# mBrace3D, Refined Analyses for Curved Steel Bridges

Manual for Refined Analysis in Bridge Design and Evaluation

May 2019



U.S. Department of Transportation Federal Highway Administration

Sponsored by Federal Highway Administration Office of Infrastructure FHWA-HIF-18-046 Reference document for FEA applied to bridges

- Different types of analyses:
   Line girder analysis (1D)
   Plate on eccentric beam analysis (2D)
   Finite element analysis (3D)
- Detailed examples -> Benchmark problems

https://www.fhwa.dot.gov/bridge/pubs/hif18046.pdf

#### Why use a Refined Analysis?

• "Capturing behavior not adequately accounted for by approximate methods and/or outside the limits of the Specifications. Even within the limits of applicability, approximate methods can give erroneous indications of a <u>structure's true behavior</u>.

• Obtaining <u>more accurate</u>, and <u>less conservative</u>, demands for existing structures, especially when approximate methods result in conservative demands which in turn result in extensive repair or replacement of structures."

Why use a Refined Analysis?

- "Improved <u>structural safety</u> by more rigorous assessment of limit states
- Increased **<u>economy</u>** by going beyond use of approximate, conservative design formulae
- Increased safety and economy by accurate modeling of system or local behavior"

#### Why use a Refined Analysis?

"This Manual promotes a <u>fundamental change in the practice of bridge engineering</u> and attempts to move our industry past the use of simplistic design specifications to achieve more optimal solutions.

#### (...)

This Manual is seen as an essential component to <u>defining proper criteria for software</u> <u>vendors to follow</u> and for engineers to demand from their tools."

#### **Further References**

G13.1 Guidelines for Steel Girder Bridge Analysis



American Association of State Highway Transportation Officials National Steel Bridge Alliance AASHTO/NSBA Steel Bridge Collaboration AASHTO/NSBA Steel Bridge Collaboration – G 13.1 Guidelines for Steel Girder Bridge Analysis, 2nd Edition, 2014

D. Coletti et al.

#### **Further References**

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

#### **NCHRP** REPORT 725

Guidelines for Analysis Methods and Construction Engineering of Curved and Skewed Steel Girder Bridges

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Subscriber Categories Bridges and Other Structures • Highways

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TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C. 2012 WWW.TRB.org NCHRP Report 725 – Guidelines for Analysis Methods and Construction Engineering of Curved and Skewed Steel Girder Bridges, 2012

D. White, D. Coletti et al.

## Arequa Gulch Bridge, Cripple Creek, CO (2001)

#### Straight plate girder bridge. 1,212 ft long, 266 ft main span, \$6 million (AISC)



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### Raccoon Creek Bridge, Pike County, KY (2006)

#### Curved tub girder bridge. 1,275 ft long, 380 ft main span, \$20.4 million (AISC)



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#### Benefits of a Refined Analysis for Curved Steel Bridges

- Curved geometries induce a combination of bending and torsion
- <u>Stability</u> during <u>erection and deck placement</u> is often critical due to large unbraced lengths and uncertainty in loads and support conditions
- 1D line analyses and 2D grid models are often inadequate for the construction phase



**Program: ABAQUS** 

## mBrace3D – "Refined" Analysis – Modeling



Plate girders (parabolic haunch)

Tub girders

#### mBrace3D – "Refined" Analysis – Deck Modeling



Curved plate girders with skewed supports

Deck meshing on irregular geometries

#### mBrace3D – "Refined" Analysis – Complex Geometries



Curved plate girders with skewed supports

Curved tubs with a point of tangency

## Parametric Modeling – Quick, user-friendly, no drawing on screen

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Geometry Boundary conditions									Number of steps: 8										
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#### Automatic Post-Processing – Moment, Shear, Torsion, Brace Forces, etc.



#### mBrace3D Capabilities

#### Analysis Types

- First-order linear elastic analysis
- Second-order geometric nonlinear analysis (with initial imperfections)
- Eigenvalue buckling analysis
- Eigenvalue frequency analysis
- Influence analysis
- Vehicle load optimization

#### Loadings

- Gravity
- Wind loads
- Flange lateral loads
- Wearing surface load / Barrier line load
- Thermal loads
- Vehicle loads (any configuration)

#### Geometries

- Straight
- Curved
- Points of tangency
- Points of compound curvature
- Haunched girders (parabolic)

**Cross-Frame Fatigue Analysis** 

D. Altman, B. Chavel, "Keeping Cross-Frames in Check", Modern Steel Construction, October 2020

"Strategy 1. The AASHTO *LRFD Specifications* 2020/9th Edition Commentary Article C6.6.1.2.1 recommends that the fatigue truck be positioned to determine the <u>maximum</u> <u>range of stress</u> or torque, as applicable, <u>with the truck confined to one critical transverse</u> <u>position</u> per each longitudinal position throughout the length of the bridge in the analysis."

## mBrace3D – Vehicle Load Optimization for Fatigue Analysis



Left isometric view

Top view

### mBrace3D – Vehicle Load Optimization for Fatigue Analysis



Maximum stress range | maximum brace force

Maximum stress range | minimum brace force

#### mBrace3D – Results Validation with LUSAS



mBrace3D – Closing Remarks

-> mBrace3D is a tool that conducts "REFINED" analyses in a <u>minimal amount</u> of time and with <u>limited FEA knowledge</u>, for the benefit of steel bridge <u>erectors and designers</u>

-> The software is a **cost-effective** alternative to other commercial programs