Development and Implementation of New Specifications for Anchor Bolt Tightening

Presenter: Zac Dietrich
An Chen: Iowa State University
Jihshya Lin: Minnesota Department of Transportation
Brent Phares: Iowa State University

Mid-Continent Transportation Research Symposium
Iowa State University
August 21st 2019
Outline

• Overview
• Development of Draft Specifications
• Implementation of Draft Specifications
• Recommended Improvements to AASHTO
Overview
Collaborators

An Chen, Ph.D., P.E.  Jihshya Lin, P.E., S.E.  Zhibin Lin, PhD, PE
Brent Phares, PhD, PE  Mijia Yang, PhD, PE
Zachary Dietrich, EIT  
Hanming Zhang  
Connor Schaefer, EIT  
Elizabeth Miller
Problem Statement

- MnDOT maintenance crews found loose anchor rod nuts in:
  - In place support structures: became loose in less than two years after being tightened
  - Newly installed overhead signs; high-mast light tower (HMLT); traffic signals; etc.
- Creates strain on resources
- Increases fatigue loading on anchor bolts
- MnDOT funded $446,000 of research projects to revise, implement, and improve specifications
Typical Connections

- **Double Nut Clamp**
  - Top nut and leveling nut “clamp” support structure to anchor rods connected into foundation
  - Grip length: distance between faces of both washers (distance that the bolt holds tension)
  - Generally tightened with a wrench in the following steps:
    - Bring to snug tight
    - Final tension with torque, turn of nut, or both
Current Specifications

- AASHTO LRFD - SLTS: 5.17.5.2
- Based on a process adapted from Garlich and Thorkildsen (2005) [2]
- Once sign is placed:
  - Nuts brought to “snug tight”
    - “the maximum nut rotation resulting from the full effort of one person on a 305-mm (12-in.) long wrench or equivalent.”
  - Star pattern utilized
  - Turn of nut tightening

<table>
<thead>
<tr>
<th>Anchor Bolt Diameter, mm (in.)</th>
<th>Top Nut Rotation beyond Snug-Tight&lt;sup&gt;a,b,c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1554 Grade 36</td>
<td>F1554 Grades 55 and 105 A449, A615, and A706 Grade 60</td>
</tr>
<tr>
<td>≤38 (&lt;1½)</td>
<td>⅙ turn</td>
</tr>
<tr>
<td>&gt;38 (&gt;1½)</td>
<td>⅛ turn</td>
</tr>
</tbody>
</table>

<sup>a</sup> Nut rotation is relative to anchor bolt. The tolerance is plus 20 degrees (⅛ turn).
<sup>b</sup> Applicable only to double-nut moment connections.
<sup>c</sup> Use a beveled washer if the nut is not in firm contact with the base plate or the outer face of the base plate is sloped more than 1:40.
Development of Draft Specifications
State Survey

- Nationwide survey
  - 24 of 29 responding states had nut loosening issues
  - Percentage of loose nuts found ranges from 1-2% to 90% of structures
  - Very few states use lock nuts, double nuts, or DTI’s
  - Many states believe improper installation is the cause
  - Definition of ‘snug-tight’ is not consistent
- No trend found to prevent loosening in all surveyed states
Site Visits and Interviews with MnDOT

- Lack of maintenance resources may lead to unsafe structures
- Proper installation is key to long term performance
- Inconsistent installation points to contractor error / lack of knowledge
- No observed verification procedure

Missing Bottom Washer found During Maintenance Operations
Lab Testing Methods

- Skidmore-Wilhelm tension Testers
  - Torque Testing to Determine Nut Constant, K
    \[ T = KFD \]
    T: applied torque, F: Pretension in the fastener, D: bolt diameter
  - Rotation Testing to investigate stiffness factor, ks and grip length
    \[ \Delta_{bolt} = k_s \left( \frac{\alpha}{360} \times P_i \right) = \frac{FL}{AE} \]
    \( \Delta \): deformation, \( Pi \): pitch factor, \( \alpha \): nut rotation in degrees

- Lab Specimen
  - Investigate fatigue resistance and performance of existing specifications
Lab Testing Results – Skidmore

- Snug Tight at approximately 10% Fy
  - Current specification could either under or over tighten
- Turn of nut depends on:
  - Initial snug tight being in linear region of connection
  - Grip length, impacts stiffness of bolt and the turn required to properly tension the connection
- Work to expand data for grip length and bolt types in Fall-Winter 2019
Lab Testing – Fatigue

- Based on instrumented over head sign collecting in-field fatigue data
- Initial tests found that the previous MnDOT specification was significantly under tightening bolts
  - Exceeded AASHTO CAFL cycles at 1 ksi, but loosened after 2000 cycles at 6 ksi
  - Higher impact of larger stress ranges
- Future work on developing CAFL for the connection loosening in Fall-Winter 2019
New Specifications

• Based on AASHTO with three changes:
  • Specifies snug tight values to ensure a correct “initial condition”
  • Grip length included as a parameter with turn-of-the-nut tightening to account for varying stiffness
  • Has a torque verification step to ensure correct pretension is achieved in the bolt.
  • “Menu” of different options along with an inspector verification form to ensure connections are correctly installed

<table>
<thead>
<tr>
<th>OH Sign Anchor Bolts &amp; Grip Lengths</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pole Type</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Type 5-7 Sign Truss</td>
</tr>
</tbody>
</table>

Sample of Tightening “Menu”
New Specification Steps

1. Verify F1554 anchor bolt grade is as specified for the project. Verify nuts are ASTM A563 heavy hex and washers are F436.

2. Verify anchor bolts are clean and not damaged and plumb – not more than 1:40 slope or 1/4" in 10" (if bolts are out of plumb or damaged contact project engineer).

3. Lubricate anchor bolts with MnDOT specified bridge grease (within 24 hours of tensioning) and turn nut down to foundation. Lubricate bearing surfaces of leveling nut and top nut prior to tightening.

4. Level leveling nuts – make sure nuts are less than one anchor bolt diameter from the foundation but no less than 1-1/4” for OH Signs.
5. Install structure with an F436 washer below and above base plate and snug top nuts. **When snugging use snuggling torque or maximum open end wrench length on both the top nut and leveling nut following the star pattern. Two cycles of snuggling shall be performed prior to Step 6.**

6. Perform turn of nut tightening. Mark the nuts and adjacent base plate and turn the **minimum required turn per appendix, but do not exceed the verification torque.**

7. Confirm verification torque was achieved, or continue to turn nut until verification torque is achieved.

8. 48 hours after initial tightening, apply re-tightening torque. The re-tightening torque is 110% of verification torque (1.1*Tv).
Implementation of Draft Specifications
Installation

- Create deliverables for MnDOT to assist with training of implementation of new specifications
- Implement specifications in field to ensure they are constructible
  - Star pattern new to many contractors, some steps found to be excessive
- Continue monitoring of sign structure

Various Installation Sites Visited
Maintenance

- Different specifications needed for in-place structures, so nuts were removed one by one and replaced at snug tight. The specification could then be followed.

- Findings:
  - 48hr re-tightening torque not feasible
  - Torque easier to use than turn of nut in many structures
  - Clearance issues in lighting structures
  - Existing conditions give varying turn of nut values

<table>
<thead>
<tr>
<th>Structure</th>
<th>Final Nut Turns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>194-601 EB</td>
<td>0</td>
</tr>
<tr>
<td>194-602 EB</td>
<td>3/24</td>
</tr>
<tr>
<td>194-603 EB</td>
<td>1/12</td>
</tr>
<tr>
<td>194-608 WB</td>
<td>0</td>
</tr>
<tr>
<td>194-606 WB</td>
<td>3/12</td>
</tr>
</tbody>
</table>
Lessons from Implementation

- Separate set of specifications for maintenance vs. new installation
- Lubrication specification is too restrictive
  - Variance of different lubrications will be investigated in Fall-Winter 2019
- 48 hour retightening torque is unlikely to be followed without enforcement
  - Literature points that error may be negligible, investigate in Fall-Winter 2019
- Current turn of nut specification difficult to follow in enclosed light pole bases
Recommended Improvements to AASHTO LRFD - SLTS
Possible Improvements

- Definition of sung tight: Important for initial condition of connection for turn of nut
- Take grip length into account: impacts final turn values for the connection
- Verify connection with torque: two methods ensure that if one is completed incorrectly the other can take up the slack.
- Consider removing the 48 hr retightening torque step: difficult for contractors to complete and literature shows scatter will be acceptable if tightened to 110% of Tv immediately
  - Will be further investigated in Fall-Winter 2019
- Include maintenance steps for retightening of existing structures
Questions
References


Thank You