Lean on Bracing

Design and Construction

Design

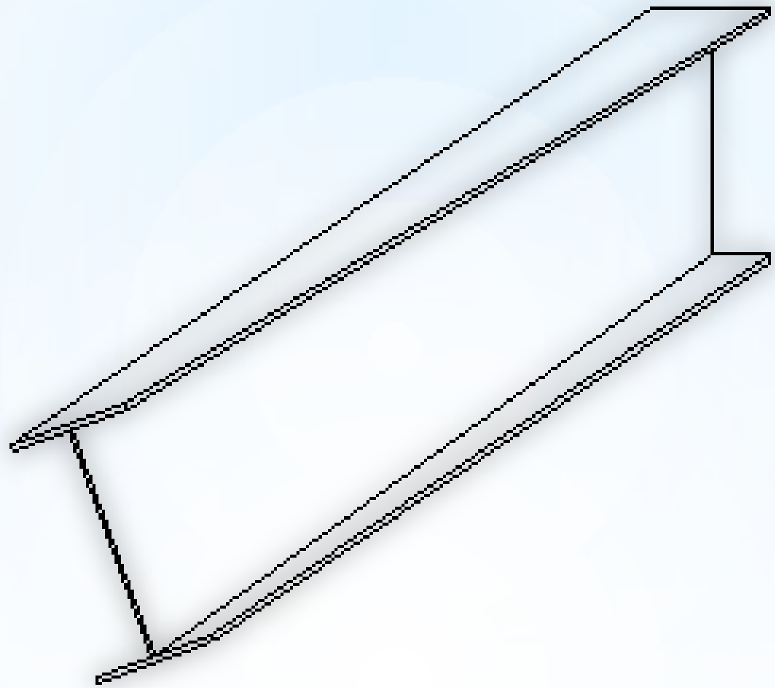
* What is Lean-on-Bracing?
* Benefits of Lean-on-Bracing
* How to design a Lean-on-Bracing System

Construction & Research Results

* US 82 Underpass @ 9th Street
* US 82 Underpass @ 19th Street EB & WB

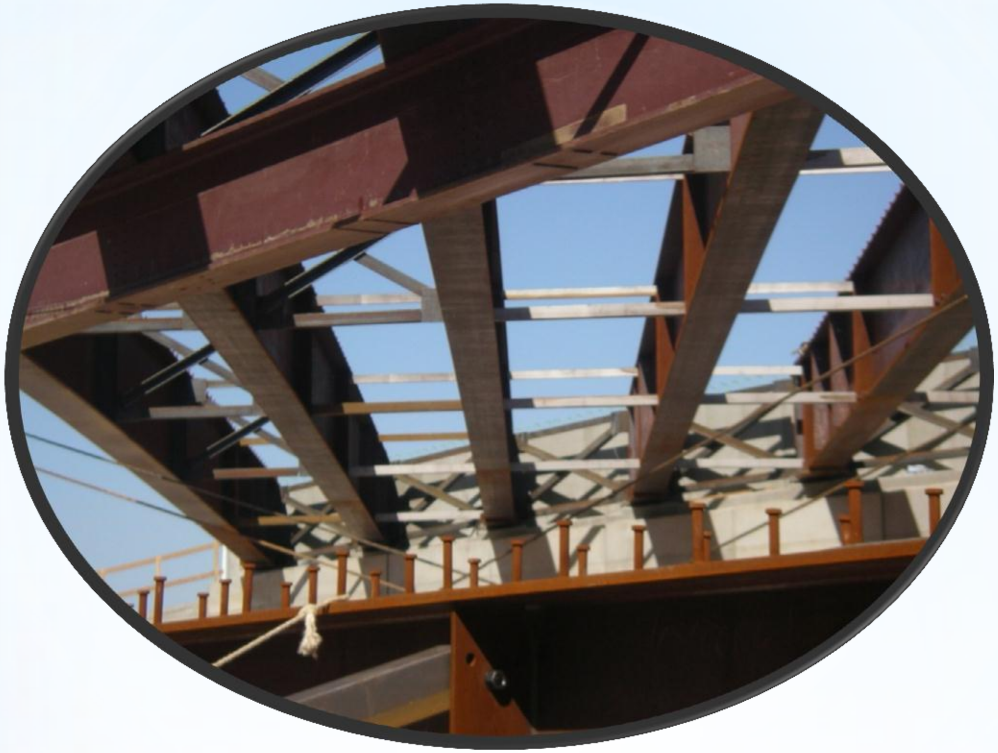
Design of Lean on Bracing

Research Report 1772-1



Lateral Torsional Buckling

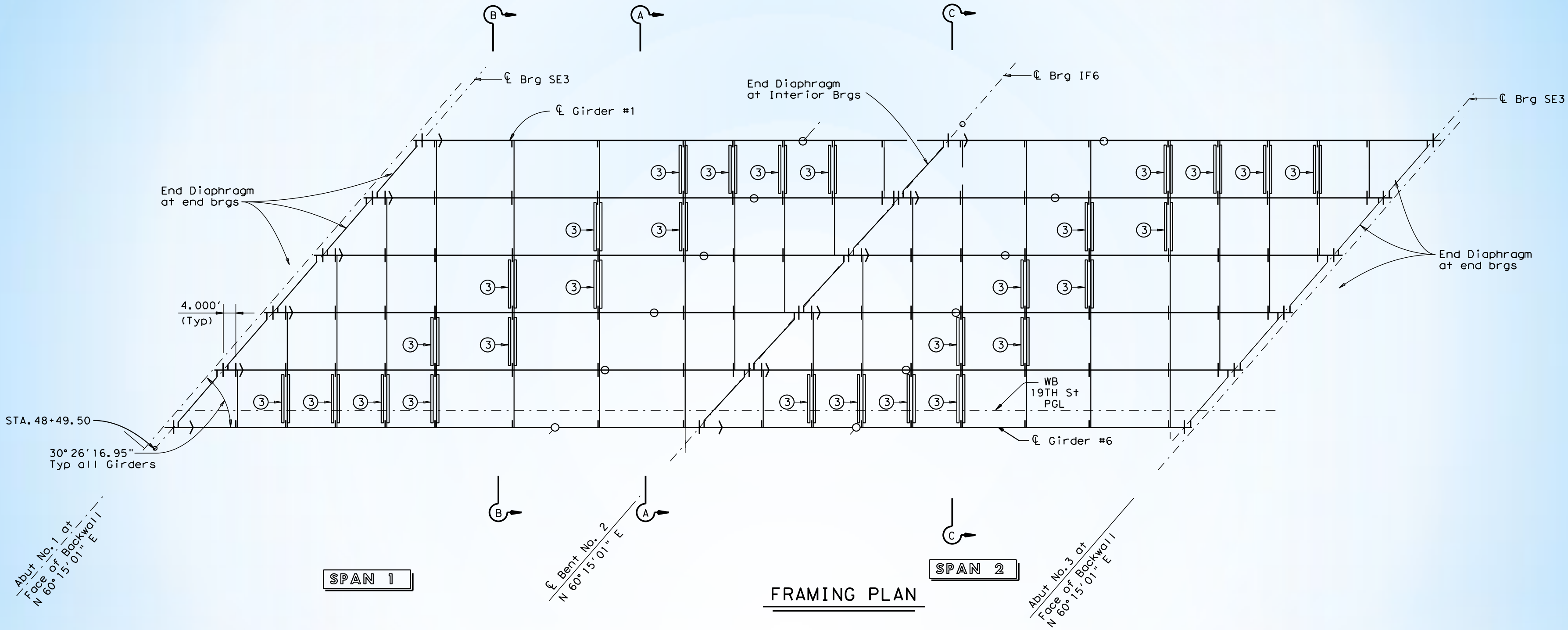
Critical Stage for Lateral Torsional Buckling



What is Lean-on-Bracing?

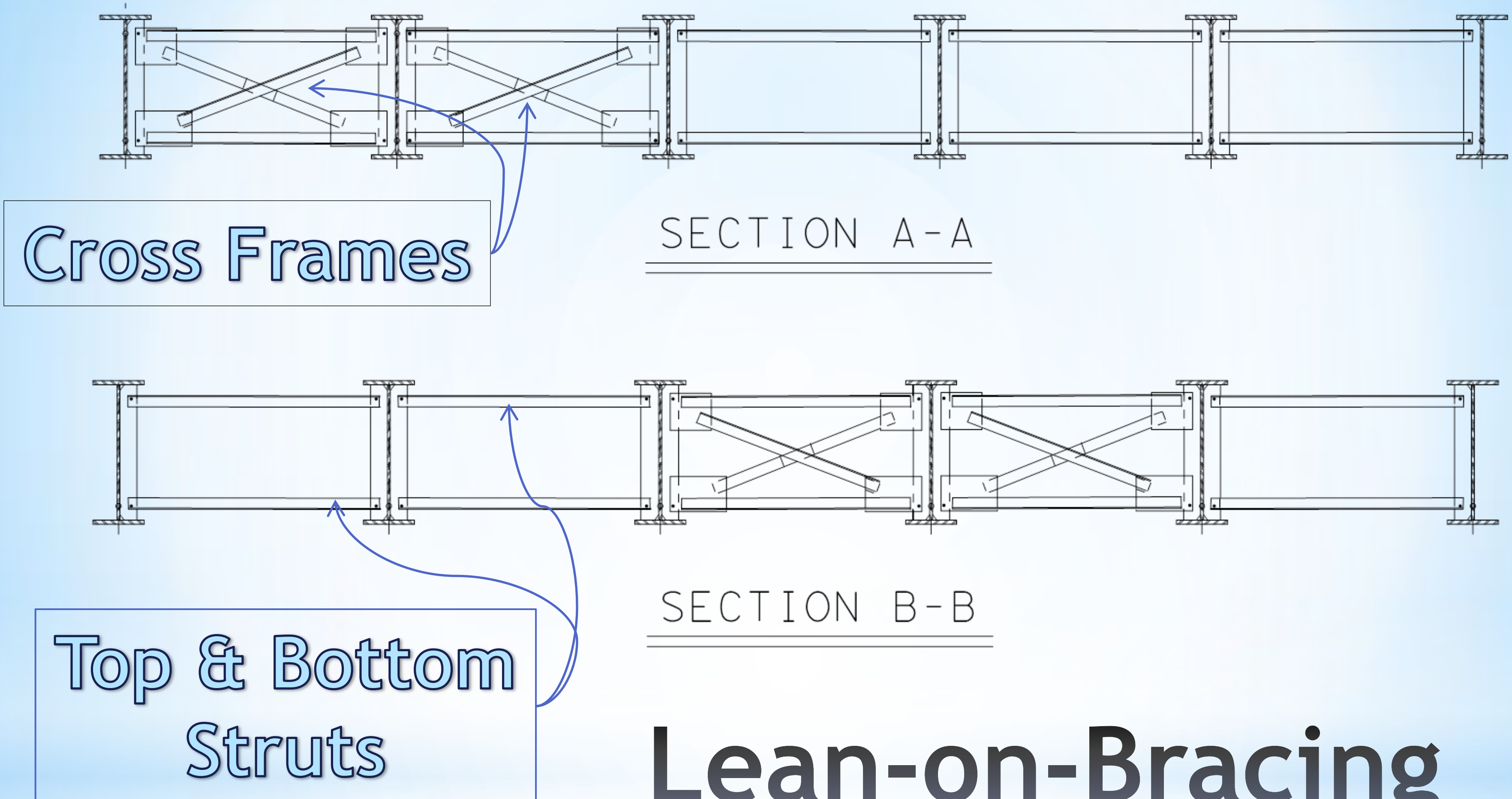
* Fewer cross frames – Significant Cost Savings
* Improved Fatigue Performance
* Reduced Construction Timeline
* Simplifies Future Inspections

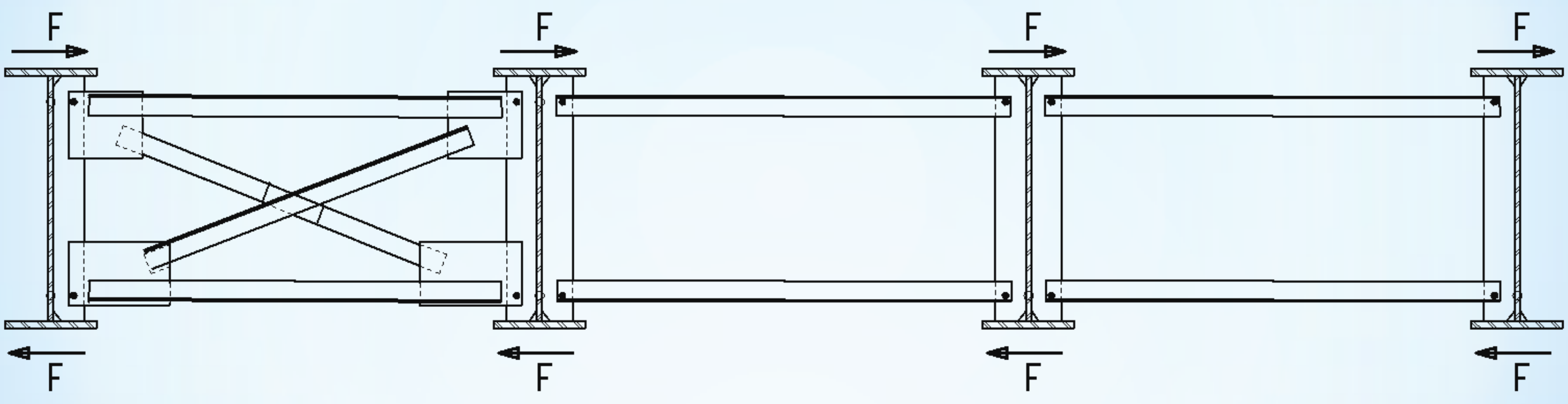
Benefits



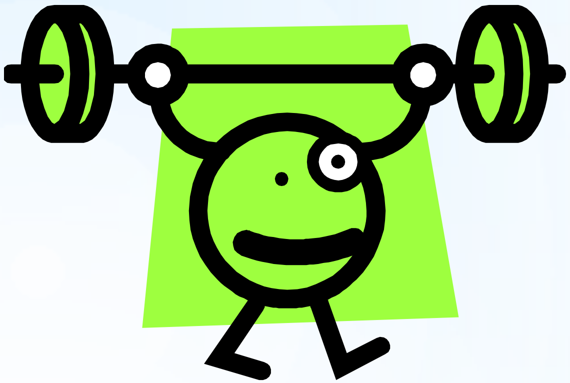
Cross Frame layout for US 82 Underpass @ 19th Street WB

Lean-on-Bracing





Force Distribution



Lean-On-Bracing Stiffness & Strength Requirements

$$\frac{1}{\beta_b} + \frac{1}{\beta_g} + \frac{1}{\beta_{sec}} = \frac{1}{\beta_t}$$

β_t = Torsional system brace stiffness

β_b = Brace stiffness

β_{sec} = Cross Section stiffness (web distortional stiffness)

β_g = In-plane girder stiffness

Brace System Stiffness

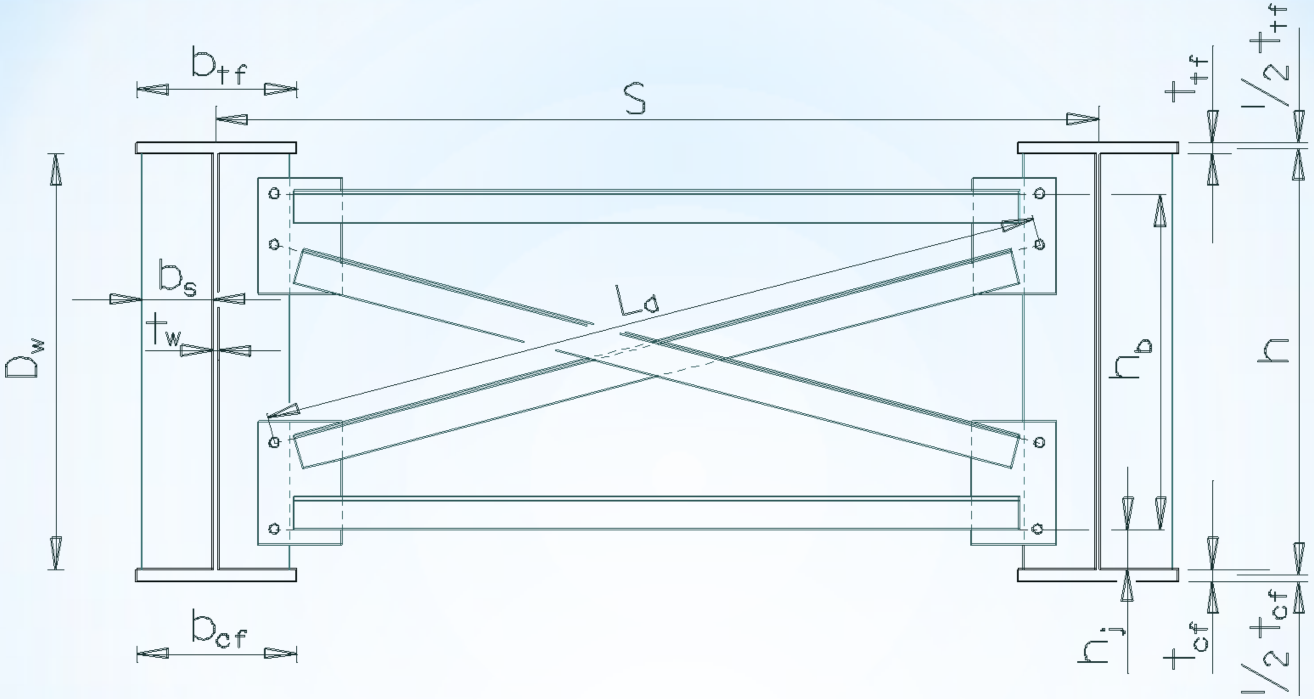
Torsional System Brace Stiffness

$$\beta_{ti} := \frac{1.2 \cdot L \cdot (Mu)^2}{C_{bb}^{\,2} \cdot n \cdot I_{eff} \cdot E}$$

Ideal Total Stiffness

$$\beta_{t} := \frac{3.2 \cdot L}{C_{bb}^{\,2} \cdot n \cdot I_{eff} \cdot E} \cdot \left(M_{dl} + M_{constll}\right)^2$$

Required System Stiffness



$$\beta_{sec} := 0.5 \cdot 3.3 \cdot \frac{E}{h_j} \cdot \left(\frac{h}{h_j}\right)^2 \cdot \left[\frac{1.5 \cdot h_j \cdot t_w{}^3}{12} + \left(\frac{t_s \cdot b_s{}^3}{12}\right)\right]$$

Cross Section Stiffness

$$\beta_g := \frac{12 \cdot (n_g - 1)^2 \cdot S^2 \cdot E \cdot I_x}{n_g \cdot L^3}$$

In-plane girder stiffness

$$\beta_{b1} := \frac{E \cdot S^2 \cdot {h_b}^2 \cdot A_b}{n_g \cdot {L_d}^3 + S^3 \cdot \left(\frac{n_g}{2}\right)^2}$$

Braces @ Mid-span

$$\beta_{b1} := \frac{E \cdot S^2 \cdot {h_b}^2 \cdot A_b}{n_g \cdot {L_d}^3 + S^3 \cdot \left(n_g - 1\right)^2}$$

Braces @ supports

Provided Brace Stiffness

$$\beta_{b2} := \frac{1}{\left(\frac{1}{\beta_t}\right) - \left(\frac{1}{\beta_g}\right) - \left(\frac{1}{\beta_{sec}}\right)}$$

$$A_b := \frac{\beta_{b2}}{\beta_{b1}}$$

Brace Area Required for Stiffness

$$\Phi_o := \frac{L_b}{500 \cdot h}$$

$$M_{br} = F_{br}\, h_b = \beta_t\, \Phi_o$$

$$F := \beta_t \cdot \frac{\Phi_o}{h_b}$$

Strength Requirements

$$F_d := \frac{n_g \cdot F \cdot L_d}{N_c \cdot S}$$

Force in Diagonal

$$F_s := (n_g - 1) \cdot \frac{F}{N_c}$$

Force in Struts @ Supports

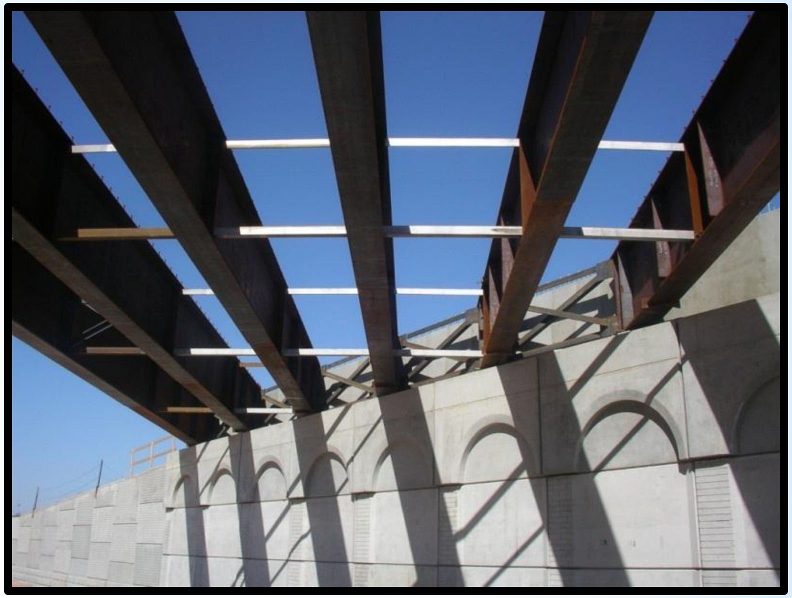
$$F_s := \left(\frac{n_g}{N_c \cdot 2}\right) \cdot F$$

Force in Struts @ Mid-Span

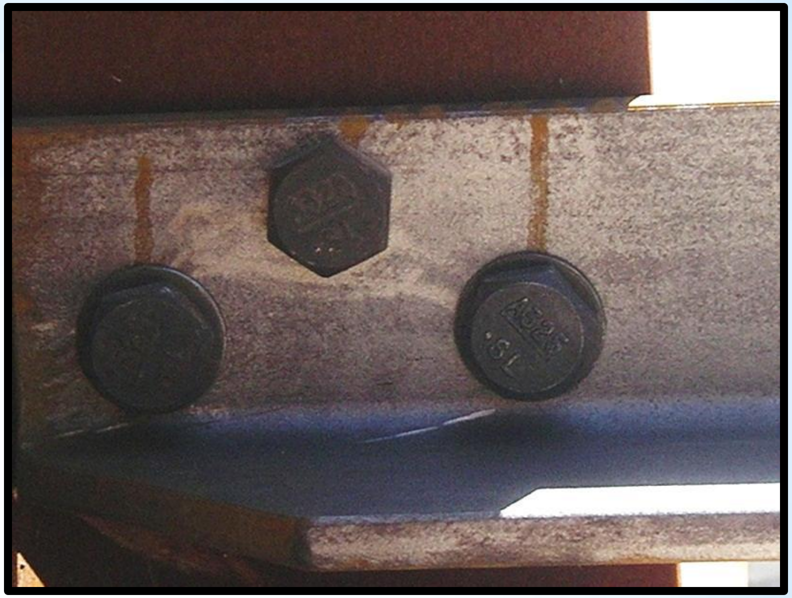
Angle Forces

Construction of Lean on Bracing

US 82 Underpass at 9th Street



US 82 Underpass at 9th Street



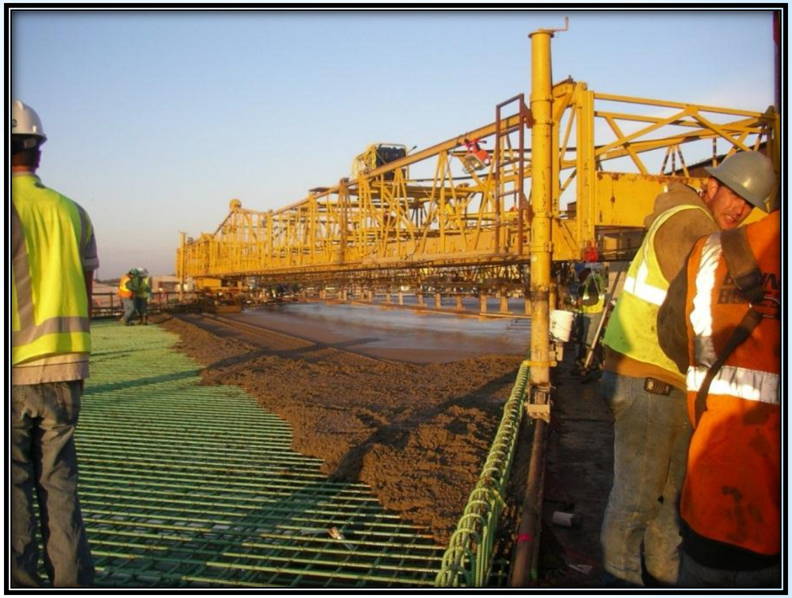
US 82 Underpass at 9th Street

US 82 Underpass at 19th Street EB & WB

US 82 Underpass at 19th Street WB

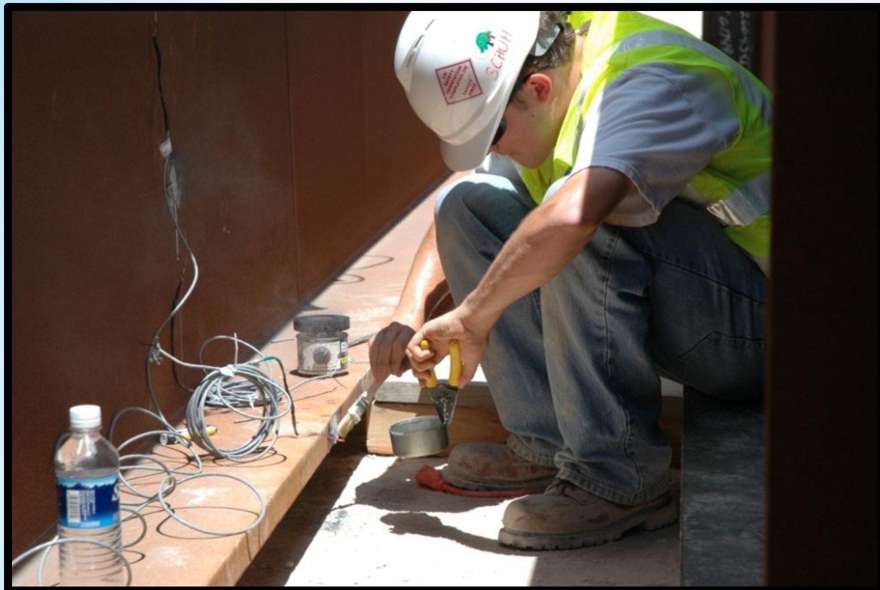
US 82 Underpass at 19th Street WB

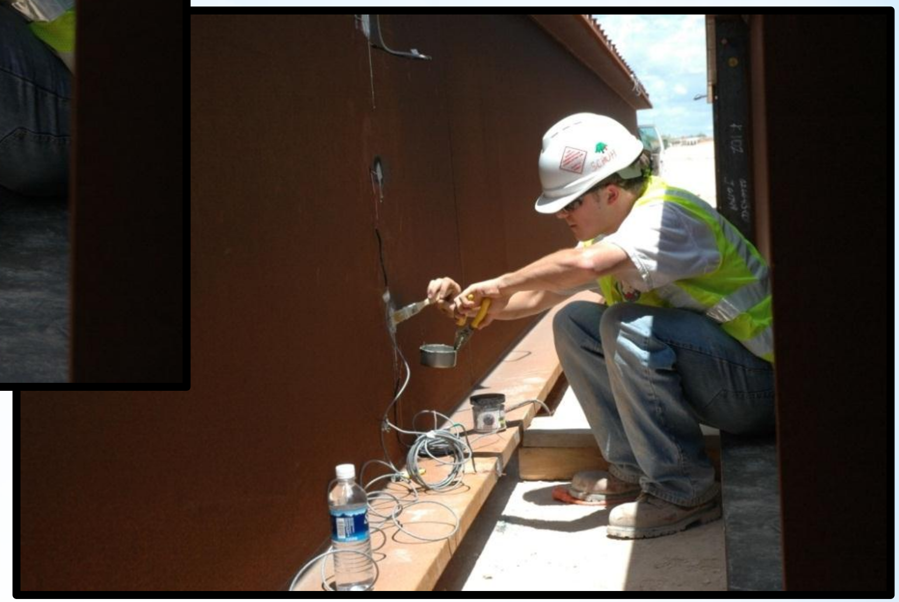


Deck Placement

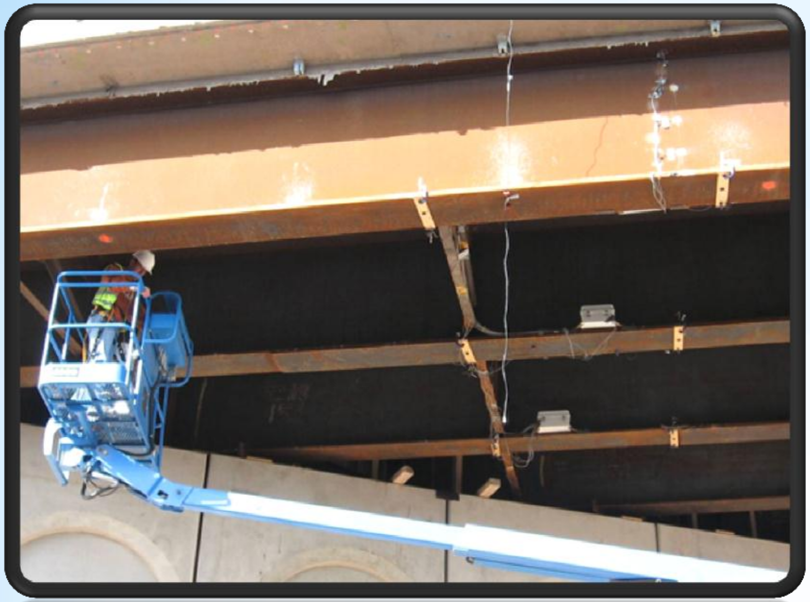
Instrumentation & Live Load Testing

Cross Frame Instrumentation





Girder Instrumentation

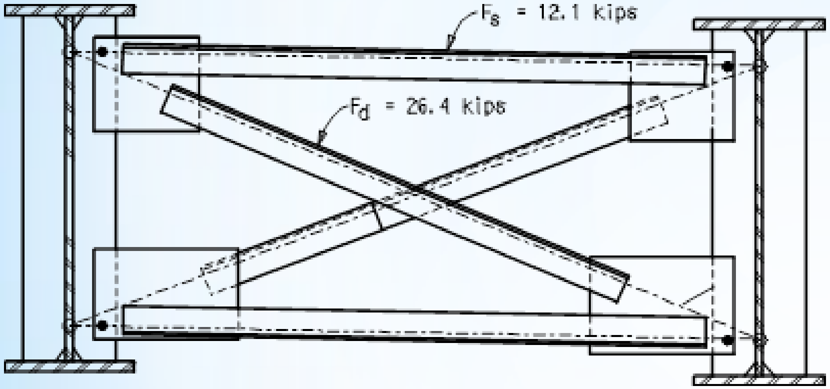


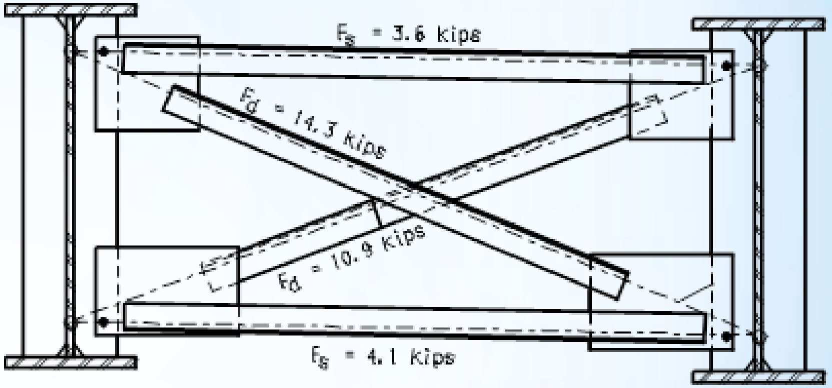
* Changes in Strain
* Girder Rotations
* Girder Deflections

Recorded Measurements

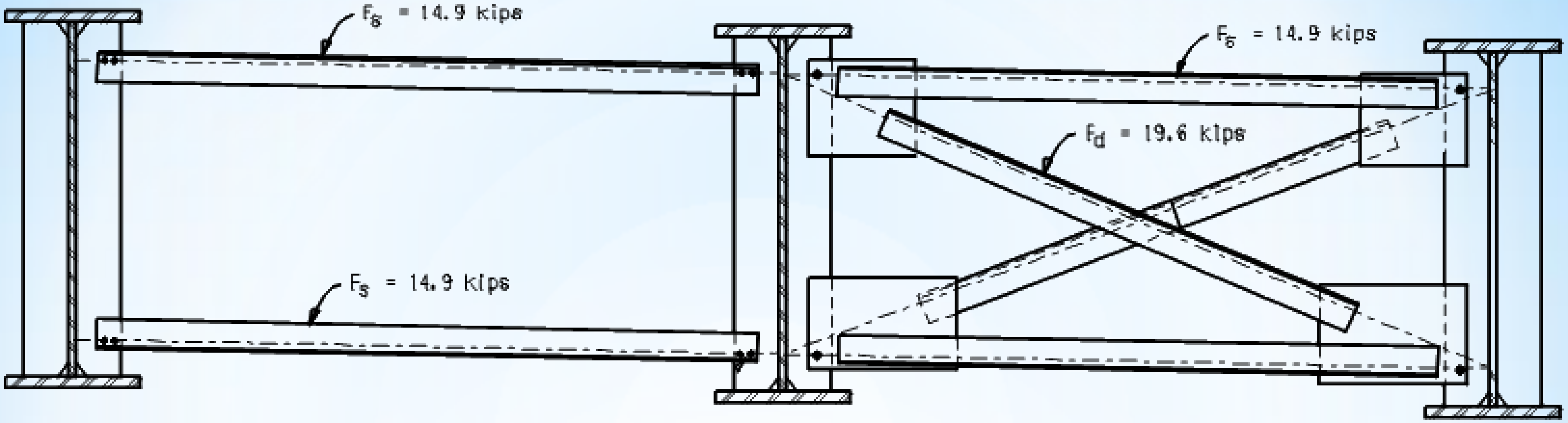
Predicted

Actual

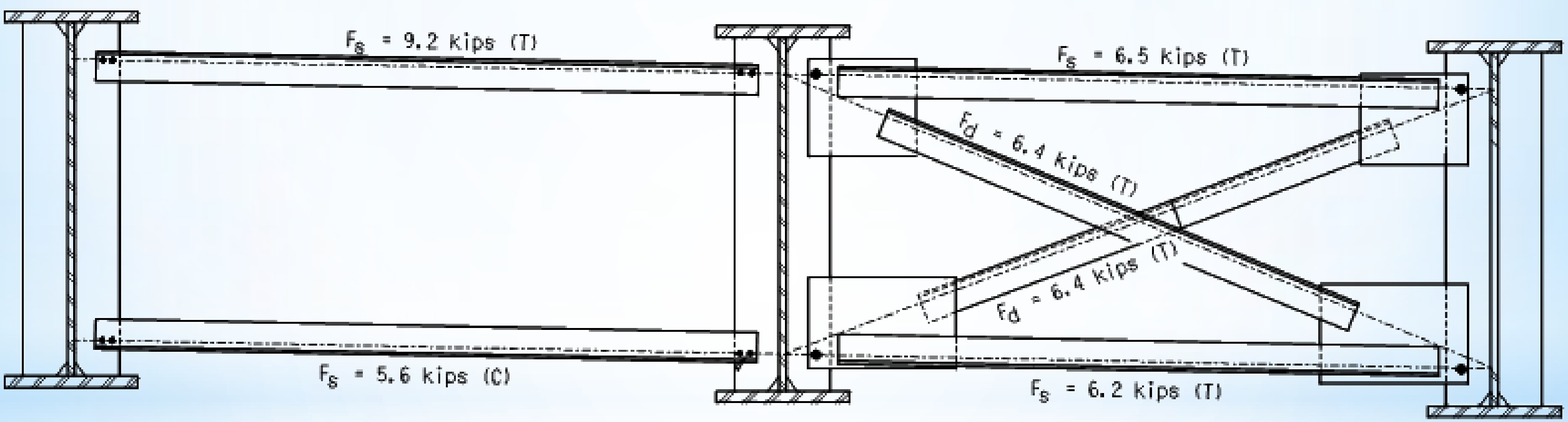




Mid-Span Cross Frame Forces



Predicted



Actual

End Cross Frame Forces

Live Load Testing

Load Test	X2-DT (kips)	Location (ft.)	X2-DB (kips)	Location (ft.)
Staggered Ahead	0.7	350	-27.8	100
Staggered Back	0.45	220	8.26	220
Side-by-Side South	0.6	350	6.8	240
Side-by-Side North	0.6	140	8.9	120
End to End South	0.5	140	-25.7	120
End to End Central	-0.28	220	10.3	100
Load Test	X3-DT (kips)	Location (ft.)	X3-DB (kips)	Location (ft.)
Staggered Ahead	18.5	140	-11.2	140
Staggered Back	11.7	150	-3.6	150
Side-by-Side South	11.4	140	-3.4	140
Side-by-Side North	-15.3	140	13.8	140
End to End South	5.5	190	-5.6	180
End to End Central	-14	140	36.1	140

Live Load Test Results

* Design of Lean-on-Bracing is not difficult
* Improves fatigue performance
* Significant cost savings
* Reduces construction time
* It is a conservative method of torsional bracing that works

Summary

Questions?

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* Anthony Battistini, M.S.E.

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