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Guide for Design of Anchorage to Concrete: Examples Using ACI 318 Appendix D

Reported by ACI Committee 355

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American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
U.S.A.
Phone: 248-848-3700
Fax: 248-848-3701

www.concrete.org

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Reported by ACI Committee 355

Donald F. Meinheit*
Chair

J. Bret Turley*
Secretary

Tarek S. Aziz
Ranjit L. Bandyopadhyay*†
Peter J. Carrato*
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Jake Olsen
Alan D. Price
John F. Silva*
Patrick J. E. Sullivan
Harry Wiewel
Richard E. Wollmershauser

*Committee 355 members who were major contributors to the development of this guide.
†Deceased.

This guide presents worked examples using the design provisions in ACI 318 Appendix D. Not all conditions are covered in these examples. The essentials of direct tension, direct shear, combined tension and shear, and the common situation of eccentric shear, as in a bracket or corbel, are presented.

Keywords: anchorage; combined tension and shear; design examples; eccentric shear; embedded bolts; headed-stud anchors; post-installed anchors; shear; tension.

CONTENTS

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CHAPTER 1—INTRODUCTION

1.1—Introduction

This guide was prepared by the members of ACI 355, Anchorage to Concrete, to provide design examples that demonstrate the provisions of ACI 318-05 Appendix D. Appendix D, which was first introduced in ACI 318-02, contains design provisions for determining the strength of anchors based on the Concrete Capacity Design (CCD) method for concrete breakout failure. The CCD method has its origins in research work done at the University of Stuttgart in Germany (Eligehausen et al. 1987; Eligehausen and Fuchs 1988; Rehm et al. 1992) and was formalized at the University of Texas at Austin in the 1990s (Fuchs et al. 1995). The CCD method calculates the concrete breakout strength using a model that is based on a breakout prism having an angle of approximately 35 degrees, rather than the traditional 45-degree cone model used since the early 1970s.

Appendix D design provisions are for both cast-in-place anchors and prequalified post-installed mechanical anchors. Separate design equations are frequently provided because cast-in-place anchors behave differently than post-installed anchors. The provisions for post-installed anchors are only intended for those post-installed anchors that are qualified under comprehensive testing protocols. The testing and evaluation requirements in ACI 355.2 are the standard for qualifying post-installed anchors used in design with Appendix D. Similar procedures, which are expected to be completed soon, are under development for adhesive anchors and concrete screw anchors.

Table 1.1—List of anchor failure modes

Tension failure mode	Shear failure mode
Steel strength of anchor	Steel strength of anchor
Concrete breakout strength	Concrete breakout strength
Concrete side-face blowout strength	Concrete pryout strength
Pullout and pull-through strength	

1.2—Discussion on design example problems

The example problems presented in this guide were developed using the code provisions in Appendix D of ACI 318-05, which were current at the time the examples were developed. The new provisions of ACI 318-08 will alter the calculations and results in these examples. Commentary in this guide describes how the new ACI 318-08 provisions modify the design results. The ACI 318-08 Appendix D provisions clarify issues when dealing with earthquake forces, ductile failure, anchor reinforcement, and supplemental reinforcement.

The design approach used in the example problems follows a basic outline of evaluating each potential failure mode in tension and shear for the anchor using the provisions of Appendix D of ACI 318-05. The provisions include modification factors that account for the effects of edges, eccentricity, and the presence or lack of cracking in the concrete, to determine the nominal strengths for each failure mode. The types of failure modes considered are shown in Table 1.1.

In addition to the failure modes in Table 1.1, minimum edge distance, anchor spacing, and thickness of the concrete member are checked to preclude the splitting of concrete. The calculated nominal strengths for each failure mode are modified by the appropriate modification factors. The minimum calculated design strength becomes the controlling design strength of the anchor or group of anchors.

1.3—Commentary on seismic requirements for Appendix D of ACI 318-02 and ACI 318-05

ACI 318-02 and ACI 318-05 use the terminology "low," "moderate," and "high" to describe the levels of seismic risk. The design strength of anchors that include earthquake forces and that are located in regions of moderate or high seismic risk are required to be controlled by failure in tension, shear, or both, of a ductile steel element. In addition, the design strengths for steel and concrete are reduced by a factor of 0.75. The nonductile, concrete failure modes include all the concrete breakout modes in tension and shear, plus the pullout and pull-through failure modes in tension. Nonductile failure can occur if the steel behaves in a brittle fashion. It is not always possible, due to geometric or material constraints, to design the anchorage for a ductile failure. Therefore, code provisions allow the attachment, which the anchor connects to the structure, to be considered as the ductile steel element.

Design Examples 1, 2, 11, and 12 demonstrate the provisions of Appendix D when earthquake forces are involved. They show the design of the anchors governed by the steel strength of a ductile steel element, according to Section D.3.3.4 of