ASCE Petrochemical Energy Committee

This document is one of five state-of-the-practice engineering reports produced, to date, by the ASCE Petrochemical Energy Committee. These engineering reports are intended to be a summary of current engineering knowledge and design practice, and present guidelines for the design of petrochemical facilities. They represent a consensus opinion of task committee members active in their development. These five ASCE engineering reports are:

1. Design of Blast-Resistant Buildings in Petrochemical Facilities
2. Guidelines for Seismic Evaluation and Design of Petrochemical Facilities
3. Wind Loads for Petrochemical and Other Industrial Facilities
4. Anchorage Design for Petrochemical Facilities
5. Design of Secondary Containment in Petrochemical Facilities

The ASCE Petrochemical Energy Committee was organized by A. K. Gupta in 1991 and initially chaired by Curley Turner. Under their leadership the five task committees were formed. More recently, the Committee has been chaired by Joseph A. Bohinsky and Frank J. Hsiu. The five reports were initially published in 1997.

Building codes and standards have changed significantly since the publication of these five reports, specifically in the calculation of wind and seismic loads and analysis procedures for anchorage design. Additionally, new research in these areas and in blast resistant design has provided opportunities for improvement of the recommended guidelines. The ASCE has determined the need to update four of the original reports and publish new editions based on the latest research and for consistency with current building codes and standards.

The ASCE Petrochemical Energy Committee was reorganized by Magdy H. Hanna in 2005, and the following four task committees were formed to update their respective reports:

- Task Committee on Anchorage for Petrochemical Facilities
- Task Committee on Blast Design for Petrochemical Facilities
- Task Committee on Seismic Evaluation and Design for Petrochemical Facilities
- Task Committee for Wind Load Design for Petrochemical Facilities

Current ASCE Petrochemical Energy Committee

Magdy H. Hanna, PE   Jacobs—Task Committee Chairman
William Bounds, PE   Fluor Corporation—Blast Committee Chairman
John B. Falcon, PE   Jacobs—Anchorage Committee Chairman
James R. (Bob) Bailey, PhD, PE   Exponent, Inc.—Wind Committee Chairman
J. G. (Greg) Soules   CB&I—Seismic Committee Chairman
The ASCE Task Committee on Anchorage Design

This updated document was prepared to evaluate the impacts of published reference data, research development and code changes that have occurred since creation of the 1997 report; and provide an updated report that will continue to serve as a source for uniformity in the design, fabrication and installation of anchorage in the petrochemical industry.

Although the makeup of the committee and the writing of this report are directed at petrochemical facility design, these guidelines are applicable to similar design situations in other industries. This report should interest engineers with responsibility for designing anchorage for equipment and structures, and operating company personnel responsible for establishing internal design, fabrication and construction practices.

This report is intended to be a State-of-the-Practice set of guidelines. The guidelines are based on published information and actual design practices. A review of current practices, internal company standards, and published documents was conducted. Also included is a list of references used by the Committee during creation of this report. The Committee acknowledges the work of Process Industry Practices (PIP) (http://www.pip.org) for providing much of the information used in this report.

In helping to create this consensus set of guidelines, the following individuals provided valuable assistance:

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The following individuals provided valuable assistance with a peer review of the report. The Peer Reviewers were:

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## Contents

**Preface** ................................................................................................................................................. ix

**Chapter 1: Introduction** ...................................................................................................................... 1

1.1 Background ........................................................................................................................................ 1
1.2 Objectives and Scope .......................................................................................................................... 1
1.3 Updates and Additions to Previous Report ....................................................................................... 2
1.4 Codes and Design Procedures ........................................................................................................... 2
1.5 State of Research ............................................................................................................................... 4
1.6 Future Research ................................................................................................................................. 5

**Chapter 2: Materials** ............................................................................................................................ 9

2.1 Introduction ....................................................................................................................................... 9
2.2 Bolt and Rod Assemblies .................................................................................................................... 9
2.3 Headed Studs .................................................................................................................................... 15
2.4 Post-Installed Anchors ....................................................................................................................... 15
2.5 Shear Lugs ....................................................................................................................................... 15
2.6 Corrosion .......................................................................................................................................... 15
2.7 Anchorage Exposed to Extreme Temperatures .............................................................................. 21

**Chapter 3: Cast-in-Place Anchor Design** ............................................................................................ 27

3.1 Introduction ....................................................................................................................................... 27
3.2 Anchor Configuration and Dimensions ......................................................................................... 28
3.3 Strength Design ............................................................................................................................... 32
3.4 Ductile Design ............................................................................................................................... 35
3.5 Anchor Reinforcement Design ........................................................................................................ 37
3.6 Frictional Resistance and Transmitting of Shear Force into Anchors ..................................... 60
3.7 Shear Lug Design ............................................................................................................................ 63
3.8 Tensioning ....................................................................................................................................... 64
3.9 Welded Anchors for Embedded Plates .......................................................................................... 75
3.10 Considerations for Vibratory Loads ............................................................................................. 78
3.11 Considerations for Seismic Loads ................................................................................................. 80
3.12 Constructability Considerations .................................................................................................... 87

**Chapter 4: Post-Installed Anchor Design** ............................................................................................ 95

4.1 Introduction ....................................................................................................................................... 95
4.2 Post-Installed Mechanical Anchors ............................................................................................... 96
4.3 Post-Installed Bonded Anchors ....................................................................................................... 99
4.4 Considerations in Post-Installed Anchor Design ........................................................................... 102
4.5 Post-Installed Anchor Design ......................................................................................................... 105
4.6 Seismic Loading ............................................................................................................................. 107
Preface

The provisions of this document are written in permissive language and, as such, offer to the user a series of options or instructions, but do not prescribe a specific course of action. Significant judgment is left to the user of this document.

This document was initially prepared to provide guidance in the design, fabrication and installation of anchorage for petrochemical facilities and was issued in 1997 as *Design of Anchor Bolts in Petrochemical Facilities*. The task committee was reestablished in 2005 to update that document.

This document has been prepared in accordance with recognized engineering principles and should not be used without the user's competent knowledge for a given application. The publication of this document by ASCE is not intended to warrant that the information contained therein is suitable for any general or specific use, and ASCE takes no position respecting the validity of patent rights. The user is advised that the determination of patent rights or risk of infringement is entirely their own responsibility.

The contents of this document are not intended to be and should not be construed to be a standard of the American Society of Civil Engineers (ASCE) and are not intended for use as a reference in purchase specifications, contracts, regulations, statutes, or any other legal document.
CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Design of anchorages by most petrochemical engineering firms and owner companies uses an extrapolation, variation, or interpretation of the American Concrete Institute (ACI), the American Institute of Steel Construction (AISC), ASCE, and other technical documents as the basis for the design of anchorage systems for the petrochemical industry. This committee's work has been influenced by the continuing need to update the development of a uniform anchorage design methodology that is acceptable throughout the petrochemical industry.

1.2 OBJECTIVES AND SCOPE

The objective of this committee was to update the previous report, summarizing the State-of-the-Practice for the design of cast-in-place anchor rods, welded anchors, and post-installed anchors as used in petrochemical facilities.

The specific objectives were to:

a. present petrochemical industry anchorage design methods for tension and shear transfer with reinforcement and other embedments;

b. summarize anchorage materials and properties;

c. present current practices for fabrication and installation of anchorage;

d. present recommendations for post-installed anchors;

e. make comprehensive recommendations for cast-in-place anchor design which are appropriate for use by the petrochemical industry;

f. present recommended fabrication, constructability, and repair practices.

The committee recognized that while several different types of anchorage systems are used in petrochemical facilities, the most common types are cast-in-place anchors, welded anchors, post-installed anchors, and shear lugs. Therefore, for this report, the committee limited its investigation and recommendations to these common types. This self-imposed limit should not be construed as an attempt to limit the importance of other types of anchorage systems. Instead, this limit allowed the committee to focus attention on the most commonly used devices.
1.3 UPDATES AND ADDITIONS TO PREVIOUS REPORT

Chapter 2 includes a reorganization of Table 2.1, defining ASTM material specifications used for bolts and rods, with expanded notes relating to material welding and galvanizing. New sections have been added for washers and nuts, sleeves, fabrication – threading, headed studs, post-installed anchors, shear lugs, and performance of anchors exposed to extreme temperatures. The ASTM A307 Grade C anchor rod material is deleted and replaced with reference to ASTM F1554 Grade 36.

Chapter 3 has been rewritten for the state-of-the-art Concrete Capacity Design (CCD) Method based on ACI 318 and ACI 349 as applied to the current state of design practices in the petrochemical industry. New and revised sections have been created for anchor configuration and dimensions, strength and ductile design, anchor reinforcement design, frictional resistance, shear lug design, tensioning of anchors, design of welded anchors for embedded plates, and considerations for vibratory and seismic loads. Detailed examples are provided for a column pedestal with supplemental tension and shear reinforcement design, vertical vessel foundation anchorage design, and shear lug design.

Chapter 4 has been revised to include present design information for post-installed mechanical and bonded anchors, including typical installations; static, seismic, and fatigue design considerations; and post-installed qualifications. Anchor types addressed are those that would typically be considered for structural as well as safety-related nonstructural applications. Other light duty fastener types such as powder-actuated fasteners and small screws are not included in this discussion. For information regarding the correct design and installation of such fastener types, the user should refer to the appropriate evaluation reports provided by ICC-ES or other evaluation bodies. It is also advised that these types of light-duty fasteners not be used as single-point fastenings, but rather only in applications where the failure of one or more fasteners will not lead to progressive collapse.

Chapter 5 has been added to present installation and repair information, focusing on post-installed anchors, constructability, and repair procedures.

1.4 CODES AND DESIGN PROCEDURES

Changes in design methodology documented in the publications discussed below have resulted in changes to the formulas and methodologies presented in the original report, which was based on the 45-degree cone method. This report is based on the CCD Method, which assumes a critical spacing of three times the effective embedment depth. This assumption corresponds to a cone angle of approximately 35 degrees. In addition, the equation for basic concrete breakout strength accounts for the size effect associated with relatively high bearing stresses (and strain gradients) in the concrete. The following is a brief summary of the ACI Committee work relating to anchorage design.
ACI Committee 355 published the *State-of-the-Art Report on Anchorage to Concrete* in 1991. This was the first of a two-volume set which emphasized behavior and did not include design methods and procedures. In 2000, ACI Committee 355 published the ACI Provisional Standard, *Qualification of Post-Installed Mechanical Anchors in Concrete (ACI 355.2-00) and Commentary (ACI 355.2R-00).* This document prescribed testing programs and evaluation requirements for post-installed mechanical anchors intended for use in concrete under the design provisions of ACI 318/318R-02. It was designated an ACI Standard in 2001 and has since been updated twice, most recently in 2007.

ACI Committee 318 first approved the inclusion of Appendix D – Anchoring to Concrete in ACI 318/318R-02. It provided strength design requirements for anchorage to concrete that consider several potential failure modes such as steel strength, concrete breakout, anchor pullout, side-face blowout, and anchor pryout (shear) in accordance with the CCD Method. ACI 318-08 includes the following important enhancements to Appendix D:

a. The requirements for the use of reinforcement to preclude concrete breakout are more clearly defined

b. A non-ductile anchor option is included in the seismic design provisions

c. A modification factor for concrete breakout strength is introduced to reduce the conservatism of the provisions for anchorages loaded in shear where the edge distance is large relative to the member thickness

ACI Committee 349 Appendix B introduced provisions for anchor design in 1976. In 1980, revisions to Appendix B based on the 45-degree cone method were proposed; they were incorporated in 1982. (Reference Cannon et al Preface [1981].) This approach involved the assumption of a conical failure surface originating from the outer edge of the bearing head and projecting at an angle of 45 degrees to the concrete surface. This assumption, combined with a calculation for equilibrium based on a uniform stress distribution of $4\sqrt{f_c}$ over the failure surface, results in an equation for breakout that is proportional to the square of the embedment depth. In 2001, ACI Committee 349 adopted the CCD Method as Appendix B of ACI 349-01. In contrast to ACI 318/318R-02 Appendix D, however, Appendix B of ACI 349-01 included provisions for non-ductile anchors as well as the use of friction to resist shear, and design provisions for shear lugs.

In 2007, ACI Committee 349 published the *Guide to the Concrete Capacity Design (CCD) Method—Embedment Design Examples.* This report presents design examples of single and multiple embedded elements in concrete members based on Appendix D (formerly Appendix B) of ACI 349-06, which is based on the CCD Method. The 2007 edition of the Guide replaced the 1997 edition, which was based on ACI 349-97 and the 45-degree cone method for establishing concrete breakout resistance.