4.1 Anchor Principles & Design

4.1.1 ASD Terminology

The following terminology is generally compliant with that used in ICC-ES acceptance criteria for allowable stress design of anchors.

A_{nom} = nominal bolt cross sectional area

A_{sl} = cross sectional area of anchor sleeve

A_{st} = tensile stress area of threaded part

c = distance from anchor centerline to free edge of base material

c_{cr} = critical edge distance

c_{min} = minimum edge distance

d = anchor bolt diameter (shank diameter)

d_{bit} = nominal drill bit diameter

d_h = diameter of clearance hole in attachment (e.g. baseplate)

d_{nom} = nominal anchor diameter

d_o = anchor O.D.

d_w = washer diameter

f_a = adjustment factor for anchor spacing

f_c = concrete compressive strength as measured by testing of cylinders

f'_c = specified concrete compressive strength

f_{RN} = adjustment factor for edge distance, tension loading

f_{RV1} = adjustment factor for edge distance, shear loading perpendicular and towards free edge

f_{RV2} = adjustment factor for edge distance, shear loading parallel to edge

f_{RV3} = adjustment factor for edge distance, shear loading perpendicular and away from free edge

f_y = specified reinforcing bar yield strength

F_y = specified bolt minimum yield strength

F_u = specified bolt minimum ultimate strength

h = thickness of member in which anchor is embedded as measured parallel to anchor axis

h_{ef} = effective anchor embedment

h_{min} = minimum member thickness

h_{nom} = standard embedment depth

h_o = depth of full diameter hole in base material

ℓ = anchor embedded length

ℓ_{th} = anchor useable thread length

$M_{uM,5\%}$ = characteristic flexural resistance of anchor bolt (5% fractile)

N_{allow} = allowable load (based on mean value from tests and a global safety factor)

N_d = design tension load (unfactored)

N_{rec} = recommended tension load

s = anchor axial spacing

s_{cr} = critical spacing between adjacent loaded anchors

s_{min} = minimum spacing between adjacent loaded anchors

s = elastic section modulus of anchor bolt

s_W = width of anchor nut across flats

t_{fix} = maximum thickness of attachment (e.g. baseplate) to be fastened

T_{inst} = recommended anchor installation torque

T_{max} = maximum tightening torque

V_{allow} = allowable shear load (based on mean value from tests and a global safety factor)

V_d = design shear load (unfactored)

V_{rec} = recommended shear load

4.1.2 LRFD Terminology

The following terminology is generally compliant with that used in ACI 318-05 Appendix D for the strength design of anchors.

A_{Nc} = the projected area of the failure surface for the anchor or group of anchors for calculation of strength in tension

A_{Nco} = the projected area of the failure surface of a single anchor without the influence of proximate edges for calculation of strength in tension

A_{sl} = cross sectional area of anchor sleeve

A_{se} = tensile stress area of threaded part

A_{Vc} = the projected area of the failure surface for the anchor or group of anchors for calculation of strength in shear

A_{Vco} = the projected area of the failure surface of a single anchor without the influence of proximate edges for the calculation of strength in shear

c = distance from anchor centerline to free edge of base material

c_{ac} = critical edge distance required to develop the basic concrete breakout strength of a post-installed anchor in uncracked concrete with out supplementary reinforcement to control splitting

$c_{a,max}$ = distance to furthest edge ($c_{a,max} < 1.5c_{ac}$) from anchor centerline

$c_{a,min}$ = distance to closest edge ($c_{a,min} < 1.5c_{ac}$) from anchor centerline

c_{a1} = distance from edge to anchor centerline; for a group of anchors, the distance from the edge to the axis of the furthest anchor row

c'_{a1} = limiting value of when anchors are located less than 1.5 h_{ef} from three or more edges

c_{a2} = distance from centerline of anchor to edge of concrete in the direction perpendicular to c_{a1}

c_{cr} = critical edge distance

c_{min} = minimum edge distance

d = anchor bolt diameter (shank diameter)

d_{bit} = nominal drill bit diameter

d_h = diameter of clearance hole in attachment (e.g. baseplate)

d_{nom} = nominal anchor diameter

d_o = anchor O.D.

e'_N = distance between geometric centroid of a group of anchors loaded in tension, and the resultant tension load applied to the group

e'_V = distance between geometric centroid of a group of anchors loaded in shear, and the resultant shear load applied to the group

f_c = concrete compressive strength as measured by testing of cylinders

f'_c = specified concrete compressive strength

f_{ya} = specified bolt minimum yield strength

f_{uta} = specified bolt minimum ultimate strength

h_a = thickness of member in which anchor is embedded as measured parallel to anchor axis

h_{ef} = effective anchor embedment

h_{min} = minimum member thickness

h_0 = depth of full diameter hole in base material

k_{cr} = coefficient for basic concrete strength in tension, cracked concrete

k_{uncr} = coefficient for basic concrete strength in tension, uncracked concrete

k_{cp} = coefficient for pryout strength

ℓ_e = load-bearing length of anchor for shear, not to exceed $8d_o$, in.

= h_{ef} for anchors with a constant stiffness over the full length of the embedded section, such as headed studs or post-installed anchors with one tubular shell over the full length of the embedment depth

= $2d_0$ for torque-controlled expansion anchors with a distance sleeve separated from the expansion sleeve

ℓ_{th} = anchor useable thread length

$M_{uM,5\%}$ = characteristic flexural resistance of anchor bolt (5% fractile)

n = number of anchors in a group

4.1 Anchor Principles & Design

4.1.2 LRFD Terminology

N_b = basic concrete breakout strength in tension of a single anchor in cracked concrete

N_{cb} = nominal concrete breakout strength of a single anchor in tension

N_{cbg} = nominal concrete breakout strength of a group of anchors in tension

N_n = nominal strength in tension

N_p = pullout strength of a single anchor in cracked concrete

N_{pn} = nominal pullout strength of a single anchor

N_{sa} = nominal strength in tension of a single anchor or group of anchors as governed by steel strength

N_{sb} = side face blowout strength of a single anchor

N_{sbg} = side face blowout strength of a group of anchors

N_{ua} = factored tensile force applied to an anchor or group of anchors

s = anchor axial spacing

s_{cr} = critical spacing between adjacent loaded anchors

s_{min} = minimum spacing between adjacent loaded anchors

s = elastic section modulus of anchor bolt

t_{fix} = maximum thickness of attachment (e.g. baseplate) to be fastened

T_{inst} = recommended anchor installation torque

T_{max} = maximum tightening torque

V_b = basic concrete breakout strength in shear of a single anchor in cracked concrete

V_{cb} = nominal concrete breakout strength of a single anchor in shear

V_{cbg} = nominal concrete breakout strength of a group of anchors in shear

V_{cp} = nominal pryout strength of a single anchor

V_{cpg} = nominal pryout strength of a group of anchors

V_n = nominal strength in shear

V_{sa} = nominal strength in shear of a single anchor or group of anchors as governed by steel strength

V_{ua} = factored shear force applied to a single anchor or group of anchors

ϕ = strength reduction factor

$\Psi_{c,N}$ = factor modifying the concrete breakout strength of anchors in tension based on whether the concrete is considered to be cracked or uncracked for design purposes

$\Psi_{c,p}$ = factor modifying the pullout strength of anchors in tension based on whether the concrete is considered to be cracked or uncracked for design purposes

$\Psi_{c,V}$ = factor modifying the shear strength of anchors based on whether the concrete is considered to be cracked or uncracked and whether supplementary reinforcement is present

$\Psi_{cp,N}$ = factor modifying the tension strength of anchors in uncracked concrete where supplementary reinforcement is not present

$\Psi_{ec,N}$ = factor modifying the tension strength of anchors subjected to eccentric tension loading

$\Psi_{ec,V}$ = factor modifying the shear strength of anchors subjected to eccentric shear loading

$\Psi_{ed,N}$ = factor modifying the tension strength of anchors based on proximity to near edges

$\Psi_{ed,V}$ = factor modifying the shear strength of anchors based on proximity to near edges

4.1.3 Definitions

Adhesive Anchor = a device for transferring tension and shear loads to structural concrete, consisting of an anchor element embedded with an adhesive compound in a cylindrical hole drilled in hardened concrete

Anchor Category = an assigned rating that corresponds to a specific strength reduction factor for concrete failure modes associated with anchors in tension. The anchor category is established based on the performance of the anchor in installation safety tests

Anchor Group = a group of anchors of approximately equal embedment and stiffness where the maximum anchor spacing is less than $3\,h_{ef}$

Anchor Spacing = centerline to centerline distance between adjacent loaded anchors

Attachment = the structural assembly, external to the surface of the concrete, that transmits loads to or receives loads from the base material

Characteristic capacity = 5% fractile of the anchor capacity, defined as that value that will be exceeded by 95% of the population with a 90% confidence

Concrete Breakout = failure of the anchor characterized by the formation of a conical fracture surface originating at or near the embedded end of the anchor element and projecting to the surface of the base material

Cracked Concrete = condition of concrete in which the anchor is installed; concrete is assumed to be cracked for anchor design purposes if cracks could form in the concrete at or near the anchor location over the service life of the anchor

Critical Spacing = required spacing between adjacent loaded anchors to achieve full capacity

Critical Edge Distance = required edge distance to achieve full capacity

Cure Time = the elapsed time after mixing of the adhesive material components to achieve a state of hardening of the adhesive material in the drilled hole corresponding to the design mechanical properties and resistances

Displacement Controlled Expansion Anchor = an expansion anchor designed to expand in response to driving a plug into the anchor body

Ductile Steel Element = an element with a tensile test elongation of at least 14% and corresponding reduction of area of at least 30% at failure

Gel Time = the elapsed time after mixing of the adhesive material components to onset of significant chemical reaction as characterized by an increase in viscosity

Edge Distance = distance from centerline of anchor to free edge of base material in which the anchor is installed

Effective Embedment Depth = effective anchor embedment equal to distance from surface of base material to point of load introduction into the base material, for expansion anchors taken as distance from surface of base material to tip of expansion element(s)

Minimum Edge Distance = minimum edge distance to preclude splitting of the base material during anchor installation

Minimum Spacing = minimum spacing between adjacent loaded anchors to preclude splitting of the base material during anchor installation

Minimum Member Thickness = required thickness of member in which anchor is embedded to prevent splitting of the base material

Projected Area = the area on the free surface of the concrete member that is used to represent the base of the assumed rectilinear failure surface

Side Face Blowout = failure mode characterized by blowout of side cover of an anchor loaded in tension

Supplementary Reinforcement = reinforcement that is proportioned and positioned to tie the concrete breakout surface into the structural member

Torque Controlled Expansion Anchor = an expansion anchor designed to expand with the application of torque to the anchor bolt or nut

Torque Controlled Adhesive Anchor = an adhesive anchor employing an anchor element designed to generate expansion forces in response to tension loading

Undercut Anchor = a mechanical anchor designed to interlock with drilled deformations (undercuts) in the base material

4.1.4 Anchors in Concrete and Masonry

Anchor bolts fulfill a variety of needs in construction, from securing column baseplates to supporting mechanical and electrical systems; from attaching facade panels to anchoring guardrails. Critical connections, i.e., those that are either safety-related or whose failure could result in significant financial loss, require robust anchor solutions capable of providing a verifiable and durable load path. The proper selection of a suitable anchor system and its incorporation in connection design requires an understanding of the fundamental principles of anchor function. An overview is provided here. Additional references are provided at the conclusion of this section.

4.1.5 Anchor Working Principles

Anchors designed for use in concrete and masonry develop resistance to tension loading on the basis of one or more of the following mechanisms:

Friction: This is the mechanism used by most post-installed mechanical expansion anchors to resist tension loads, including the Hilti Kwik Bolt, HDI and HSL. The frictional resistance resulting from expansion forces generated between the anchor and the wall of the drilled hole during setting of the anchor may also be supplemented by local deformation of the concrete. The frictional force is proportional to the magnitude of the expansion stresses generated by the anchor. Torque-controlled expansion anchors like the KWIK Bolt and HSL use follow-up expansion to increase the expansion force in