Stability of Long Span Steel Bridges During Design and Construction

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COLLAPSE OF QUEBEC BRIDGE OVER ST. LAWRENCE RIVER - 1907
COLLAPSE OF ROUTE 69 BRIDGE OVER TENNESSEE RIVER - 1995
STABILITY
As defined by the Merriam-Webster dictionary is “the property of a body that causes it when disturbed from a condition of equilibrium or steady motion to develop forces or moments that restore the original condition”

Another, more bridge specific definition is the lack of undesirable deflections or rotations.

STRENGTH
As defined by the Merriam-Webster dictionary is “the quality or state of being strong: capacity for exertion or endurance”

Another, more bridge specific definition is the lack of undesirable member stresses.
ECONOMICAL STRUCTURAL DESIGN
The goal is to determine a system where stability is provided using members that require the least amount of material above that needed to meet strength requirements.

INSTABILITY
Can occur at various stages during the life of a long span steel girder bridge.

Completed Bridge (Responsibility of Designer)
Deck Placement (Responsibility of Designer)
Completed Framing (Responsibility of Designer)
Girder Erection (Responsibility of Erector)
APC FALL SEMINAR

PART I

STABILITY OF LONG SPAN BRIDGES DURING DESIGN
SR0903 BRIDGE OVER LEHIGH RIVER
JIM THORPE, PA
NOTE: STRAIGHT BRIDGE
NO V-LOAD OR CENTRIFUGAL FORCES
SR0903 BRIDGE OVER LEHIGH RIVER
JIM THORPE, PA

HISTORIC CANAL LOCK

READING BLUE MOUNTAIN RAILROAD

LEHIGH RIVER

NORFOLK SOUTHERN RAILROAD

READING BLUE MOUNTAIN RAILROAD
SR0903 BRIDGE OVER LEHIGH RIVER
JIM THORPE, PA

CONCRETE DECK

CONNECTION PLATES

CROSS FRAMES

COMPLETED BRIDGE STAGE
WHERE STRESS CAPACITY WAS LESS THAN YIELD USING 25' CROSS FRAME SPACING, CAPACITY WAS INCREASED BY REDUCING CROSS FRAME SPACING TO ABOUT 16.5'.
(BOTTOM FLANGE IN COMPRESSION – NEGATIVE MOMENT)

COMPLETED BRIDGE STAGE
WHERE STRESS CAPACITY WAS LESS THAN YIELD USING CROSS FRAME SPACING FROM DESIGN OF THE COMPLETED STRUCTURE, CAPACITY WAS INCREASED BY REDUCING SPACING TO ABOUT 16.5’.
(TOP FLANGE IN COMPRESSION – POSITIVE MOMENT)

DECK PLACEMENT STAGE
STEP 1
DETERMINED WIND LOAD PER BD-620M. COMPUTED STRESSES AND DEFLECTIONS IN TOP AND THEN BOTTOM FLANGES UNDER SELF-WEIGHT AND WIND LOAD WITHOUT ANY LATERAL BRACING. APPLIED ½ THE WIND LOAD TO EACH ANALYSIS. COMPARED STRESSES TO BUCKLING RESISTANCE BASED ON FULL SPAN LENGTH. COMPARED LATERAL DEFLECTION TO L/150 (BD-620M).
NOTE – SINCE ALL FIVE GIRDERS WERE IDENTICAL, THEY SHARED THE WIND LOAD EQUALLY. THUS A SINGLE GIRDER WAS ANALYZED AND 1/5 THE WIND LOAD WAS APPLIED.
RESULT - LATERAL BRACING REQUIRED (OVERSTRESS BUT ONLY L/215 DEFLECTION OR ABOUT 19”).
Step 2
Decided to laterally brace the bottom flange. This is the preferred approach by BD-620M to avoid conflict with SIP form support angles at the top flange. Decided to add braces in only one bay. Recomputed stresses in the bottom flange using a truss analysis and only two girders. Applied entire wind load. Compared combined axial-flexure stress to buckling resistance based on cross frame spacing. Result overstress eliminated throughout girders. Deflections reduced to approximately 10% of those computed without lateral bracing.
SR0903 BRIDGE OVER LEHIGH RIVER
JIM THORPE, PA

PORTION OF SPAN 3 FRAMING PLAN

LATERAL BRACING
A = 6"x6"x1/2"
B = (2) 6"x6"x1/2"

STEP 3
DESIGN LATERAL BRACING MEMBERS BASED ON AXIAL FORCE FROM TRUSS ANALYSIS.
DETAIL THE CONNECTION BETWEEN BRACING MEMBERS AND BOTTOM FLANGES.
NOTE – WT SHAPES ARE BETTER SUITED FOR BRACING THAN DOUBLE ANGLES.

COMPLETED FRAMING STAGE
LATERAL STABILITY BRACING
DESIGN CRITERIA FOR GIRDRE BRIDGES

PRIOR TO DECK COMPLETION*

The criteria in this standard apply only to compressive forces, and
sustainability, and the need for the stability of the critical
loadings in the various stages of erection prior to installation of all
members and components in the horizontal plane of the
construction. The design of the lateral stability bracing for

1. PROVIDE LATERAL BRACING FOR BRIDGES WIDE THAN EXCEEDS
   THE WIDTHS OF THE FOOTERS OF THE BRIDGE. DESIGN FORcing
   FOR THE SPECIFIED WIND LOADS.

2. EVALUATE THE NEED FOR LATERAL BRACING FOR SPANS IN EXCESS OF
   300 FT, Based on Lateral Friction.

3. CONSIDER SHED DESIGN OF NO LATERAL BRACING IS NECESSARY
   FOR SPANS WIDE THAN THE WIDTHS OF THE FOOTERS OF THE
   BRIDGE. DESIGNING FOR THE SPECIFIED WIND LOADS.

4. EVALUATE LATERAL REACTION OF STEEL STRUCTURE FOR A
   PERMISSIBLE COMBINATION OF LATERAL LOAD ANALYSIS
   LIMIT TO ACCURACY. AN APPROXIMATE ANALYSIS MUST BE MADE
   AT 5% OF THE LOADS FOR THE SPECIFIED WIND LOADS.

5. CIRCULAR CONSTRUCTION IS NEW AND THE COMBINATION OF LOADS
   MUST BE ASSESSED. FULLY, IF THE ANALYSIS LIMIT TO THE:
   THE COMBINATION LOAD CAN BE ASSESSED AS A K IN THE
   TABLE OF LOADS. IT IS ADVERSE TO ALLOW FULLY
   COMBINATION LOADS. A MORE ACCURATE ANALYSIS
   MUST BE USED IN THIS CONDITION.

6. USE THE AVERAGE DESIGN LOAD SPECIFIED IN THE TABLE ON THIS SHEET,
   DESIGNED FOR 50% OF WIND LOAD, BASED ON THE WIND LOAD.

7. ADD LOADS TO THE CIRCULAR FOOTERS OF THE BRIDGE.

8. PROVIDE BRACING OF THE LATERAL LOADS, EXCEPT FOR SPANS
   IN EXCESS OF 300 FT.

9. ADD LOADS TO THE CIRCULAR LOADS TO DESIGN THE LATERAL LOADS.

10. PROVIDE AN APPROPRIATE COMBINATION OF LOADS FOR THE PROPER
    DESIGN LOADS.

11. PROVIDE AN APPROPRIATE COMBINATION OF LOADS FOR THE PROPER
    DESIGN LOADS.

MINIMUM DESIGN WIND PRESSURE (PSF)
FOR LATERAL BRACING DURING CONSTRUCTION

<table>
<thead>
<tr>
<th>WIND Speed</th>
<th>0-20</th>
<th>21-40</th>
<th>41-60</th>
<th>61-80</th>
<th>81-100</th>
<th>&gt;100</th>
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<tr>
<td>S.L.</td>
<td>90</td>
<td>120</td>
<td>150</td>
<td>180</td>
<td>210</td>
<td>240</td>
</tr>
<tr>
<td>K.S.</td>
<td>75</td>
<td>105</td>
<td>135</td>
<td>165</td>
<td>195</td>
<td>225</td>
</tr>
</tbody>
</table>

NOTES:
1. LATERAL BRACING FOR SPANS IN EXCESS OF 300 FT.
2. PROVIDE BRACING FOR SPANS IN EXCESS OF 300 FT.
3. PROVIDE BRACING FOR SPANS IN EXCESS OF 300 FT.
4. PROVIDE BRACING FOR SPANS IN EXCESS OF 300 FT.

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION

STANDARD STEEL GIRDER BRIDGES
LATERAL BRACING CRITERIA AND DETAILS

REFERENCE SHEETS
BD-620M
**ADDITIONAL LATERAL STABILITY CRITERIA FOR SKewed STEEL BRIDGES**

**FOR STRAIGHT STEEL GIRDERS**

1. Use top or bottom flange bracing for straight girders. For girders with narrow top flange, it is recommended to use bottom flange lateral bracing.

2. The engineer shall identify the need for and location of bracing and provide information as far as is feasible on: (a) the design and location of the bracing, and (b) the responsibility of the contractor.

3. The designer shall develop the design of bracing in plan positions using the design load. The location and design of bracing shall be in accordance with the requirements in the plans.

4. The designer shall ensure that the bracing is designed to carry all live loads along the girder, and is not carried by the girder, such that the girder is not braced by the lateral bracing.

**FOR CURVED STEEL GIRDERS**

1. The design engineer shall, when curved steel girders are used, apply the following criteria:

   a. The bracing shall be designed for the loads indicated in the plans.

   b. The bracing shall be designed to carry all live loads along the girder.

   c. The bracing shall be designed to carry all live loads along the girder.

   d. The bracing shall be designed to carry all live loads along the girder.

**ADDITIONAL LATERAL STABILITY CRITERIA FOR CURVED STEEL GIRDERS**

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   c. The bracing shall be designed to carry all live loads along the girder.

   d. The bracing shall be designed to carry all live loads along the girder.
PLAN
LATERAL BRACING (PREFERRED)

FOR USE OF NUMBER OF OTHERS, ENTER BRACING ONE BY ONE.

TYPICAL BRACING STRUCTURE MAY DEPEND ON NUMBER OF PLANES.

PLAN
ALTERNATE LATERAL BRACING - TYPE 1

TYPICAL BRACING STRUCTURE

PLAN
ALTERNATE LATERAL BRACING - TYPE 2

TYPICAL BRACING STRUCTURE

NOTES

1. USE INCREMENTAL BRACING POINTS AS NECESSARY, AS NUMBER OF PLANES DEPENDS ON NUMBER OF PLANES.

2. USE AS MANY POINTS AS POSSIBLE.

3. LATERAL BRACING POINTS MUST BE MARKED FOR SIMPLE.

4. FOR NUMBER OF PLANES, ENTER CORRECT FLEX OR SYMMETRICAL.

5. IF PLANES DEPEND ON NUMBER OF PLANES, ENTER CORRECT NUMBER OF PLANES.

6. PARTIAL LATERAL BRACING IS PERMITTED.
PART I ASSESSMENT

Question: True or False, The goal of economical structural designs is to determine a system where stability requires more material than that needed to meet strength requirements.

A – True
B – False
PART I ASSESSMENT

**Question**: True or False, The goal of economical structural designs is to determine a system where stability requires more material than that needed to meet strength requirements.

A – True
B – False

**Answer**: False – The goal is to NOT require more material for stability than for strength.
QUESTIONS
APC FALL SEMINAR

PART II

STABILITY OF LONG SPAN BRIDGES DURING ERECTION
REFERENCES:
1. PADOT BD 620M (which Kevin has discussed)
2. NHI Course
3. AASHTO/NSBA S10.1-2014 Steel Bridge Erection Guide Specification

"Those who don't know history are destined to repeat it."
Santayana/Burke
EVALUATE CRITICAL STEPS

Start w/visual layout based upon feasible crane placements.
As a minimum, the following are typically checked:
• D+W (temp: pick, initial, partial erection)
• curvature amplification (Mz) as applicable
• unusual (unique) component loads
• \( \frac{f_{bx}/F_{bx} + f_{by}/F_{by}}{\Phi} < 1 \) LRFD
• \( f_{bx}/F_{bx} + f_{by}/F_{by} < 1 \) (<1.25), ASD
• cranage & rigging loads
• splice & CF connections (<50%, t window)
• often, global as well as local stability.
• Shoring, tie-down reactions (vert/lat/longit.)
• (if applicable) grade/superelev/thermal effects.
• Bearing fixities (temporary conditions).
“BACK OF THE ENVELOPE” CHECKS

Critical stages & load combinations (e.g., D+W (temporary) may not be intuitively apparent, even if the structure has as-designed lateral bracing.

For quick hand-checks of a complex analysis, the following tools have proven handy for the presenter:

AASHTO Standard Specifications for Highway Bridges, 17th Edition, Table 10.32.1A :

\[ F_{b,c} = \frac{50 \times 10^6 C_{\text{i},\rho}}{S_{\rho} A_{\rho}} \sqrt{0.772 M_{\rho} + 0.87(d/h)^3} \]

\( < 0.55 f_y \) ksi

For horizontally curved girders, the lateral torsional effect ("roll") is amplified, but may be approximated as an initial check as shown.

For constructibility checks, \( L_{\text{UC}}/b_{\text{FC}} \leq 85 \) (< 90 if analyzed)

\[ M_{\text{UNBAL}} = \Sigma M_y \text{ where :} \]

- \( M_{ij} = w_i y_i \)
- TTD = temporary tie-down (LTB)
This spreadsheet must check $\Phi M_n$ for a given unbraced length.

- Lateral torsional buckling (LTB)
- Flange local buckling (FLB)
- Occasional web-bend buckling (WBB)
# CASE STUDIES

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Structure</th>
<th>Max Span</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SR 903 Lehigh Co. PA</td>
<td>335 ft</td>
<td>4-span Multi-girder</td>
</tr>
<tr>
<td>2</td>
<td>SR 6026/322 Centre Co. PA</td>
<td>332 ft</td>
<td>Multi-girder w/Temp LB</td>
</tr>
<tr>
<td>3</td>
<td>SR 322EB/SR6220 Centre Co. PA</td>
<td>275 ft</td>
<td>2-span Multi-girder (R = 1,900 ft)</td>
</tr>
<tr>
<td>4</td>
<td>I-495/I-95/I-390, Fairfax Co. VA</td>
<td>300 ft</td>
<td>Continuous, curved multi-girder</td>
</tr>
<tr>
<td>5</td>
<td>NY Rte 270 over Erie Canal, NY</td>
<td>305 ft</td>
<td>Thru Truss</td>
</tr>
<tr>
<td>6</td>
<td>I-95/I-695, Towson Md (Ramp GG)</td>
<td>260 ft</td>
<td>Continuous, curved mult-girder [Q&amp;A]</td>
</tr>
</tbody>
</table>
CASE STUDY I: JIM THORPE, PA
Several iterations were performed coordinating with Designer & PADOT etc.
Purpose: jobsite conditions (including archaeological historical significance).
Shipping Calculations were performed to check:

- Axle Loadings
- Geometry (height)
- $L_b$ & $F_{bX+Y}(\Phi M_n)$
Erection Stability analysis was performed to check:

- Crane capacities (picks)
- $L_b$ & $F_{bX+Y} (\Phi M_n)$
- UT Bridge validation of STAAD
CASE STUDY II: CENTRE CO. PA
At completion (longest, curved steel girder span in PA):

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

As abandoned:

\[ L_{OH} = 100 \text{ ft} \]
\[ \Delta_X = 1 \text{ FT} \]
\[ \Delta_Y = 1 \text{ FT} \]

Stability = 60 mph+

RIGHT-SIZED, ADJUSTABLE SHORING TOWERS CAN FACILITATE ALIGNMENT CONTROL AS ERECTION PROGRESSES.
INITIAL STABILIZATION
LATERAL ADJUSTMENT (CONT’D)
CASE STUDY III: PORT MATILDA, PA

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

B) SHORING TOWER FOR VERTICAL LOAD/DEFLECTION PERFORMANCE (SHOWN ADJACENT TO DISTINGUISHED GENTLEMEN AT CENTRE COUNTY, PA STRUCTURE)
ERECATION ON FALSEWORK
TEMPORARY BRG CONDITIONS

For longer span bridges, temporary bearing alignment & securement against differential thermal conditions is important, as well as the ability to jack into final position.
ERECTION ON FALSEWORK
STABILIZING LONG-SPANS

L = 300 ft
W = 100 Tons
Lift height = 100 ft
CASE STUDY V: BUFFALO, NY

Roll-in/Float-in of a Prefabricated Truss Bridge
Launching of NY Rte 270 (Campbell Blvd) over the Erie Barge Canal
ABC: Truss launch sequence (SCHEMATIC)

The truss was analyzed using RISA3D for D+WS
The falsework was designed per AISC ASD. (Ftgs AASHTO/ACI).
Bathymetric survey was performed, bc the barge had a bluff stern & raked bow. Draft, freeboard & metacentric considerations were addressed.
LOAD TRANSFER FROM L4-L6 (50%/50%) TO L4-L8 (ON BARGE)

Erie Canal Truss Project - Amherst, NY ~ Dave Miller Photographer

View from South Shore:
Load transfer to barge

View from North Shore:
Crossing channel

View from North Shore:
Truss lands on ending falsework (load transfer from barge)
CASE STUDY VI: I-695/95, TOWSON MD
IT’S…QUIZ TIME!!!

Question: when checking the stability of an I-girder during erection, what are four good criteria for the bridge erection engineer to evaluate:

Answers:
1) LTB (AASHTO LRFD 6.10.8.2.3)
2) FLB (AASHTO LRFD 6.10.8.2.2)
3) WBB (esp deep, slender webs)
4) Web crippling/yielding (brg points)
QUIZ TIME (CONTINUED)

QUESTION: what are the first TWO things that you should do when starting an erection stability analysis for a longer span multi-girder bridge?

ANSWERS:

1) ID critical erection sequence stages

2) Determine unbraced lengths $L_b$ (AASHTO 6.10.8.2.3)
QUIZ TIME (CONTINUED)

QUESTION: what are THREE things that you should check after the girders have been stabilized on the piers & abutments?
ANSWERS:

1) Temporary tie-down reactions/uplifts
2) Temporary bearing conditions (fixities)
3) Lateral/longitudinal reactions to falsework headers (in addition to gravity)
Thanks for your attention. 😉

QUESTIONS ?

So…we want to push this thing over that-away, right?