KDOT STEEL LOAD RATING PROJECT

- Deliverables – AASHTOWare Model of Every Bridge or Unit – 46 total steel units of varying superstructure type and complexity
- To be used in KDOT’s K-TRIPS
- Kansas Truck Routing and Intelligent Permitting System

Curved I-Girder Bridges (SFCC, SFSC)
- Heavy Slab Curved Multi-Girder Systems with Hinges, AASHTOWare 3D FEM
- Curved Two-Girder Systems with Hinges, AASHTOWare 3D FEM

Straight and Curved Steel Tub Girder Bridges (SBCC)
- Equivalent I-Girder Method in AASHTOWare (presented today)

Tied Arch Bridges (STAT)
- Floor System in AASHTOWare with external verification to ensure arch ribs, hangers, and ties did not control
KDOT STEEL LOAD RATING PROJECT

- K-Frame Grasshopper Bridges (SRFC, WRFC)
  - Simplified AASHTO Spring Constant Method with external verification to ensure frame legs did not control
  - Once legs shown not to control, simplified AASHTO method was used for girders inside AASHTO/Bridge Analyst

- Deck Truss Bridges (SDTS, SDTH, SDTC)
  - AASHTO/Ware 2D Truss Module
  - Floor System performed in AASHTO/Ware using:
    - Floor Line (isolated members)
    - Floor System

BOX GIRDER LOAD RATING

- Box Girders as Line Girders
  - Goal to get rating factors for shear and moment into one equivalent girder.
**ACTUAL BOX GIRDER VS. EQUIVALENT I-GIRDER**

- **Box Girder (Fully Composite)**
  - Web Shear
  - Flange Yield (Top and Bottom Flanges)
  - Local Flange Buckling (Bottom Flange)
  - No lateral torsional buckling
- **Equivalent I-Girder (Fully Composite)**
  - Web Shear
  - Flange Yield (Top and Bottom Flanges)
  - Local Flange Buckling (Bottom Flange)
  - Lateral Torsional Buckling
- **Boxes are 100 to 1000 times torsionally stiff than I-Girders.**

**VS.**

- **Box Girder (Fully Composite)**
  - Web Shear
  - Flange Yield (Top and Bottom Flanges)
  - Local Flange Buckling (Bottom Flange)
- **Equivalent I-Girder (Fully Composite)**
  - Web Shear
  - Flange Yield (Top and Bottom Flanges)
  - Local Flange Buckling (Bottom Flange)
- **“Dummy” bracing added at every 5 ft to simulate box girder torsional rigidity and ensure lateral torsional buckling in the equivalent I-Girder does not control**

**ACTUAL BOX GIRDER**

**¼ I-GIRDER EQUIVALENT**

- Set SEQ = ½ SBOX
- Set DFLLEQ = ½ DFLLBOX
- Set FcrEQ = FcrBOX for bottom flange local buckling
- Set EffwidthEQ = ½ EffwidthBOX
- $f_{cE} = f_{cB}$ (for $f = Mc/I = M/S$)

**BOX/TUB GIRDER OBJECTIVES**

- Captured
  - Load Rating for Major Axis Bending – Positive and Negative Forces, Top and Bottom Flanges
  - Load Rating for Minor Axis Shear – Flange
- Not Captured
  - St. Venant’s Torsional Stresses
  - Cross Sectional Distortion Stresses
  - System Effects (Line Girder Only)
  - Skew Effects (Bridges had minor skew or were square)
  - Curvature Effects (Bridges had minor curvature >5000’ radius or were straight)
EQUIVALENT STRESSES: BOX GIRDER VS. EQUIVALENT I-GIRDER

- ½ Girder Steel = ½ Shear Dead Load
- ½ Effective Deck Width = ½ Effective Deck Section for n and 3n
- ½ Tributary Deck Width = ½ Concrete Dead Load
- ½ Live Load Distribution Factor = ½ Live Load (Membrane, Shear)

EQUIVALENT SHEAR FORCE: BOX GIRDER VS. EQUIVALENT I-GIRDER

- With C factor included in calculation, ~2% error or less in most cases with d0 normalized over the difference in D of the web
- AASHTO Std. Spec. 17th Ed. 2002

LIVE LOAD DISTRIBUTION

- AASHTO Std. Spec. 17th Ed. 2002

- Compute DF of actual box girder
LIVE LOAD DISTRIBUTION

DF Equivalent I-Girder = ½ DF Actual Box Girder

SETTING SECTION GEOMETRY – ACTUAL BOX

- For every longitudinal section
  - Steel Only Section – DC1 Load
  - n Section – Transient Short-Term Live Load
  - 3n Section – Long-Term Dead Load (DC2, DW)

SETTING SECTION GEOMETRY – ACTUAL BOX (CONTIN.)

- For every longitudinal section transition
  - Calculate Actual Bottom Flange Buckling Capacity
DOUBLE ITERATION OF BOTTOM FLANGE

- All critical buckling stresses Box vs. Equivalent I-Girder within 1% or less
- All bottom flange areas ½ Box vs. Equivalent I-Girder within 1% or less
  - Contributes to section property comparison of section moduli (S, in^3)

SECTION PROPERTY COMPARISON: ACTUAL BOX VS. EQUIVALENT I-GIRDER

- All Sections Section Moduli Within ~3% or less

BOX GIRDERS WITH OR WITHOUT LONGITUDINAL STIFFENERS

- b/t ratio of bottom flange of equivalent I-Girder can be iterated to match the local buckling capacity of the bottom flange of an actual box section with or without longitudinal stiffeners
- On KDOT Load Rating Project we had both scenarios
SECTION GEOMETRY IN AASHTOWARE BRR

- Transverse Stiffener Spacing and Geometry
  - Same as actual box girder web
  - Fictional diaphragms every 5 to 6 ft – simulates box girder torsional rigidity, ensures lateral torsional buckling doesn’t control rating

TRANSVERSE STIFFENERS

KDOT LOAD RATING VEHICLES
SPECIFICATION CHECKS

Span 2 – 17.50 ft
Longitudinal Stiffener Termination Location

Even though $\frac{I_{yc}}{I_y}$ falls outside of 0.1 and 0.9 limits, AASHTOWare still computes Mbr...
SPECIFICATION CHECKS

• The girder does not satisfy noncompact criteria for compressive strength as AASHTOWare takes the minimum of the partially braced compressive capacity or the local flange buckling capacity.
• Since the partially braced capacity is the fictional bracing input at every 5', local flange buckling controls.
• Therefore, for the bottom flange, AASHTOWare checks capacity to Fy and Fcr only, mimicking the behavior of the actual box girder.
• Fy = 50 ksi
• Fcr = 4.86 ksi
• Mu=Fcr x S = 4.86 ksi x 691.73 in^3 x 1/12 in = 280 k-ft (verified)

FINAL BOX GIRDER RATING SUMMARY

• N.B. I-635 over E.B. I-35

• Results:
  - Typically areas of high moment or areas with abrupt changes in capacity i.e. flange transitions or longitudinal stiffener termination locations controlled the rating.
  - Shear controlled rating for areas of high shear, heavy axle or various truck, panel length changes due to changes in transverse stiffener spacing.
OTHER STEEL RATING METHODS

- Modeling of K-Frame Grasshopper Bridges using simplified spring method with external verification
- Other Steel Rating Methods

- Deflections not to scale
- Amplified Deflected Shape

- Legs of Frame
- Combined Axial-Bending (concurrent forces needed)
- Strong Axis Axial Buckling
- Weak Axis Axial Buckling
- Moment
- Shear

Amplified Deflected Shape
## OTHER STEEL RATING METHODS

- Modeling of K-Frame Grasshopper Bridges using simplified spring method with external verification

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VS.

- AASHTOWare BrR
- STAAD FEM/Excel Post-Processing

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OTHER STEEL RATING METHODS

- Modeling of Hinges (Shelf Plate) in 3D FEM I-Girder Models
  - Moment to "zero" at hinge, shear carried across hinge, hinges rated for local moment externally using shear force generated from AASHTOWare model

- OTHER STEEL RATING METHODS
  - Spans Modeled for load only, High Fy, fully stiffened
    - Actual unit being rated
    - Spans Modeled for load only, High Fy, fully stiffened

- Shear Diagram: Example Bridge with Hinges
  - High shear spike due to difference in stiffness (I,E)
OTHER STEEL RATING METHODS

- Reverse Curvature Bending in longitudinal members

- 2014 AASHTO LRFD 7th Edition, 6.10.8.2.3

\[ T = T_0 \left\{ 1 + \frac{1}{2} \left( \frac{L}{R} \right)^2 \right\} \frac{I}{I_0} - \frac{R}{R_0} \]  (6.10.8.2.3)

- For columns and other members where

\[ \frac{L}{R} \geq 3 \]

- For other cases,

\[ T = T_0 \left\{ 1 + \frac{1}{2} \left( \frac{L}{R} \right)^2 \right\} \frac{I}{I_0} - \frac{R}{R_0} \]  (6.10.8.2.3)

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OTHER STEEL RATING METHODS

- Reverse Curvature Bending in longitudinal members
- C_b factor modification

OTHER STEEL RATING METHODS

- Reverse Curvature Bending in longitudinal members
- Braces at DL inflection points
- Hand calculations to verify C_b with AISC Equations after braces are added

THE TEAM

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