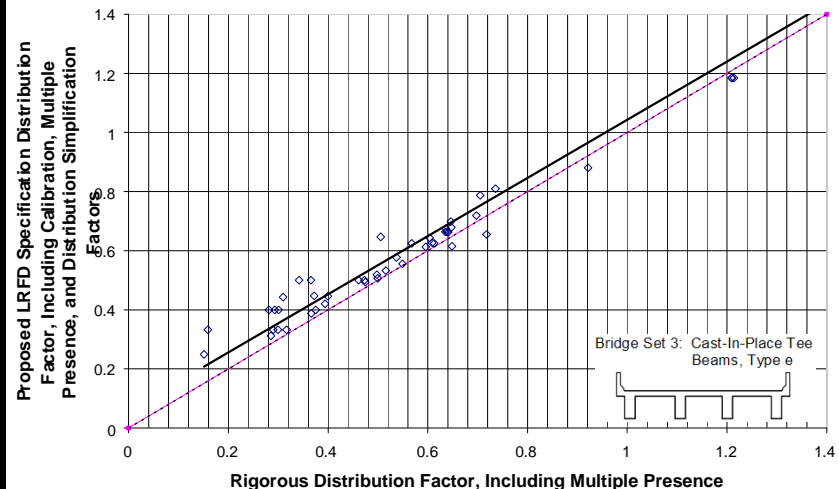
$y = 1.0195x + 0.0042$
 $R^2 = 0.9309$

Shear in the Exterior Girder, 1 Lane Loaded, Location 100.00

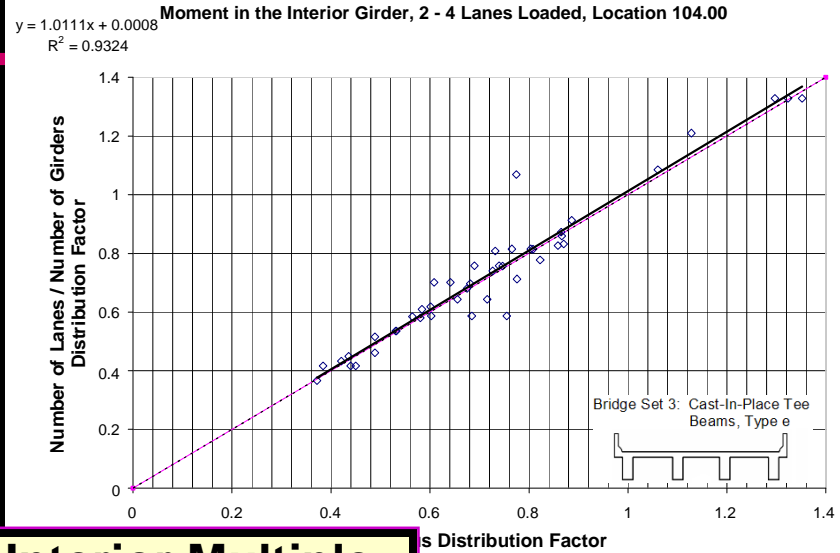
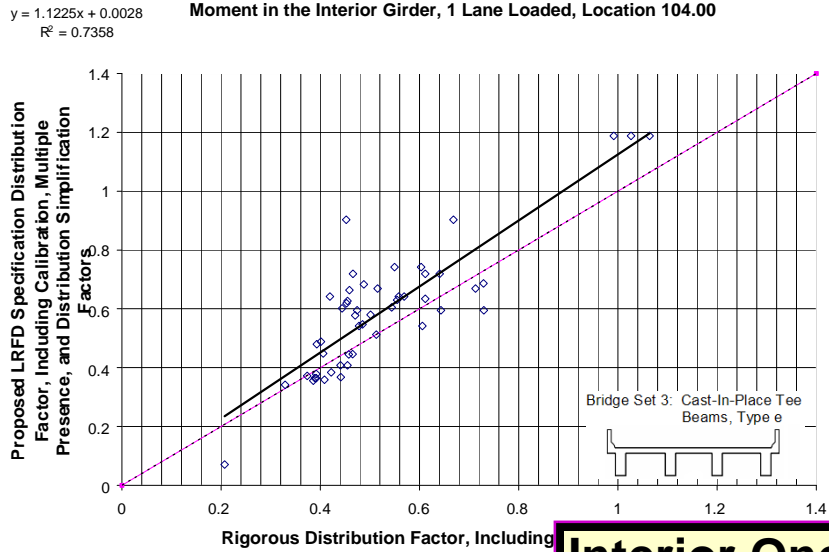


$y = 1.0697x + 0.0017$
 $R^2 = 0.9370$

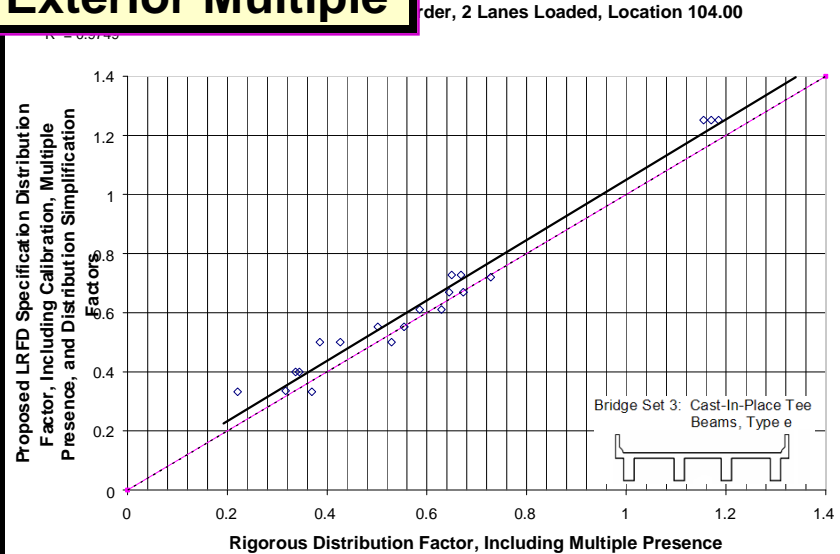
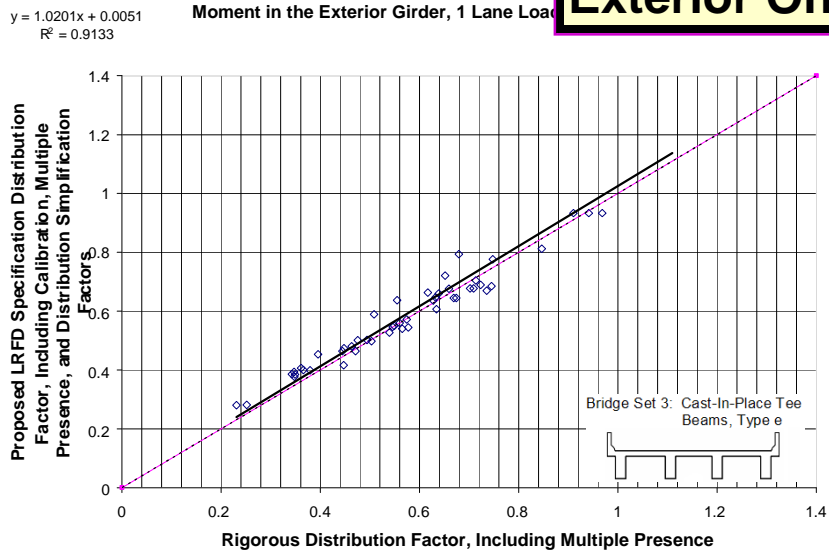
Shear in the Exterior Girder, 2 Lanes Loaded, Location 100.00



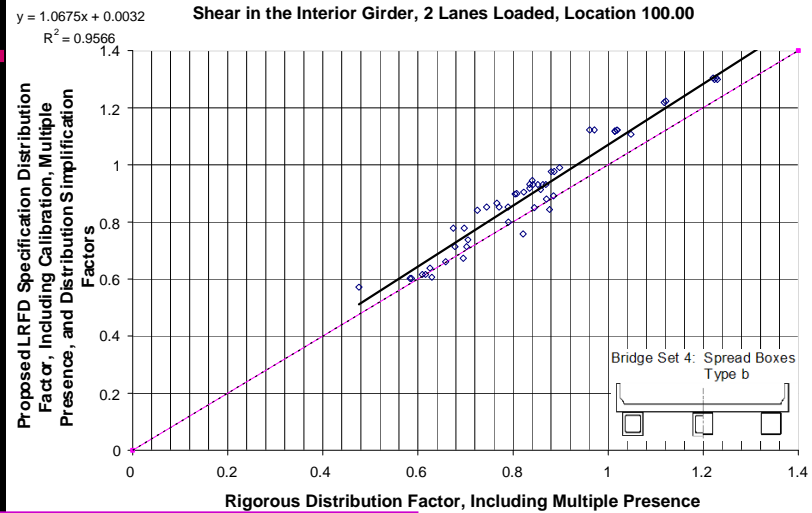
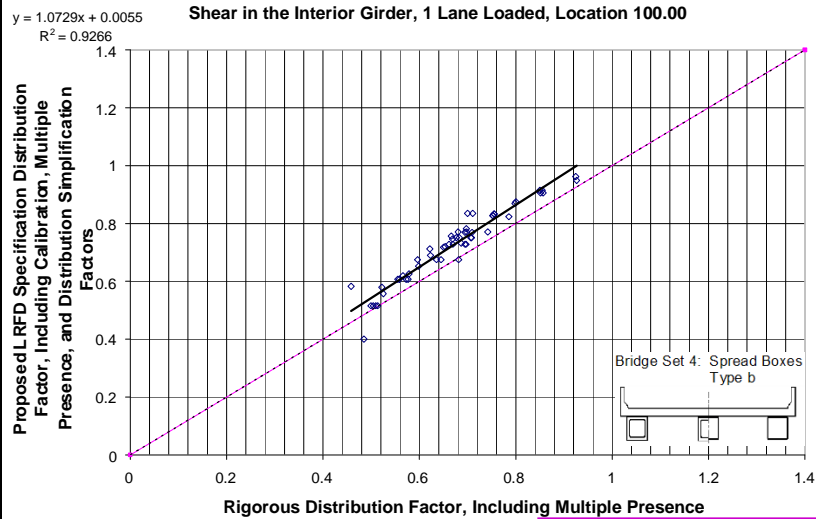
Concrete Tee Beams Moment



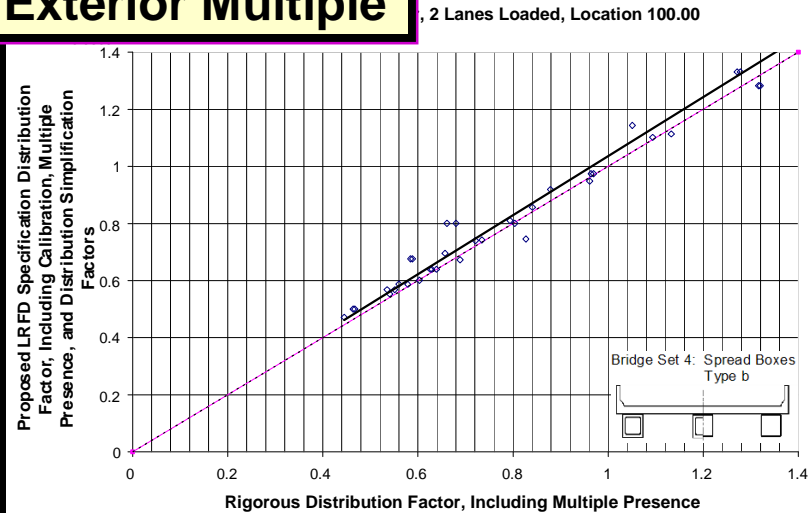
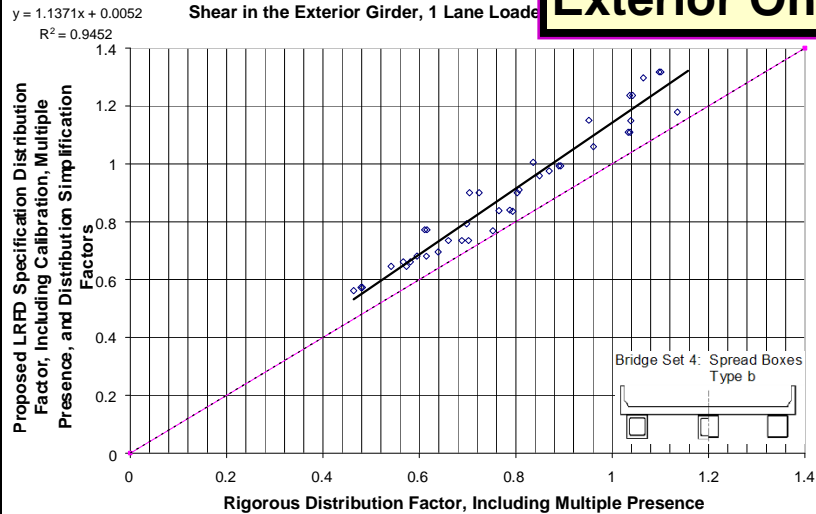
Interior One	Interior Multiple
Exterior One	Exterior Multiple



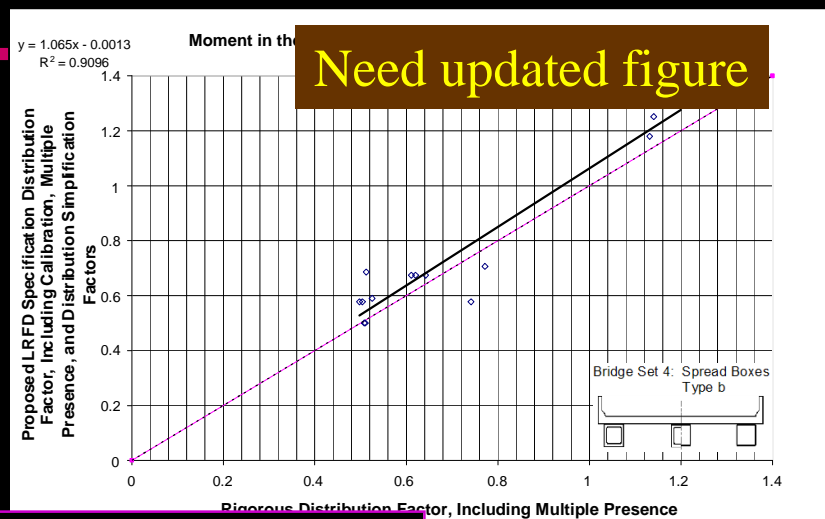
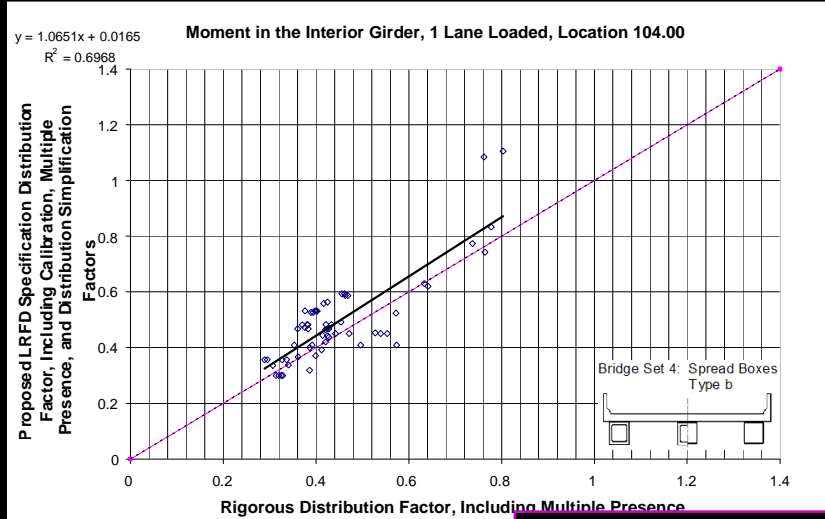
Spread Box Beams Shear



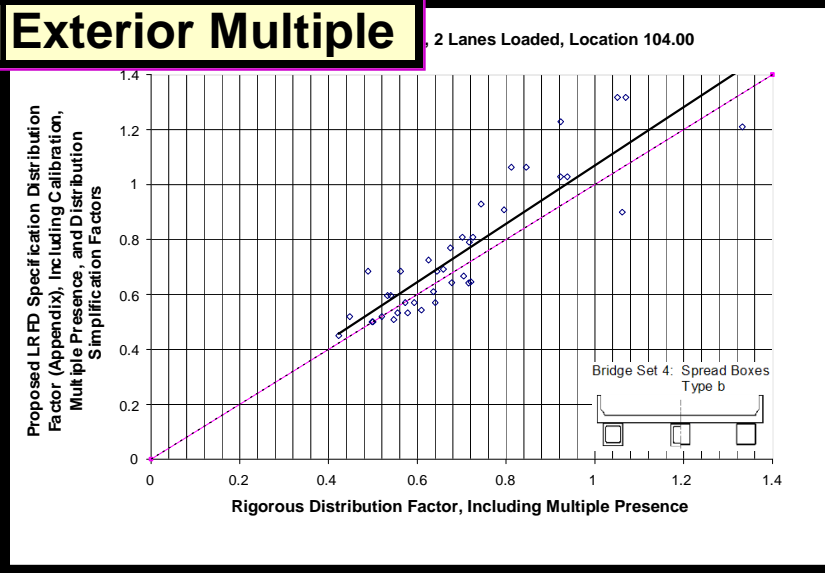
Interior One	Interior Multiple
Exterior One	Exterior Multiple



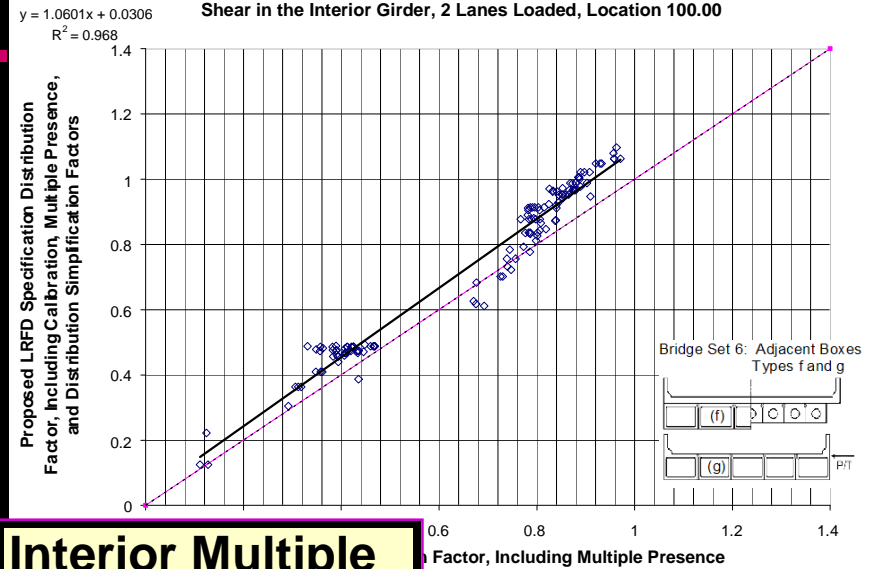
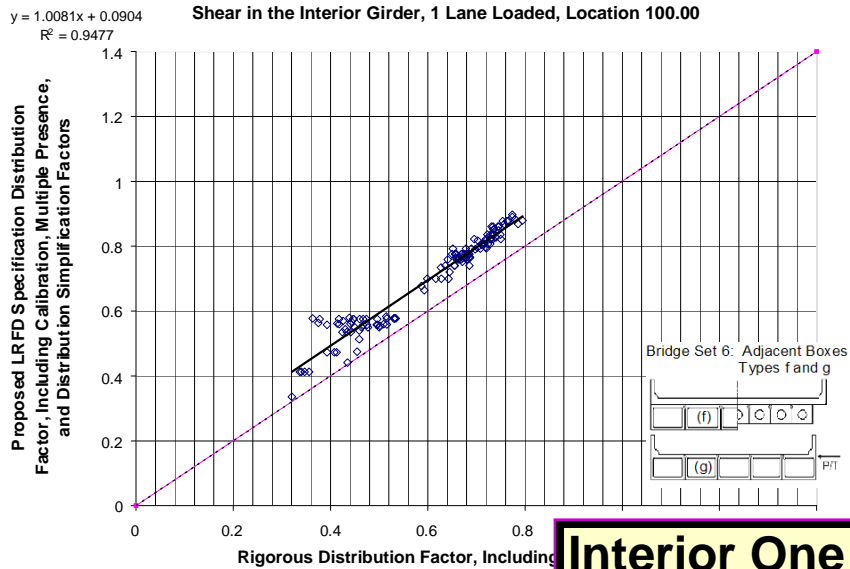
Spread Box Beams Moment



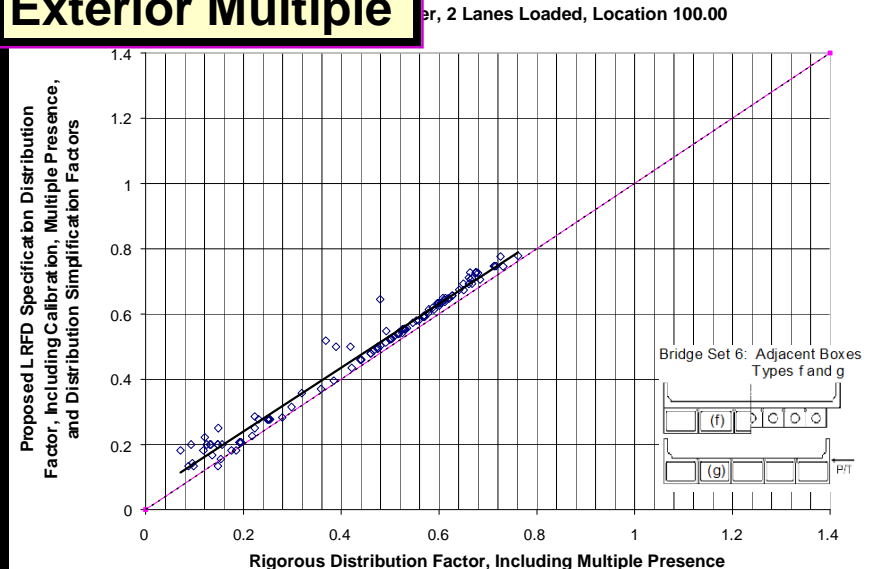
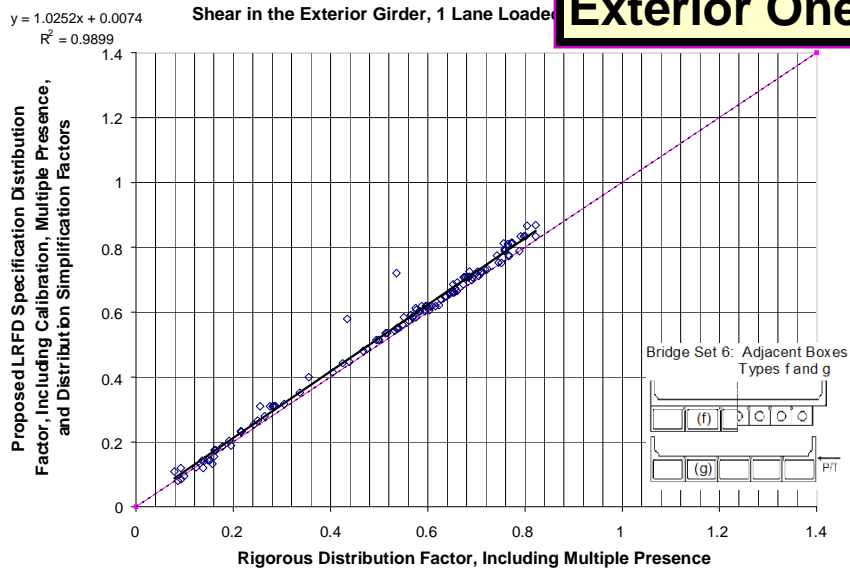
Interior One **Interior Multiple**
Exterior One **Exterior Multiple**



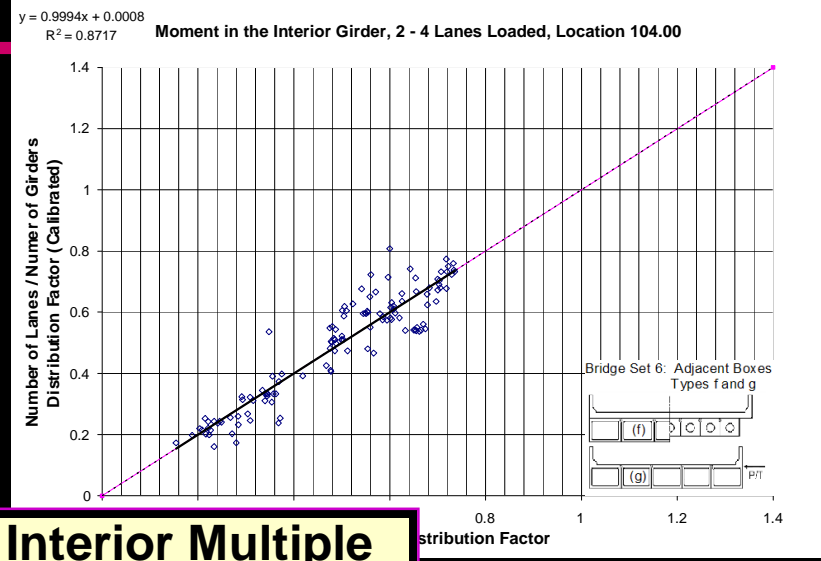
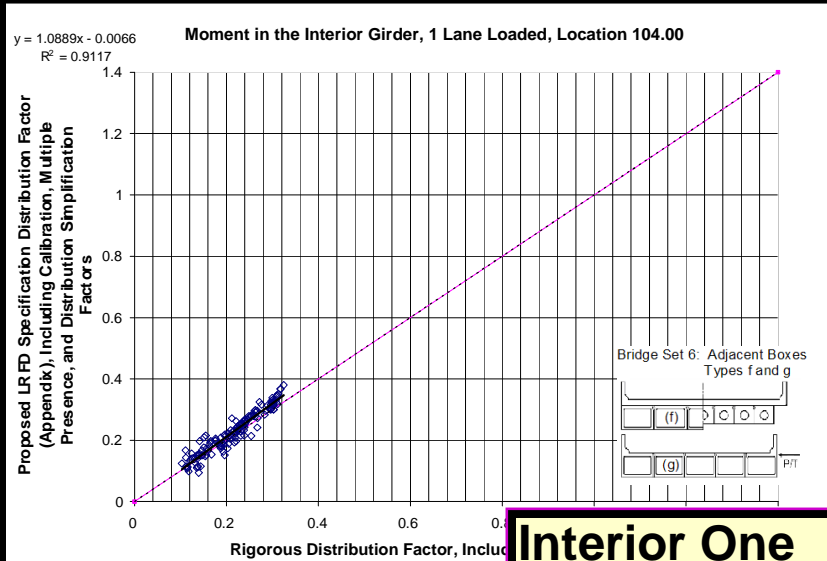
Adjacent Boxes Shear (f & g)



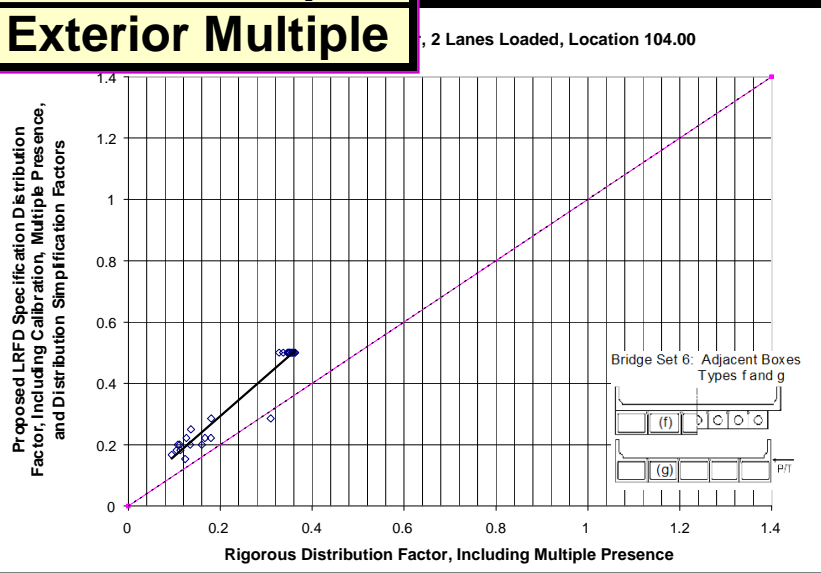
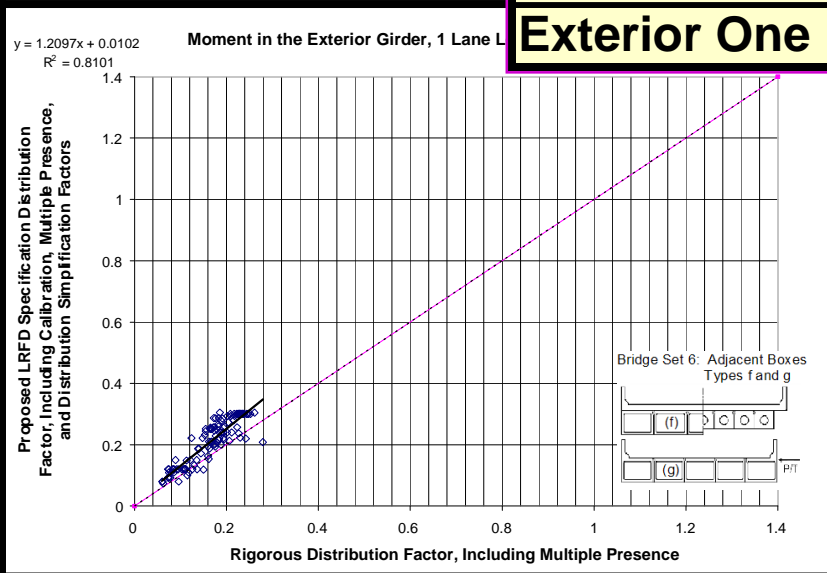
Interior One **Interior Multiple**
Exterior One **Exterior Multiple**



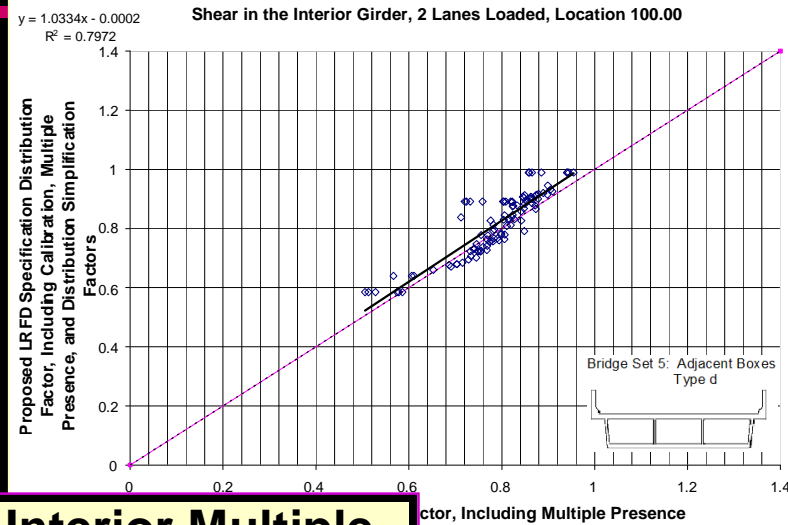
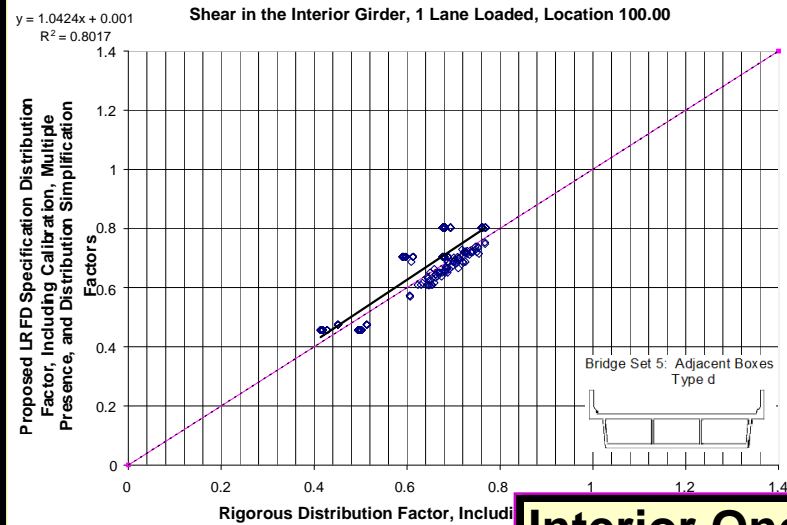
Adjacent Boxes Moment (f & g)



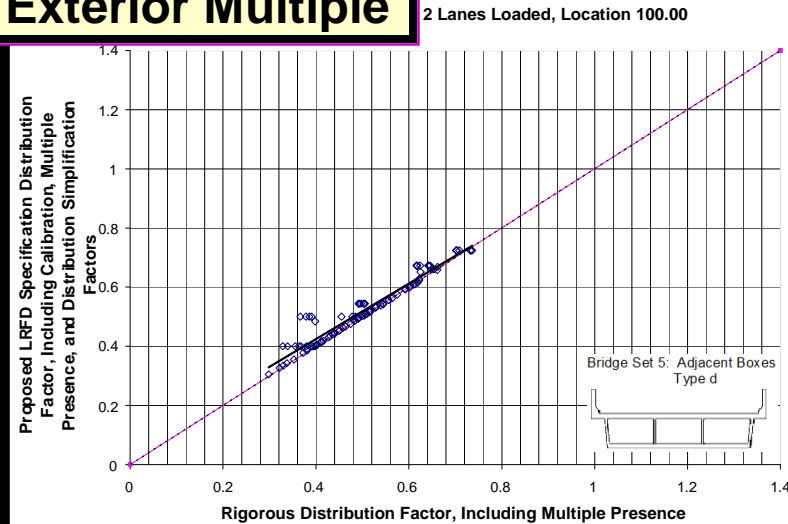
Interior One
Interior Multiple
Exterior One
Exterior Multiple



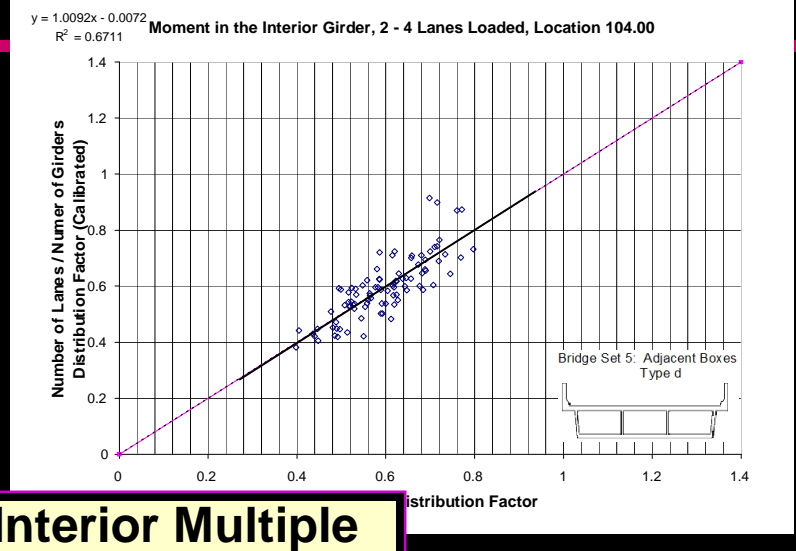
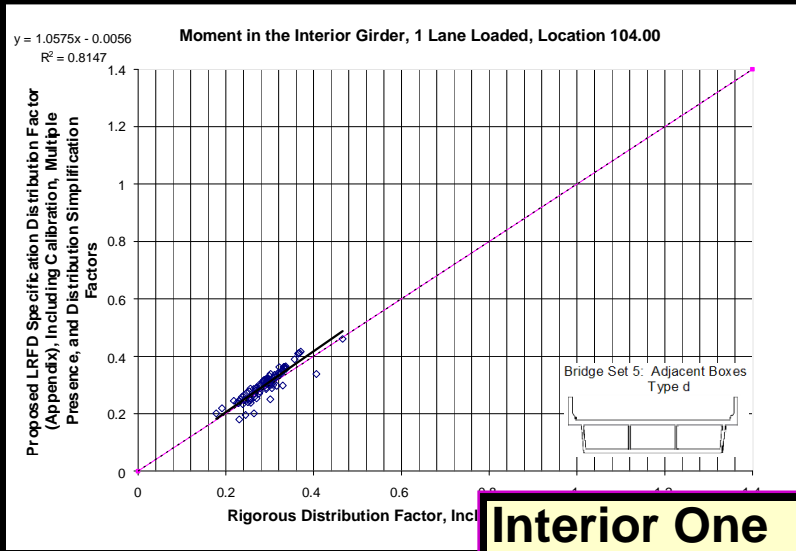
Adjacent Boxes Shear (d)



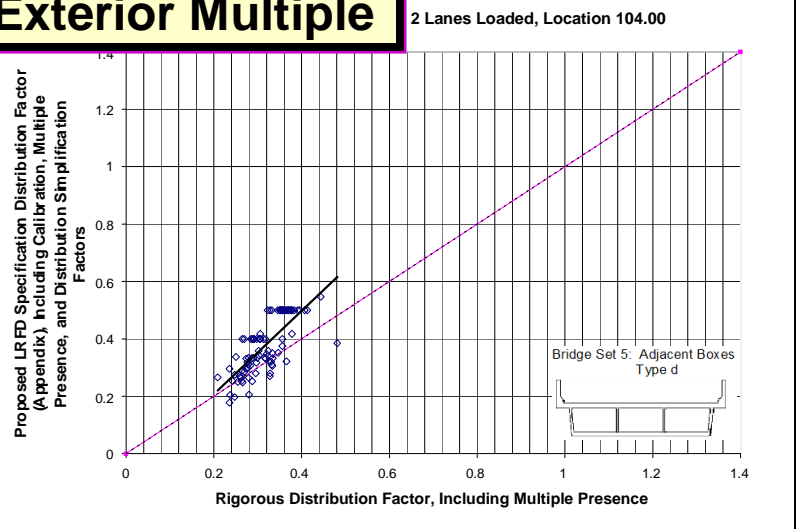
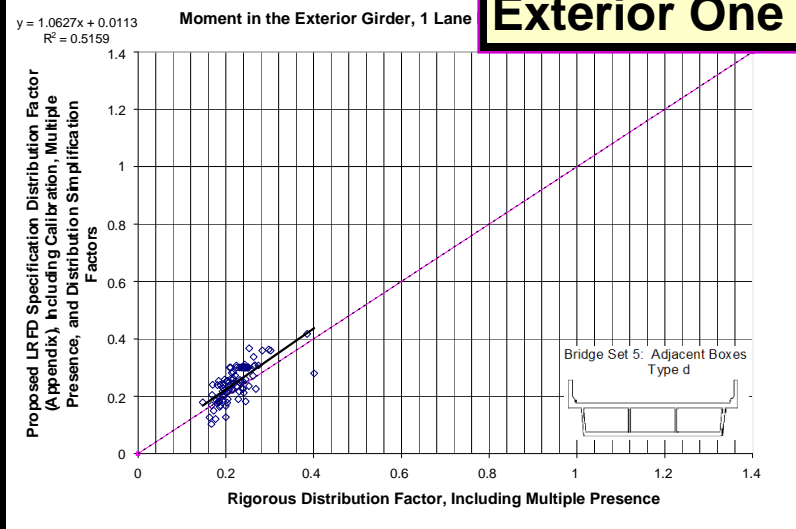
Interior One	Interior Multiple
Exterior One	Exterior Multiple



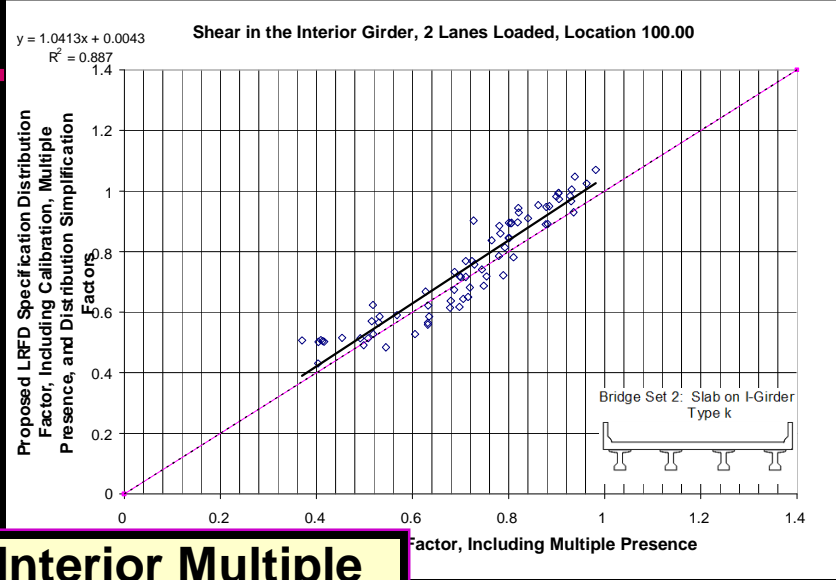
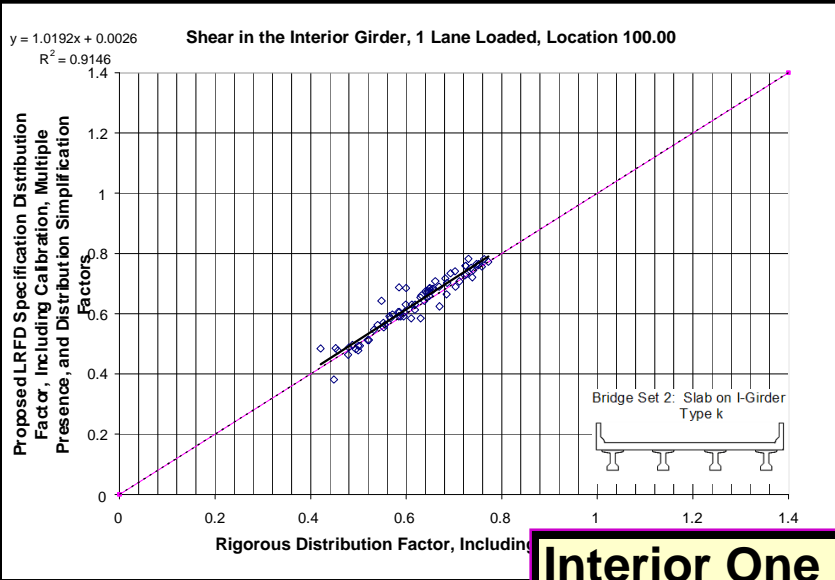
Adjacent Boxes Moment (d)



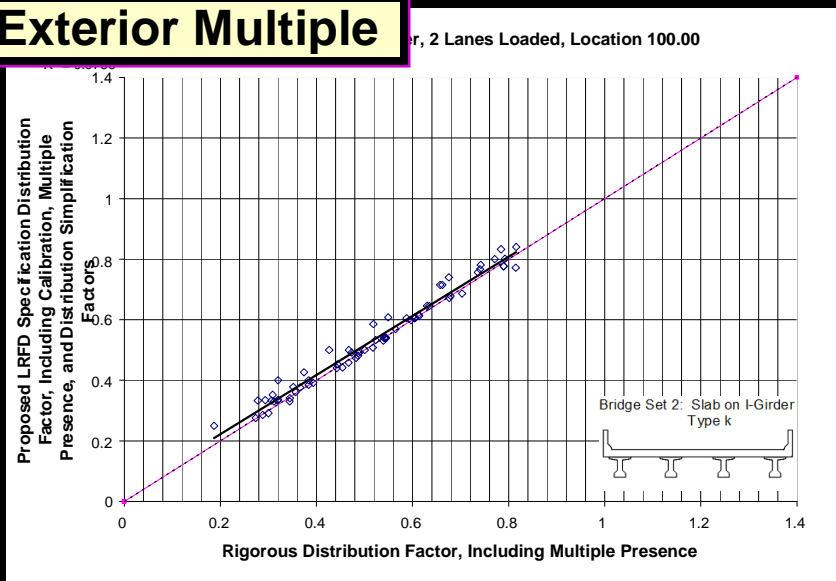
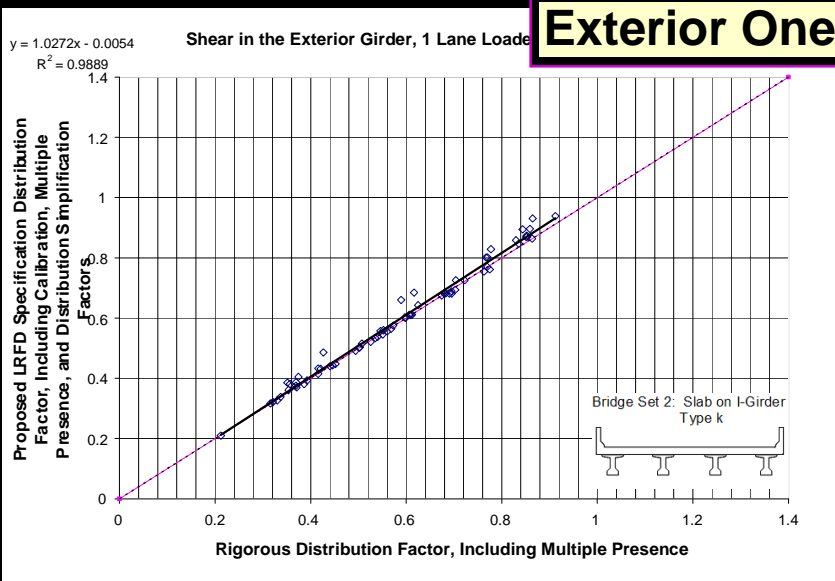
Interior One	Interior Multiple
Exterior One	Exterior Multiple



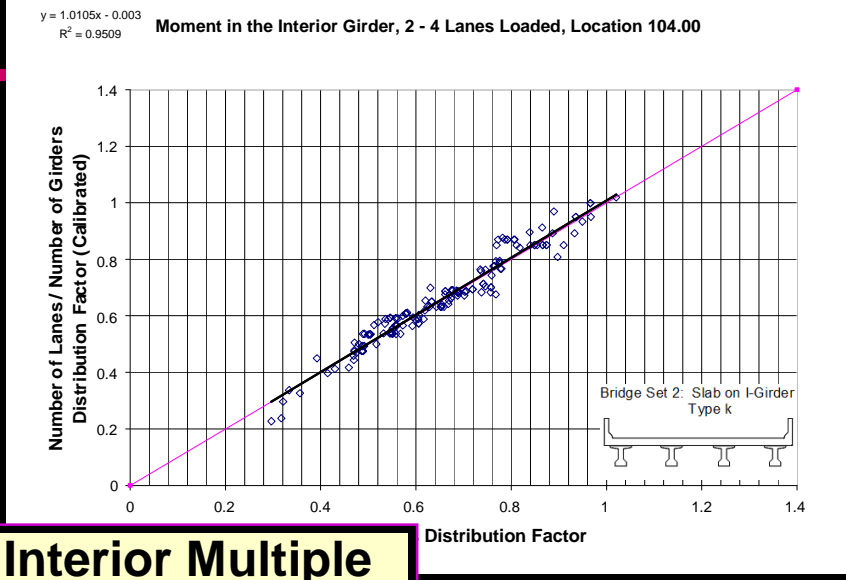
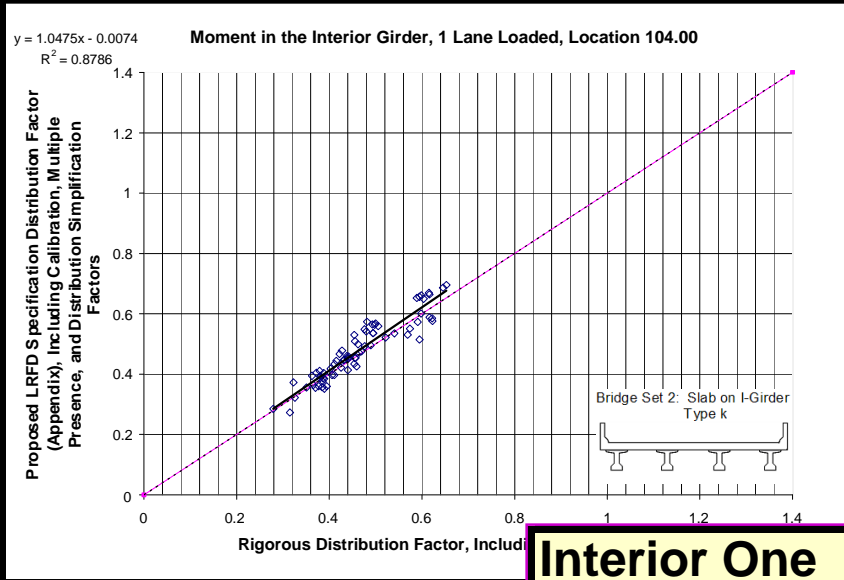
Concrete I Section Shear



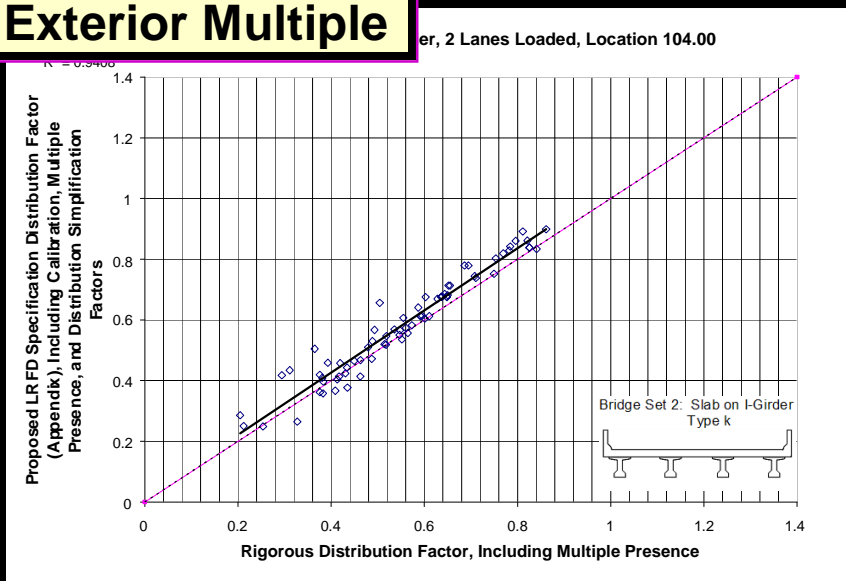
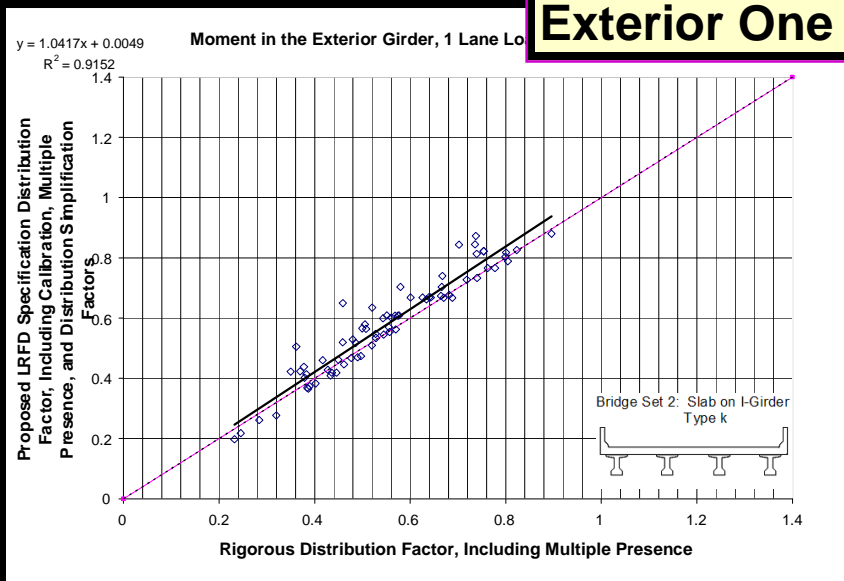
Interior One	Interior Multiple
Exterior One	Exterior Multiple



Concrete I Section Moment



Interior One	Interior Multiple
Exterior One	Exterior Multiple

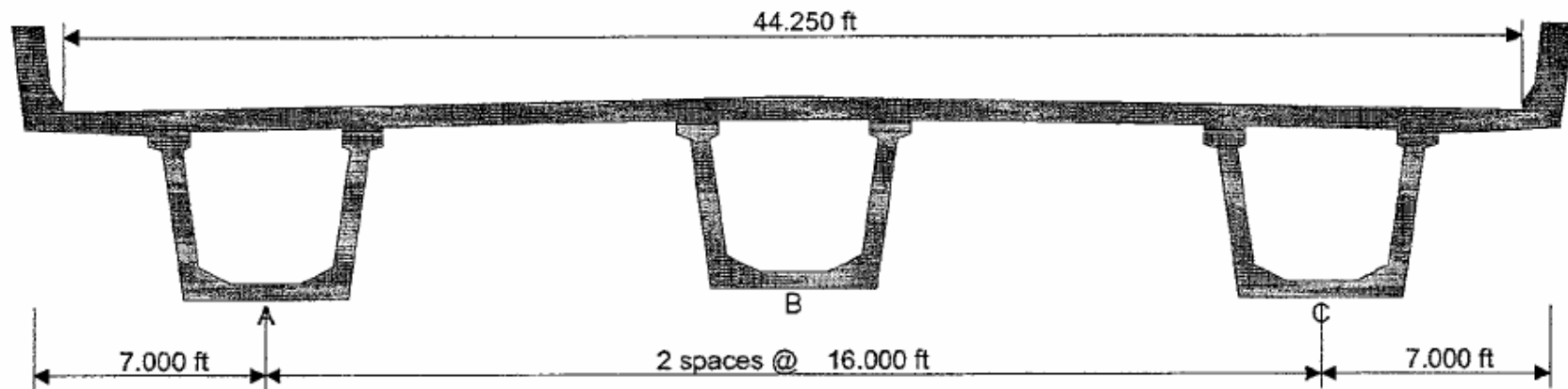


Three-girder bridges

- Current uses Equations for boxes
- Proposed requires lever rule

WS DOT Example

- Three-girder tub
- 16 ft spacing
- 60 degree skew



Outstanding Issues (as I see 'em)

???????????

- Over simplified?
- Should we postpone????
- Different coefficients for number of lanes?
- Change from unified approach to *best* approach for each type, i.e., LR, Uniform adjusted?
Remove uniform approach for all.
- Three girders
 - Boxes
 - Open sections
- Skew adjustment for moment – stiffness?
- Combine slab on girder bridge types

Questions, Discussion

End of Talk

Additional work

- Review/revise tub girder systems
- Develop presentation materials to help explain this in a more understandable manner
- Suggestions welcome!

	excellent ≥ 0.9	0.90 > good ≥ 0.80	0.80 > acceptable ≥ 0.70	0.70 > poor ≥ 0.50	bad < 0.5							
Bridge Set	Action	Girder Locations	Lanes Loaded	Method								
				Sanders and Elleby	AASHTO Standard Specification	CHBDC	LRFD	Alternate for Moment	Uniform Distribution	Lever Rule	Best Method	
1	Shear	Exterior	1	bad	bad	bad	good	NA	bad	excellent	Lever	
			2 or more	bad	bad	bad	good		bad	excellent	Lever	
		Interior	1	good	good	good	good		acceptable	good	excellent	Lever
			2 or more	good	good	good	acceptable		good	excellent	Lever	
	Moment	Exterior	1	bad	bad	bad	acceptable	bad	poor	good	Lever	
			2 or more	bad	bad	bad	good	bad	poor	good	Lever	
Interior	1	bad	bad	bad	bad	poor	bad	bad	Alternate			
	2 or more	acceptable	poor	acceptable	acceptable	acceptable	good	acceptable	Uniform			
2	Shear	Exterior	1	bad	bad	bad	excellent	NA	poor	excellent	Lever	
			2 or more	bad	bad	bad	acceptable		poor	excellent	Lever	
		Interior	1	good	good	good	good		excellent	acceptable	excellent	Lever
			2 or more	good	good	good	good		good	excellent	good	Uniform
	Moment	Exterior	1	bad	bad	bad	good	bad	poor	excellent	Lever	
			2 or more	bad	bad	bad	good	bad	poor	excellent	Lever	
Interior	1	poor	poor	acceptable	good	good	bad	poor	Alternate			
	2 or more	good	good	good	good	good	excellent	good	Uniform			
3	Shear	Exterior	1	poor	poor	poor	good	NA	good	excellent	Lever	
			2 or more	poor	poor	poor	excellent		excellent	excellent	Uniform	
		Interior	1	good	good	excellent	excellent		acceptable	excellent	Lever	
			2 or more	excellent	good	excellent	good		excellent	good	Uniform	
	Moment	Exterior	1	poor	poor	poor	good	bad	acceptable	excellent	Lever	
			2 or more	poor	poor	poor	excellent	bad	excellent	excellent	Uniform	
Interior	1	poor	acceptable	good	excellent	poor	poor	acceptable	Lever			
	2 or more	good	acceptable	good	excellent	poor	excellent	poor	Lever			
4	Shear	Exterior	1	acceptable	good	acceptable	excellent	NA	good	excellent	Lever	
			2 or more	good	good	good	excellent		excellent	excellent	Lever	
		Interior	1	good	excellent	good	good		acceptable	excellent	Lever	
			2 or more	excellent	excellent	excellent	excellent		poor	excellent	Lever	
	Moment	Exterior	1	poor	poor	acceptable	poor	poor	poor	poor	CHBDC	
			2 or more	good	good	good	good	bad	poor	good	CHBDC	
Interior	1	bad	poor	bad	poor	poor	poor	bad	poor	Lever		
	2 or more	bad	poor	poor	poor	poor	excellent	poor	Uniform			
5	Shear	Exterior	1	bad	bad	bad	good	NA	acceptable	good	Lever	
			2 or more	bad	bad	bad	acceptable		acceptable	excellent	Lever	
		Interior	1	bad	good	good	acceptable		poor	good	CHBDC	
			2 or more	bad	good	good	good		poor	acceptable	LRFD	
	Moment	Exterior	1	bad	bad	bad	bad	poor	bad	bad	Alternate	
			2 or more	bad	bad	bad	bad	poor	poor	bad	Alternate	
Interior	1	bad	bad	bad	bad	good	bad	bad	Alternate			
	2 or more	bad	bad	bad	poor	good	bad	bad	Alternate			
6	Shear	Exterior	1	good	good	good	excellent	NA	good	excellent	Lever	
			2 or more	good	good	good	excellent		excellent	excellent	Lever	
		Interior	1	acceptable	acceptable	acceptable	good		acceptable	excellent	Lever	
			2 or more	good	good	good	excellent		excellent	excellent	Lever	
	Moment	Exterior	1	poor	poor	poor	acceptable	acceptable	poor	acceptable	Alternate	
			2 or more	poor	poor	poor	good	acceptable	excellent	acceptable	Uniform	
Interior	1	bad	bad	bad	bad	excellent	bad	bad	Alternate			
	2 or more	poor	poor	poor	poor	good	excellent	poor	Uniform			

Slab On Steel I

Slab on Concrete I

CIP Tees

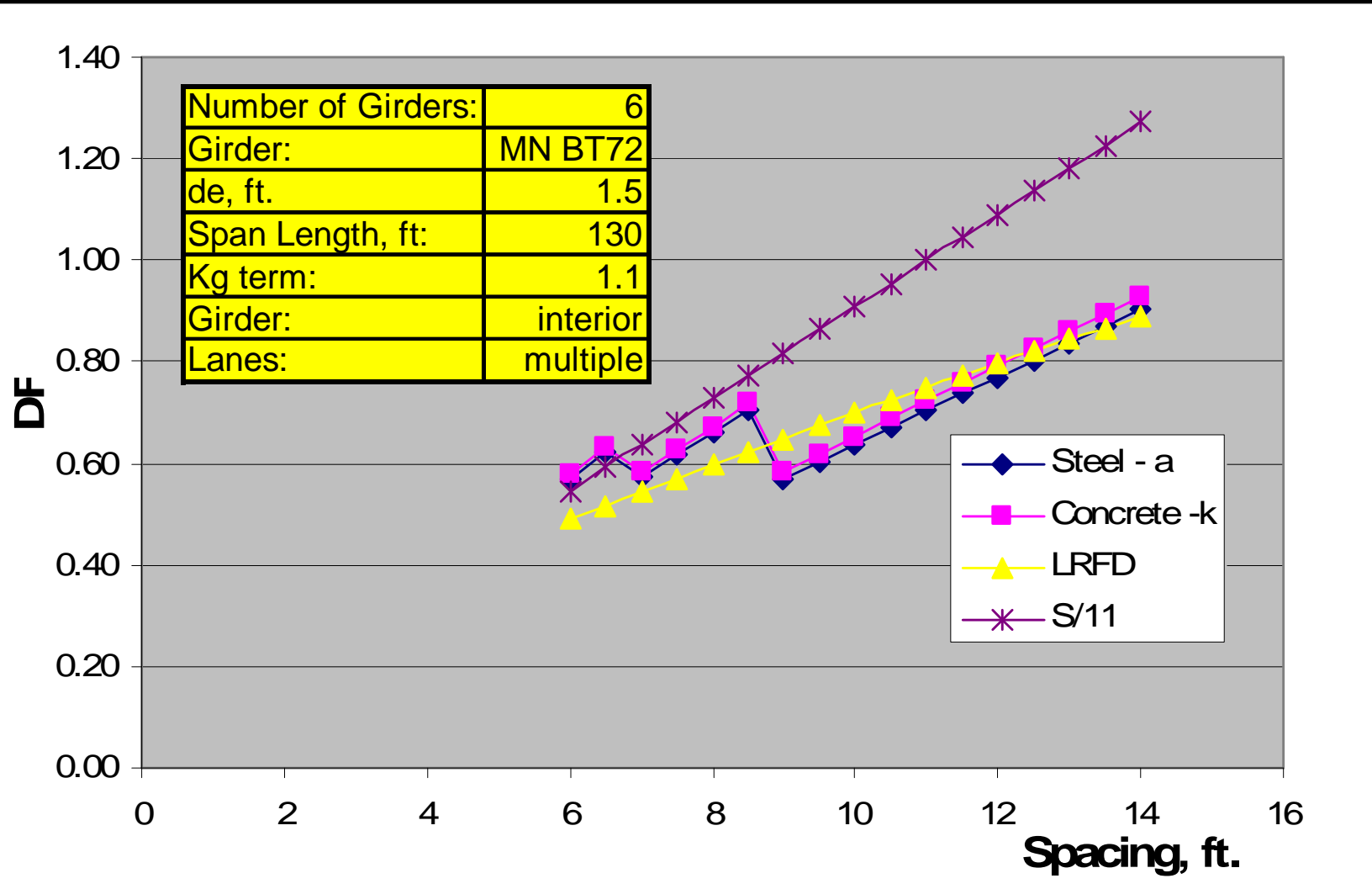
Spread Boxes

Cast-In-Place Boxes

Adjacent Boxes

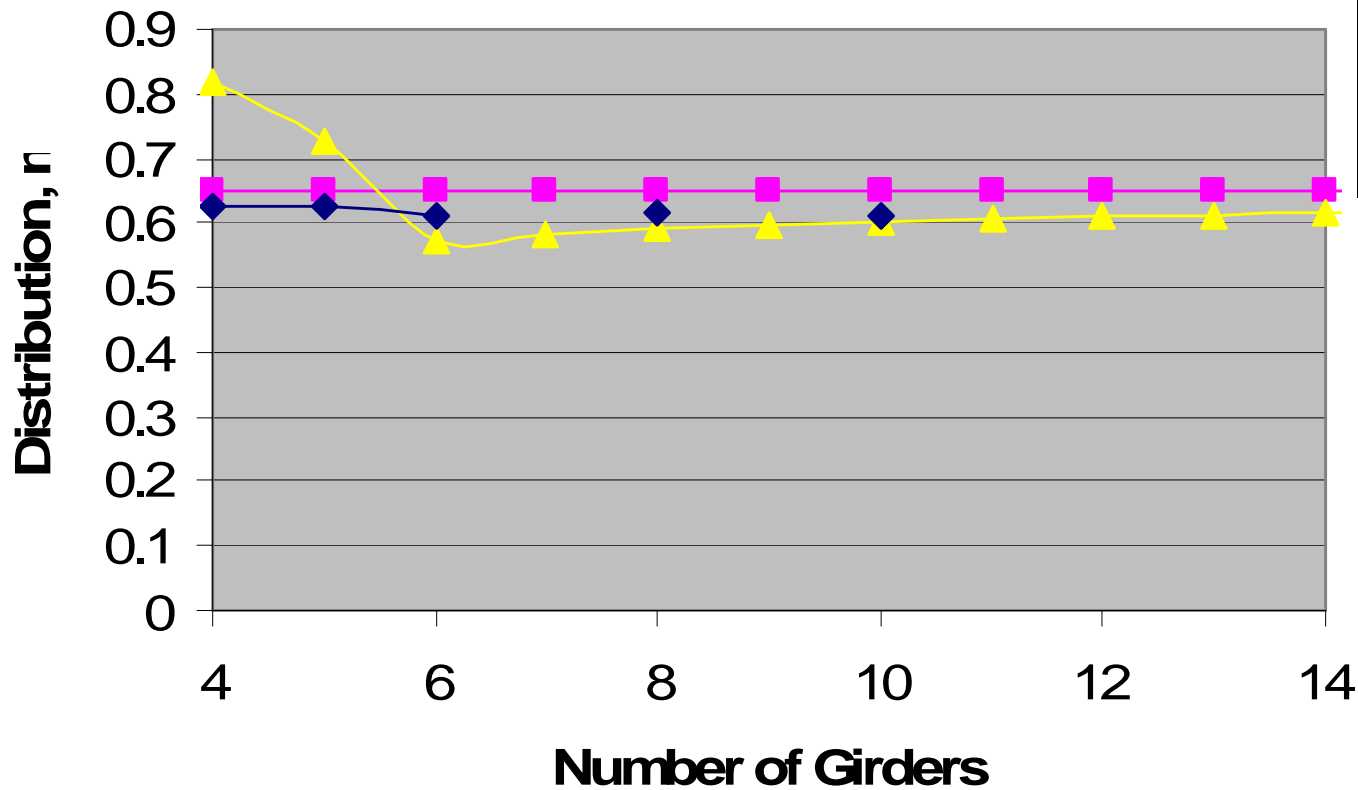
Moment		Method				
	Bridge Set	Lanes Loaded	Alternate for Moment	Uniform Distribution	Lever Rule	Best Method
Exterior	1	1	bad	poor	good	Lever
		2 or more	bad	poor	good	Lever
	2	1	bad	poor	excellent	Lever
		2 or more	bad	poor	excellent	Lever
	3	1	bad	acceptable	excellent	Lever
		2 or more	bad	excellent	excellent	Uniform
	4	1	poor	poor	poor	CHBDC
		2 or more	bad	poor	good	CHBDC
	5	1	poor	bad	bad	Alternate
		2 or more	poor	poor	bad	Alternate
	6	1	acceptable	poor	acceptable	Alternate
		2 or more	acceptable	excellent	acceptable	Uniform
Interior	1	1	poor	bad	bad	Alternate
		2 or more	acceptable	good	acceptable	Uniform
	2	1	good	bad	poor	Alternate
		2 or more	good	excellent	good	Uniform
	3	1	poor	poor	acceptable	Lever
		2 or more	poor	excellent	poor	Lever
	4	1	poor	bad	poor	Lever
		2 or more	poor	excellent	poor	Uniform
	5	1	good	bad	bad	Alternate
		2 or more	good	bad	bad	Alternate
	6	1	excellent	bad	bad	Alternate
		2 or more	good	excellent	poor	Uniform

Side Study



Side Study

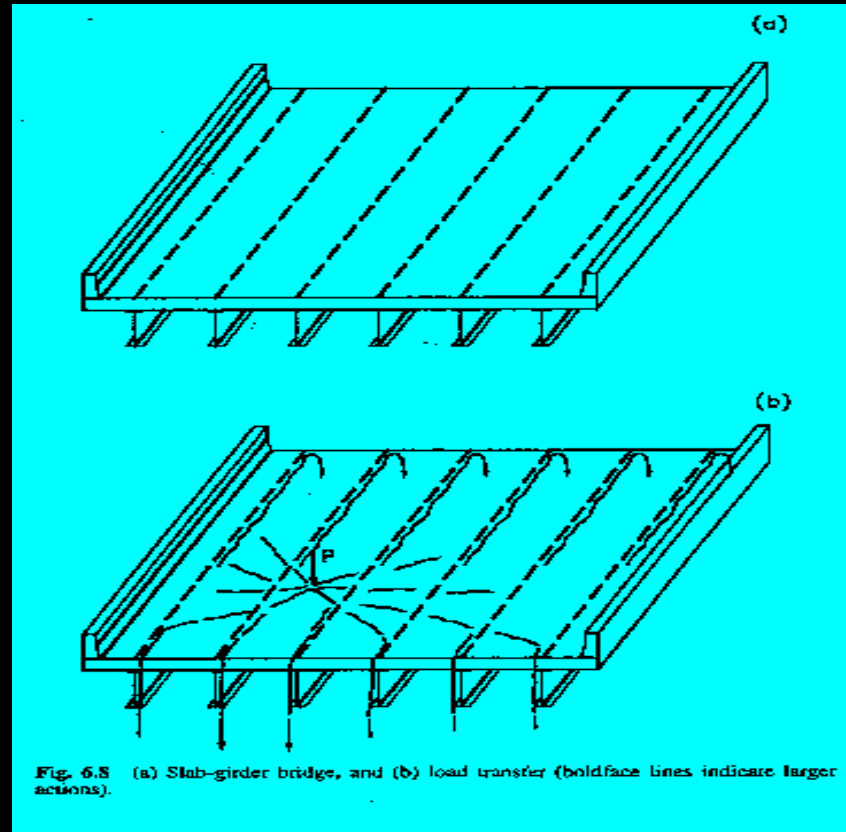
MN Design Manual Bridge

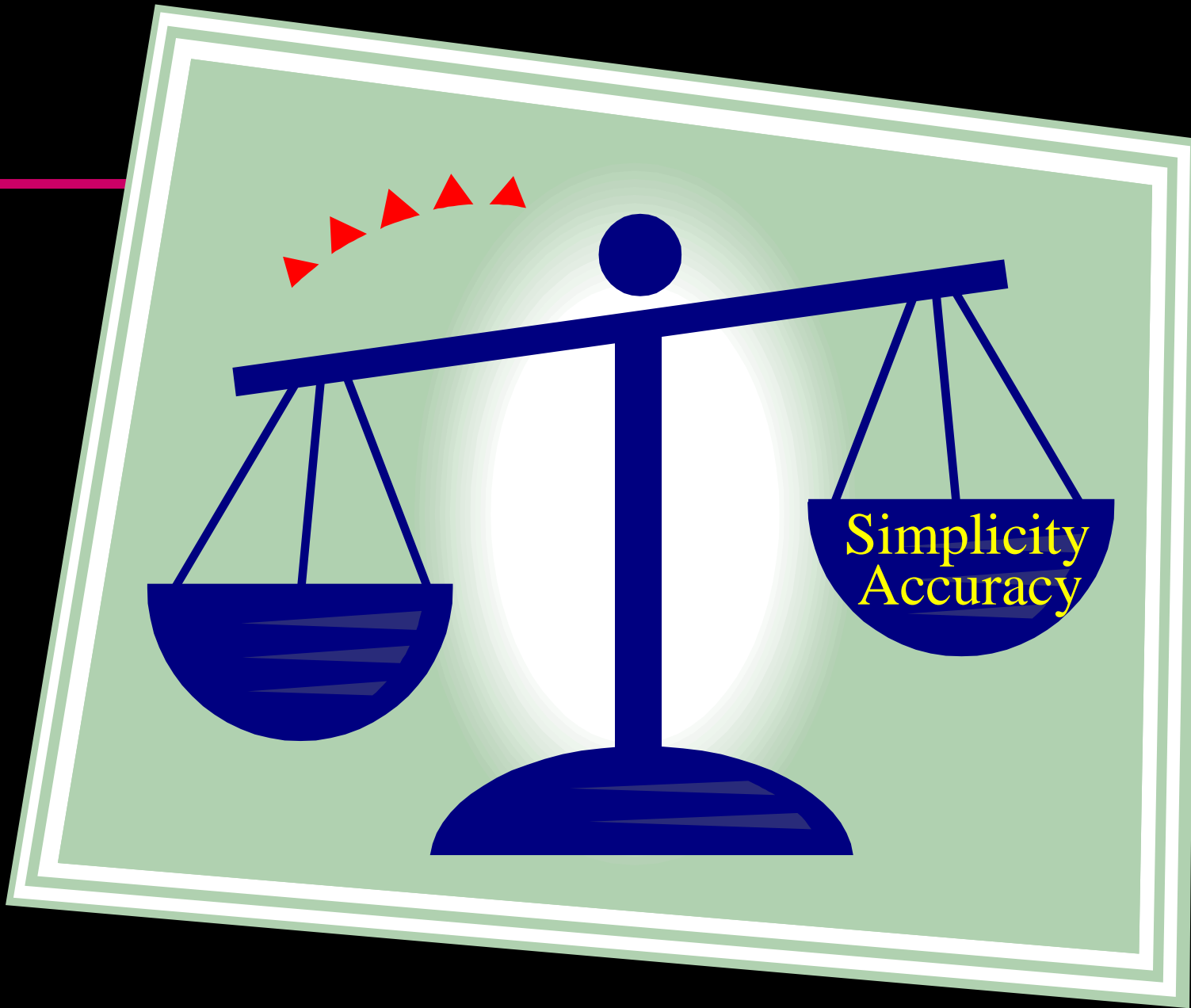


MN manual	
Barrier Width, ft.=	1.66
S, ft. =	9.00
L, ft. =	130.00
$\gamma_s =$	1.01
$a_m =$	1.23
$b_m =$	-0.12

- Present
- Proposed
- Rigorous

The Problem





Adjustment above Mean

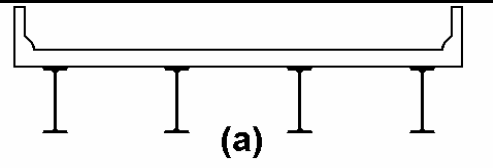
Slab-on-Steel I Girder Bridges

Type of Bridge	Action	Basic Method	Girder Location	Lanes Loaded	Figures	Analysis Factor Computations											
						Ratio of Means	Inverse	COV	No. of Std. Dev. Offset $\beta = 1$ - Used for Specification and Appendix			No. of Std. Dev. Offset $\beta = 0.5$ - For Reference			No. of Std. Dev. Offset $\beta = 0.0$ - For Reference		
									No. of Std. Dev. Offset	Computed Analysis Factor	Rounded Analysis Factor ($\beta = 1$)	No. of Std. Dev. Offset	Computed Analysis Factor	Rounded Analysis Factor ($\beta = 0.5$)	No. of Std. Dev. Offset	Computed Analysis Factor	Rounded Analysis Factor ($\beta = 0.0$)
									S/R	$(S/R)^{-1}$	V_{SR}	β	γ_a	γ_a (rounded)	β	γ_a	γ_a (rounded)
Steel I Girders (type a)	Shear	Calibrated Lever	Exterior	1 Lane	13c	1.006	0.994	0.056	1.0	1.050	1.05	0.5	1.022	1.00	0.0	0.994	1.00
				2 or More Lanes	14c	1.011	0.989	0.072	1.0	1.061	1.05	0.5	1.025	1.00	0.0	0.989	1.00
			Interior	1 Lane	15c	1.016	0.984	0.078	1.0	1.062	1.05	0.5	1.023	1.00	0.0	0.984	1.00
				2 or More Lanes	16c	1.015	0.985	0.116	1.0	1.101	1.10	0.5	1.043	1.05	0.0	0.985	1.00
	Moment	Calibrated Lever	Exterior	1 Lane	17c	1.004	0.996	0.086	1.0	1.082	1.10	0.5	1.039	1.05	0.0	0.996	1.00
				2 or More Lanes	18c	0.996	1.004	0.133	1.0	1.137	1.15	0.5	1.071	1.10	0.0	1.004	1.00
		Uniform Distribution	Interior	1 Lane	19c	0.993	1.007	0.198	1.0	1.205	1.20	0.5	1.106	1.10	0.0	1.007	1.00
				2 or More Lanes	20c	0.988	1.012	0.059	1.0	1.071	1.10	0.5	1.042	1.05	0.0	1.012	1.00
	Alternate Method for Moments																
	Moment	Calibrated Lever	Exterior	1 Lane	61c	1.004	0.996	0.086	1.0	1.082	1.10	0.5	1.039	1.05	0.0	0.996	1.00
				2 or More Lanes	62c	1.008	0.992	0.129	1.0	1.121	1.15	0.5	1.057	1.05	0.0	0.992	1.00
		Uniform Distribution	Interior	1 Lane	63c	1.008	0.992	0.099	1.0	1.091	1.10	0.5	1.042	1.05	0.0	0.992	1.00
2 or More Lanes				64c	0.988	1.012	0.059	1.0	1.071	1.10	0.5	1.042	1.05	0.0	1.012	1.00	

Proposed 4.6.2.2

Proposed Appendix C

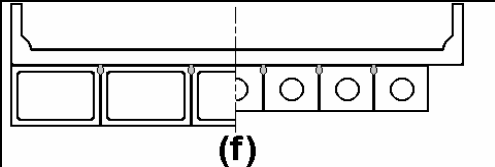
Quite Good (typical)



Adjustment above Mean Adjacent Boxes

Action	Basic Method	Girder Location	Lanes Loaded	Figures	Analysis Factor Computations												
					Ratio of Means	Inverse	COV	No. of Std. Dev. Offset $\beta = 1$ - Used for Specification and Appendix			No. of Std. Dev. Offset $\beta = 0.5$ - For Reference			No. of Std. Dev. Offset $\beta = 0.0$ - For Reference			
								No. of Std. Dev. Offset	Computed Analysis Factor	Rounded Analysis Factor ($\beta = 1$)	No. of Std. Dev. Offset	Computed Analysis Factor	Rounded Analysis Factor ($\beta = 0.5$)	No. of Std. Dev. Offset	Computed Analysis Factor		Rounded Analysis Factor ($\beta = 0.0$)
								S/R	$(S/R)^{-1}$	V_{SR}	β	γ_a	γ_a (rounded)	β	γ_a		γ_a (rounded)
Shear	Calibrated Lever	Exterior	1 Lane	53c	1.005	0.995	0.067	1.0	1.062	1.10	0.5	1.029	1.05	0.0	0.995	1.00	Proposed 4.6.2.2
			2 or More Lanes	54c	0.982	1.018	0.083	1.0	1.101	1.10	0.5	1.060	1.05	0.0	1.018	1.00	
		Interior	1 Lane	55c	0.975	1.026	0.251	1.0	1.277	1.30	0.5	1.151	1.15	0.0	1.026	1.00	
			2 or More Lanes	56c	0.987	1.013	0.174	1.0	1.187	1.20	0.5	1.100	1.10	0.0	1.013	1.00	
Moment	Calibrated Lever	Exterior	1 Lane	57c	0.975	1.026	0.245	1.0	1.271	1.30	0.5	1.148	1.15	0.0	1.026	1.00	
			2 or More Lanes	58c	0.980	1.020	0.149	1.0	1.169	1.20	0.5	1.095	1.10	0.0	1.020	1.00	
	Uniform Distribution	Interior	1 Lane	59c	0.991	1.009	0.405	1.0	1.414	1.45	0.5	1.212	1.20	0.0	1.009	1.00	
			2 or More Lanes	60c	0.989	1.011	0.087	1.0	1.098	1.10	0.5	1.055	1.05	0.0	1.011	1.00	
Alternate Method for Moments																	
Moment	Alternate Method	Exterior	1 Lane	81c	0.978	1.022	0.273	1.0	1.295	1.30	0.5	1.159	1.15	0.0	1.022	1.00	Proposed Appendix C
			2 or More Lanes	82c	0.980	1.020	0.149	1.0	1.169	1.20	0.5	1.095	1.10	0.0	1.020	1.00	
	Uniform Distribution	Interior	1 Lane	83c	0.978	1.022	0.111	1.0	1.133	1.15	0.5	1.078	1.10	0.0	1.022	1.00	
			2 or More Lanes	84c	0.989	1.011	0.087	1.0	1.098	1.10	0.5	1.055	1.05	0.0	1.011	1.00	

Good (typical) but Some are high



Analysis Simplification Factors

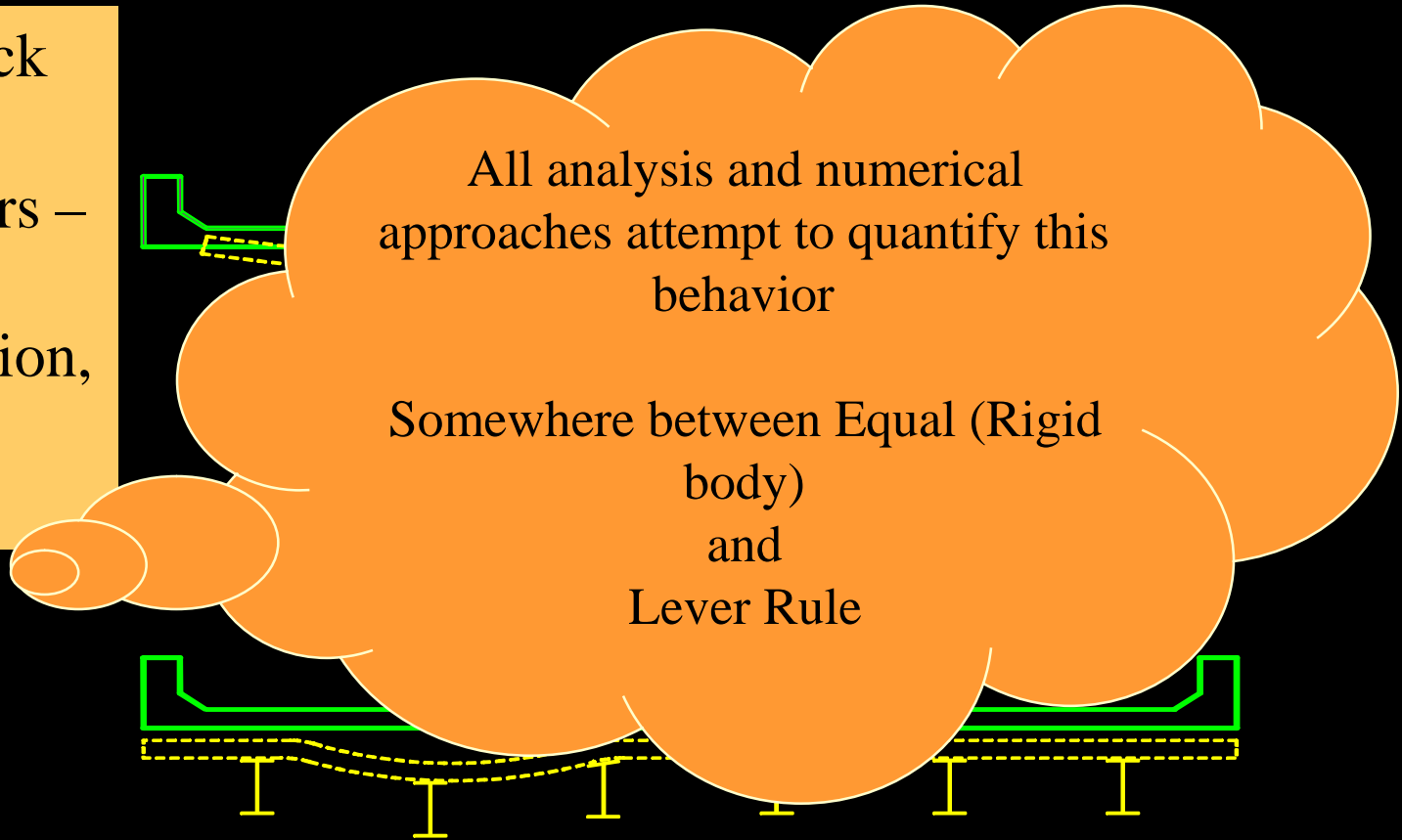
Type of Bridge	Action	Basic Method	Girder Location	Lanes Loaded	Figures	Analysis Factor Computations													
						Ratio of Means	Inverse	COV	No. of Std. Dev. Offset $\beta = 1$ - Used for Specification and Appendix			No. of Std. Dev. Offset $\beta = 0.5$ - For Reference			No. of Std. Dev. Offset $\beta = 0.0$ - For Reference				
									No. of Std. Dev. Offset	Computed Analysis Factor	Rounded Analysis Factor ($\beta = 1$)	No. of Std. Dev. Offset	Computed Analysis Factor	Rounded Analysis Factor ($\beta = 0.5$)	No. of Std. Dev. Offset	Computed Analysis Factor		Rounded Analysis Factor ($\beta = 0.0$)	
									S/R	$(S/R)^{-1}$	$V_{S/R}$	β	γ_a	γ_a (rounded)	β	γ_a		γ_a (rounded)	β
Steel I Girders (type a)	Shear	Calibrated Lever	Exterior	1 Lane	13c	1.006	0.994	0.056	1.0	1.050	1.05	0.5	1.022	1.00	0.0	0.994	1.00	Proposed 4.6.2.2	
				2 or More Lanes	14c	1.011	0.989	0.072	1.0	1.061	1.05	0.5	1.025	1.00	0.0	0.989	1.00		
			Interior	1 Lane	15c	1.016	0.984	0.078	1.0	1.062	1.05	0.5	1.023	1.00	0.0	0.984	1.00		
				2 or More Lanes	16c	1.015	0.985	0.116	1.0	1.101	1.10	0.5	1.043	1.05	0.0	0.985	1.00		
	Moment	Calibrated Lever	Exterior	1 Lane	17c	1.004	0.996	0.086	1.0	1.082	1.10	0.5	1.039	1.05	0.0	0.996	1.00		
				2 or More Lanes	18c	0.996	1.004	0.133	1.0	1.137	1.15	0.5	1.071	1.10	0.0	1.004	1.00		
		Uniform Distribution	Interior	1 Lane	19c	0.993	1.007	0.198	1.0	1.205	1.20	0.5	1.106	1.10	0.0	1.007	1.00		
				2 or More Lanes	20c	0.988	1.012	0.059	1.0	1.071	1.10	0.5	1.042	1.05	0.0	1.012	1.00		
	Alternate Method for Moments																		
	Moment	Calibrated Lever	Exterior	1 Lane	61c	1.004	0.996	0.086	1.0	1.082	1.10	0.5	1.039	1.05	0.0	0.996	1.00		Proposed Appendix C
				2 or More Lanes	62c	1.008	0.992	0.129	1.0	1.121	1.15	0.5	1.057	1.05	0.0	0.992	1.00		
		Alternate Method	Interior	1 Lane	63c	1.008	0.992	0.099	1.0	1.091	1.10	0.5	1.042	1.05	0.0	0.992	1.00		
2 or More Lanes				64c	0.988	1.012	0.059	1.0	1.071	1.10	0.5	1.042	1.05	0.0	1.012	1.00			

Basics Behavior

Stiff Deck
relative
to Girders –
better
distribution,
more
uniform

All analysis and numerical
approaches attempt to quantify this
behavior

Somewhere between Equal (Rigid
body)
and
Lever Rule



PI Bias for a Simple Method

- Analytically based approach
- Canadian Specification
Orthotropic Plate Theory
 α – β space

Supporting Components	Type of Deck	AASHTO Letter (see Table 4.6.2.2.1-1)	Analytical Group Type	Number of Bridges		
				NBI 1990 - most recent	NBI Total Inventory	Number Skewed
Steel Beam	Cast in place concrete slab, precast concrete	a	slab on girders	14275 30.0%	151398	66263 43.8%
Closed Steel or Precast Concrete Boxes	Cast in place concrete slab	b	slab on girders	1464 3.1%	4847	3075 63.4%
Open Steel or Precast Concrete Boxes	Cast-in-place concrete slab, precast concrete slab	c	slab on girders	1811 3.8%	5718	3546 62.0%
Cast-in-Place Concrete Multicell Boxes	Monolithic Concrete	d	slab on girders	360 0.8%	5633	3677 65.3%
Cast-in-Place Concrete Tee Beam	Monolithic Concrete	e	slab on girders	629 1.3%	28106	11340 40.3%
Precast Solid, Voided, or Cellular Concrete Boxes with Shear Keys	Cast-in-place concrete overlay	f	monolithic slab and girders	5329 11.2%	17766	9514 53.6%
Precast Solid, Voided, or Cellular Concrete Boxes with Shear Keys and with or without Transverse Posttensioning	Integral Concrete	g	monolithic slab and girders	933 2.0%	2848	1396 49.0%
Precast Concrete Channel Sections with Shear Keys	Cast-in-place concrete overlay	h	slab on girders	40 0.1%	895	82 9.2%
Precast Concrete Double Tee Section with Shear Keys and with or without Transverse Posttensioning	Integral Concrete	i	slab on girders	208 0.4%	851	300 35.3%
Precast Concrete Tee Section with Shear Keys and with or without Transverse Reinforcement	Integral Concrete	j	slab on girders	208 0.4%	851	300 35.3%
Precast Concrete I or Bulb- Tee Sections	Cast-in-place concrete, precast concrete	k	slab on girders	14168 29.8%	53285	26691 50.1%
Wood Beams	Cast-in-place concrete or plank, glued/spiked panels or stressed wood	l	slab on girders	1571 3.3%	26629	4213 15.8%
Slabs	Not Applicable	Not Applicable	Slabs	6799 14.3%	55869	20728 37.1%
			Total:	47587 100.0%	353845	150825 42.6%

NBI Database

Using Distribution Factors

$$M_{design(rigorous\ estimate)} = M_{beam} g$$

Affine Transformation (example)

$$y_1 = 1.63x - 0.2644$$

$$y_2 = \frac{y_1}{1.63} = \frac{1.63x}{1.63} - \frac{0.2644}{1.63} = x - 0.1622$$

Unit
slope

$$y_3 = y_2 + 0.1622 = \frac{y_1}{1.63} + 0.1622 = x - 0.1622 + 0.1622 = x$$

Unit
slope

$$g_{(\text{Calibrated lever rule})} = a_m g_{\text{Lever rule}} + b_m$$

where

$$a_m = \frac{1}{1.63} = 0.61 \text{ and } b_m = 0.1622$$

and

$g_{(\text{Calibrated lever rule})}$ is the calibrated distribution factor, and

$g_{(\text{Lever rule})}$ is the lever rule distribution factor computed with the typical manual approach.

Observations

- Several errors in user test cases with present method
- User typically applied proposed correctly
- Misunderstandings have been clarified with Revision 1 modifications
- Revised DOT computations have been provided with rigorous in many cases