Technical Memorandum

To: **Electronic Distribution Recipients**

From: **Nancy T. Daubenberger, P.E.**
Assistant Commissioner, Engineering Services

Subject: Adhesive Anchoring Systems in Sustained Tensile-Load Applications

Expiration

This Technical Memorandum supersedes TM 13-03-B-01 which expired February 5, 2018 and will expire on December 10, 2023 unless superseded prior to that date.

Implementation

Apply guidance contained herein on all new and ongoing Trunk Highway projects and State Aid projects. Local road authorities are encouraged to adopt similar guidelines. This policy and its instructions are effective immediately.

Introduction

Past MnDOT policy prohibited the use of adhesive anchors in sustained tension. This policy was based on reactions to the ceiling collapse of the I-90 Seaport Connector Tunnel in Boston, MA and FHWA Technical Advisory (TA) T5140.26 which strongly discouraged the use of adhesives in “permanent sustained tension applications.”

FHWA has since issued TA T5140.34 on January 16, 2018, which permits use of adhesive anchors in sustained tension applications when the anchor has been designed in accordance with the provisions of ACI 318-14 or later and if the adhesive has been evaluated using ACI 355.4-11 or later. MnDOT has also made adjustments to design procedures and construction practices to mitigate installation issues.

In consideration of industry changes, FHWA guidance, and internal guidance, MnDOT will permit the use of adhesive anchors for limited applications in accordance with the following guidelines.

Purpose

This Technical Memorandum outlines new guidance with respect to the use of adhesive anchors in sustained tension.

Guidelines

The design and construction guidelines of this memo are written for adhesive products listed on the MnDOT Approved Products Lists (APLs) entitled 'Concrete Anchorages – Reinforcing Bar Applications' for rebar anchors and 'Concrete Anchorages – Threaded Rod Applications' for threaded rod anchors found at https://www.dot.state.mn.us/products/bridge/index.html. Approved adhesives located on the MnDOT APL entitled 'Concrete Anchorages (non-bridge applications)' are not to be used on projects for anchorages designed in accordance with ACI 318 Chapter 17 and are not addressed as part of this memo.

Design Guidelines

Adhesive anchors used to support sustained tensile-loads are ***prohibited*** for both permanent and temporary construction in the following applications:

- Pier cap retrofits, support, or repairs;
- Abutment paving brackets that support approach slabs over voided abutments;
- Primary reinforcing for deck overhang repairs or replacement;
- Primary reinforcing for abutment stem and wingwall widenings and retrofits;
- Corbels supporting any element that carries directly applied traffic loads (e.g. beams), excluding paving brackets supporting approach panels on grade;
- Supports for overhead cantilever signs;
- Supports for utilities and drainage systems; and
- Supports for catwalks.

Adhesive anchors, ***whether in sustained tension or otherwise***, are ***prohibited*** from installation in delaminated or structurally unsound concrete.

Adhesive anchors used to support sustained tensile-loads are ***allowed*** in the following applications and must include as part of the design a sustained tension load check in accordance with ACI 318 17.3.1.2 and the attached "Adhesive Anchorage Design Procedure":

- Attachment of bridge mounted signs;
- Any applications in abutment and wingwall retrofits not expressly prohibited in this memo;
- Deck repairs not expressly prohibited in this memo; and
- All other cases, not expressly prohibited in this memo, where the factored sustained tension load exceeds 10% of the factored nominal anchor capacity in tension and with approval from the State Bridge Design Engineer.

If the sustained tension load is less than 10% of the factored nominal tensile capacity of the anchor, the provisions of ACI 318 Article 17.3.1.2 need not be considered and the anchor may be installed using any adhesive on the MnDOT Approved Products List.

The following applications were identified as having sustained tension, however the consequence of failure is low. These applications are ***allowed*** without consideration of sustained tensile-loads in design and may be installed with any adhesive on the MnDOT APL, regardless of the magnitude of the sustained tension load:

- Attachment of paving brackets to abutments where the approach panel rests on grade;
- End post retrofits cantilevered off the back of an abutment;
- End blocks on parapet type abutments;
- Attachment of shear brackets to the back of retaining walls;
- Attachment of base plates with threaded rod anchorages where the sustained tension load is only due to the tightening of threaded rod nuts; and
- Support of pier struts retaining soil.

Consider the following factors when the use of adhesive anchors in sustained tension is an option:

- **Consequence of Failure:** Applications where failure would pose a direct threat to the safety of the traveling public (e.g. components which are likely to cause death or injury if an anchor fails) are ***prohibited***;
- **Installation Over Traffic:** Bridge mounted signs and deck repairs are permitted as noted above. Otherwise, this application is ***prohibited***;
- **Overhead Applications:** Overhead applications are defined as anchorages which are installed in a vertical upward position. Overhead applications of adhesive anchorages are ***prohibited***.
- **Supporting Traffic:** Except for deck repairs and paving brackets supporting approach panels on grade, this application is ***prohibited***; and
- **Concrete Condition:** Concrete which is delaminated or otherwise structurally unsound is not appropriate for support of adhesive anchors.

For anchorages designed to resist sustained tension in accordance with ACI 318 Article 17.3.1.2 use the pay item ***2433.502 "ANCH TYPE REINF BARS (TYPE ST)"*** or ***2433.502 "ANCH TYPE THREADED RODS (TYPE ST)"*** and clearly note in the plan that the anchor is a 'Sustained Tension Application.'

Construction Guidelines

Use the special provision titled 'SB2018-2433.8 A TYPE ST Anchorages' located at http://www.dot.state.mn.us/bridge/construction.html under **Resources**, *2018 "SB" Bridge Special Provisions*, when specifying Type ST anchorages. For all ***Type ST*** anchorages, the third party testing agency responsible for proof loading anchorages is required to do the following:

- Check that the adhesive is on the MnDOT Approved Products list (APL) entitled 'Concrete Anchorages – Reinforcing Bar Applications' for rebar anchors or 'Concrete Anchorages – Threaded Rod Applications' for threaded rod anchors and is indicated approved for sustained tension applications; and
- Initial the testing documents indicating that the sustained tension is allowed and is found on the MnDOT APL.

The MnDOT APL and construction forms for adhesive anchors have been updated to reflect this change.

Questions

Any questions regarding the technical provisions of this Technical Memorandum can be addressed to either of the following:

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(651) 366-4485

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(651) 366-4506

Any questions regarding publication of this Technical Memorandum should be referred to the Design Standards Unit, DesignStandards.DOT@state.mn.us. A link to all active and historical Technical Memoranda can be found at http://techmemos.dot.state.mn.us/techmemo.aspx.

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Attachments:

Adhesive Anchorage Design Procedure

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1.1 Overview

MnDOT utilizes current AASHTO LRFD Bridge Design Specifications (AASHTO) and ACI 318 (ACI) Chapter 17 design principles when performing design checks for adhesive anchorages. When designing an adhesive anchorage or group of anchorages, loads can be resolved into tension loads and shear loads. Tension loads are further divided into sustained tension loads and transient tension loads. AASHTO Load Factors are applied.

Eight failure modes are considered when designing an adhesive anchorage:

1. Steel rupture in tension;
2. Steel rupture in shear;
3. Concrete breakout in tension;
4. Concrete breakout in shear;
5. Splitting;
6. Bond failure in tension;
7. Pryout failure in shear; and
8. Creep failure under sustained tension.

Also, consider interaction effects as part of the design when both shear and tensile loads are applied to an anchorage or anchorage group.

This document outlines the design procedure for adhesive anchorages in general and provides detailed guidance on the procedure for checking an adhesive anchorage's sustained tension load capacity.

1.2 Resistance Factors

Resistance factors in ACI are chosen based on concrete condition and anchorage category. Anchorages may be divided into 3 different categories. Category 1 are anchorages with low sensitivity to installation and high reliability. Category 2 are anchorages with moderate sensitivity to installation and moderate reliability. Category 3 are anchorages with high sensitivity to installation and low reliability. An adhesive anchorage's category is determined through testing in accordance with ACI 355.4 and is therefore product specific. However, MnDOT assesses anchorage products prior to approval and ensures that anchorages will be at least Category 2 under field conditions. Note that the installation procedure for Category 1 and Category 2 anchorages does not change significantly. Because of this, concrete breakout capacity uses Category 1 resistance factors. Also, because adhesive anchorages in sustained tension are installed in locations where it may be difficult to install and inspect, the anchorage is considered a Category 3 anchorage for this check.

Concrete condition is determined based on the reinforcing present in the section to which an anchorage is attached. For design purposes, any regularly reinforced section with appropriate temperature and shrinkage steel and/or distribution steel is considered Condition A. All other sections are considered Condition B. Unreinforced sections where temperature and shrinkage reinforcing is not required are Condition B. Condition B should be assumed for pryout and creep failure modes. Table 1-1 outlines the resistance factors used for each failure mode for all adhesive anchorage designs except for pedestrian metal railing anchorages.

MnDOT uses higher resistance factors for pedestrian metal railing anchorage design. The current controlling live load factor in ACI is 1.6, whereas the AASHTO Strength I live load factor is 1.75. Because MnDOT uses the AASHTO load factors and pedestrian anchorage design is governed by the Strength I case, the current ACI resistance factors are overly conservative for design. The resistance factors to be used for pedestrian metal railing anchorages are listed in Table 1-2. Note that Table 1-2 does not include a creep rupture failure mode because sustained tension loads are not required to be checked for pedestrian metal rail anchorages.

Table 1-1 – Resistance Factors for General Anchorage Design Except for Pedestrian Metal Railing Anchorages

Failure Mode	Resistance Factors		Code Reference
	Condition A	Condition B	
Steel – Shear	0.75		AASHTO 6.5.4.2
Steel – Tension	0.80		AASHTO 6.5.4.2
Concrete Breakout - Shear	0.75	0.70	ACI 17.3.3
Concrete Breakout – Tension (Cat. 1)	0.75	0.65	ACI 17.3.3
Bond (Cat. 2)	0.65	0.55	ACI 17.3.3
Pryout		0.55	ACI 17.3.3
Creep Rupture (Cat. 3)		0.45	ACI 17.3.3

Table 1-2 – Resistance Factors for Design of Pedestrian Metal Railing Anchorages

Failure Mode	Resistance Factors		Code Reference
	Condition A	Condition B	
Steel – Shear	0.75		AASHTO 6.5.4.2
Steel – Tension	0.80		AASHTO 6.5.4.2
Concrete Breakout - Shear	0.85	0.75	MnDOT Policy
Concrete Breakout – Tension (Cat. 1)	0.85	0.75	MnDOT Policy
Bond (Cat. 2)	0.75	0.65	MnDOT Policy
Pryout		0.65	MnDOT Policy

1.3 Steel Tensile Rupture

Steel tensile rupture is checked in accordance with the provisions of AASHTO Article 6.13.2.11. Use a resistance factor, ϕ, of 0.80 per AASHTO Article 6.5.4.2. Interaction effects are considered as per AASHTO Article 6.13.2.11. The factored load is the summation of all tension loads, transient and sustained. Calculate factored loads in accordance with AASHTO requirements.

1.4 Steel Shear Rupture

Steel shear rupture is checked in accordance with the provisions of AASHTO Article 6.13.2.7. Use a resistance factor, ϕ, of 0.75 per AASHTO Article 6.5.4.2. Interaction effects are considered as per AASHTO Article 6.13.2.11. The factored load is equal to the summation of all shear loads.

1.5 Concrete Breakout - Tension

Concrete breakout in tension is checked in accordance with the provisions of ACI 17.4.2. Use a resistance factor, ϕ, per Table 1-1 or Table 1-2. Concrete failure modes are calculated assuming a cracked concrete condition. Interaction effects are considered as per ACI, but not in conjunction with steel rupture modes, as the interaction effects for these modes are considered as part of AASHTO. The factored load is the summation of all tension loads, transient and sustained.

1.6 Concrete Breakout - Shear

Concrete breakout in shear is checked in accordance with the provisions of ACI 17.5.2, with load factors as defined in AASHTO Section 3. Use a resistance factor, ϕ, per Table 1-1 or Table 1-2. Concrete failure modes are calculated assuming a cracked concrete condition. Interaction effects are considered per ACI but not in conjunction with steel rupture modes, as the interaction effects for these modes are considered as part of AASHTO. The factored load is equal to the summation of all shear loads.

1.7 Splitting Failure

Splitting failure is inherent in the design considerations of ACI and need not be considered using any other methods. For more information refer to ACI Chapter 17.

1.8 Bond Failure

Bond failure is checked in accordance with the provisions of ACI 17.4.5, using a resistance factor, ϕ, per Table 1-1 or Table 1-2. Bond capacity is calculated assuming either cracked or uncracked concrete properties depending on the likelihood that a crack will form through the adhesive and on whether or not cracks are likely to be working cracks. Uncracked bond strength can be assumed in the following cases:

1. Pedestrian rail anchorages in regularly reinforced concrete sections;
2. Crash strut anchorages into existing concrete footings;
3. Paving brackets anchored to abutment backwalls;
4. End posts anchored to abutment backwalls and wingwalls; and
5. Anchorages used in temporary installations.

In all other cases, assume cracked bond properties. Note that ACI requires that the critical edge distance, c_{Na}, always be found using uncracked properties.

Interaction effects are considered as per ACI but not in conjunction with steel rupture modes, as the interaction effects for these modes are considered as part of AASHTO. The factored load is the summation of all tension loads, transient and sustained.

1.9 Pryout Failure

Pryout failure is a shear failure mode. However, the capacity of the concrete in pryout is estimated using the concrete breakout capacity in tension or the bond capacity in tension. Check the pryout capacity of an anchorage whenever shear loads are expected to be transferred by an anchorage regardless of whether or not there are any tensile loads on the anchorage. Use ACI 17.5.3 and load factors as defined in AASHTO Section 3. Select a resistance factor, ϕ, from Table 1-1 or Table 1-2. The factored load is equal to the summation of all shear loads.

1.10 Creep Failure

Creep failure of an adhesive is a time dependent failure mode. When an adhesive is subjected to sustained tension loads over an extended period of time, the material will begin to relax and elongate. Eventually, the adhesive will deform enough to cause structural failure.

There are three main contributors to a creep type failure:

1. The magnitude of the load;
2. The length of time that an anchor is exposed to sustained loads; and

3. The material properties of the adhesive.

ACI 355.4 contains the acceptance criteria for adhesives intended to support sustained tension loads. Adhesives tested in accordance with these provisions are considered to have material properties which will perform adequately under sustained loads. MnDOT reviews adhesives submitted for placement on the MnDOT Approved Products List and will indicate if the appropriate testing has been performed to allow for use of an adhesive in sustained tension applications. Adhesives approved for use in sustained tension applications are required to be used when indicated in the plan documents or as required by TM 18-11-B-01.

Unless otherwise specified in TM 18-11-B-01, if the factored sustained tension load is equal to or in excess of 10% of the controlling factored nominal tensile capacity (i.e. the controlling tension failure mode of steel rupture in tension, concrete breakout in tension, and bond failure) the capacity of the anchorage is to be checked in accordance with ACI 17.3.1.2 as modified by AASHTO 5.13.2.2.

Designers should be aware that the design provisions of ACI 17.3.1.2 as modified by AASHTO 5.13.2.2 assume a 100 year life at moderate temperatures. Anchorages expected to sustain loads for longer than 100 years or for more severe temperatures require a more stringent loading criteria than those suggested by AASHTO.

1.10.1 Design Outline for Creep Rupture Check

The outline on the following page is a summary of the design process for adhesive anchors under sustained loads.

Creep Rupture Outline for Sustained Tension Check

1. Calculate factored loads
    a. Determine factored sustained tension load on a single anchorage, $(T_{u.sus})_{single}$
    b. If required, determine factored sustained tension load on the anchorage group, $T_{u.sus}$
       (Note: for a single anchorage, $T_{u.sus} = (T_{u.sus})_{single}$)
    c. Determine factored tension load, T_u

2. Find factored nominal tension resistance
    a. Calculate factored nominal steel rupture strength in tension, ϕT_n (AASHTO 6.13.2.11)
    b. Calculate factored nominal concrete breakout strength in tension, ϕN_{cbg} (ACI 318 17.4.2)
    c. Calculate factored nominal bond strength, ϕN_{ag} (ACI 318 17.4.5)

3. Compare $T_{u.sus}$ to ϕT_n, ϕN_{cbg}, and ϕN_{ag}
    a. ϕN_{min} is the minimum of ϕT_n, ϕN_{cbg}, and ϕN_{ag}
    b. If $T_{u.sus} < 0.10 \cdot \phi N_{min}$, then a sustained tension check ***is not required***
    c. If $T_{u.sus} \geq 0.10 \cdot \phi N_{min}$, then a sustained tension check ***is required***

4. When a sustained tension check ***is required***, perform in accordance with ACI 17.3.1.2 as modified by AASHTO 5.13.2.2
    a. Calculate the basic bond strength of a single anchor, N_{ba}
    b. Use a resistance factor, $\phi = 0.45$
    c. Check that $(T_{u.sus})_{single} \leq 0.50 \cdot \phi \cdot N_{ba}$