

**MICHIGAN DEPARTMENT OF TRANSPORTATION  
MDOT**

**Design Procedures for Concrete Anchors  
(Mechanical Expansion and Bonded Anchors)**

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**Michigan Transportation Commission  
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## INTRODUCTION

Concrete anchors are often used to make attachments to the concrete surfaces of bridges and highway barriers. Various department publications provide quality control and guidance so these anchors are safe, efficient, and economical. During this study, the Structural Research Unit reviewed the department's procedures and specifications for designing and accepting two types of concrete anchors, mechanical expansion anchors and bonded anchors. We studied design procedures of various national codes, design guides, and research publications. We also collected and reviewed numerous manufacturers' recommendations, product data, and installation procedures.

This report provides clarification and instruction to designers as to the proper design and use of concrete anchors. In the following sections, we discuss general characteristics of concrete anchorages, design philosophies, and detailed design procedures for each type of anchor. In addition, we provide recommendations for changes to the *Michigan Design Manual-Bridge Design, Volume 5* (design manual) and the *1996 Standard Specifications for Construction*.

During the scope of this report, we did not evaluate either of the anchor types (mechanical expansion or bonded) for creep. Therefore, until further research is performed, designers should avoid using post installed concrete anchors for connections requiring sustained loading.

Undercut anchors were also beyond the scope of this report.

## GENERAL CHARACTERISTICS

The American Concrete Institute (ACI) provides a good reference for concrete anchors in Report 355.1R-91, *State-of-the-Art Report on Anchorage to Concrete*. This ACI report discusses cast-in-place anchorages as well as anchorages to existing concrete structures (post-installed systems). For the latter type, the department allows two types of anchoring systems, mechanical expansion anchors and bonded anchors. The following sections briefly describe each system.

### **Mechanical Expansion Anchors**

The department allows three types of mechanical expansion anchors: stud, drop-in, and self-drilling. All three work by applying force to the sides of a predrilled hole, which in turn prevents pullout through frictional forces developed on the sides of the hole.

The stud mechanical expansion anchor consists of a threaded rod with an expansive device on one end (refer to Figure 1). This anchor is set by placing it into a predrilled hole and turning the nut to the recommended torque. The expansive device expands into the side of the hole as the nut is torqued.

The second type of mechanical expansion anchor is the drop-in anchor (refer to Figure 2). This anchor is also placed into a predrilled hole, but it is secured with the aid of a setting tool and/or a

hammer depending on the type of plug, whether it is internal or external. The internal plug is set by driving the plug toward the bottom of the anchor with a setting tool and a hammer. As the plug moves toward the end of the anchor, the anchor sleeve expands. Similarly, the external plug is set by driving the anchor down around the plug, thus expanding the body of the anchor.

The final type of mechanical expansion anchor is the self-drilling anchor (refer to Figure 3). The self-drilling anchor attaches to a roto-hammer, which is used to drill the proper size hole. The anchor and external plug are then inserted into the hole and tightened in the same manner as the drop-in anchor with an external plug.

Mechanical expansion anchors are preferred in certain situations that require the anchor to sustain immediate loading. As soon as they are installed, attachments can be made and loads can be applied. This may be advantageous for applications that require traffic control or limited installation time.

Through field experience we found that when mechanical expansion anchors are installed into a hole that intersects rebar, the anchor fails to meet the required load. Mechanical expansion anchors are sensitive to proper installation. The predrilled hole must be round not oblong. If steel reinforcement is encountered when drilling into concrete, the bit travels around the reinforcement creating an oblong hole. This odd shaped hole decreases the required bearing area and in turn decreases the anchor's load carrying capacity. Designers should avoid using mechanical expansion anchors in heavily reinforced areas to avoid this problem.

### **Bonded Anchors**

The department allows two categories of bonded anchor systems: adhesive anchors and grouted anchors. Adhesive anchors work by creating a chemical bond between the anchor and the concrete. The setting material for adhesive anchors is a two-part (epoxy or polyester) system. Depending on the type of packaging, the mixing of the resin and hardener occurs either as the material flows through a mixing nozzle or in the predrilled hole as the glass capsule is broken by the rotating anchor rod or rebar. One note about adhesive anchors, there is a gel time and cure time. Gel time refers to the time until the adhesive initially sets. Cure time is how long the product takes to fully dry and stabilize. Only after the cure time has elapsed can the anchor withstand the desired loading. Grouted anchors work by creating a cement bond between the anchor and the concrete. The setting material for the grouted anchor is mixed with potable water and placed into the predrilled hole. As with adhesive anchors, grouted anchors must fully cure before the application of load.

Bonded anchors are preferred in situations that require anchors to be installed next to reinforcing steel, reinforcement to be post-installed, and/or epoxy coated anchors. Unlike mechanical expansion anchors, bonded anchors can operate properly if the predrilled hole intersects reinforcement. The adhesive compound/grout flows around the reinforcement, filling all voids between the attachment and the oblong hole sides. Although mechanical expansion anchors only permit a threaded rod or bolt be inserted into hardened concrete, bonded anchors can be used with either threaded rods, bolts, or deformed reinforcement bars. Finally, bonded anchors are preferred when the design detail calls for epoxy coated anchors. When installing anchors with the bonded systems, the epoxy coated anchors will not be damaged. Mechanical expansion anchors require either turning a nut to the

specified torque or driving a plug into the end to set the anchor, both of which remove the existing epoxy coating.

## DESIGN PHILOSOPHIES

There are two philosophies used for designing anchorages into concrete. The first philosophy designs the anchorage to ensure that the tensile strength of the steel reinforcement is achieved; this type of anchorage is referred to as a deep embedment. Deep embedments are commonly placed prior to the placement of concrete at a depth deep enough to obtain the required development length.

The second philosophy designs for concrete failure (i.e., shallow embedment). A shallow embedment will crack or spall the concrete prior to developing the tensile strength of the anchor, therefore the strength of the concrete controls the allowable loads.

Post-installed concrete anchors are to be designed for deep embedments (i.e. steel failure). However, through our laboratory experience, we found that most post installed anchoring systems normally fail prior to the actual yielding of the anchor steel (i.e. they fail as a shallow embedment) even though the anchor meets the minimum specified yield point in pullout. This may be due to the fact that the anchor steel tensile yield strength is actually higher than minimum specified. Therefore, the engineer should design for a ductile steel failure and be aware that our laboratory experience has shown that post-installed anchors may have a brittle failure because the steel has a higher yield point than the minimum specified.

## DETAILED DESIGN PROCEDURES FOR ANCHORAGES IN HARDENED CONCRETE

When designing for mechanical expansion or bonded anchors, the following publications can be used for design guidance:

- *State-of-the-Art Report on Anchorage to Concrete*, ACI 355.1R-91, ACI Committee 355, July 1991.
- ACI 349 - Appendix B - *Steel Embedments*, American Concrete Institute, pp 349-80 to 349-86.

Anchors loaded with the combination of tension and shear simultaneously must be evaluated for the load interaction. Therefore, designers must check that the tensile stress and shear stress are proportioned to satisfy the following interaction equation:

$$\frac{\text{actual tensile stress}}{\text{allowable tensile stress}} + \frac{\text{actual shear stress}}{\text{allowable shear stress}} \leq 1$$

In the following sections, acceptance and design procedures are discussed. Design examples are shown for each type of anchor.

## **Mechanical Expansion Anchors**

For a mechanical expansion anchor to be used by the department, it must meet the criteria set forth in the *Qualification Procedure for Mechanical Expansion Anchored Bolts*, which is provided in Appendix A. Each anchor size must be able to develop a required proof tensile load and shear load. The proof tensile loads are 125 percent of the anchor steel's yield strength applied to the tensile stress area of the bolt (i.e., - net section through the threads). The shear loads are 100 percent of the shear strength of the bolt across the tensile stress area. It should be noted that these values should not be confused with allowable design loads, which are discussed later in this report. Since most manufacturers only provide U. S. Customary unit anchors at this time, both metric and U. S. Customary units are shown in the qualification procedure. Some manufacturers have stated that metric anchors will be available in the near future. Therefore, when the metric anchors are submitted, the Structural Research Unit will investigate and evaluate them.

The *Qualified Products List for Mechanical Expansion Anchors* (included in Appendix B) lists the anchors that meet the department's qualification procedure. The list has categories for the three types of anchors; stud, drop-in, and self-drilling. For a stud anchor, the list shows the required minimum embedment depth due to the variety of embedment depths listed by the manufacturer. The embedment depths for the remaining anchors shall be obtained from the manufacturer's recommendations.

The department provides design guidance for mechanical expansion anchors in the design manual, Subsections 7.06.02 and 8.09.01. During this research project, we discovered the values in this manual need adjustment to meet our current acceptance criteria and meet the available anchors the industry has to offer. Subsection 7.06.02 should be revised from the existing section (refer to Figure 4) to the proposed section (refer to Figure 5). A commonly used industry standard is to apply a factor of safety of 4 to the proof tensile load of the anchor when determining the allowable design tensile load. ACI 349 Section B.7.2 references a reduction factor of 0.33 times the average tension and shear test failure loads. This reduction factor can be used as an alternative to the safety factor of 4 when the applied loads are factored in accordance to Subsection 9.2 of ACI 349. For normal tensile design loads, we recommend using a factor of safety of 4, but for vibratory tensile loads a safety factor of 12 should be used. Subsection 7.06.02 C of the design manual (Figure 5) should be added to inform the designer about allowable shear loads. Figure 6 shows a comparison between the existing Subsection 7.06.02 of the design manual and the proposed section. The allowable loads for small diameter anchors have decreased, while the allowable loads for larger diameter anchors have increased. Also, the non-critical category has been removed. From our experience, mechanical expansion anchor bolts begin to slip at approximately 50 percent of the proof tensile load. Because of this, and again to be in alignment with industry standards, we removed the non-critical category. Since mechanical expansion anchor bolts are dependent on installation procedures to develop their strength and because the performance of these anchors can be variable, redundancy should always be designed into the system. Therefore, the following note should be added to Subsection 7.06.02 of the design manual to ensure safety: "Design details should always call for two or more anchors for redundancy."

Similarly, Subsection 8.09.01 of the design manual should be revised from the existing section (refer to Figure 7) to the proposed section (refer to Figure 8). We propose removing the existing Note B.

Since the testing requirements for mechanical expansion anchors are specified in Subsection 712.03.J.2 of the *1996 Standard Specifications for Construction*, the existing Note B is redundant and should be removed.

Additional considerations when designing mechanical expansion anchors are: installation location, condition and strength of the concrete, and strength reduction factors resulting from the edge spacing, anchor spacing, and concrete compressive strength. Guidance is specified in the two ACI publications, *State-of-the-Art Report on Anchorage to Concrete*, ACI 355.1R-91, ACI Committee 355, July 1991, and ACI 349 - Appendix B - *Steel Embedments*, American Concrete Institute. All qualification procedures were established on a concrete compressive strength of 28 MPa. If the host concrete compressive strength is less, then the following design strength reduction should be taken  $\sqrt{f'/c_1}/\sqrt{f'/c_2}$ , where  $f'/c_2$  equals 28 MPa. If the host concrete compressive strength is greater than the minimum specified strength, no adjustment shall be made. Refer to Appendix C for a mechanical expansion anchor design example.

Once the design is completed, the next step is installation. Subsection 712.03.J of the *1996 Standard Specification for Construction* describes the requirements for anchor selection, installation, and field testing requirements. Keeping in line with the previously mentioned changes, proof tensile load and anchor size must be revised. The proof tensile loads along with the anchor diameters need to be revised to reflect the soft conversion of mechanical expansion anchors, and the slip requirement needs to be revised from 2 mm to 1,600  $\mu\text{m}$ . As revised, the field test shall demonstrate that the anchor will provide a minimum pull-out resistance of 50 percent of the proof tensile load at 1,600  $\mu\text{m}$  slippage, not 2 mm slippage. When the initial slip requirement of 800 $\mu\text{m}$  was determined, it was an arbitrary value set for pavement lane ties. For mechanical expansion anchors, we found most manufacturers and codes specified load values at 1,600  $\mu\text{m}$  of slip. During our laboratory testing, most of the mechanical anchors did slip 1,600  $\mu\text{m}$  at 50 percent of the proof tensile load. Therefore, we incorporated the manufacturer's slip requirement of 1,600  $\mu\text{m}$  into our specifications - refer to Appendix D for the Special Provision for Mechanical Expansion Anchored Bolts. Although, it is the requirement of the contractor to determine the embedment depth and anchor type, designers must be familiar with typical hole diameters and depths so they can place the anchors in appropriate locations. The *1996 Standard Specifications for Construction* requires the contractor to use a pachometer to locate reinforcing steel so that it will not be cut or interfere with the installation of the anchor.

### **Bonded Anchors**

Before a bonded anchor can be used in department projects, it must meet the requirements set forth in the *Qualification Procedure for Anchoring Reinforcing Bars or Bolts with Adhesive*. The qualification procedure, included in Appendix E, requires that the pull-out strength of a bonded anchor be greater than 125 percent of the yield strength of an A307 bolt or Grade 420MPa steel reinforcement with less than 1,600  $\mu\text{m}$  slip when installed according to the manufacturer's recommended minimum embedment depth.

Bonded anchors that have met the department's qualifications are listed in the *Qualified Products List for Adhesive Systems for Structural Anchors and Lane Ties* (refer to Appendix F). To further enhance the partnering between the department and the contractors, embedments depths are not listed



on the qualified products list. Instead, a note is provided stating that the anchors shall be installed per manufacturer's recommendations.

Bonded anchors are designed for steel failure, even though our laboratory experience has shown that post-installed anchors fail prior to the actual yielding of the anchor steel as previously discussed. To obtain the allowable design strength, a safety factor of 4 should be applied to 125 percent of the threaded rod/reinforcements yield strength. Similar to mechanical expansion anchors, this factor of safety of 4 is a common industry standard. The safety factor applies to all situations where a bonded anchor is designed (i.e., non-critical, static or shock loads, and vibratory loads). Subsection 7.06.02 B (Figure 5) should be added to the design manual to inform designers of the safety factor. Similar to mechanical expansion anchors, as an alternative design (LRFD), ACI 349 Subsection B.7.2 can be used with a reduction factor of 0.33 times the required tested load when the loads are factored in accordance with Subsection 9.2 of ACI 349. Also, Subsection 7.06.02 C of the design manual (Figure 5) should be added to inform the designer about allowable shear loads.

The current practice for detailing vertically bonded anchors is to state the anchor size, embedment depth, and hole size. We propose, due to the variations between bonded anchor embedment depths and hole diameters, that the department no longer state the required hole diameter nor the embedment depth for a bonded installation, except where noted. As referenced in Subsection 712.03.I of the *1996 Standard Specifications for Construction*, "The Contractor shall propose for the Engineer's approval, complete details of the drilling, cleaning, and bonding systems from the QPL to be used for anchoring the reinforcement. If hole sizes are shown on the plans, they are for epoxy mortar adhesive systems." Therefore, to create consistency between the plans and 1996 Standard Specifications for Construction, we recommend that bridge designers discontinue specifying embedment depths and hole sizes for post-installed concrete anchors, except when used in concrete barriers due to past problems associated with bottom of deck spalls. A plan note should be added stating, "Concrete anchors shall be installed according to the manufacturer's recommendations." However, designers must be familiar with typical hole diameters and depths so they can place the anchors in appropriate locations.

The design manual provides recommended plan notes for bonded anchors in Subsection 8.09.01. During our investigation, we discovered that Subsection 8.09.01 requires revision. Currently, Note C states "Systems for anchoring horizontal (reinforcement) (bolts) in existing concrete shall be either Hilti HVA or Molly Parabond. (Use only where bar or bolt will be subjected to a sustained load.)" Since neither of these products are currently listed on our current Qualified Products List for Adhesive Systems for Structural Anchors and Lane Ties, the note should be revised to the following: "Systems for anchoring horizontal or vertical (reinforcement) (bolts) in existing concrete shall be chosen from the department's current Qualified Products List." In addition to the change in the existing Note C, an additional note should also be added: "All concrete anchors shall be installed according to the manufacturer's recommendations, unless otherwise stated." Refer to Figure 7 for the existing notes and to Figure 8 for the revised notes.

Subsections 6.29.08A and 6.29.09 of the design manual also instruct designers when designing for bonded anchors. This guide, which details bridge barrier railing, Type 5 and Type 4 (modified), specifies the hole diameter and embedment depth for the vertical concrete anchors. Due to past problems associated with bottom of deck spalls, these guides should not be altered.

Construction guidance for bonded anchors is given in Subsection 712.03.I of the *1996 Standard Specifications for Construction*. During our investigation, we discovered this subsection requires modification. As with the mechanical expansion anchor bolts, the slip requirement should be changed from 2 mm to 1,600  $\mu\text{m}$ . Therefore, field installed bonded anchors must develop the yield strength of the anchor with less than 1,600  $\mu\text{m}$  slip, not 2 mm slip, when tested prior to use. Also, the anchor shall develop 90 percent of the bar's yield strength with less than 1,600  $\mu\text{m}$  slip, not 2 mm slip, when tested is a separate test block. Refer to Appendix G for the Special Provision for Bonded Anchors describing these changes.

Additional items designers must consider for bonded anchors are: type and size of the anchor (reinforcement or threaded rod), the installation location, the condition and strength of the concrete, and the strength reduction factors resulting from the edge spacing, anchor spacing, and concrete compressive strength. Guidance is provided in the two ACI publications previously mentioned. All qualification procedures were established on a concrete compressive strength of 28 MPa. If the host concrete compressive strength is less, then the following design strength reduction should be taken  $\sqrt{f'c_1}/\sqrt{f'c_2}$ , where  $f'c_2$  equals 28 MPa. If the host concrete compressive strength is greater than the minimum specified strength, no adjustment shall be made. Refer to Appendix H for a bonded anchor design example. Although designers must provide details that are feasible to build, it is the requirement of the contractor to determine the embedment depth and bonded anchor type.

## **Conclusion**

The department specifies two types of concrete anchors: mechanical expansion and bonded. Both anchors are intended to be installed in hardened concrete and designed for deep embedments (i.e. yielding of the anchor steel). However, our laboratory experience has shown that post-installed concrete anchors systems fail prior to the actual yielding of the anchor steel (i.e. they fail as a shallow embedment) even though the minimum specified yield point is met. The brittle failure may be due to the fact that the anchor tensile yield strength is actually higher than the minimum specified.

Mechanical expansion anchors and bonded anchors must have the appropriate safety factors specified in *Michigan Design Manual-Bridge Design, Volume 5*, Subsection 7.06.02 applied during design. Additional design guidance is provided by the ACI 349 - Appendix B-Steel Embedments and the ACI Committee 355 publication, *State-of-the-Art Report on Anchorage to Concrete*.

There are advantages and disadvantages for each type of concrete anchor system. Advantages that the bonded anchors have over mechanical expansion anchors are as follows: they can be installed next to steel reinforcement, they can attach either threaded rod or steel reinforcement to hardened concrete, and bars can be epoxy coated. The main advantage that the mechanical expansion anchor has over the bonded anchor is the set time required before loading. The bonded anchor must be fully cured before the desired load is applied, whereas mechanical expansion anchors can withstand a load as soon as they are installed.

## **RECOMMENDATIONS**

### **Design**

1. Design guidance shown in ACI 349 - Appendix B-Steel Embedments, and/or ACI committee 355 publication, *State-of-the-Art Report on Anchorage to Concrete*, should be followed when designing mechanical expansion anchors or bonded anchors.
2. Update the *Michigan Design Manual-Bridge Design, Volume 5*, as stated in this report and as shown in Figures 5 and 8.
3. Add the special provision shown in Appendix D to all proposals that list the pay item, “Bolt, Mechanical Expansion Anchored.”
4. Add the special provision shown in Appendix G to all proposals that list any of the following pay items: “Adhesive Anchoring of Vertical Bars,” “Adhesive Anchoring of Horizontal Bar,” and/or “Bolt, Adhesive Anchored.”

### **Structural Research Unit**

1. Investigate metric mechanical expansion anchors when submitted.
2. Investigate the need for “creep” acceptance criteria for bonded anchors.
3. Keep up to date with the latest technology and design methods used for mechanical expansion anchors and bonded anchors.

## REFERENCES

1. *State-of-the-Art Report on Anchorage to Concrete*, ACI 355.1R-91, ACI Committee 355, July 1991
2. *American Association of State Highway and Transportation Officials, Standard Specifications for Highway Bridges*, 16<sup>th</sup> ed., Washington, D.C., 1996 Section 8.25
3. ACI 349 - Appendix B-Steel Embedments, American Concrete Institute, pp 349-80 to 349-86 and 349R-18 to 349R-27
4. ICBO Evaluation Service, *Acceptance Criteria for Expansion Anchors in Concrete and Masonry Elements*, January 1993
5. ACI Structural Journal, *Straight Talk about Anchorage to Concrete-Part 1*, Title 92-S56, Robert W. Cannon, September-October 1995, pp 580-586
6. ICBO Evaluation Service, *Acceptance Criteria for Adhesive Anchors in Concrete and Masonry Elements*, April 1995

## **FIGURES**

## **APPENDIX**

**APPENDIX A**

**Qualification Procedure  
For  
Mechanical Expansion Anchored Bolts**

1. Scope

1.1 This document covers the procedure to be followed by producers in order to have a mechanical expansion anchor included on the Michigan Department of Transportation's (MDOT) Qualified Products List.

2. Submittal Procedure

2.1 *Qualified Products Evaluation Form* - There is no form required for submittal. However information about the product can be submitted to the following MDOT address.

Structural Research Unit  
Construction & Technology Division  
8885 Ricks Road  
P.O. Box 30049  
Lansing, MI 48909

2.2 *Product Data Sheets* - Submit a copy of product literature describing the product's use and other pertinent information such as design drawings, manufacturer's name and address, manufacturer's trade name, model number, etc.

2.2.1 The producer shall include verified test results from an independent testing laboratory including static load tests for tension and shear, tested in accordance with ASTM E-488.

2.3 *Evaluation based on the following standards* - Submit three mechanical expansion anchors per size for evaluation by MDOT.

2.3.1 Mechanical expansion anchors shall meet the following proof tensile loads (125% yield strength \* tensile stress area) and shear loads (yield strength \* tensile stress area) when attached to a 28 MPa hardened concrete:

Ultimate Load		Bolt Diameter, mm									
		9.52 (3/8")*	10	12	12.70 (1/2")*	15.88 (5/8")*	16	19.05 (3/4")*	20	22.22 (7/8")*	24
Tension (Pull-out)	kN	15.7	18.1	26.3	28.6	45.6	49.1	67.3	76.6	93.1	110.3
Shear	kN	12.6	14.50	21.1	22.9	36.5	39.3	53.9	61.3	74.5	88.3

\* Anchors manufactured to English Customary Units

2.3.2 Mechanical expansion anchors shall develop 50% of the proof tensile load at less than or equal to 1600  $\mu$ m displacement.

2.4 *MDOT Contacts* - The following MDOT personnel may be contacted if questions arise regarding submittal and/or evaluation of this product:

Person in charge of Qualified Products List	-	David A. Juntunen
Telephone	-	(517) 322-5707
Person in charge of Testing	-	Chris Davis
Telephone	-	(517) 322-1649



2.5 *Evaluation Scheduling* - Completed Qualification Procedure packets, including evaluation forms and product submittal, must be received by MDOT no later than January 15 to be included in that year's evaluation. Addition of new products to the Qualified Products List will be made only once a year upon completion of evaluations for all materials submitted by the January 15 deadline. Subsequent modifications (for purposes other than the addition of new products) will be at the discretion of MDOT.

3. Evaluation

3.1 The submitted information will be reviewed and samples will be tested for conformance to the specified requirements. The product's susceptibility to corrosion, method of load transfer, installation procedure, workmanship, reliability, and requirements specific to a particular design, will also be evaluated. If the product meets the requirements it will be included on the Qualified Products List. The submitter will be notified in writing concerning the results of the evaluation. Michigan Department of Transportation reserves the right to verify submitted test information or re-evaluate a product at any time by conducting its own tests.

4. Disqualification

4.1 A product may be immediately removed from the Qualified Products List should any problem develop related to installation or performance of the product. A product may also be removed due to specification changes made by either MDOT or the product manufacturer.

5. Requalification

5.1 A product which has been disqualified and removed from the Qualified Products List will be considered for re-evaluation only after submittal of a written request along with the acceptable evidence that the problems causing the disqualification have been corrected.

**APPENDIX B**

**Material: Structure Expansion Anchors (Mechanical Expansion Anchors)**

**Basis of Acceptance:** Must be on a "Qualified Products" list. Pull-out testing is required per Q.A. Manual.

Normal Sampling Frequency:

Sample Size:

Maximum for V.I.:

**Qualified Products:**

Mechanical Expansion Anchors ( soft conversion, for 3/8" use 10mm, 1/2" use 13mm, 5/8" use 16mm, 3/4" use 19mm, 7/8" use 22mm ) Shall be set by applying the manufacturer's specified torque. The turn of the nut method will not be an acceptable alternative.

- (1) Self Drilling
  - (a) ITW Ramset/Redhead - Self Drilling Anchor (10mm, 13mm, 16 mm dia. anchors only)
  - (b) Powers Rawl - Saber Tooth (10mm, 13mm, 16mm dia. anchors only)
- (2) Pre-Drilled - Flush Type
  - (a) Hilti HDI (10 mm, 13 mm, 19 mm dia. anchors only)
  - (b) ITW Ramset/Redhead-Multi-Set II (10mm, 13mm, 16mm dia. anchors only)
  - (c) Powers Rawl Drop-In - Internal Plug (all sizes noted above accepted)
- (3) Pre-Drilled - Stud Type - Not suitable for lane ties or for guardrail end shoes because of exposed thread.
  - (a) Hilti Kwik-Bolt II (10mm dia. anchor - min. embedment = 65mm)  
 (13 mm dia. anchor - min. embedment = 90 mm)  
 (16 mm dia. anchor - min. embedment = 100 mm)  
 (19 mm dia. anchor - min. embedment = 120 mm)  
 NOTE: 22 mm dia. anchor not available
  - (b) Powers Rawl Stud (10mm dia. anchor - min. embedment = 40 mm)  
 (13 mm dia. anchor - min. embedment = 60 mm)  
 (16 mm dia. anchor - min. embedment = 100 mm)  
 (19 mm dia. anchor - min embedment = 130 mm)  
 (22 mm dia. anchor - min. embedment = 150 mm)

**Material: Bolts for Structure Expansion Anchors**

**Basis of Acceptance:** Test.

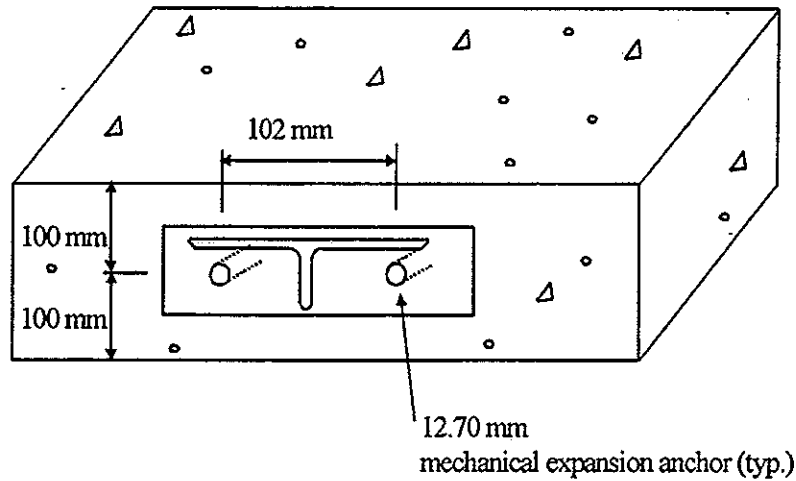
Normal Sampling Frequency: 1 per 5000 units or fraction thereof

Sample Size: 1 bolt

Maximum for V.I.: 250 units

**APPENDIX C**

**Example 1** - Determine the allowable design load that can be applied to this connection under service design loading condition using two 12.70-mm mechanical expansion anchors.



Embedment Depth ( $h_{ef}$ ) = 90 mm (*Hilti Kwik-Bolt II*)  
 Host concrete  $f'_c=28\text{MPa}$   
 Mechanical Expansion Anchor Bolts;  $f_y=250\text{ MPa}$  ;  $f_{ult}=420\text{ MPa}$

Allowable Design Strength of One Anchor without Modification Factors

Subsection 7.06.02, Michigan Bridge Design Manual (Metric)

Tension =  $[125\% * f_y * (\text{tensile stress area})]/4 = [1.25 * 250\text{ MPa} * 0.000092\text{ m}^2] / 4 = 7.2\text{ kN}$

Shear =  $0.30 * f_y * (\text{tensile stress area}) = 0.30 * 250\text{ MPa} * 0.000092\text{ m}^2 = 6.9\text{ kN}$

AASHTO Std Spec for Highway Bridges, Table 10.32.3A

Tensile Stress Area =  $0.7854 (D - 0.9382P)^2$

Metric Fastener Standards, 2<sup>nd</sup> ed., 1983, page A-3

D = nominal thread diameter (basic major diameter), mm

P = thread pitch, mm

D = 12.70 mm

P = 1/threads per mm

=  $1/0.51 = \underline{2.0}$

Therefore, Tensile Stress Area =  $0.7854 (12.70\text{ mm} - 0.9382 * 2.0\text{ mm})^2 = 92\text{ mm}^2$

### Critical Edge Distance

$$\text{Critical Edge Distance} = 1.5 h_{ef} = 1.5 (90 \text{ mm}) = 135 \text{ mm}$$

Note: These are the minimum critical distances that the anchors can be located to a free edge without requiring load reduction factors. If the anchor(s) does fall within this distance, use the following equation for the appropriate modification factor.

Per proposed ACI 318 chapter 23

$c_{min}$  = the smallest of the edge distances that are less than or equal to  $1.5 h_{ef}$ .

$\Psi$  = modification factor for edge distance

$$\Psi = 0.7 + 0.3 \frac{c_{min}}{1.5 h_{ef}} \text{ if } c_{min} \leq 1.5 h_{ef}$$

Since  $c_{min}$  (100 mm) is less than  $1.5 h_{ef}$  (135 mm), determine the modification factor for edge distance.

$$\Psi = 0.7 + 0.3 \frac{100 \text{ mm}}{135 \text{ mm}} = 0.92$$

### Critical Anchor Spacing

Anchors must be spaced far enough apart so that the embedment failure planes do not overlap. Therefore, the critical anchor spacing is twice that of the critical edge distance. If the anchors are spaced closer than the critical anchor spacing, refer to ACI 355.1R-91 'State-of-the-Art Report on Anchorage to Concrete', eq 3.10 for the appropriate modification factors.

$$\text{Critical Anchor Spacing} = 2 * \text{Critical Edge Distance} = 2 * (135 \text{ mm}) = 270 \text{ mm}$$

Our example does not meet the critical anchor spacing. Therefore, a modification factor must be calculated.

ACI 355.1R-91 'State-of-the-Art Report on Anchorage to Concrete', eq 3.10, reference 1

$$X_a = 1 + a/a_{crit} \leq 2$$

where; a = distance between center of anchors  
= 102 mm  
a<sub>crit</sub> = critical distance between center of anchors  
= 3 \* h<sub>ef</sub>  
= 3 \* (90 mm)  
= 270 mm  
X<sub>a</sub> = modification factor for anchor spacing

$$\begin{aligned} X_a &= 1 + 102 \text{ mm} / 270 \text{ mm} \leq 2 \\ &= 1 + 0.4 \leq 2 \\ &= \underline{1.4} \leq 2 \text{ O.K.} \end{aligned}$$

### Host Concrete Compressive Strength

Manufacturers pull-out values are for concrete compressive strength equal to 28 MPa. For weaker strength concrete, use the following modification factor.

ACI Structural Journal, 'Straight Talk About Anchorage to Concrete-Part 1', pg 582, reference 5

$$\frac{\sqrt{f'c}}{\sqrt{(28\text{MPa})}} \leq 1$$

Note: Since the concrete compressive strength used in this example is  $f'c=28$  MPa this equation does not apply.

### Allowable Design Strength

$F_{\text{allowable}}$  ( $V_{\text{allowable}}$ ) = strength of one anchor \* modification factors

$$F_{\text{allowable}} = 7.2 \text{ kN} * 0.92 (\Psi) * 1.4 (Xa) = \underline{9.3 \text{ kN}}$$

$$V_{\text{allowable}} = 6.9 \text{ kN} * 0.92 (\Psi) * 1.4 (Xa) = \underline{8.9 \text{ kN}}$$

Note:

- a. Check tension/shear interaction equation as required.

$$\frac{\text{actual tensile stress}}{\text{allowable tensile stress}} + \frac{\text{actual shear stress}}{\text{allowable shear stress}} \leq 1$$

- b. Concrete tensile strength is taken into account during our qualification procedure. Therefore, it does not need to be checked during design.

**APPENDIX D**



MICHIGAN  
DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION  
FOR  
MECHANICAL EXPANSION ANCHORED BOLTS

C&T:DEN

1 of 1

04-07-98

C&T:APPR:RDT:JTL 05-07-98

a. **Description.**-This work shall be in accordance with Subsection 712.03.J of the 1996 Standard Specifications for Construction except as modified below.

b. **Construction Methods.**-

1. Anchoring Bolts.-

The table in Subsection 712.03.J.1 is deleted and is replaced by the following information:

Diameter (mm)	Load (kN)
9.52	15.7
12.70	28.6
15.88	45.6
19.05	67.3
22.22	93.1

2. Field Testing.-

The second sentence in Subsection 712.03.J.2 is deleted and is replaced with the following sentence:

The field test shall demonstrate that the anchor will provide a minimum pull-out resistance of 50 percent of the proof tensile load at 1,600  $\mu\text{m}$  slippage.

**APPENDIX E**

**Qualification Procedure  
For  
Anchoring Reinforcing Bars or Bolts With Adhesive**

1. Scope

1.1 This document covers the procedure to be followed by producers to have an Adhesive Anchor System included on the Michigan Department of Transportation's (MDOT) Qualified Products List.

2. Submittal Procedure

2.1 *Qualified Products Evaluation Form* - There is no form required for submittal, however, information about the product shall be submitted to the following MDOT address.

Structural Research Unit  
Construction & Technology Division  
8885 Ricks Road  
P.O. Box 30049  
Lansing, MI 48909

2.2 *Product Data Sheets* - Submit two copies of product literature describing the product's use and other pertinent information such as design drawings, manufacturer's name and address, manufacturer's trade name, model number, etc.

2.2.1 Include product literature describing the product's use and other pertinent information such as mixing, working times and component ratios of mixed ingredients. Also include anchor type, application, packaging, limitations, and installation.

2.2.2 Submit product safety data sheets.

2.3 *Evaluation based on the following standards* - The producer shall show the minimum embedment depth, for A307 bolt diameters 9.52 mm to 22.22 mm and Grade 420 MPa metric rebar diameters #13 to #25, required to develop the yield strength of the anchor. Test results, in accordance with ASTM E-488, are required from an independent laboratory for verification of the minimum embedment depth and shear strength.

2.3.1 Long term load (creep) tests should be performed in accordance with ASTM E-1512. The results shall be submitted prior to acceptance.

2.3.2 Resin Adhesive System Anchors, when subjected to tension, shall develop 125% the yield strength of the rebar or bolt at less than or equal to 1600  $\mu$ m displacement in 28 MPa concrete. The anchor shall develop the yield strength when subjected to shear. The tensile stress area of the bolt (nominal area for reinforcing steel) will be used when determining the yield load.

2.3.3 Submit a minimum of 300 cubic centimeters of epoxy and/or three capsules per anchor size 12.70 mm and 22.22 mm, a dispenser, four nozzles and any special equipment necessary for installation for evaluation by MDOT.

2.4 *MDOT Contacts* - The following MDOT personnel may be contacted if questions arise regarding submittal and/or evaluation of this product:

Person in charge of Qualified Products List	-	Douglas Needham
Telephone	-	(517) 322-1979
Person in charge of Testing	-	Chris Davis
Telephone	-	(517) 322-1649

3. Evaluation

3.1 The submitted information and test data will be reviewed for conformance to the specified requirements. The product's susceptibility to corrosion, method of load transfer, installation procedure, workmanship, reliability and requirements specific to a particular design will also be evaluated. If the product meets the requirements, it will be included on the Qualified Products List. The submitter will be notified in writing concerning the results of the evaluation. Michigan Department of Transportation reserves the right to verify submitted test information or re-evaluate a product anytime by conducting its own tests.

4. Disqualification

4.1 A product may be immediately removed from the Qualified Products List should any problem develop related to installation or performance of the product. A product may also be removed due to specification changes made by either MDOT or the product manufacturer.

5. Requalification

5.1 A product that has been disqualified and removed from the Qualified Products List will be considered for re-evaluation only after submittal of a written request along with the acceptable evidence that the problems causing the disqualification have been corrected.

**APPENDIX F**

**Material: Adhesive Systems for Structural Anchors and Lane Ties**

**Basis of Acceptance:** Must be a Qualified Product

Normal Sampling Frequency: ---

Sample Size: ---

Maximum for V.I.: ---

**Qualified Products:**

B. Adhesive Systems for Structural Anchors and Lane Ties.  
 Product can be packaged in any form on the Qualified Products List. "X" denotes most popular type of packaging.

Product Name	Manufacturer	Type of Adhesive	Type of Packaging	
			Mixing & Injection Devices	Glass Capsules
HY-150	Hilti	Epoxy	x	
Ceramic 6	ITW Ramset	Epoxy	x	
Granite 5	ITW Ramset	Epoxy	x	
Chem-Stud	Powers Rawl	Polyester		x
Hammer-Capsule	Powers Rawl	Epoxy		x
Needle-Capsule	Powers Rawl	Epoxy		x
CIA-Gel 7000	Covert Operations	Epoxy	x	
Super Por-Rok	Minwax Construction	Non-shrink Grout	x	

NOTE: 1. Anchors shall be installed per manufacturer's recommendations.  
 2. Material is limited to the shelf life recommended by the manufacturer.

**APPENDIX G**

**APPENDIX H**



MICHIGAN  
DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION  
FOR  
**ANCHORING REINFORCING BARS  
OR BOLTS WITH ADHESIVE**

C&T:DEN

1 of 1

05-04-98

C&T:APPR:RDT:JTL 05-07-98

**a. Description.**-This special provision revises Subsection 712.03.I of the 1996 Standard Specifications for Construction. All work shall be in accordance with Subsection 712.03.I of the 1996 Standard Specifications except as modified by this specification.

**b. Construction Methods.**-The following changes are made in Subsection 712.03.I.

1. Anchoring Bars or Bolts - The last two sentences of the first paragraph of Subsection 712.03.I.1 is deleted and replaced with the following:

The tests of the proposed systems shall consistently demonstrate that 125% of the anchored bars yield strength can be developed in pull-out tests and that the bars shall be bonded to the concrete a minimum of 90 percent of the bar length and area. Bar slippage at yield strength shall not average more than 1,600  $\mu\text{m}$ .

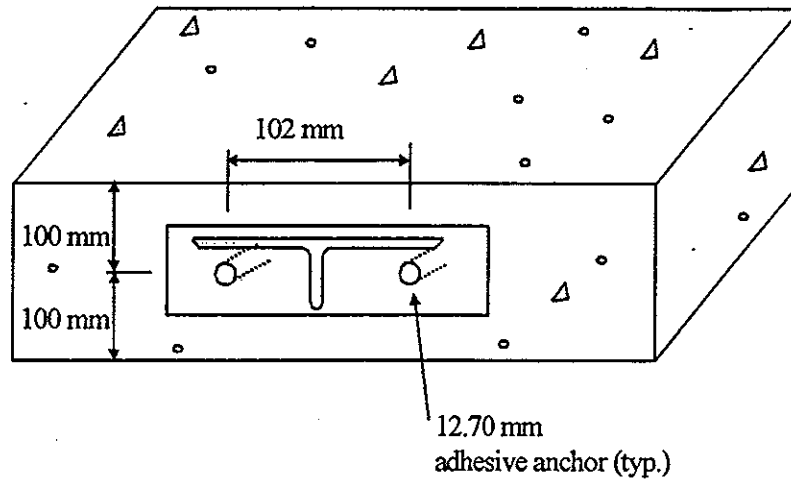
2. Field Testing - The second and fourth sentence of the first paragraph of Subsection 712.03.I.2 is deleted and replaced with the following:

A. The pull-out test shall demonstrate that 90% of the bar's yield strength develops with less than 1,600  $\mu\text{m}$  slip"

B. Acceptance tests must equal 90% of the bar's yield strength with less than 1,600  $\mu\text{m}$  slip".

**c. Measurement and Payment.**-Add the following to the second to last paragraph of page 7.141, "Payment for both **Adhesive Anchoring of Vertical Bar** and **Adhesive Anchoring of Horizontal Bar** will include testing."

**Example 2** - Determine the allowable design load that can be applied to this connection under normal design loading condition using two 12.70 mm adhesive anchors.



Embedment Depth = 110 mm (*Hilti HY-150*)  
 Host concrete  $f'_c = 28$  MPa  
 A 248MPa threaded rod;  $f'_y = 250$  MPa ;  $f_{ult} = 420$  MPa  
 Tensile Area of 12.70 mm threaded rod = 92 mm<sup>2</sup>

Allowable Design Strength of One Anchor

**Tension**

When designing an adhesive anchoring system, the engineer must design for the allowable strength of the anchoring system. For an adhesive anchoring system to be placed on MDOT's Qualified Products List (Q.P.L.) for Adhesive Systems for Structural Anchors and Lane Ties, it must demonstrate that its ultimate anchoring system tensile strength, at the manufacturers recommended embedment depth, is at least equal to 125% of the anchoring steels yield strength (i.e. threaded rod or steel reinforcement).

With that in mind, we have set the ultimate tensile strength of the adhesive anchoring system equal to that of 125% yield strength of the anchor steel. From our review of numerous codes and manufactures data, we have accepted that the allowable tensile strength of adhesive anchoring system equals that of the ultimate tensile strength of the anchoring system divided by 4.

Substituting 125% yield strength of the anchoring steel for the ultimate anchoring system tensile strength, the allowable tensile strength of the adhesive anchor is  $0.25 * 125% f'_y$  (anchor steel). Therefore,

$$F_{allow} = 0.25 * 125% f'_y * (\text{tensile stress area}) = 0.25 * 125% * 250 \text{ MPa} * 0.000092 \text{ m}^2 = \underline{7.2 \text{ kN}}$$

**Shear**

$$V_{allow} = 0.30 * f'_y * (\text{tensile stress area}) = 0.30 * 250 \text{ MPa} * 0.000092 \text{ m}^2 = \underline{6.9 \text{ kN}}$$

AASHTO Std  
 Spec for Highway  
 Bridges,  
 Table 10.32.3A

$$\text{Tensile Stress Area} = 0.7854 (D - 0.9382P)^2$$

Metric Fastener Standards, 2<sup>nd</sup> ed.,  
1983, page A-3

D = nominal thread diameter (basic major diameter), mm

P = thread pitch, mm

$$D = 12.70 \text{ mm}$$

$$P = 1/\text{threads per mm}$$

$$= 1/0.51 = \underline{2.0}$$

$$\text{Therefore, Tensile Stress Area} = 0.7854 (12.70 \text{ mm} - 0.9382 * 2.0 \text{ mm})^2 \\ = 92 \text{ mm}^2$$

### Critical Edge Distance

$$\text{Critical Edge Distance} = 1.5 h_{ef} = 1.5 (110 \text{ mm}) = 165 \text{ mm}$$

Note: These are the minimum critical distances that the anchors can be located to a free edge without requiring modification factors. If the anchor(s) does fall within this distance, use the following equation for the appropriate modification factor.

Per proposed ACI 318 chapter 23

$c_{min}$  = the smallest of the edge distances that are less than or equal to  $1.5 h_{ef}$

$\Psi$  = modification factor for edge distance

$$\Psi = 0.7 + 0.3 \frac{c_{min}}{1.5h_{ef}} \text{ if } c_{min} \leq 1.5h_{ef}$$

Since  $c_{min}$  (100 mm) is less than  $1.5 h_{ef}$  (165 mm), determine the modification factor for edge distance.

$$\Psi = 0.7 + 0.3 \frac{100 \text{ mm}}{165 \text{ mm}} = 0.88$$

### Critical Anchor Spacing

Anchors must be spaced far enough apart so that the embedment failure planes do not overlap. Therefore, we will state that the critical anchor spacing is roughly twice that of the critical edge distance. If the anchors are spaced closer than the critical anchor spacing, refer to ACI 355.1R-91 'State-of-the-Art Report on Anchorage to Concrete', eq 3.10 for the appropriate modification factors.

$$\text{Critical Anchor Spacing} = 2 * \text{Critical Edge Distance} = 2 * (165 \text{ mm}) = 330 \text{ mm}$$

Our example meets the critical anchor spacing for tension but not for shear. Therefore, a modification factor must be calculated.

ACI 355.1R-91 'State-of-the-Art Report on Anchorage to Concrete', eq 3.10, reference 1

$$\lambda a = 1 + a/a_{crit} \leq 2$$

where; a = distance between center of anchors

$$= 102 \text{ mm}$$

$a_{crit}$  = critical distance between center of anchors

$$\begin{aligned}
 &= 3 * \text{embedment depth} \\
 &= 3 * (110 \text{ mm}) \\
 &= 330 \text{ mm} \\
 X_a &= \text{modification factor for anchor spacing} \\
 X_a &= 1 + 102\text{mm}/330\text{mm} \leq 2 \\
 &= 1 + 0.3 \leq 2 \\
 &= \underline{1.3} \leq 2 \text{ O.K.}
 \end{aligned}$$

### Host Concrete Compressive Strength

Manufacturers pull-out values are for concrete compressive strength equal to 28 MPa. For weaker strength concrete, use the following modification factor.

ACI Structural Journal, 'Straight Talk About Anchorage to Concrete-Part 1', pg 582, reference 5

$$\frac{\sqrt{f'c}}{\sqrt{(28\text{MPa})}} \leq 1$$

Note: Since the concrete compressive strength used in this example is  $f'c=28$  MPa this equation does not apply.

### Allowable Design Strength

$F_{\text{allowable}} (V_{\text{allowable}}) = \text{strength of one anchor} * \text{modification factors}$

$$F_{\text{allowable}} = 7.2 \text{ kN} * 0.88 (\Psi) * 1.3 (X_a) = \underline{8.2 \text{ kN}}$$

$$V_{\text{allowable}} = 6.9 \text{ kN} * 0.88 (\Psi) * 1.3 (X_a) = \underline{7.9 \text{ kN}}$$

Note:

- a. Check tension/shear interaction equation as required.

$$\frac{\text{actual tensile stress}}{\text{allowable tensile stress}} + \frac{\text{actual shear stress}}{\text{allowable shear stress}} \leq 1$$

- b. Concrete tensile strength is taken into account during our qualification procedure. Therefore, it does not need to be checked during design.