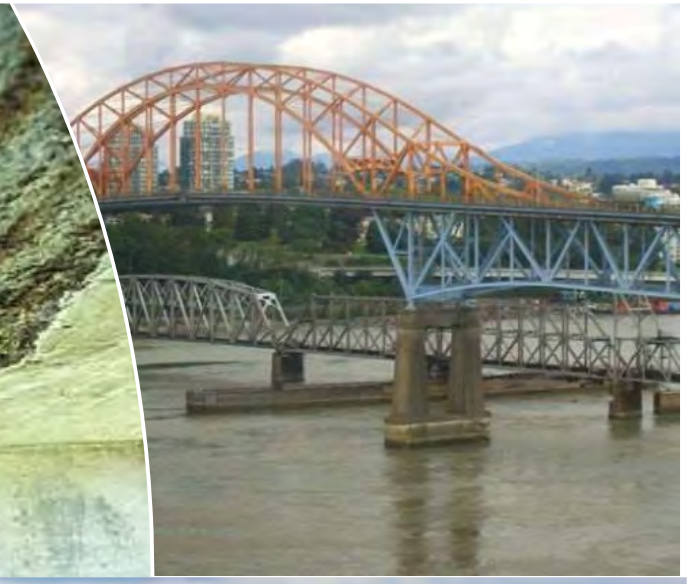
Development of Explicit Equations for Live Load Capacity Factor (LLCF) under Combined/Coupling Load Effects

Application in BF75555 – Steel Rigid Frame Bridge Load Evaluation

Tao Yong, M.Eng., P.Eng.
Senior Engineer

Lungui Li, Ph.D., P.Eng., P.E.
Project Engineer

Why evaluate bridges

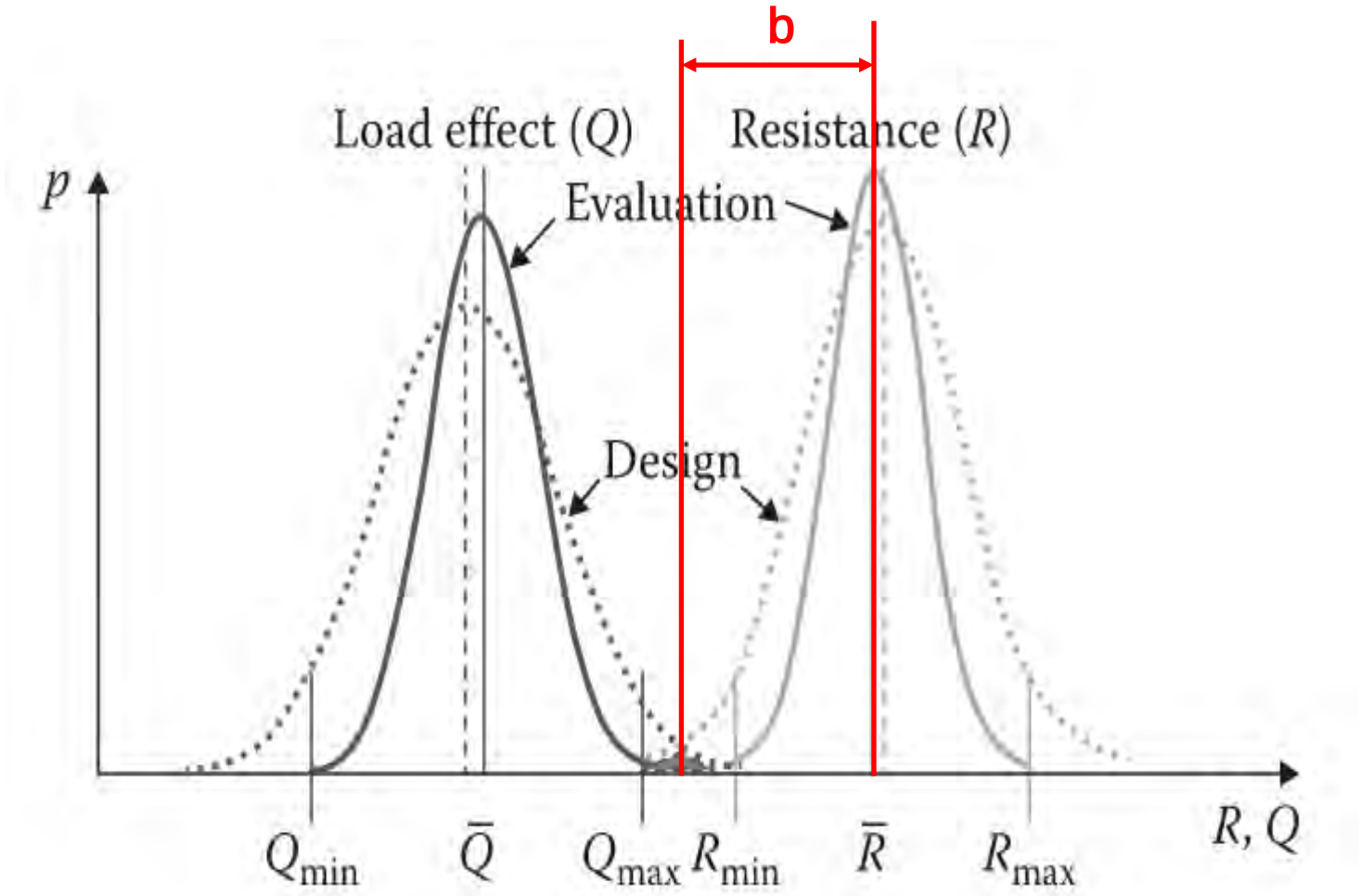


- Capacity is unknown or codes change
- Legal or permit vehicle loadings change
- Deterioration or damage of bridge components

Fundamental differences between evaluation and design

Evaluation of Existing Bridges	Design of New Bridges
Specific dead loads and vehicle loads	**Codified** combinations of design loads
Load distribution is determined by the **as-built condition** of the structural system, the **actual positions of travel lanes**	Load distribution among structural components is based on **provisions of design specifications**
The **remaining strength** of the materials and structural components after aging and deterioration over time	The **full strength** of materials and structural components based designed cross-section

Safety Margin and Reliability Index b Between Evaluation and Design



Target Reliability Index b and Probability of Failure P_f

Table 14.5
Target reliability index, β, for normal traffic and for PA, PB, PS, and PC traffic
(See Clauses 14.12.1 and 14.12.5.)

System behaviour category	Element behaviour category	Inspection level		
		INSP1	INSP2	INSP3
S1	E1	4.00	3.75	3.75
	E2	3.75	3.50	3.25
	E3	3.50	3.25	3.00
S2	E1	3.75	3.50	3.50
	E2	3.50	3.25	3.00
	E3	3.25	3.00	2.75
S3	E1	3.50	3.25	3.25
	E2	3.25	3.00	2.75
	E3	3.00	2.75	2.50

TABLE 14.1 Corresponding Values of β and p_f

β	p_f
1.0	1.59×10^{-1}
2.0	2.3×10^{-2}
2.5	6.2×10^{-3}
3.0	1.3×10^{-3}
3.5	2.33×10^{-4}
4.0	3.17×10^{-5}

3.5 for new design in AASHTO
3.75 for new design in CHBDC

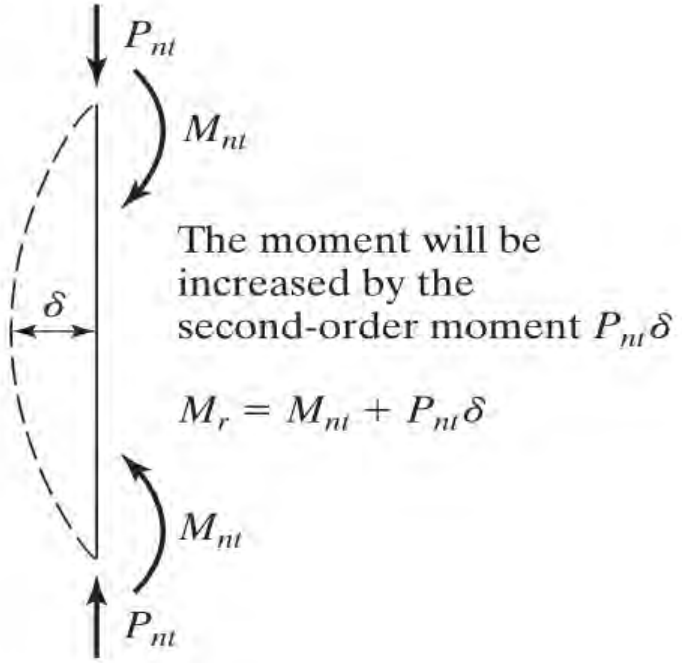
Live Load Capacity Factor (LLCF

$$F = \frac{UR_r - \Sigma\alpha_D D - \Sigma\alpha_A A}{\alpha_L L(1 + I_D)}$$

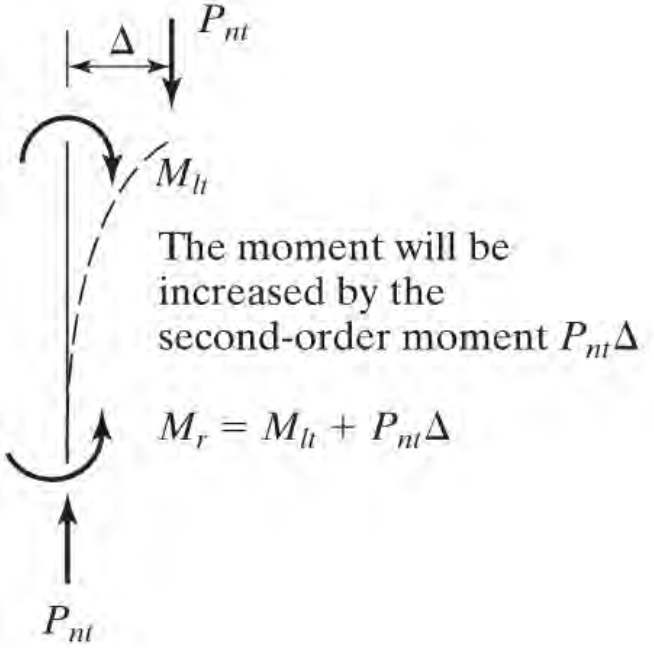
U: Resistance adjustment factor

aD, aA, aL: Load factors – determined by target reliability index b

Members Subject to Compression and Bending



Moment amplification of a column that is braced against sidesway.



Column in an unbraced frame.

This Explicit Equation cannot be used to establish the rating factor directly

$$F = \frac{UR_r - \Sigma\alpha_D D - \Sigma\alpha_A A}{\alpha_L L(1 + I_D)}$$

Combined/Coupling Loadings in Consideration

Combined Loading Case 1:
shear and bending

$$0.727\frac{M_f}{M_r} + 0.455\frac{V_f}{V_r} < 1.0$$

Combined Loading Case 2:
axial tension and bending

$$\frac{T_f}{T_r} + \frac{M_f}{M_r} \leq 1.0$$

Coupling Loading Case 3:
axial compression and bending
(class 1 and 2 section)

$$\frac{C_f}{C_r} + 0.85\frac{U_{1x}M_{fx}}{M_{rx}} + \beta\frac{U_{1y}M_{fy}}{M_{ry}} \leq 1.0$$

Explicit Equations for Combined Loading Case 1

Combined Loading Case 1: Shear and Bending

$$0.727\frac{M_f}{M_r} + 0.455\frac{V_f}{V_r} < 1.0$$

$$F_{m,v} = \frac{U_m M_r U_v V_r - \left(0.727 U_v V_r M_{fD} + 0.455 U_m M_r V_{fD}\right)}{\left(0.727 U_v V_r M_{fL} + 0.455 U_m M_r V_{fL}\right)(1+I)}$$

Truck Load

$$F_{m,v} = \frac{U_m M_r U_v V_r - \left[0.727 U_v V_r \left(M_{fD} + M_{fLl}\right) + 0.455 U_m M_r \left(V_{fD} + V_{fLl}\right)\right]}{\left(0.727 U_v V_r M_{fLt} + 0.455 U_m M_r V_{fLt}\right)}$$

Lane Load

Explicit Equations for Combined Loading Case 2

Combined Loading Case 2: Axial Tension and Bending

$$\frac{T_f}{T_r} + \frac{M_f}{M_r} \leq 1.0$$

$$F_{t,m} = \frac{U_t T_r U_m M_r - \left(U_m M_r T_{fD} + U_t T_r M_{fD}\right)}{\left(U_m M_r T_{fL} + U_t T_r M_{fL}\right)(1+I)}$$

Truck Load

$$F_{t,m} = \frac{U_t T_r U_m M_r - \left[U_m M_r \left(T_{fD} + T_{fLl}\right) + U_t T_r \left(M_{fD} + M_{fLl}\right)\right]}{\left(U_m M_r T_{fLt} + U_t T_r M_{fLt}\right)}$$

Lane Load

Explicit Equations for Coupling Loading Case 3

Combined Loading Case 3: axial compression and one-way bending (class 1 and 2 sections)

$$\frac{C_f}{C_r} + 0.85\frac{U_{1x}M_{fx}}{M_{rx}} \leq 1.0$$

$$F_{c,m} = \frac{U_c C_r U_m M_r - \left(U_m M_r C_{fD} + 0.85 U_{1x} U_c C_r M_{fD}\right)}{\left(U_m M_r C_{fL} + 0.85 U_{1x} U_c C_r M_{fL}\right)(1+I)}$$

Truck Load

$$F_{c,m} = \frac{U_c C_r U_m M_r - \left[U_m M_r \left(C_{fD} + C_{fLl}\right) + 0.85 U_{1x} U_c C_r \left(M_{fD} + M_{fLl}\right)\right]}{\left(U_m M_r C_{fLt} + 0.85 U_{1x} U_c C_r M_{fLt}\right)}$$

Lane Load

Explicit Equations for Coupling Loading Case 4

Combined Loading Case 3: axial compression and two-way bending (class 1 and 2 sections)

$$\frac{C_f}{C_r} + 0.85\frac{U_{1x}M_{fx}}{M_{rx}} + \beta\frac{U_{1y}M_{fy}}{M_{ry}} \leq 1.0$$

$$F_{c,m} = \frac{U_c C_r U_{mx} M_{rx} U_{my} M_{ry} - \left(U_{mx} M_{rx} U_{my} M_{ry} C_{fD} + 0.85 U_{1x} U_c C_r U_{my} M_{ry} M_{fxD} + \beta U_{1y} U_c C_r U_{mx} M_{rx} M_{fyD}\right)}{\left(U_{mx} M_{rx} U_{my} M_{ry} C_{fL} + 0.85 U_{1x} U_c C_r U_{my} M_{ry} M_{fxL} + \beta U_{1y} U_c C_r U_{mx} M_{rx} M_{fyL}\right)(1+I)}$$

Truck Load

er to updat is fo

$$F_{c,m} = \frac{U_c C_r U_{mx} M_{rx} U_{my} M_{ry} - \left[U_{mx} M_{rx} U_{my} M_{ry}\left(C_{fD} + C_{fLl}\right) + 0.85 U_{1x} U_c C_r U_{my} M_{ry}\left(M_{fxD} + M_{fxLl}\right) + \beta U_{1y} U_c C_r U_{mx} M_{rx}\left(M_{fyD} + M_{fyLl}\right)\right]}{\left(U_{mx} M_{rx} U_{my} M_{ry} C_{fLt} + 0.85 U_{1x} U_c C_r U_{my} M_{ry} M_{fxLt} + \beta U_{1y} U_c C_r U_{mx} M_{rx} M_{fyLt}\right)(1+I)}$$

Lane Load

Verification with AASHTO

If $\frac{P_u}{P_r} > 0.2$

$$\frac{P_u}{P_r} + \frac{8}{9}\frac{M_{ucx}}{M_{rx}} \le 1.0$$

$$RF = \frac{1-\gamma_D\left[\frac{P_{DL}}{P_r}+\frac{8}{9}\delta_b\left(\frac{M_{DL}}{M_r}\right)\right]}{\gamma_L\left[\frac{P_{LL+IM}}{P_r}+\frac{8}{9}\delta_b\left(\frac{M_{LL+IM}}{M_r}\right)\right]}$$

If $\frac{P_u}{P_r} < 0.2$

$$\frac{P_u}{2P_r} + \frac{M_u}{M_r} \le 1.0$$

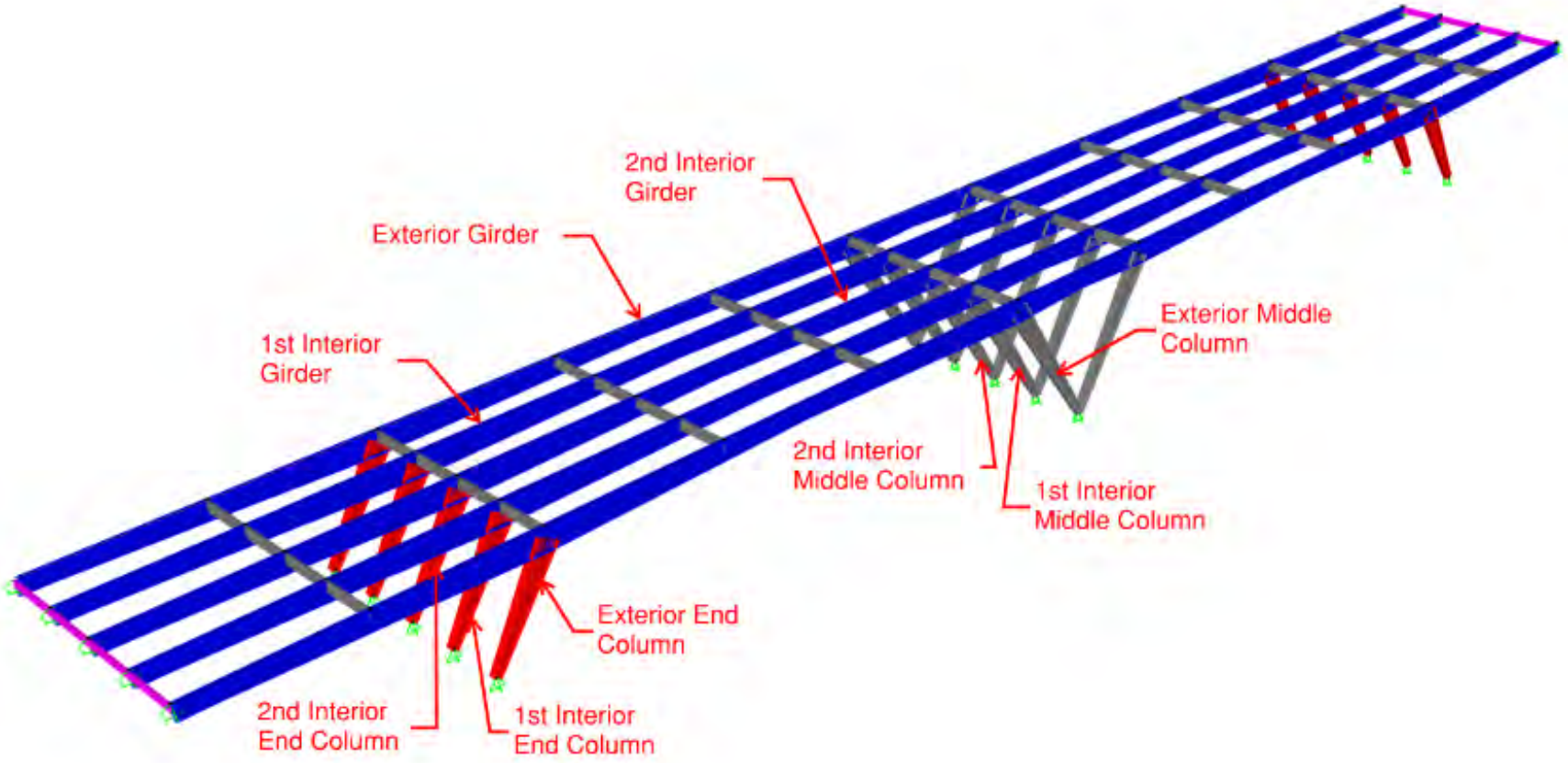
$$RF = \frac{1-\gamma_D\left[\frac{P_{DL}}{2P_r}+\delta_b\left(\frac{M_{DL}}{M_r}\right)\right]}{\gamma_L\left[\frac{P_{LL+IM}}{2P_r}+\delta_b\left(\frac{M_{LL+IM}}{M_r}\right)\right]}$$

Bridge Description – BF 75555

Inspection Condition

Evaluation Members

- Exterior Girder
- 1st Interior Girder
- 2nd Interior Girder
- Exterior End Column
- 1st Interior End Column
- 2nd Interior End Column
- Exterior Middle Column
- 1st Interior Middle Column
- 2nd Interior Middle Column
- Side Pedestal
- Middle Pedestal



Determination of Target Reliability Index **b**

Interior/Exterior Girders:

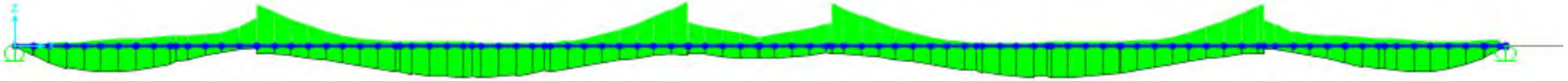
- System behaviour S3, moment/shear in continuous girder spans with 4 or more girder lines
- Element behaviour E1, shear fail elastic buckling without tension field action
- Inspection level INSP2, inspection is to the satisfaction of the evaluator

Middle/End Columns:

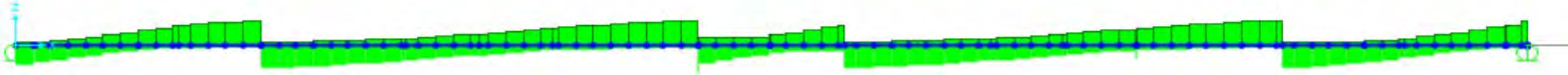
- System behaviour S3, moment/shear in continuous girder spans with 4 or more girder lines
- Element behaviour E1, elastic buckling of steel compression members
- Inspection level INSP2, inspection is to the satisfaction of the evaluator

Combination Loading Effects along Girders

Moment

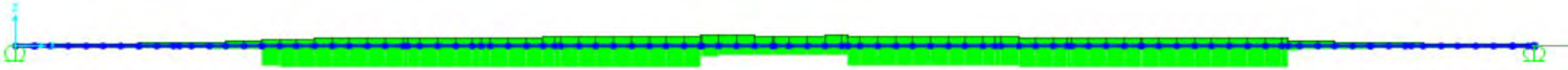


Shear



slide master to upd

Axial Force



Combination Loading Effects along Columns

Moment

Shear

Axial Force

Live Load Capacity Factor (LLCF) for Exterior Girder

Item	Location	Station (m)	CS1 Truck	CS2 Truck	CS3 Truck	CS1 Lane	CS2 Lane	CS3 Lane
M-	Pier 1/Sect Change/Frame 2	12.8	2.47	1.60	1.52	3.11	2.01	1.91
M+	Sect Change/Middle	54.7	2.44	1.99	2.05	3.41	2.78	2.86
Shear	Pier 1/Sect Change/Frame 2	12.8	4.79	3.34	3.23	7.04	4.91	4.75
Shear	Abutment 2	78.9	3.72	2.98	3.32	5.53	4.44	4.93
Tension+M	Sect Change/Middle	27.2	1.57	1.26	1.30	2.62	2.10	2.17
Compression+M	Sect Change/Middle	24.2	1.35	1.04	1.03	2.31	1.74	1.63

Live Load Capacity Factor (LLCF) for Exterior Middle Column

Item	Location	CS1 Truck	CS2 Truck	CS3 Truck	CS1 Lane	CS2 Lane	CS3 Lane
M	Fixed End	6.10	3.96	3.79	8.71	5.66	5.41
Shear	Pined End	8.85	5.76	5.52	12.97	8.44	8.08
Compression+M	Fixed End	2.41	1.53	1.40	3.39	2.14	1.95

Acknowledgment

Alberta Transportation and Economic Corridors:

- Red Deer Region
- Technical Standards Branch

WSP:

- Ming Jiao
- Yong Tao

Thank you

wsp.com