Erection of Skewed Bridges: Keys to an Effective Project

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High Steel Structures 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
Case Study 1

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

Span: 265 ft  
Skew: 65° (PA 25°)  
Web Layover: 2 1/2" : 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.

YELLOW = TWISTED AT ERECTION (STEEL DL PROFILE)
BLUE = PLUMB UPON APPLICATION OF DEADLOADS

SHORED TO DEVELOP ERECTED PROFILE

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

- Twist: 15mm (5/8"

- Camber: 65mm (2 1/2"

- Rte 9 over Connecticut River (New Hampshire & Vermont) Erector: Cianbro Corp.

- Twist at other end to transition shall be smooth & constant

- Member shall be twisted end to end

- LB1, LB2

- Section: W380 x 134, W14 x 99

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<tr>
<th>Metric</th>
<th>English</th>
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<tbody>
<tr>
<td>d</td>
<td>350</td>
</tr>
<tr>
<td>tw</td>
<td>56</td>
</tr>
<tr>
<td>b</td>
<td>360</td>
</tr>
<tr>
<td>t</td>
<td>16</td>
</tr>
<tr>
<td>L</td>
<td>9.94 m</td>
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Detailing and Fabrication for Severe Skew

**ERECTOR NOTE:**

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

- DETAILER CONFIRMS IF OWNER WANTS STRUCTURE PLUMB AT ERECTION OR "FINAL POSITION"
- DETAILED TO **FINAL 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, \( \Theta \)
• Dead Load Camber (especially, concrete DL), \( \delta_{\text{CONC}} \)
• Girder Depth, \( D \)

GIRDER END Rotation IS COMPUTED.

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

\[
\Theta_{\text{STEEL}} = \frac{4\delta_{\text{STEEL}}}{L}; \text{ similarly, } \Theta_{\text{CONC}} \propto \delta_{\text{CONC}}
\]

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:

\[
\text{L.O.} = \{ \sin \left[ \tan^{-1}(\Theta_{\text{CONC}}) \right] \times \text{Depth} \} / \tan (\text{Skew})
\]

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)

“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, 60° ± REASONABLE (65° ± 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=65°

2) Two span continuous
   • L = 160 ft
   • Θ_xy=70°

3) Curved & skewed
   • L = 110 ft
   • R=400 ft
   • Θ_xy=65°

4) Skewed widening
   • L = 230 ft
   • Θ_xy=75°

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<th>Structure</th>
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<td>HBSI Job No.</td>
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</tr>
<tr>
<td>D, ft</td>
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<td>Web Layover, in</td>
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<tr>
<td>Shop Dims</td>
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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

**ERECUTION:**
- 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)  20° 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

TOWERS & TIE-DOWNS FACILITATE TWIST
Case Study 3

Combining Curvature, Severe Skew & Stiffness Successfully.

Spans: 130 ft - 130 ft
Skew: 64° (PA 26°), & varies
Web Layover: 1 1/2" 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
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).

SIMPLE SPAN SUB-GIRDERS FRAMED INTO CONTINUOUS MAIN GIRDERS NEAR 0.6L₂ (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).

WEB LAYOVER: 2 ¼”+/− MAX (varies)
RELATIVE DL DEFLECTIONS (4 1/2” 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.
Thank you for your attention.

QUESTIONS?

Long Island Expwy over Cross-Island Parkway
NYS DOT Contract D258437
Contractor: Perini Corp.

Curved, FCM Trapezoidal Box Girders
Radius = 325 ft (min.)