Erection of Skewed Bridges: Keys to an Effective Project




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HIGH STEEL STRUCTURES INC.

An Affiliate of High Industries Inc.

Introduction

CASE STUDY 1

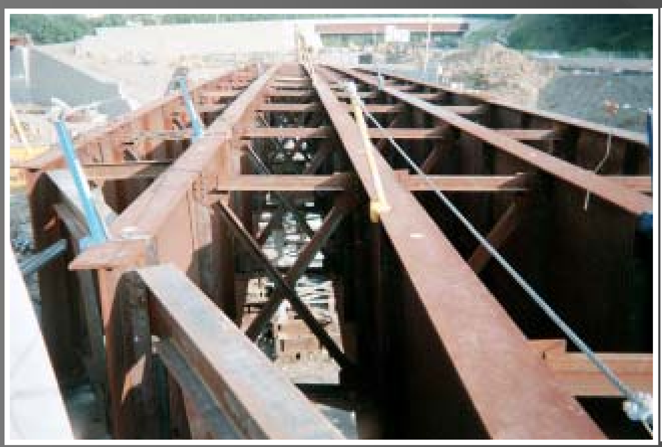
I-87 NB Connector over I-287 EB
Erector: Yonkers Contracting Co.

CASE STUDY 2

SR 0031 over PA Turnpike
Somerset Co., PA
Erector: High Steel Structures, Inc.

CASE STUDY 3

SR 0028 OVER CSX RR
Erector: Alvarez, Inc./High Steel Joint effort



HSSI Job No. NY 01066

HSSI Job No. PA 01004

HSSI Job No. PA 3127

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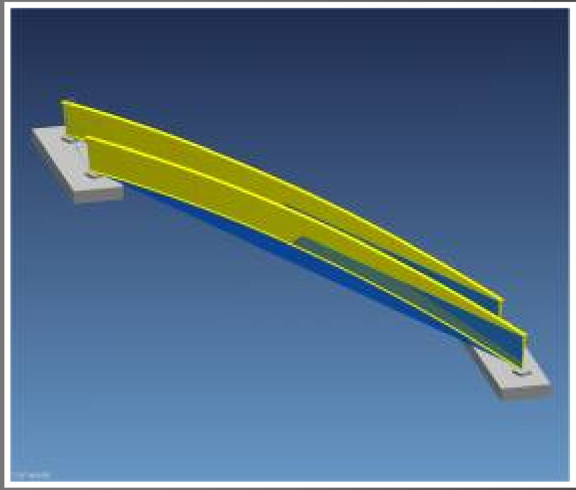
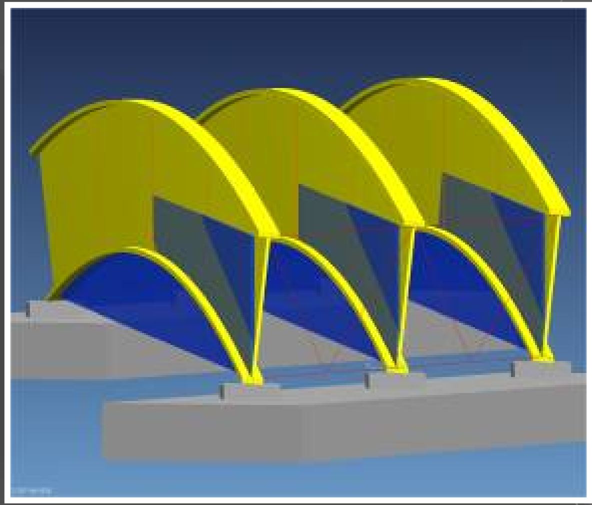
Case Study 1

Single-Span Skewed Structure. Each end twists in opposite directions



Span: 265 ft



Skew: 65 º (PA 25 º)

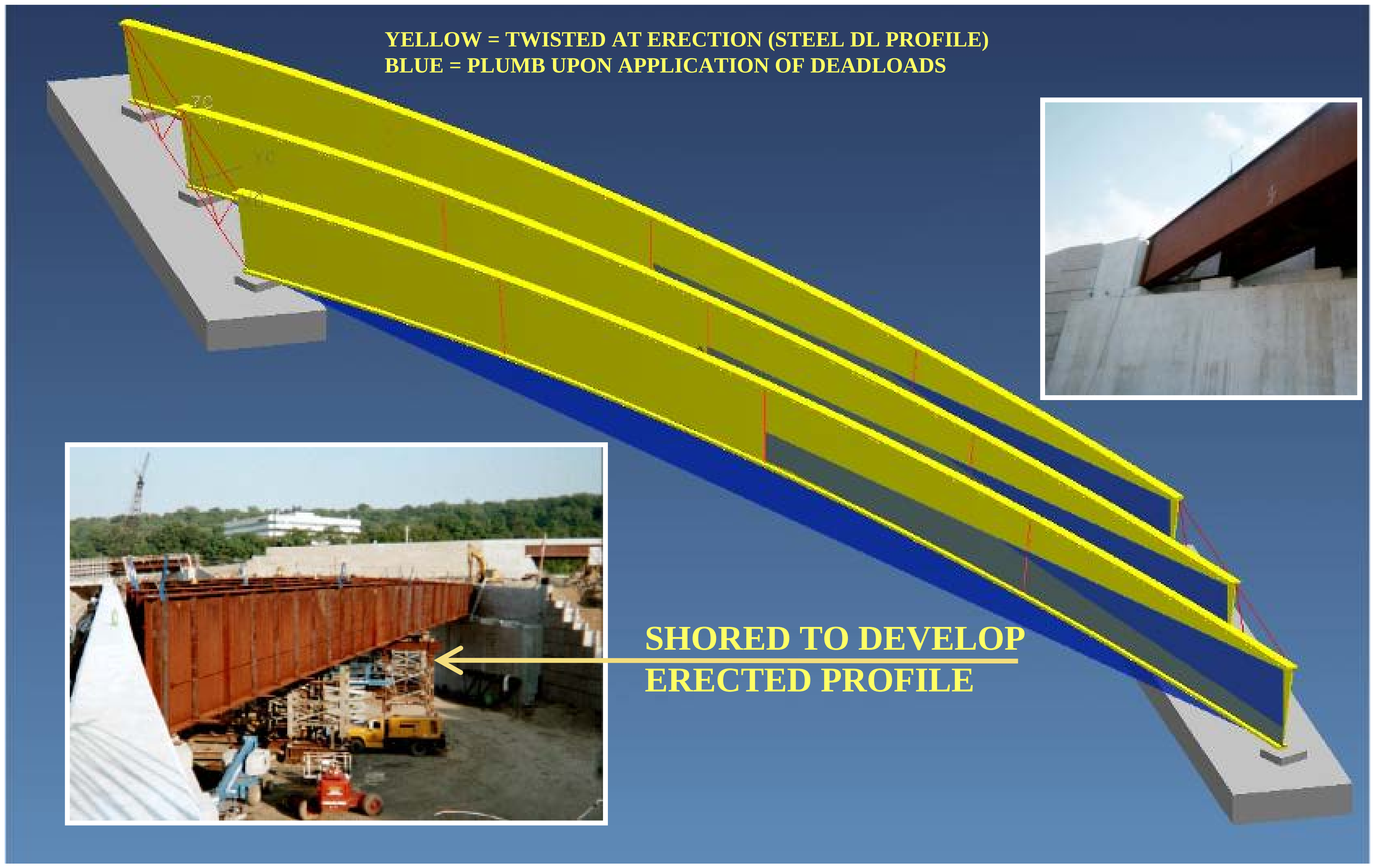
Web Layover: 2½” : 120”
(4” at full no-load profile)

Restores to plumb at application of dead loads

I-87 NB Connector over I-287 EB

Erector: Yonkers Contracting Co.

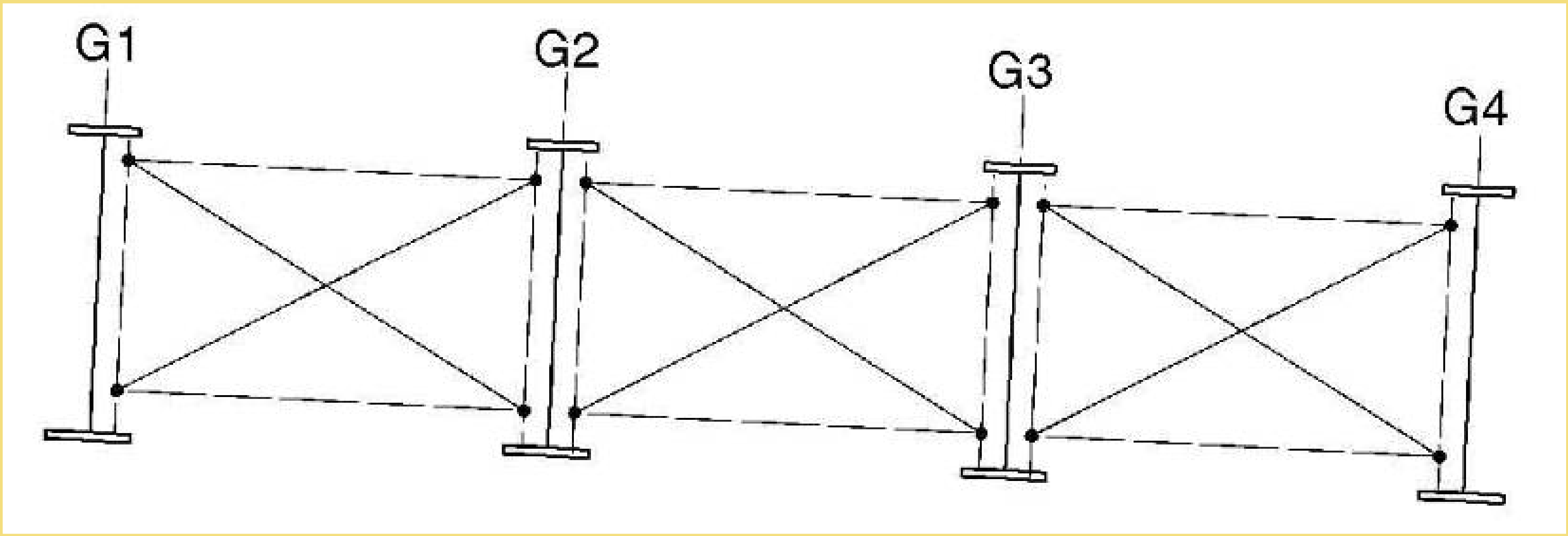
LONG-SPAN, DEEP, HIGHLY SKEWED STRUCTURES TEND TO UN-TWIST AS DEADLOAD DEFLECTIONS OCCUR.



I-87 NB Connector over I-287 EB

Erector: Yonkers Contracting Co.

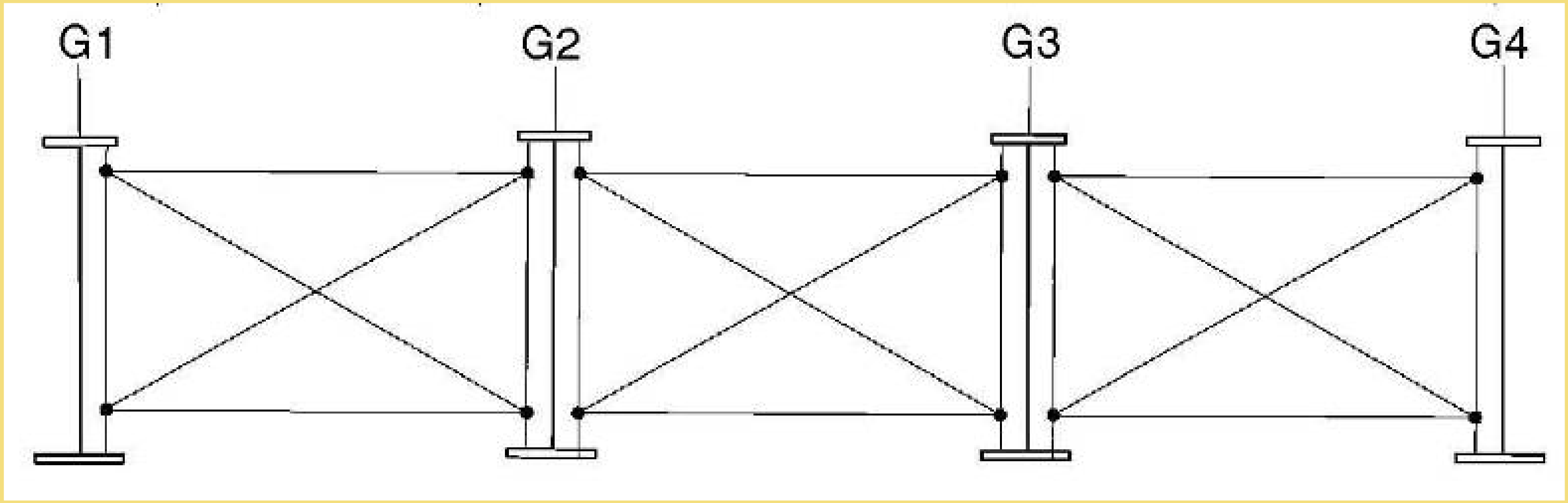
Skewed Bridge Erection



Steel Dead Load

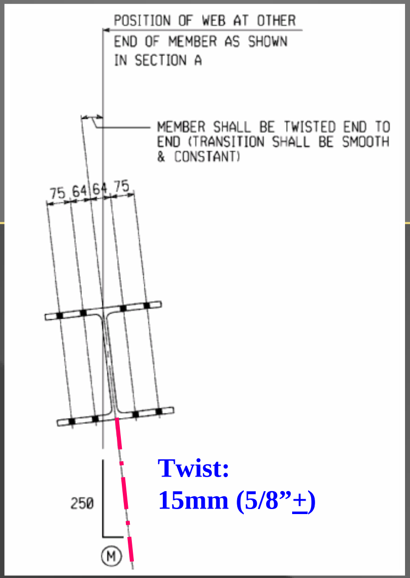
Source: AASHTO/NSBA Steel Bridge Collaboration G12.1-2003, Fig. 1.6.1.B
Guidelines for Design for Constructibility (see www.steelbridges.org)

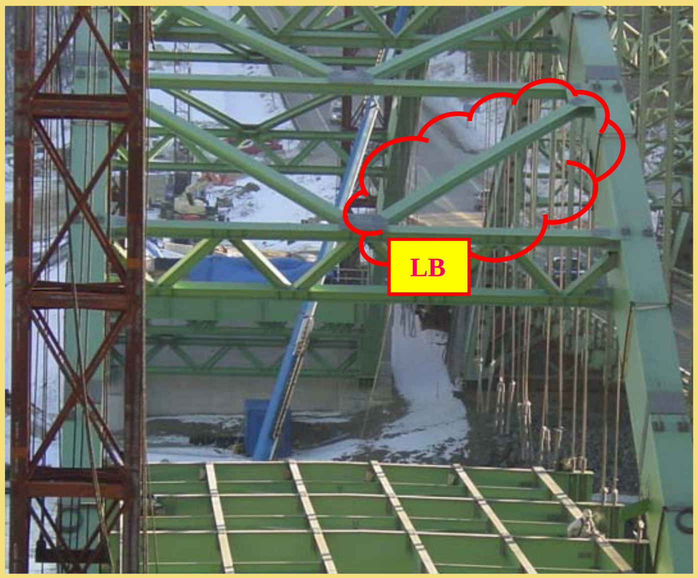
Skewed Bridge Erection



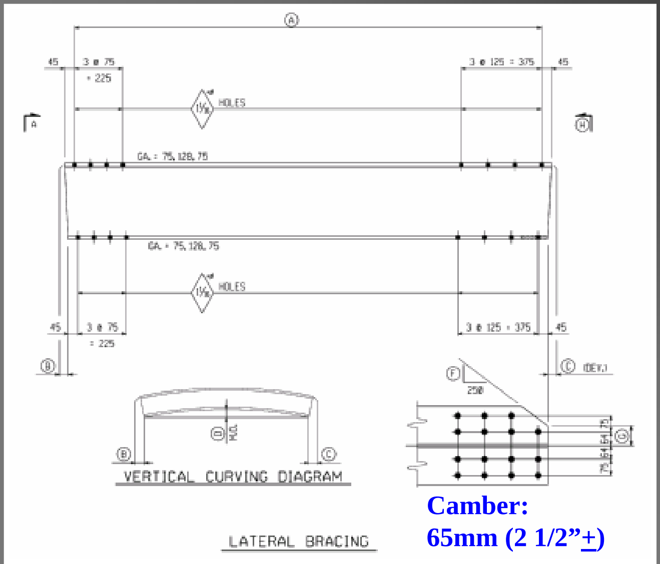
Complete Dead Load

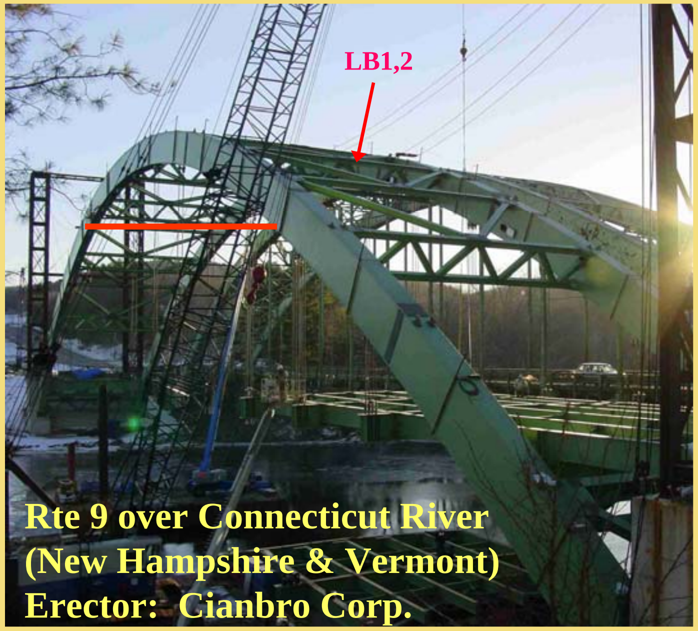
Twisted Arch Lateral Bracing





	Metric	English
Section	W360x134	W14x99
d	356	14 1/8
t_w	11	1/2
b_f	369	14 5/8
t_f	18	3/4
	(mm)	(in)
L	9.94 m	33 ft

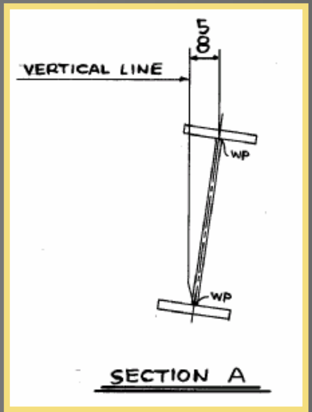


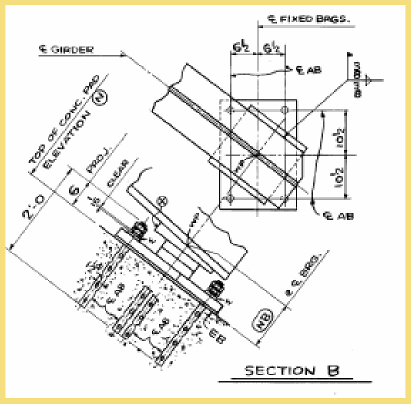


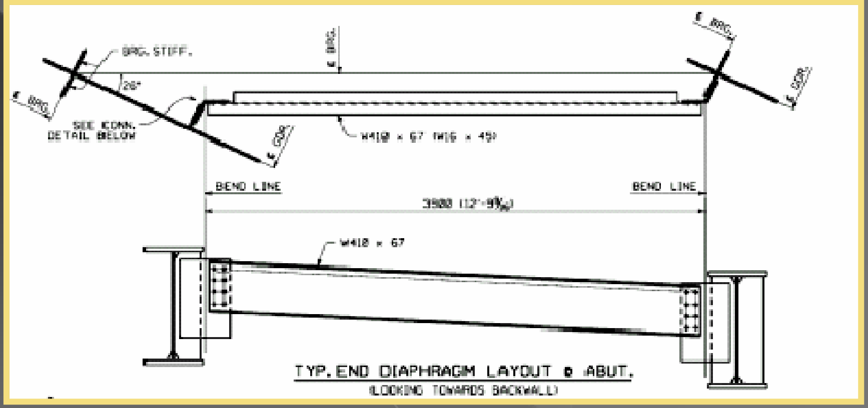
Detailing and Fabrication for Severe Skew

ERECTOR NOTE:

WEB LAYOVER IS SHOWN AT THE COMPLETION OF STEEL ASSEMBLY. GIRDERS WILL ROTATE TO VERTICAL AFTER THE CONCRETE SLAB IS PLACED.

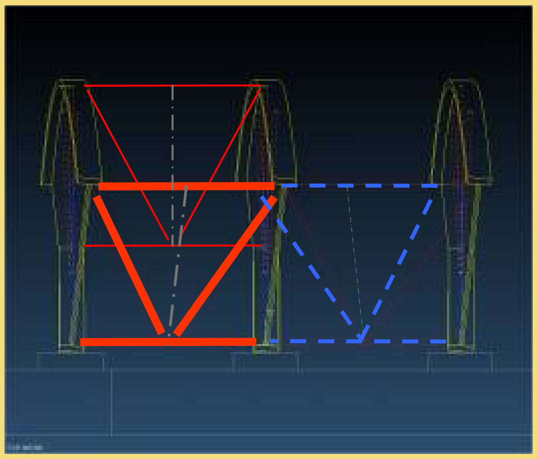






- DETAILER CONFIRMS IF OWNER WANTS STRUCTURE PLUMB AT ERECTION OR "FINAL POSITION"
- DETAILED TO <u>FINAL</u> POSITION: DURING ERECTION, CROSSFRAMES FORCE/TWIST THE GIRDER WEBS OUT OF PLUMB.

GIRDER WEB LAYOVER IS COMPUTED PURELY AS A GEOMETRIC EFFECT, BASED ON:



- Span, L
- Skew, Θ
- Dead Load Camber (especially, concrete DL), δ_{CONC}
- Girder Depth, D

GIRDER END ROTATION IS COMPUTED.

Ref. NYSDOT's Elastomeric Bearing Design Manual (1979), p. 15:

$\Theta_{STEEL} = (4\delta_{STEEL})/L$; similarly, $\Theta_{CONC} \propto \delta_{CONC}$

NEXT, BASED UPON ROTATION & SKEW, THE OUT-OF-PLAN LAYOVER OF THE WEBS IS COMPUTED AT SUPPORTS (OPPOSITE SENSE AT ABUTMENTS). IF COMPUTED TO ACCOMMODATE SLAB DL:

L.O. = { SIN [$Tan^{-1}(\Theta_{CONC})$] x Depth }/Tan (Skew)

FOR A SIMPLE SPAN, SKEWED BRIDGE, DETAILING TO FINAL POSITION CREATES A TWIST IN THE GIRDERS AT TIME OF ERECTION, WHICH RELAXES UPON APPLICATION OF CONCRETE DEADLOADS (Like wringing a towel).

ASSUMPTIONS:

- **THE GIRDERS ARE FLEXIBLE ALONG THEIR SPANS, SO THE BRIDGE CROSS-SECTION AT DIAPHRAGM LINES RETAINS ITS INTEGRITY**
- **SIMILAR TO THE CHICAGO TRUSS ERECTION METHOD, WHERE:**

> **"… (TRUSS) MEMBERS, AS ERECTED UNDER A NO STRESS (OR PRACTICALLY SO) CONDITION, MUST BE BENT AND FORCED TO FIT THE END CONNECTIONS, THUS INTRODUCING AN INITIAL REVERSE SECONDARY STRESS WHICH WILL THEORETICALLY DISAPPEAR WHEN THE STRUCTURE ASSUMES THE LOADING FOR WHICH IT IS CAMBERED".** (AREMA Ch.15, Sect 9.3.2.7)

DESIGNER MUST EITHER :

- ENSURE SUFFICIENT TORSIONAL FLEXIBILITY TO PERMIT WEB-LAYOVER (TWIST), OR
- INCREASE VERTICAL (X-X) AND/OR TORSIONAL (CURVED) STIFFNESS TO REDUCE DEFLECTIONS

Examples:

- Short-span, heavy through girders
- Closely-spaced, deep girders
- deck placement sequence can restrain relaxation (DL deflection)

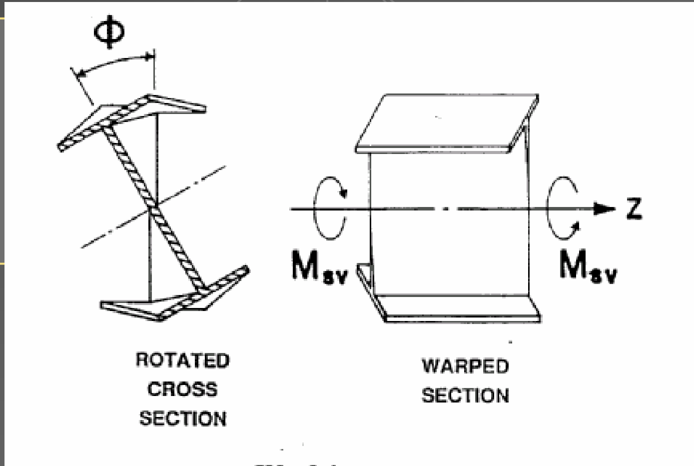


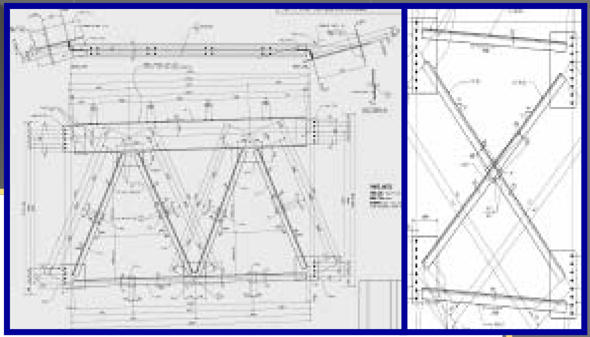
FIG. 6-4
SAINT VENANT TORSION OF A GIRDER SECTION

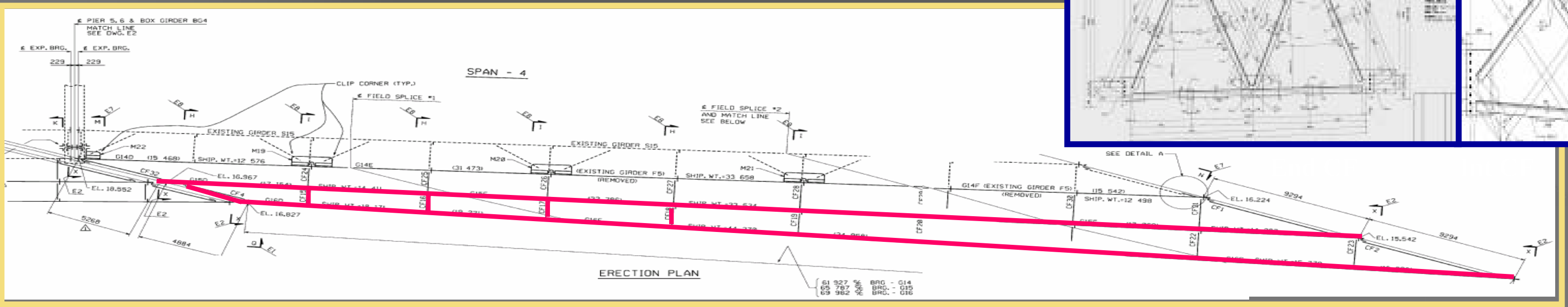
Source: FHWA, Bridge Engineering (Vol I), NHI Course No. 13064, pp. 13-31 thru 13-38 (1994).

"Twisting of the cross section about the z axis is resisted by St. Venant and warping torsion. Conditions of geometry, restraints and loading will determine the relative importance of the two types of torsion."

- FHWA Bridge Engineering Course

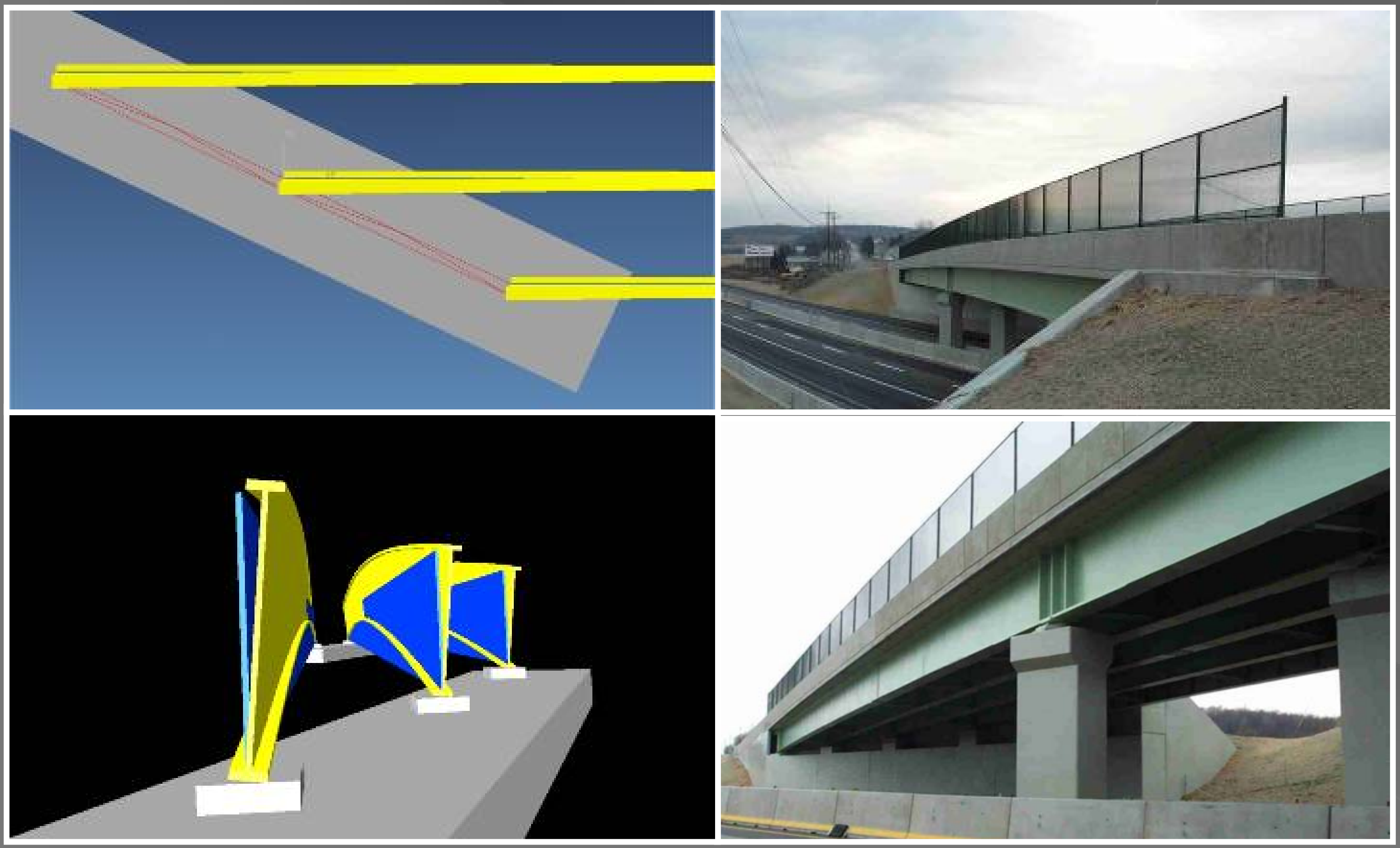
St. Venant-type is pure, uniform & un-restrained torsion. When the cross section is restrained or prevented from warping, warping torsion develops.





Case Study 2

Two Equal-span Skewed Structure. Each Span Twists in Opposite Directions Centered About the Parallel Pier



Spans:
161 ft each

Skew:
70 ° (PA 20 °)

Web Layover:
1 ½" : 48"

Restores to plumb at application of dead loads

SR 0031 over PA Turnpike Somerset Co., PA

Erector: High Steel Structures Inc.

General, Practical Skew Limits:

< 300 ft SPAN, 60º ± REASONABLE (65º ± FOR 200 thru 250 ft)

- Possibly higher for shorter spans
- Check bearing rotational limit

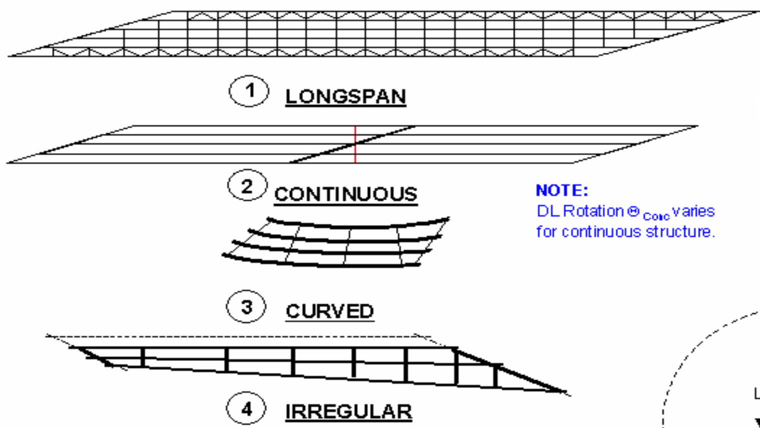
SAMPLE COMPUTATIONS

1) Long-span (single)
- L = 270 ft
- Θ_{XY}=65º

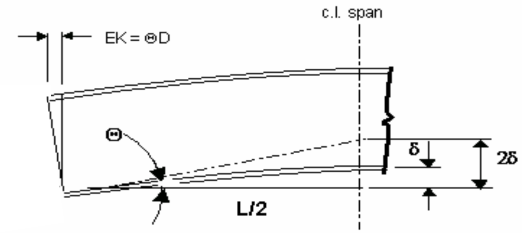
2) Two span continuous
- L = 160 ft
- Θ_{XY}=70º

3) Curved & skewed
- L = 110 ft
- R=400 ft
- Θ_{XY}=65º

4) Skewed widening
- L = 230 ft
- Θ_{XY}=75º



NOTE:
DL Rotation Θ_{Conc} varies for continuous structure.



DEAD LOAD ROTATION (SIMPLE SPAN)

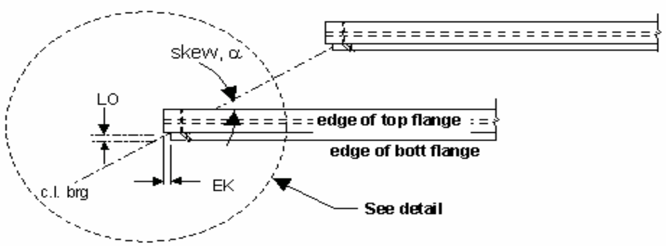
Formulae:

Slab DL Rotation $(4\delta_{TOT,CONC})/L = \tan\Theta$

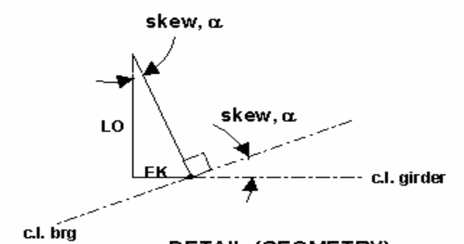
Web Layover=sin $[\tan^{-1}\Theta]D/\tan(\text{Skew})$

Structure	REFERENCE ONLY 1	2	3	4
HSSI Job No.:	NY 01066	PA 01004	MA 99124	NJ 00194
Remarks:	HPS70W long-span	2-span continuous	curved Abuts //	G16D/E (PG 9)
L, ft	270	160	110	229.50
skew, °	25	20	35	14.481
D, ft	10	5.75	5	8.94
$\delta_{TOT, CONC}$, in	12	3.5	2.4	5.16
Slab DL Rotation	0.015	0.007	0.007	0.007
Θ, rad	0.015	0.007	0.007	0.007
Web Layover, in	3.812	1.382	0.623	3.112
Shop Dwgs:	3.622	1.457	0.625	3.150

79 mm±



PLAN VIEW: WEB LAYOVER

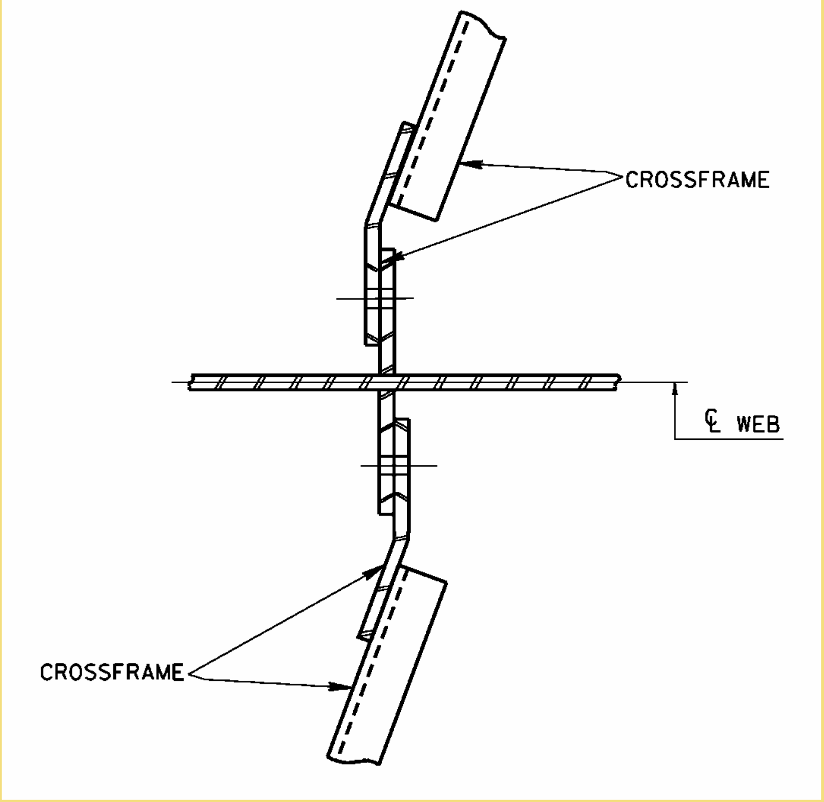


DETAIL (GEOMETRY)

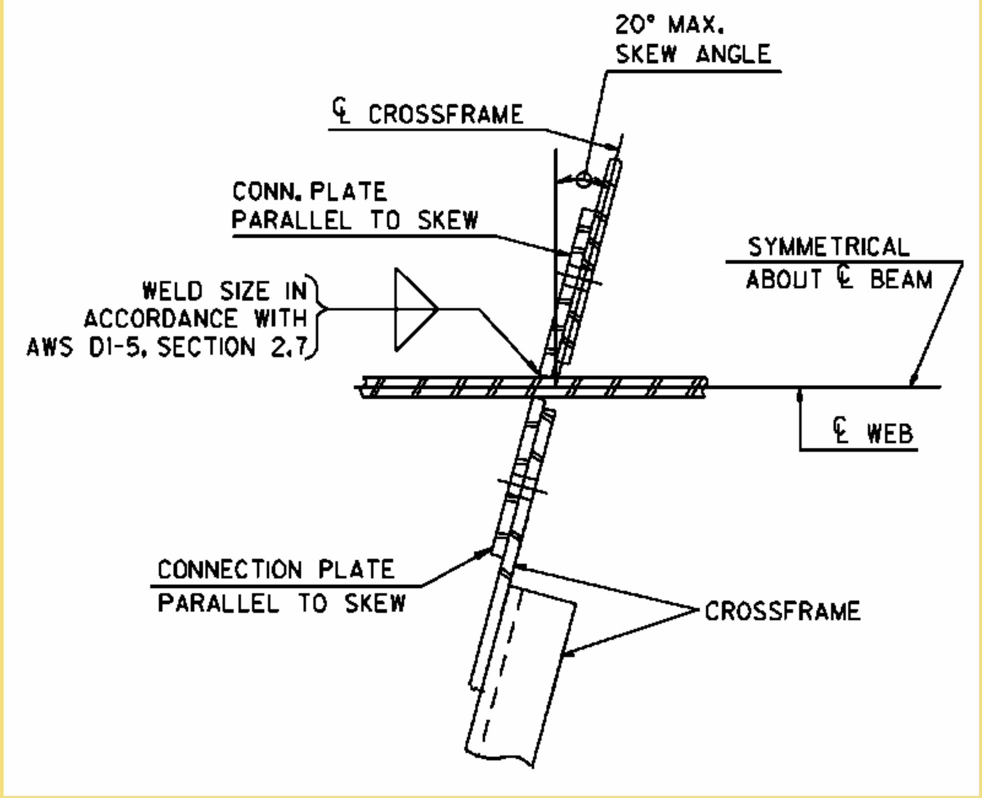
Fabricating and Erecting Skewed Structures

- FABRICATION:
  - Girders built as for un-skewed structures, to no-load “Laydown” profile
  - Cross-frame drops detailed to reflect no-load, steel DL or final position
- ERECTION:
  - Girders erected to approximate no-load profile.
  - Shop-assembled cross frames will normally force the required twist condition
  - If knock-down (field-assembled strut) cross frames, can be problematic.

Cross Frame Connections

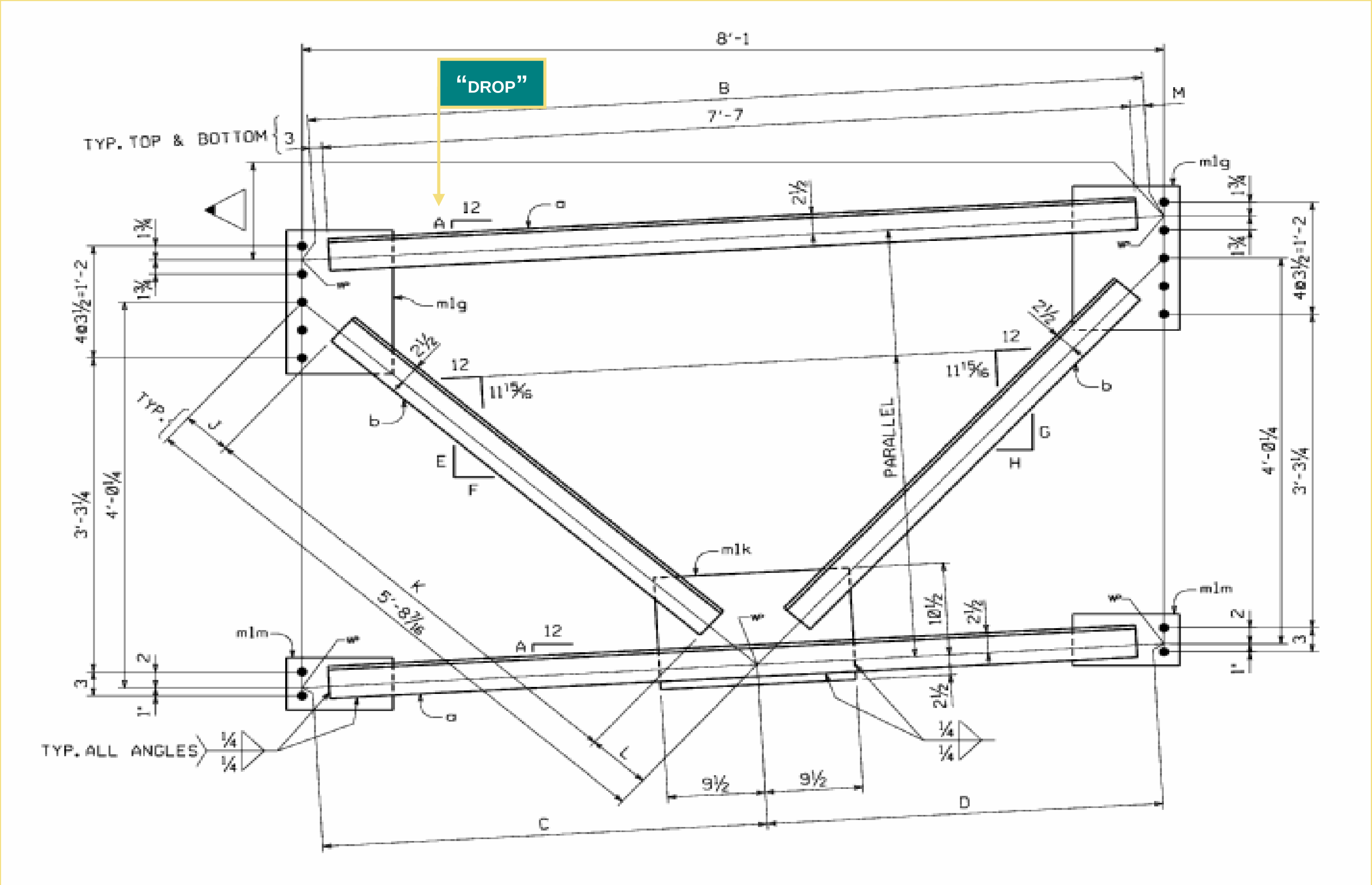


preferred (by fabricators)



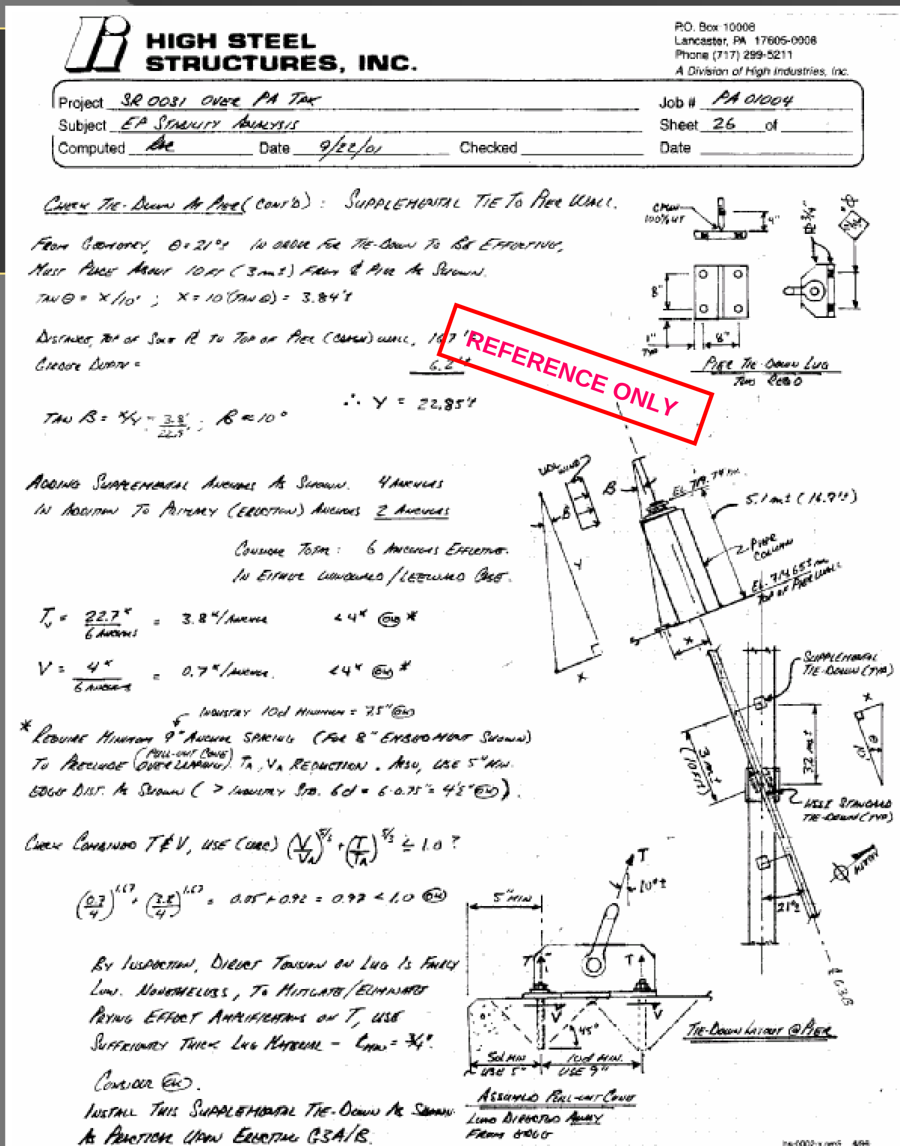
20º maximum skew

Note: In the intermediate cross frame detail shown,Dimension A is the drop (usually tabulated beneath the detail for similar cross frames.)



Skewed connection parts can be complicated, especially when combined with knock-down crossframes.

Erecting Highly-Skewed Structures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Project SR 0031 OVER PA TPK Job # PA 01004
Subject EP STABILITY ANALYSIS Sheet 26 of
Computed Date 9/22/01 Checked Date

CHECK TIE-DOWN AT PIER (CONT'D): SUPPLEMENTAL TIE TO PIER WALL.

FROM GEOMETRY, θ = 21°± IN ORDER FOR TIE-DOWN TO BE EFFECTIVE, MUST PLACE ABOUT 10 FT (3 m±) FROM ℄ PIER AS SHOWN.

TAN θ = X/10' ; X = 10 (TAN θ) = 3.84'±

DISTANCE TOP OF SOLE R TO TOP OF PIER (CAP) WALL, 10.7' CLOSURE DEPTH = 6.2'

TAN B = X/Y = 3.8'/22.5' ; B ≈ 10° ∴ Y = 22.85'

ADDING SUPPLEMENTAL ANCHORS AS SHOWN. 4 ANCHORS
IN ADDITION TO PRIMARY (ERECTION) ANCHORS 2 ANCHORS

CONSIDER TOTAL: 6 ANCHORS EFFECTIVE.
IN EITHER WINDWARD/LEEWARD CASE.

$T_v = \frac{22.7^k}{6 \text{ ANCHORS}} = 3.8^k/\text{ANCHOR}$ < 4^k OK *

$V = \frac{4^k}{6 \text{ ANCHORS}} = 0.7^k/\text{ANCHOR}$ < 4^k OK *

INDUSTRY 10d MINIMUM = 7.5" OK

* REQUIRE MINIMUM 9" ANCHOR SPACING (FOR 8" EMBEDMENT SHOWN) TO PRECLUDE OVERLAPPING (PULL-OUT CONES) T_A, V_A REDUCTION. ALSO, USE 5" MIN. EDGE DIST. AS SHOWN (> INDUSTRY STD. 6d = 6·0.75" = 4½" OK).

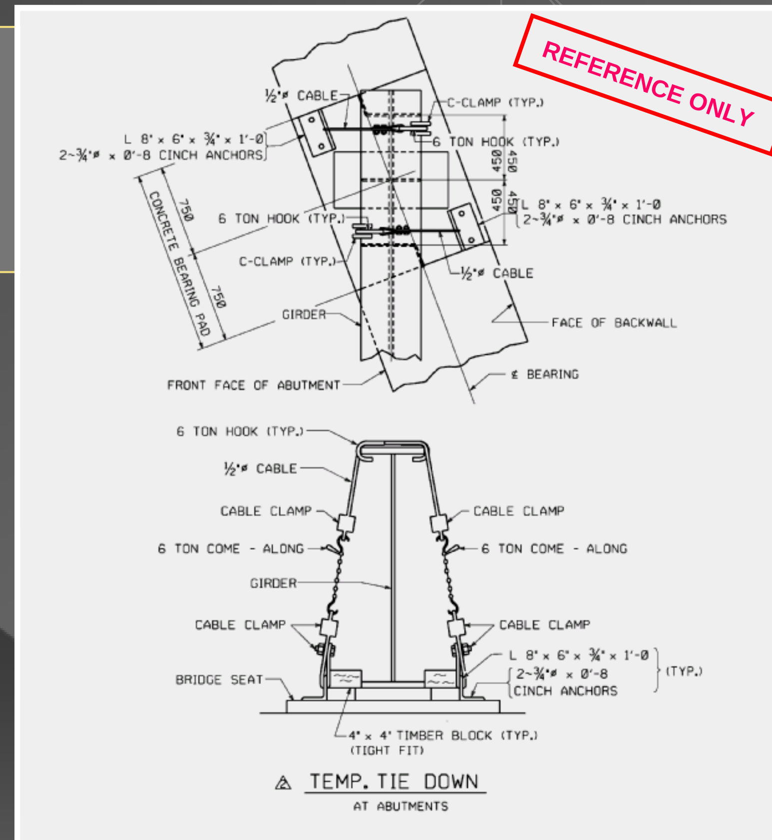
CHECK COMBINED T & V, USE (CONC) $\left(\frac{V}{V_A}\right)^{5/3} + \left(\frac{T}{T_A}\right)^{5/3} \le 1.0$?

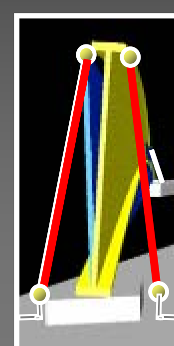
$\left(\frac{0.7}{4}\right)^{1.67} + \left(\frac{3.8}{4}\right)^{1.67} = 0.05 + 0.92 = 0.97 < 1.0$ OK

BY INSPECTION, DIRECT TENSION ON LUG IS FAIRLY LOW. NONETHELESS, TO MITIGATE/ELIMINATE PRYING EFFECT AMPLIFICATIONS ON T, USE SUFFICIENTLY THICK LUG MATERIAL – t_{MIN} = ¾".

CONSIDER OK.

INSTALL THIS SUPPLEMENTAL TIE-DOWN AS SHOWN AS PRACTICAL UPON ERECTING G3A/B.





TOWERS & TIE-DOWNS FACILITATE TWIST

Case Study 3

Combining Curvature, Severe Skew & Stiffness Successfully.

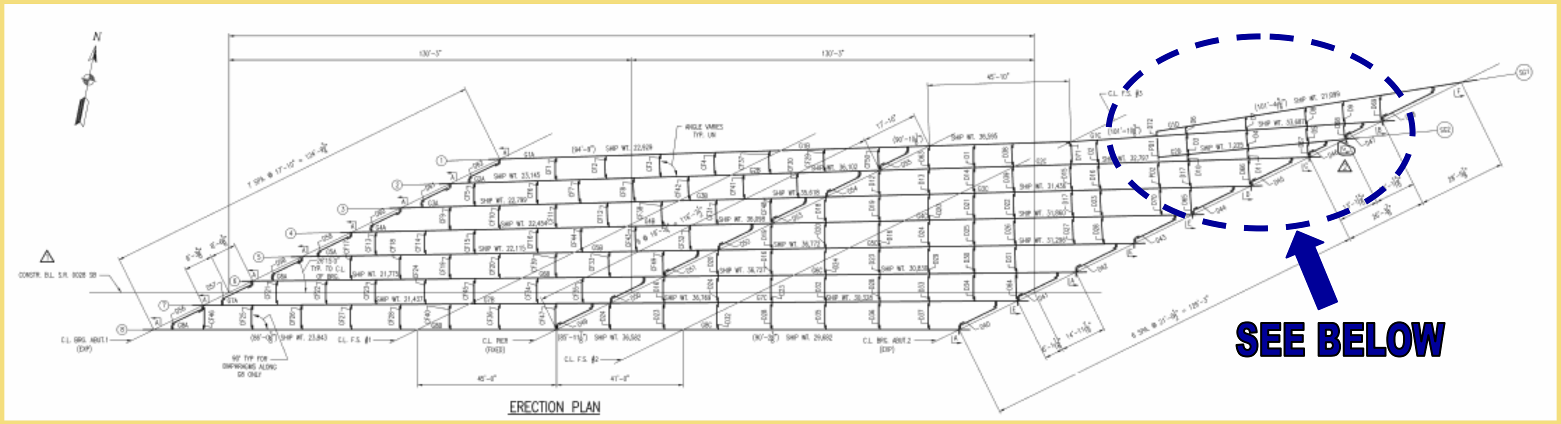
Spans: 130 ft -130 ft

Skew: 64 º (PA 26 º), & varies

Web Layover: 1 ½" max : 4 ft"

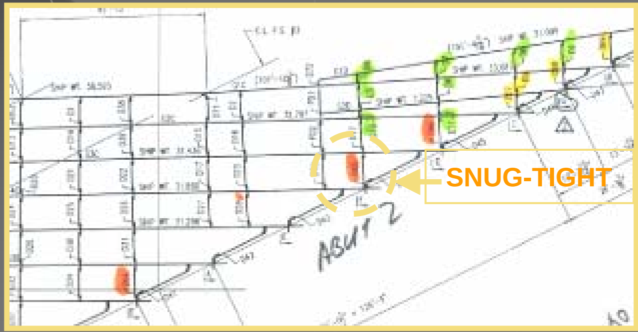
- Asymmetrical, continuous flared structure
- sub-girders framed rigidly into main girders at narrow spacing
- vertical sag-curve
- radius: 1,000 ft+/- (varies, chorded)

SR 0028 over CSX RR, Allegheny County, PA **Erector: Alvarez, Inc./HSSI joint effort**

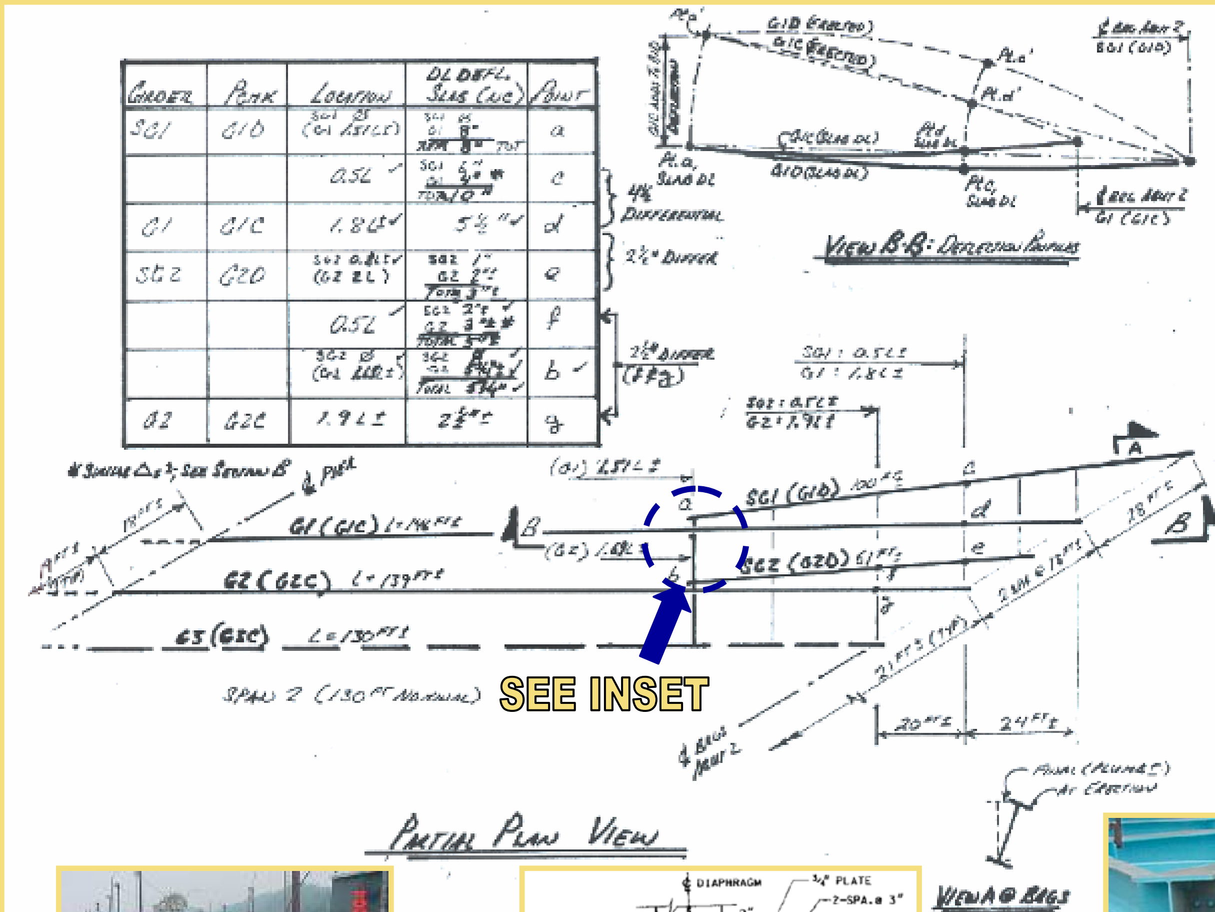


SIMPLE SPAN SUB-GIRDERS FRAMED INTO CONTINUOUS MAIN GIRDERS NEAR $0.6L_2$ (MAX M^+). DESIGNER BALANCED RELATIVE STIFFNESSES OF ADJACENT GIRDERS VIA 3DFE MODEL, TO MINIMIZE DIFFERENTIAL DEFLECTION.

WHERE RESTRAINT BY CLOSELY SPACED DIAPHRAGMS WAS ANTICIPATED, CONNECTIONS WERE LEFT SNUG TIGHT UNTIL AFTER DECK POUR (UTILIZED O.S.H. AT THE DIAPHRAGM PLY OF CONNECTION).



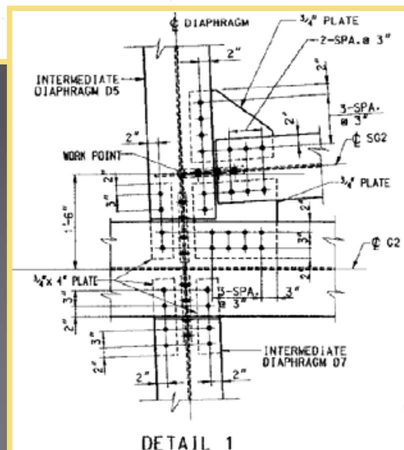
Snug-tight locations at time of pour



RELATIVE DL DEFLECTIONS (4 ½” MAXIMUM) BETWEEN THE CLOSELY SPACED SUB-GIRDERS AND MAIN GIRDERS.

Through effective communication among key parties on the project, only two holes (shown below) failed to come into full alignment.

Sub-girder SG1



Sub-to-main girder connection

Minor, localized mis-alignment

SETTING STEEL

Thank you for your attention.

QUESTIONS?

HIGH STEEL STRUCTURES INC.
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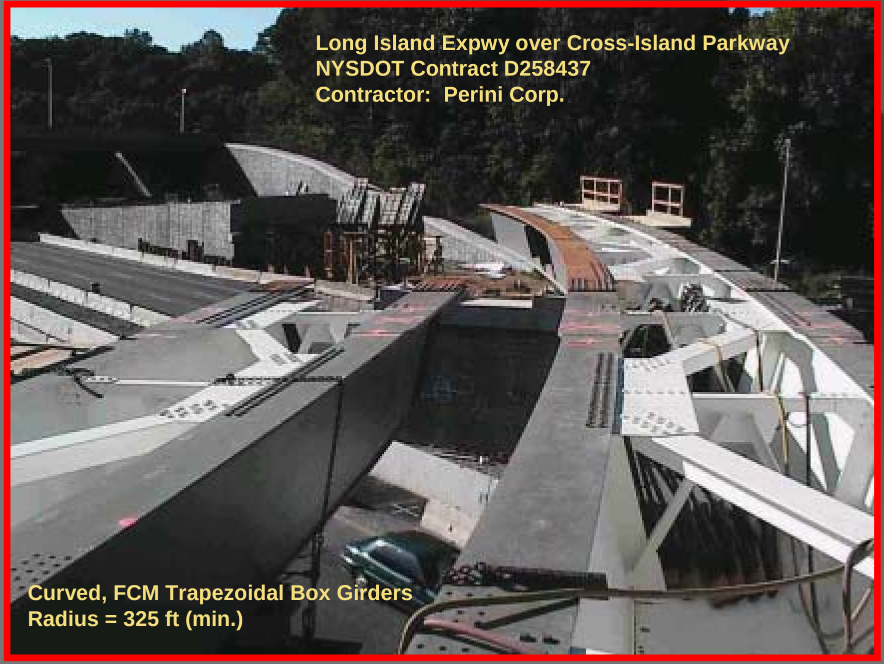

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