Anchorage Design for Petrochemical and Other Industrial Facilities

SECOND EDITION



Task Committee on
Anchorage Design

ASCE

Anchorage Design for Petrochemical and Other Industrial Facilities

Second Edition

Other Titles of Interest

Design of Blast-Resistant Buildings in Petrochemical Facilities: Second Edition, edited by William L. Bounds. (ASCE/Energy Division, 2010). This report provides general guidelines for the structural design of blast-resistant petrochemical facilities, updating the 1997 original edition. (ISBN 978-0-7844-1088-2)

Seismic Evaluation and Design of Petrochemical and Other Industrial Facilities: Third Edition, by the Task Committee on Seismic Evaluation and Design of Petrochemical Facilities. (ASCE/Energy Division, 2020). This report offers practical recommendations regarding the design and safety of new and existing petrochemical facilities during and following an earthquake. (ISBN 978-0-7844-1548-1)

Wind Load Design for Petrochemical and Other Industrial Facilities: Second Edition, by the Task Committee on Wind-Induced Forces. (ASCE/Energy Division, 2020). This report provides state-of-the-practice guidelines for the computation of wind-induced forces on industrial facilities with structural features outside the scope of current codes and standards. (ISBN 978-0-7844-1561-0)

Design of Secondary Containment in Petrochemical Facilities, by the Task Committee on Secondary Containment. (ASCE/Energy Division, 1997). This technical report provides guidelines for the design of secondary containment and leak detection systems in petrochemical and other industrial facilities. (ISBN 978-0-7844-8136-3)

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Petrochemical Energy Committee

This publication began as one of the five state-of-the-practice engineering reports produced by the ASCE Petrochemical Energy Committee. These engineering reports were intended to be a summary of current engineering knowledge and design practice and present guidelines for the design of petrochemical facilities. They represented a consensus opinion of task committee members active in their development. These five ASCE engineering reports were initially published in 1997 in four separate reports, with the reports on wind and anchor bolts being printed together in a combined document for publishing convenience, and they are

Design of Blast-Resistant Buildings in Petrochemical Facilities
Guidelines for Seismic Evaluation and Design of Petrochemical Facilities
Wind Loads for Petrochemical and Other Industrial Facilities
Anchorage Design for Petrochemical Facilities
Design of Secondary Containment in Petrochemical Facilities

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. In addition, new research in these areas and in blast-resistant design has provided opportunities for improvement of the recommended guidelines. 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 Petrochemical Energy Committee was reorganized in 2005, and the following four task committees were formed to update their respective reports:

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

In 2012, ASCE published a subsequent version of the *Anchorage Design for Petrochemical Facilities.* However, because the 1997 edition of the report was published in a combined document with *Wind Loads for Petrochemical and Other industrial Facilities*, and the 2012 version of the report was a standalone document, that version was denoted as a first edition.

Since the publication of the first edition in 2012, notable updates to relevant design codes and standards cited in the report have been issued. As a result, in 2019, the Energy Division Executive Committee directed that a task committee be formed to update the report to ensure consistency with current building codes and standards. That effort has resulted in the current book, *Anchorage Design for Petrochemical and Other Industrial Facilities*, Second Edition.

Task Committee on Anchorage Design

This book is intended to be a state-of-the-practice set of guidelines. It is based on reviews of current practice, internal company standards, published documents, and the work of related organizations. The report includes references that provide additional information, commercial publications, and government reports.

In preparing the second edition, an effort was made to evaluate the impacts of published reference data, research development, and code changes that have occurred since the creation of the 2012 technical report. It is the hope of the task committee that this report will continue to serve as a source for uniformity in the design, fabrication, and installation of anchorage in the petrochemical and other industrial facilities.

This report should interest engineers with the responsibility for designing anchorage for equipment and structures, and operating company personnel responsible for establishing internal design, fabrication, and construction practices.

The Task Committee acknowledges the work of Process Industry Practices (PIP) (http://www.pip.org, 3925 West Braker Lane(R4500), Austin, Texas 78759) for providing much of the information used in this report, as well as previous editions.

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Notation

$A_{\text{bearing_anc}}$	Assumed bearing area of a compression strut on an anchor in a strut-and-tie model for shear, in.^{2} (mm^2)
A_{brg}	Net bearing area of the head, bearing nut, or bearing plate of a stud or anchor, in.^{2} (mm^2)
A_d	Nominal area of an anchor, in.^{2} (mm^2)
A_{Nc}	Projected concrete failure area of a single anchor or a group of anchors for the calculation of strength in tension, in.^{2} (mm^2)
A_{Nco}	Projected concrete failure area of a single anchor for the calculation of strength in tension if not limited by edge distance or spacing, in.^{2} (mm^2)
AP	Anchor plate
A_p	Pedestal area, in.^{2} (mm^2)
A_{req}	Bearing area required for a shear lug, in.^{2} (mm^2)
A_s	Area of nonprestressed longitudinal tension reinforcement, in.^{2} (mm^2)
$A_{se,N}$	Effective cross-sectional area of an anchor in tension, in.^{2} (mm^2)
$A_{se,V}$	Effective cross-sectional area of an anchor in shear, in.^{2} (mm^2)
A_{se_tie}	Area of one leg of tie reinforcement, in.^{2} (mm^2)
A_{st}	Minimum required area of longitudinal nonprestressed reinforcement, in.^{2} (mm^2)
A_{Vc}	Projected concrete failure area of a single anchor, a group of anchors, or a shear lug for the calculation of the strength in shear, in.^{2} (mm^2)
A_{Vco}	Projected concrete failure area of a single anchor, for the calculation of the strength in shear, if not limited by corner influences, spacing, or member thickness, in.^{2} (mm^2)
A_w	Area of a weld, in.^{2} (mm^2)
b_1	Pedestal dimension in one direction, in. (mm)
b_2	Pedestal dimension in the direction perpendicular to b_1, in. (mm)
C	Cover distance to the top of a rebar, in. (mm)
C_d	Ratio of deflection of a vertical vessel owing to deflection from elastic analysis to total deflection
$c_{a,\max}$	Maximum distance from the center of an anchor shaft to the edge of concrete, in. (mm)
$c_{a,\min}$	Minimum distance from the center of an anchor shaft to the edge of concrete, in. (mm)
c_{a1}	Distance from the center of an anchor shaft to the edge of concrete in one direction, in. (mm). If shear is applied to the anchor, c_{a1} is taken in the direction of the applied shear. If tension is applied to the anchor, c_{a1} is the minimum edge distance.

c_{a2}	Distance from the center of an anchor shaft to the edge of concrete in the direction perpendicular to c_{a1}, in. (mm)
c_{a3}	Distance from the center of an anchor shaft to the edge of the effective tensile stress area toward the center of an octagon-shaped concrete pedestal, in. (mm). *See* Example 2.
c_{a4}	Distance from the center of an anchor shaft to the edge of the effective tensile stress area opposite to c_{a2} of an octagon-shaped concrete pedestal, in. (mm). *See* Example 2.
D	Vertical dead load, lbs (N); diameter of a pipe or weld, in. (mm)
D_{bc}	Bolt circle diameter, in. (mm)
D_p	Face-to-face dimension of a pedestal, ft (m)
d	Depth of a column in. (mm)
d_a	Outside diameter of the anchor or the shaft diameter of the headed stud, headed bolt, or hooked bolt, in. (mm)
d_{actual}	Actual distance between an anchor and reinforcing bars under consideration, in. (mm)
d_b	Nominal diameter of a rebar, in. (mm)
d_{max}	Maximum distance between an anchor and reinforcing bars where the reinforcing bars can be considered to be effective for resisting anchor tension, in. (mm)
d_s	Diameter of a sleeve shell, in. (mm)
d_{tie}	Nominal diameter of a tie reinforcement bar, in. (mm)
E_{sh}	Coefficient for shrinkage, in./in. (mm/mm)
E_v	Vertical component of a seismic load, kips (kN)
$EA_{\text{bearing_rebar}}$	Assumed bearing area of a compression strut on a reinforcing bar in a strut-and-tie model for a shear, in.^{2} (mm^2)
F	Side-face blowout force, kips (kN)
F_c	Compression force at anchors, kips (kN)
F_{cor}	Factor to modify the side-face blowout near a corner
F_{EXX}	Electrode classification number, ksi (MPa)
F_W	Nominal strength of weld metal per unit area, ksi (MPa)
F_r	Maximum horizontal dynamic force, kips (kN)
F_t	Tension force at anchors, kips (kN)
F_y	Specified yield strength of structural steel, psi (kPa)
f_c'	Specified compressive strength of concrete, psi (kPa)
$f_{cc,200}$	Concrete compressive strength based on a 200-mm cube, psi (kPa)
f_{ce}	Effective compressive strength of concrete in a strut or nodal zone (Strut-and-Tie Model [STM]), psi (kPa)
f_t	Desired tensile stress in anchor owing to tensioning, psi (kPa)
f_{uta}	Specified tensile strength of anchor steel, psi (kPa)
f_w	Weld stress, ksi (MPa)
f_y	Specified yield strength of reinforcement, psi (kPa)
f_{ya}	Specified yield strength of anchor steel, psi (kPa)
G	Grout thickness, in. (mm)

H	Height of the pipe used for a shear lug, in.; the height of a vertical vessel, in. (mm)
h	Distance from the center of a seismic load on a vertical vessel to the bottom of the vertical vessel base plate, in. (mm)
h_{ef}	Effective embedment depth of an anchor, in. (mm)
h_e'	Minimum nut-sleeve clearance, in. (mm)
h_{ef}'	Limiting value of h_{ef} when anchors are located less than 1.5 h_{ef} from three or more edges, in. (mm)
h_s	Height of a sleeve, in. (mm)
I	Importance factor
k_c	Coefficient for basic concrete breakout strength in tension
L	Length of an anchor, in. (mm); the length of a weld, Figure 5-5, in. (mm)
LA	Lever arm between the centroid of tension loads on anchors and the centroid of the compression load, in. (mm)
L_g	Grip dimension of an anchor bolt, in. (mm)
L_{stretch}	Anchor stretch length (the distance between the top and the bottom nuts on the anchor), in. (mm)
L_t	Thread length at the bottom of an anchor, in. (mm)
l_d	Development length in the tension of reinforcement, in. (mm)
l_{da}	Available development length of reinforcement, in. (mm)
l_{dh}	Development length in the tension of reinforcement with a standard hook, in. (mm)
l_{dha}	Available development length of a hairpin, in. (mm)
l_e	Load-bearing length of an anchor for shear, in. (mm)
M_n	Nominal flexural strength, k-in. (kN-mm)
M_u	Factored overturning moment, k-ft (kN-m)
M_u^E	Factored overturning moment at the vessel base owing to the seismic effect acting alone, k-ft (kNm)
N_{arf}	Tension to be taken by anchor reinforcement, lb (N)
N_b	Basic concrete breakout strength in the tension of a single anchor in cracked concrete, lb (N)
N_{cb}	Nominal concrete breakout strength in the tension of a single anchor, lb (N)
N_{cbg}	Nominal concrete breakout strength in the tension of a group of anchors, lb (N)
N_{dse}	Controlling tension for ductile steel element failure, lb (N)
N_n	Nominal strength in tension, lb (N)
N_p	Pullout strength in the tension of a single anchor in cracked concrete, lb (N)
N_{pn}	Nominal pullout strength in the tension of a single anchor owing to the crushing of concrete under an anchor head, lb (N)
N_{sa}	Nominal strength of a single anchor or a group of anchors in tension as governed by the steel strength, lb (N)
N_{sb}	Side-face blowout strength of a single anchor, lb (N)
N_{sbg}	Side-face blowout strength of a group of anchors, lb (N)

N_u	Factored axial normal to cross-section occurring simultaneously with Vu or Tu; to be taken as a positive for the compression applied and negative for tension, lb (N)
N_{ua}	Factored tensile force applied to an anchor or a group of anchors, lb (N)
n or n_a	Number of anchors
n_layers	Required number of layers of ties to resist the resultant of the radial horizontal component of diagonal concrete struts (assumed to be similar to side-face blowout force)
n_t	Anchor threads per in. (mm)
P_u^E	Factored compression force at the top of a pedestal owing to the seismic effect acting alone (including the vertical component of a seismic load acting upward), lb (N)
P_u	Normal factored compression force, lb (N)
p	Bearing pressure on the head of an anchor, psi (kPa)
r	Radius, in. (mm)
S_p	Face dimension of an octagonal pedestal, ft (m)
S_x	Section modulus of a weld, in.^{3} (mm^3)
s	Center-to-center spacing of anchors, reinforcement, or other items in one direction, in. (mm)
s_1	Center-to-center spacing of anchors in one direction, in. (mm)
s_2	Center-to-center spacing of anchors in the direction perpendicular to s_1, in. (mm)
T, T_1	Tensile force on a tie, lb (N)
T_u^E	Factored tension design load from load combinations that include an overstrength factor of 2.5 applied to seismic loads (per anchor), lb (N)
T_2	Tensile force on a hairpin, lb (N)
t	Wall thickness of a pipe; the thickness of a weld, in. (mm)
t_f	Flange thickness
V_b	Basic concrete breakout strength in the shear of a single anchor in a cracked section, lb (N)
V_{cb}	Nominal concrete breakout strength in the shear of a single anchor or a shear lug, lb (N)
V_{cbg}	Nominal concrete breakout strength in the shear of a group of anchors, lb (N)
V_{cp}	Nominal concrete pryout strength of a single anchor, lb (N)
V_{dse}	Controlling shear for ductile steel element failure, lb (N)
V_f	Resisting friction force, lb (N)
V_n	Nominal shear strength, lb (N)
V_{sa}	Nominal strength in the shear of a single anchor or a group of anchors as governed by the steel strength, lb (N)
V_u	Factored shear force at a section, lb (N)
V_{ua}	Factored shear force applied to a single anchor, a group of anchors, or a shear lug, lb (N)
W_a	Equipment weight at an anchor location, lb (N)
W_e	Vessel empty weight, lb (N)

W_o	Vessel operating weight, lb (N)
Z	Plastic section modulus, in.^{3} (mm^3)
z	Vertical hairpin concrete cover + $0.5d_b$, in. (mm); also, the internal lever arm between the centroid of anchors in tension and the centroid of a compression force on foundation, in. (mm)
α	Ratio of F to N_{ua}
β_n	Factor to account for the effect of the anchorage of ties on the effective compressive strength of a nodal zone
Δ_A	Amplified displacement at the top of a vertical vessel, in. (mm)
Δ_a	Amount of stretch in an anchor, in. (mm)
Δ_{ie}	Inelastic portion of displacement at the top of a vertical vessel, in. (mm)
Δ_s	Deflection at the top of a vertical vessel from elastic analysis, in. (mm)
λ	Modification factor related to the unit weight of concrete
λ_p	Limiting slenderness parameter for a compact element
μ	Coefficient of friction
ϕ	Strength reduction factor Strength reduction factor, tension loads
ϕ_V	Strength reduction factor, shear loads
ϕ_b	Resistance factor for flexure (structural steel)
ϕ_s	Strength reduction factor used for anchor reinforcement design
ϕ_v	Resistance factor for shear (structural steel)
$\Psi_{c,P}$	Factor used to modify the pullout strength of anchors based on the presence or absence of cracks in concrete
$\Psi_{c,V}$	Factor used to modify the shear strength of anchors based on the presence or absence of cracks in concrete and the presence or absence of supplementary reinforcement
$\Psi_{c,N}$	Factor used to modify the tensile strength of anchors based on the presence or absence of cracks in concrete
$\Psi_{cp,N}$	Factor used to modify the tensile strength of post-installed anchors intended for use in uncracked concrete without supplementary reinforcement
Ψ_e	Factor used to modify the development length because of reinforcement coating
$\Psi_{ec,N}$	Factor used to modify the tensile strength of anchors based on the eccentricity of applied loads
$\Psi_{ec,V}$	Factor used to modify the shear strength of anchors based on the eccentricity of applied loads
$\Psi_{ed,N}$	Factor used to modify the tensile strength of anchors based on proximity to the edges of a concrete member
$\Psi_{ed,V}$	Factor used to modify the shear strength of anchors based on proximity to the edges of a concrete member
$\Psi_{m,N}$	Modification factor for an overturning moment
Ψ_t	Factor used to modify the development length based on the reinforcement location
Ω_o	Seismic overstress factor

CHAPTER 1
Introduction

1.1 BACKGROUND

Petrochemical and other industrial engineering firms and owner companies commonly use extrapolations and interpretations of the code provisions provided by the American Concrete Institute (ACI), the American Institute of Steel Construction (AISC), ASCE, and other standards development organizations as the basis for the design of anchorage systems. This committee's work has been influenced by the continuing need to establish a uniform anchorage design methodology that is acceptable for use throughout petrochemical and other industrial facilities.

1.2 OBJECTIVES AND SCOPE

The objective of this committee has been to update the previous versions of this publication, summarizing the state-of-the-practice for the design of cast-in-place anchors, welded anchors, and post-installed anchors as used in petrochemical and other industrial facilities.

The specific objectives were to

1. Present petrochemical and other industrial facilities anchorage design methods for tension and shear transfer into concrete with reinforcement and other embedments;
2. Summarize anchorage materials and properties;
3. Present current practices for fabrication and installation of anchorage;
4. Present recommendations for post-installed anchors;
5. Make comprehensive recommendations for cast-in-place anchor design, which are appropriate for use in petrochemical and other industrial facilities;
6. Present recommended constructability and repair practices.