Steel Bridge Erection Plan/Procedure: Safety and Performance

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WHAT’S IN IT, WHAT DOES IT MEAN?

NOTE: this presentation illustrates one erector’s recent efforts to safely navigate their progress from the ASD/LFD to LRFD bridge environment; no guarantee is made regarding suitability of specific means/methods to particular projects. It is not a substitute for code requirements and engineering prudence.
Introduction

CASE STUDY 1: short-span, LRFD Erection
SR 2024 over Towanda Creek
Bradford Co. PA
Erector: High Steel Structures, Inc.

CASE STUDY 2A: long span, crane only (no falsework)
I-95 SB over I-395NB
Springfield Interchange, VA
Erector: High Steel Structures, Inc.

CASE STUDY 2B: long span, right-sized falsework
S.R. 6026 over S.R. 322
Centre County, PA
Erector: HSSI/Aycock joint effort
## Introduction

**CASE STUDY 3:** environmentally sensitive area  
Shorter span, limited falsework placement  
- U.S. Rte. 340 over Shenandoah River  
  Jefferson Co. WV  
- Erector: High Steel Structures, Inc.

**CASE STUDY 4:** curved tub girders  
Shorter span, limited falsework placement  
- Washington Metro over I-95 Beltway  
  St. Georges County, MD  
- Erector: High Steel Structures, Inc.

**CASE STUDY 5:** longer span  
Liberal falsework placements  
- I-695/I-95 Interchange  
  Baltimore County, Maryland (Towson)  
- Erector: High Steel Structures, Inc.

Source: [http://static-content.org/bigfoot/photos/at141-harpersferry](http://static-content.org/bigfoot/photos/at141-harpersferry)
Erection Plan

The bridge erection plan drawing generally provides the erector with information such as the following:

- General framing layout
- Orientation of field section (pieces) with respect to marked end
- “Estimated weights” for main members
- Typical field bolted/welded connections w/details not otherwise indicated on the drawings
- Bearing point elevations (usually to bottom of steel/bearing)
- List of field bolt hardware and appropriate connection information

For additional information, please refer to:
AASHTO/NSBA Steel Bridge Collaboration G1.3-2002, Shop Detail Drawing Presentation Guidelines, Section 10 (www.steelbridges.org)
Erection Procedure

Provides the erector with a step-by-step direction to safely assemble the bridge. Often accompanied by calculations, technical data (“cut sheets”) & the following:

- Crane model, boom length & radius for indicated lifts
- Spreader beams, tie-downs, equipment to temporarily stabilize members
- Lifted section weights (include crossframes if to be lifted w/girders)
- Center(s) of gravity for complex/asymmetrical lifts
- Key equipment considerations (e.g., outriggers extended, 360° vs. rear-only lifting, hook block weight, etc)
- Minimum amount of sequential framing to maintain stable structure
- Quantity/location of bolts/pins before members are self-supporting
- Location of shoring towers/holding cranes
- Windspeed for safe erection of members & partially completed framing
- Traffic closure duration (location & delivered orientation of members)

For additional information, please refer to:
Case Study 1

(Effective 2007) AASHTO LRFD Now Requires that One Plausible Method of Erection Be Investigated.

AASHTO LRFD 3rd ed. (interim) Specifications

SR 2024 over Towanda Creek
Bradford Co. PA
Contractor: Susquehanna Valley Construction Corp.
Erector: High Steel Structures, Inc.
Resources used for Case Studies:

- AASHTO LRFD 2.5.3, Constructibility Considerations
- AASHTO LRFD 3.4.2, load factor $\gamma_{DC,WS} \geq 1.25$ was used for steel erection (2008 note: 1.5 may be required; under review by T-14 & market states)
- When performing ASD (SLD) erection analysis, for wind loadings:
  - ANSI/ASCE 7-95, Minimum Design Loads for Buildings and Other Structures
  - AASHTO Guide Design Specifications for Bridge Temporary Works
  - PADOT BD-620M (25psf, except 30psf over live traffic)
  - HSSI normally uses 25 MPH for picking/same shift erection; 40-50 MPH for overnight, & 25/30 psf (50-65 MPH) for partially erected steel beyond scope of local short-term weather forecast

Disclaimer: the above is what we used during the 2004-2007 period. As AASHTO LRFD becomes standard practice, the erection engineer must apply their own competent judgment for specific application: High Steel Structures, Inc. takes no responsibility for suitability of the above for a particular project.
2008 SUPPLEMENT (for IBC Bridge Construction Seminar)

This month, AASHTO has put out several pertinent publications including:

• LRFD BRIDGE DESIGN SPECIFICATIONS, 4TH EDITION
• LRFD BRIDGE CONSTRUCTION SPECIFICATIONS, 2ND EDITION
• GUIDE DESIGN SPECIFICATIONS FOR BRIDGE TEMPORARY WORKS, 2008 INTERIM
• CONSTRUCTION HANDBOOK FOR BRIDGE TEMPORARY WORKS, 2008 INTERIM

These documents may very well have new information (not yet included herein) which makes aspects of this presentation obsolete. The engineer is cautioned to become familiarized accordingly with the specifications & handbooks as applicable.

See:  http://downloads.transportation.org/aashto_catalog.pdf (AASHTO 5-23-08 e-mail)
Fabricating and Erecting Skewed/curved Structures

**FABRICATION:**
- Girders profile usually similar to un-skewed structures (no-load “laydown” profile)
- Cross-frame (CF) drops detailed to reflect no-load, steel DL or final position (owner preference)
- Additional information may be found at:
  1) Symposium Session 2A, Erection of Skewed Bridges
  2) [http://www.highsteel.com/contactus/newsroom/freeinfo](http://www.highsteel.com/contactus/newsroom/freeinfo)
     Summer 2007 Newsletter: Skewed Bridge Presentation

**ERECTION:**
- Girders initially held to approximate no-load profile
- Shop-welded/bolted CFs will normally force the required twist condition
- Crossframe-braced girders released to steel DL state
- Note: if knock-down (field-assembled) CF, must support member **before** it can withstand gravity.
Large/Curved Girder Erection

- As with fabrication, there are many means and methods:
  - NSBA/AISI/AISC effort: Advanced Erector Certification Program
  - Again, AASHTO/NSBA S10.1, Steel Bridge Erection Guide Specification

- States divided between two camps:
  1. Those who want engineered erection procedures (Complexity-based)
  2. Those who do not want the exposure of formal procedure/calcs review.
Case Study 2A

Erecting girders without shoring

IF JOBSITE CONDITIONS LIMIT EFFECTIVE TOWER PLACEMENTS, SPREADER BEAMS CAN STABILIZE THE GIRDERS...

- 250 ft spans
- R = 1000 ft (min)

GIRDERS MAY BE SPLICED ON THE GROUND, THEN PICKED AS A UNIT. Example:
- L=300 ft
- Weight =115 Tons

...TWO CRANE PICKS MAY BE NECESSARY TO LIFT VERY LONG FIELD SECTIONS.

I-95SB over I-395NB (Bridge B610), Fairfax Co. VA  Erector:  High Steel Structures, Inc.
TIE-DOWNS INITIALLY SECURE THE GIRDERS.

AS STABLE GIRDER PAIR IS LANDED, HOLDING CRANAGE IS FREED UP, TO EXPEDITE CROSSFRAME ERECTION.
Case Study 2B

Right-sized, adjustable shoring towers can facilitate alignment control as erection progresses.

As abandoned:
$L_{OH} = 100 \text{ ft}^+$
$\Delta X = 1 \text{ FT}$
$\Delta Y = 1 \text{ FT}$
Stability = 60mph+

At completion:
Length: 1,000 ft
Three Span (300ft – 330 ft – 270 ft) continuous unit
Radius: 1,900 ft
Depth: 10'-9"
Spacing: 9'-9"

Erected by High Steel Structures, Inc. & Aycock, Inc.

S.R. 6026 OVER S.R. 322  CENTRE COUNTY, PA  (then-longest, curved steel girder span in PA)
Critical stages and load combinations (e.g., D+W (temporary) may not always be immediately apparent, even when the structure is designed with lateral bracing.

In addition to conventional LTB AASHTO Standard Specifications for Highway Bridges, 17th Edition, Table 10.32.1A:

\[ F_{b,\varepsilon} = \frac{(50 \times 10^3 C_{\varepsilon} \lambda_s)}{S_{\varepsilon t_0}} \sqrt{0.772 M_{\varepsilon} + 0.87 (\Delta T)^2} \leq 0.55 F_{\varepsilon} \text{ ksi} \]

- for curved girders, lateral torsional effect is amplified and may be approximated as shown
- for simple and practical guidance, refer to PennDOT website BD 620M

Example: Quantifying Lateral Imbalance During Girder Erection

\[ \sum M_{iY} \text{ where:} \]
- \[ M_{iY} = w_i l_i Y \]
- See following sheets for computation
LATERAL STABILITY BRACING
DESIGN CRITERIA FOR GIRDER BRIDGES
PRIOR TO DECK COMPLETION:

The criterion in this standard applies only to completely erected steel superstructure, without the deck. The stability of partial and completed girders in the various stages of erection prior to installation of all girders and diaphragms is the responsibility of the contractor as specified in Publication 408 Section 1503.4.1(1). (Applied to tangent, skewed and curved bridges. Applies to single and multi-span bridges.)

1. PROVIDE LATERAL BRACING FOR BRIDGES WITH SPANS IN EXCESS OF 91.440 (300 FT) TO AID IN CONSTRUCTION OF THE BRIDGE. DESIGN BRACING FOR THE SPECIFIED WIND LOADS.

2. EVALUATE THE NEED FOR LATERAL BRACING FOR SPANS IN EXCESS OF 81.000 (250 FT) BASED ON WIND DELETION.

3. GIRDER SPANS MUST BE DESIGNED SUCH THAT NO LATERAL BRACING IS NECESSARY.

4. GIRDER SPANS BETWEEN 36.000 AND 54.000 (1200 AND 1800 FT) SHOULD BE wrestled WITH 4 OR MORE GIRDERS, AN ENCLOSED TOP PLATE, AND A BRIDGE. DESIGN THE CONNECTIONS CONSISTENT WITH THE CONNECTION DETAILING ACCEPTABLE.

5. ENSURE GIRDER STRESSES FOR COMPLETED STEEL SUPERSTRUCTURE BE MENTIONED IN WIND LOADS USING THE SERVICE LOAD METHOD.

6. MINIMUM DESIGN WIND PRESSURE - 1.2 kPa (25 PSF); EXCEPT FOR BRIDGES OVER TRAFFIC. USE 1.4 kPa (50 PSF).

7. WIND LOAD PER FOOT OF BRIDGE IS GIRDERS DEPTH • DECK THICKNESS AT FRASCA GIRDERS X DESIGN WIND PRESSURE. UNLESS THE FRASCA GIRDERS ARE LOADED FOR GIRDER SPACING UP TO 4300 (144 FT). THIS ASSUMES THAT THE OTHER GIRDERS ARE SHIELDED FROM THE WIND FOR A TYPICAL BRIDGE.

8. FOR GIRDER SPACING GREATER THAN 4300 (144 FT) USE THE LOADS DESCRIBED IN 6 ON THE WINDWARD GIRDERS AND A LOAD OF 50 PERCENT OF THE LOAD TALKED FOR THE WINDWARD GIRDERS ON THE LEANER (OTHER FRASCA) GIRDERS. APPLY THE LOADS IN THE SAME DIRECTION.

9. DESIGN BRACING FOR SERVICE CONDITION COMBINATION OF BRACING DEANS SELF-WEIGHT LOAD PLUS WIND LOAD WITH 1.3X INCREASE IN BASIC ALLOWABLE STRESS AS SPECIFIED IN AASHTO'S STEEL DESIGN SPECIFICATION FOR BRIDGE TEMPORARY WORKS (1985). USE OVERSIZED OR SLOTTED HOLES IN THE GIRDERS.

10. DESIGN THE CONNECTION OF THE BRACING TO GIRDERS TO PREVENT SLIP FROM WIND FORCES WITH THE PERMISSIBLE INCREASE IN ALLOWABLE SLIP FORCE. DESIGN CONNECTIONS FOR ACTUAL FORCES. PROVIDE OVERSIZED OR SLOTTED HOLES AND DESIGN THE CONNECTION FOR WIND FORCES ONLY.

11. USE PERMANENT BRACING ARRANGEMENTS SECURED BRACING IS NOT CONSIDERED PERMANENT. PROVIDE SAME CORROSION PROTECTION USED IN THE AS-DESIGNED STRUCTURAL STEEL.

12. GIRDER SECTION CHECKS FOR THE PERMANENT CONDITION ARE BEYOND THE SCOPE OF THESE CRITERIA. THE CRITERIA FOR THESE CHECKS ARE SPECIFIED IN AASHTO AND DESIGN MANUAL 4.4.10 WITH METHODOLOGY SHOWN IN THE AISC STEEL BRIDGE DESIGN HANDBOOKS.

NOTE: EITHER ALL METER OR ALL ENGLISH VALUES MUST BE USED ON PLANS. METRIC AND ENGLISH VALUES SHOWN MAY NOT BE MIXED.

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAY

STANDARD
STEEL GIRDER BRIDGES
LATERAL BRACING CRITERIA AND DETAILS

REFERENCE DRAWINGS

BD-620M
ADDITIONAL LATERAL STABILITY CRITERIA
FOR CURVED STEEL GIRDER BRIDGES

1. THE DESIGN ENGINEER SHALL CHECK CURVED STEEL GIRDER BRIDGES FOR THE FOLLOWING LOADING CONDITIONS:

   A) WIND LOADING ON THE STEEL SUPERSTRUCTURE PRIOR TO DECK PLACEMENT - THE PROCEDURE SHALL FOLLOW THAT USED FOR THE STRAIGHT, UNSKewed BRIDGE. THE LOADED AREA IS THE SURFACE AREA OF THE LONGEST GIRDER. ALLOWABLE HORIZONTAL DEFLECTIONS SHALL BE BASED ON CRITERIA FOR STRAIGHT UNSKewed GIRDER AND BRIDGES PRIOR TO DECK PLACEMENT.

   B) PARTIAL WIDTH LOADING UNDER STAGED CONSTRUCTION FOR FUTURE DECK REPLACEMENT AS DIRECTED BY THE DEPARTMENT.

   C) VERTICAL AND LATERAL DEFLECTIONS SHALL ALSO BE EVALUATED FOR STEEL SELF-WEIGHT AND THE DECK DEAD LOAD.

2. BEARINGS SHALL BE DESIGNED TO ACCOMMODATE GIRDER ROTATION DURING THE DECK PLACEMENT AND OUT OF THE GIRDER PLANE. GIRDER AND THEIR BEARING STIFFENERS SHALL BE VERTICAL AT THE BEARINGS UNDER FULL DEAD LOAD. UPLIFT SHALL BE EVALUATED AT EACH BEARING FOR WORST LOADING CONDITION IN EACH CONSTRUCTION PHASE.

3. INCLUDE LATERAL WIND BRACING IN THE DESIGN OF GIRDER THAT DO NOT MEET THE CRITERIA AS SHOWN ON SHEET 1. DESIGN LATERAL BRACING TO CARRY WIND LOADS ONLY AND DETAIL THE BRACING SO THAT IT WILL NOT PARTICIPATE IN CARRYING PRIMARY STRUCTURE FORCES.

4. THE ENGINEER SHALL IDENTIFY THE NEED FOR AND LOCATION OF FALSEWORK AND PROVIDE INFORMATION AS PER DMM 02.5.3 IPN; HOWEVER, THE DESIGN AND FOUNDATION OF THE FALSEWORK IS THE RESPONSIBILITY OF THE CONTRACTOR.

5. DESIGN LATERAL BRACING FOR WIND LOADS. DESIGN AND DETAIL THE LATERAL BRACING SO THAT TORSIONAL FORCES FROM DEAD LOADS AND LIVE LOADS ON THE GIRDER ARE NOT RESISTED BY THE LATERAL BRACING.
Case Study 3: Harpers Ferry Bridge B4144
DATA SUMMARY:
Eight Span Continuous (Piers 3,4 fixed)
END SPANS: 140 ft
INTERIOR: 180 ft - 200 ft
R= +/- 1,150 ft
An erection stability analysis is often necessary during steel multi-girder bridge erection.

- For curved, multi-span structures over variable terrain, this often warrants a visual layout based upon feasible crane placements.
- The following must be checked:
  - D+W (temp: pick, initial, partial erection)
  - Curvature amplification ($M_z$) as applicable
  - Unusual (unique) component loads
  - $\frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} < 1$ (poss. 1.25, ASD)
  - Cranage & rigging loads
  - Splice & CF connections $<50\%$ (time window)
  - Often, global as well as local stability.
  - Shoring, tie-down reactions (vert/lat/longit.)
  - (if applicable) grade/superelev/thermal effects.
Additional crucial stages may also occur even after the initial spans have been set.
With careful planning, a beautifully crafted project is completed well.
Harpers Ferry Bridge Utilized a Combination of:

A) LATERAL STAYS (SHOWN HERE STABILIZING PRE-BD 620M TYPE PA STRUCTURE, CENTRE COUNTY PA)

B) SHORING TOWER FOR VERTICAL LOAD/DEFLECTION CONTROL (SIMILAR TO ABOVE CENTRE COUNTY, PA STRUCTURE TO LEFT OF DISTINGUISHED GENTLEMEN)

WV 99017 TEMPORARY SHORED TIE-DOWN (MIDSPAN, IN LIEU OF HOLDING CRANE OR FULL TOWER ASSEMBLY)
Case Study 4

Trapezoidal Box Girders (Tub girders)

Tub girders generally erect more rapidly than I-girders

Washington Metro over I-95 Beltway, MD

Contractor: Lane Construction Corp.
Erector: High Steel Structures, Inc.
GENERAL CONSIDERATIONS FOR:

- Internal stability
- Balance of curvature during handling
Tie-down Restraint May Be Needed (To Resist Lateral Roll Under D+W)

FOR AN INITIAL “QUICK CHECK”, EVALUATE ERECTION SPANS, OVERHANGS AND RADII, SOLVING FOR NET UNBALANCED $M_{\text{UNBAL}}$

Balancing curved picks, etc. Compute $M_{\text{UNBAL}} = \Sigma M_{y_i} \text{ where }$
  - $M_{y_i} = w_i y_i \text{ where } \Sigma y_i = R\Theta_i$
  - $A = R \cos(\Theta/2)$
  - $b_{MC} = R - A$
  - See AISC 9th Ed (ASD) p.6-16 to determine $x_i$ & $y_i$

Tie-down to “deadman”

Computing $M_y$
UNLIKE FLEXIBLE, CURVED I-GIRDERS, WHICH MAY BE CHOKED (UNLESS PAINTED), CURVED TRAPEZOIDAL BOX GIRDERS MAY TEND TO LEAN (ROLL):
FIRST, ONE WAY DURING SHOP HANDLING...

**Diagram**

**Table**

**Text**

**Reference Only**
THEN, GIRDER MAY LEAN (ROLL) IN THE OPPOSITE DIRECTION DURING SHIPPING/ERECTION, REQUIRING TEMPORARY/PERMANENT SUPPORTS.....
Thus, curved box girder rigidity warrants global (stability), in addition to the conventional torsional stability check.
Case Study 5

Erecting I-girders with temporary shoring when liberal placements are feasible

CASE STUDY 5: longer span Liberal falsework placements

- < 250 ft spans
- R ≥ 1000 ft

I-695/I-95 Interchange: Ramp GG, Structure S6
Baltimore County, Maryland (Towson)
Owner: Maryland Transportation Authority
Contractor: Wagman/Corman/McLean Tri-venture
Fabricator/Erector: High Steel Structures, Inc.
Sections 3.1.3 (Temporary Works) and 3.2 (Falsework) provide direction regarding established and generally accepted codes or specifications (verify acceptance criteria with the Engineer).

**CAUTION:** do not mix codes without due consideration of resistance level consistency among various falsework components, & erection equipment. Be especially alert for LFRD, LFD & SLD (ASD) based differences, such as:
- limit states
- resistance factors
- working loads
- explicit/inherent factors of safety.
SOUND ENGINEERING JUDGEMENT IS KEY IN APPLYING APPROPRIATE, SITE-SPECIFIC WINDLOAD(S) FOR CONTROLLING ERECTION LOADCASES.

CASE STUDY 5 (continued)

HIGH STEEL STRUCTURES, INC.
I-95/99-I Interchange
HSS Job No. MD 05130

SOUND ENGINEERING JUDGEMENT IS KEY IN APPLYING APPROPRIATE, SITE-SPECIFIC WINDLOAD(S) FOR CONTROLLING ERECTION LOADCASES.

TOWER 1 (SPRING):
• wind on tower
• wind on partially erected structure
• Skewed substructure considerations

TOWER 2 (SUMMER):
• wind on tower
• wind on partially erected structure
• contingency (hurricane) tie-downs & anchorage

TOWER 1 (SPRING):
• wind on tower
• wind on partially erected structure
• Skewed substructure considerations

Subject structure used Engineer-accepted, site-specific (inland coastal) wind-levels for:
• tower alone (prior to girder erection)
• picking/setting girders (within single shift)
• partially erected structure (e.g., weekend)
• longer-term contingency (monitoring local weather)
SITE-SPECIFIC EXAMPLE: TOWER 2
STAGES CHECKED (CONTROLLING COMBINATIONS USED)

INITIAL GIRDER LINES
WEEKEND ($V_{WIND} \leq 40$ MPH)

PARTIAL LOADING
SHORT-TERM ($V_{WIND} \leq 50$ MPH)

PARTIAL LOADING
LONGER-TERM ($V_{WIND} \leq 80$ MPH)
Bridge erection methodologies bear scrutiny & innovation. Example: consider field welding of I-girder/tub girder field splices (Texas practice). Advantages include smoother appearance than bolting (ratholes may be filled with caulk).
Thank you for your attention.

QUESTIONS?

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IBC Bridge Const. Seminar
June 2nd, 2008

Long Island Expwy over Cross-Island Parkway
NYS DOT Contract D258437
Fabricator: High Steel Structures, Inc.
Contractor/erector: Perini Corp.

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