Load Rating of Pile-Supported Bridges
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Mr. Bridges
Safe Weight Lifting Load

Superstructure

Load Rating 200 lbs.

Substructure

Load Rating 120 lbs.

120 lbs.
Mr. Bridges

Leg Collapse

Superstructure

Substructure

Failure

Load Rating
200 lbs.

Load Rating
120 lbs.
Mr. Bridges
Safe Lifting via Weight Bench

- Load Rating of Pile-Supported Bridges
  - Superstructure
    - Load Rating 200 lbs.
  - Substructure
    - Load Rating 250 lbs.
Bridge load rating is traditionally based on the superstructure components. Rarely does the bridge load rater consider the load carrying capacity of the substructure.
• Manual for Condition Evaluation of Bridges (MCEB) (AASHTO 2010) states:

“...members of substructures need not be routinely checked for load capacity”.

and

“Substructure elements should be checked in situations where the Engineer has reason to believe that their capacity may govern the load capacity of the entire bridge”.
• MCEB requirement related to considering the substructure in a bridge load rating is applicable to bridges over waterways

• State of Practice about Substructure:
  a) No mention at all
  b) Left to bridge engineers’ judgment
  c) Using a qualitative rather than a quantitative approach
  d) Considering structure integrity but not soil failure, if done

• **Substructure**: Weakest Link in Bridge Load Rating

• **Bridges Over Waterways Need to be Re-Evaluated**
  - Prevent Catastrophic Failure
  - Reduce Maintenance/Repair Costs
Inventory Bridge Loading Flowchart

**Inventory Bridge Load Rating**

- Lower Rating/FS is High

**Substructure**
- Via S/B-C
  - ASD
    - Loads \( \leq \eta_g \sum Q_o / FS \)
    - Deformation \( \leq \Delta_i \)
  - LRFD
    - Loads \( \leq \eta_g \sum \phi Q_o \)
    - Deformation \( \leq \Delta_i \)
  - LFD
    - Loads \( \leq \eta_g \sum \phi Q_o \)
    - Deformation \( \leq \Delta_i \)

**Superstructure**
- Via AASHTO
  - ASD
    - Loads = \( R \)
    - \( RF = (C - A_f D) / A_2 L (1 + 1) \)
  - LRFD
    - Loads = \( \sum \gamma_i R_i \)
    - \( RF = [C - (\lambda_{DC})(DC) - (\lambda_{DW})(DW) + (\lambda_{P}) P] / (\lambda_{P})(LL + IM) \)
  - LFD
    - Loads = \( \gamma_p \sum \beta_i R_i \)
    - \( RF = (C - A_f D) / A_2 L (1 + 1) \)
## Load Factors

<table>
<thead>
<tr>
<th>Rating Methodology</th>
<th>LRFR</th>
<th>LFR</th>
<th>ASR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead Load Factors</td>
<td>( \lambda_{DC} - 1.25 )</td>
<td>( A_1 = 1.0 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \lambda_{DW} - 1.25 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Live Load Factors</td>
<td>( \lambda_L )</td>
<td>( A_2 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inventory - 1.75</td>
<td>Inventory - 2.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operating - 1.35</td>
<td>Operating - 1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Legal - 1.4 to 1.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Permit - 1.15 to 1.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic Load Allowance/Impact Factor</td>
<td>Constant</td>
<td>Span Length Dependent</td>
<td>Article 6.7.4 (AASHTO 2000)</td>
</tr>
</tbody>
</table>

Source: AASHTO (2008; 2010)
Substructure Rating
Proposed Method

• Static/Back-Calculation (S/B-C) is used to perform the analysis - an iterative process using finite element modeling (FB-MultiPier)

  → Axial Loads & tip elevations - FB-Deep, Driven, etc.

  → Graph FEM results - live load vs. corresponding settlement

• Loading level corresponding to a pre-defined deformation (settlement criteria) is determined as the load rating.
Settlement Considerations

Superstructure
### Settlement Criteria for Bridges

*(After Xanthakos 1995)*

<table>
<thead>
<tr>
<th>Settlement Magnitude (inch)</th>
<th>Basis for Recommendation</th>
<th>Recommended By</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Not Harmful</td>
<td>Bozozuk (1978)</td>
</tr>
<tr>
<td>2.5</td>
<td>Ride Quality</td>
<td>Walkinshaw (1978)</td>
</tr>
<tr>
<td>&gt;2.5</td>
<td>Structural Distress</td>
<td>Walkinshaw (1978)</td>
</tr>
<tr>
<td>4</td>
<td>Ride Quality and Structural Distress</td>
<td>Grover (1978)</td>
</tr>
<tr>
<td>4</td>
<td>Harmful but Tolerable</td>
<td>Bozozuk (1978)</td>
</tr>
<tr>
<td>&gt;4</td>
<td>Usually Intolerable</td>
<td>Wahls (1990)</td>
</tr>
</tbody>
</table>
### Angular Distortion for Bridges

**(After Xanthakos 1995)**

<table>
<thead>
<tr>
<th>Angular Distortion</th>
<th>Basis for Recommendation</th>
<th>Recommended By</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.004</td>
<td>Tolerable for Continuous Bridges</td>
<td>Moulton, et al. (1985) Duncan and Tan (1991)</td>
</tr>
<tr>
<td>&lt; 0.008</td>
<td>Tolerable for Simple-Span Bridges</td>
<td>Duncan and Tan (1991)</td>
</tr>
</tbody>
</table>
Settlement Considerations

Substructure


**Substructure**

- **Ultimate Pile Load** \( (Q_o) \)

\[
Q_o = Q_p + Q_s
\]

Where

- \( Q_p \) = Ultimate Tip (Point) Load
- \( Q_s \) = Ultimate Shaft (Skin) Load

- **Full Mobilization of** \( Q_s \)

0.25 to 0.40 Inch

(Vesic 1977)

- **Full Mobilization of** \( Q_p \)

10% \( B \) Driven Piles

Up To 30% \( B \) Bored Piles

Where \( B \) = Pile Width (Diameter)

(Vesic 1977)
Proposed Settlement Criteria

- Settlements of 1 to 1.25 inches and 2 to 2.25 inches have been proposed to establish inventory and operating substructure load rating, respectively.
Case Histories
Bridge No. 030064
Collier County, Florida

Typical Bridge Components
Bridge No. 030064

Bridge Deck
1'-10''
13-1/2''
10'-0''
30''
18'' PCP
Battered 1-1/2''/ft.

Boring No. 5
(1965 Boring Report)

- SPT "N" Value
- Water Level
- ELEV in feet, NGVD

1. Sand and Rock
2. Coarse Sand with trace of Shell
3. Hard Rock
4. Coarse Sand
5. Hard Rock with Sand Pockets

Bent No. 2

- Water Level
- Original Mudline EL -1.93
- Scoured Mudline EL -9.3 (Overtopping)
- Pile Tip EL -13.93
(1965 pile driving records)
Bridge No. 170039
Sarasota County, Florida

Typical Bridge Components
Bridge No. 170039

Bridge Deck
3' 1-1/2" x 38' - 0"
14" x 40' - 8"

Boring No. 1
(2006 Boring Report)

SPT “N” Value

N/A (Drilled)

Bent No. 2

14” Composite Concrete and Steel Piles

Water Level

Existing Mudline
EL 0.7

Original Mudline
EL -0.9

Scoured Mudline
EL -1.0 (100 yr)
Pile Tip EL
-3.6 (1962 pile driving records)

ELEV in feet, NVD

Limestone
Clay

1
2

14"
3' - 7"
10' - 6"
10' - 6"
10' - 6"
3' - 7"

30"

Sayed | Sunna | Moore

Load Rating of Pile-Supported Bridges
Bridge No. 390005
Union County, Florida

Typical Bridge Components
Bridge No. 390005

Bridge Deck
- 7"x9" Timber Post
- 3'-6"
- 9"x9" Curb (typ)
- 21'-6"
- 20'-0"

Pilecap
- 21"x24"
- 12"
- 9'-0"

10" Dia. Timber Pile
- 3'-0"
- 8'-0"
- 8'-0"
- 3'-0"

3"x10" Timber Bracing

Boring No. 2
- Water Level
- 10" Dia. Timber Pile
- SPT "N" Value
  - 10
  - 67
  - 32
  - 50/4"
  - 49
  - 50/3"
- Scoured Mudline
  - EL 80.7 (100 yr)

Bent No. 22
- Original Mudline
  - EL 96.5
- Critical Scoured Mudline
  - EL 93.5
- Pile Tip
  - EL 91.6 (1954 Pile Driving Records)

1 Sand with Organics
2 Sand with Phosphate
Allowable Stress Rating (ASR)

Percent Live Load

Pile Settlement, in.

- Bridge no. 030064
- Bridge no. 170039
- Bridge no. 390005
- Corresponding to truck HS-20 (or 64% SU4)

Percent Live Load
Ratio of applied live load per pile to the live load per pile corresponding to truck HS-20 (or 64% SU4)

Existing mudline
100 yr or overtopping scoured mudline
Critical mudline

A Not harmful (Bozozuk 1978)
B Ride quality (Walkinshaw 1978)
C Structural distress (Walkinshaw 1978)
D Harmful but tolerable (Bozozuk 1978; Grover 1988)
E Usually intolerable (Wahls 1990)

Allowable Stress Design (ASD)
- Factor of Safety = 2.5
Load Factor Rating (LFR)

Load Factor Design (LFD)
- Resistance Factor $\varphi = 0.65$

- Bridge no. 030064
- Bridge no. 170039
- Bridge no. 390005
- Corresponding to truck HS-20 (or 64% SU4)

Percent Live Load
Ratio of applied live load per pile to the live load per pile corresponding to truck HS-20 (or 64% SU4)

Existing mudline
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- Usually intolerable (Wahls 1990)
# Superstructure and Substructure Load Rating

<table>
<thead>
<tr>
<th>Consultant</th>
<th>Bridge No.</th>
<th>Superstructure&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Substructure&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LFR Methodology</td>
<td>@ Existing Mudline Elevation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inventory (tons) Operating (tons)</td>
<td>Inventory (tons) Operating (tons)</td>
</tr>
<tr>
<td>Ayres &amp; GCI (2006)</td>
<td>030064&lt;sup&gt;a&lt;/sup&gt;</td>
<td>45 75</td>
<td>36 40 81 58</td>
</tr>
<tr>
<td></td>
<td>170039&lt;sup&gt;a&lt;/sup&gt;</td>
<td>39 65</td>
<td>15 6 43 18</td>
</tr>
<tr>
<td>Collins &amp; GCI (1997)</td>
<td>390005&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13 22</td>
<td>10 3 12 4</td>
</tr>
</tbody>
</table>

- **HS-20** (36 tons)
- **SU-4** (35 tons)
- **ASR** Allowable Stress Rating
- **LFR** Load Factor Rating
- **N/A** Not available due to excessive displacement or non-convergence (i.e., instability)
Conclusions

• Current practice usually assigns load ratings based on evaluation of the superstructure. Load rating a bridge based on the superstructure alone could cause either catastrophic or functional failure.

• The load carrying capacity of substructure decreases as scour occurs.

• Definitive methodology for assigning substructure load rating to bridges should be initiated.
Conclusions continued

- All bridges over waterways should be analyzed for a substructure load rating considering the existing mudline and potential scour
- Substructure load rating should be dependent on the settlement
- Settlements of 1 to 1.25 inch and 2 to 2.25 inch have been proposed to establish inventory and operating substructure load rating respectively
- Further field monitoring and research needed to establish optimum settlement criteria.