Anchoring to Concrete

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URP S-09 Training
Module XX

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Anchorage to Concrete – Allowable Stress Design

2009 IBC Section 1911 – Where strength design is used, or where load combinations include earthquake effects, the design strength of anchors shall be determined in accordance with Section 1912.

No ASD for anchors in BNBC-2020.

Anchorage to Concrete – Strength Design

2009 IBC Section 1912 – The provisions of this section shall govern the strength design of anchors installed in concrete for purposes of transmitting structural loads from one connected element to the other.

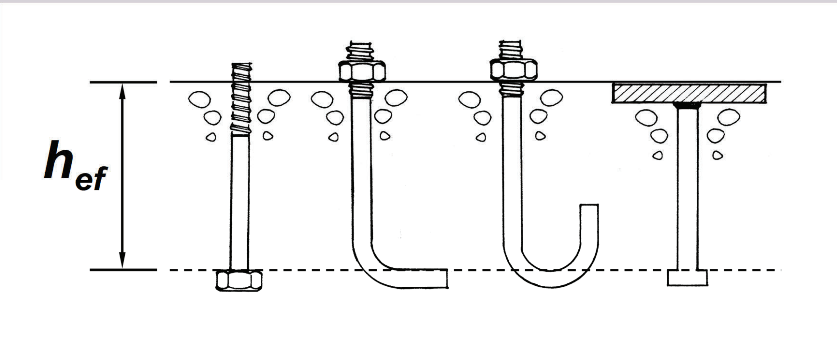
Headed bolts, headed studs and hooked (J- or L-)bolts cast in concrete and expansion anchors and undercut anchors installed in hardened concrete shall be designed in accordance with Appendix D of ACI 318 as modified by Section 1908.1.9 and 1908.1.10, provided they are within the scope of Appendix D.

No comparable provision in BNBC-2020, except for:

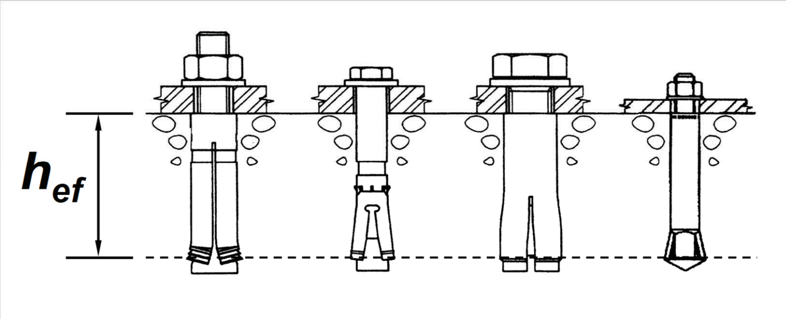
6.8.8.3 [Part 2, Chapter 6] In precast construction, anchor bolts or suitable mechanical connectors shall be permitted for satisfying 6.8.8.1. Anchor bolts shall be designed in accordance with Appendix K.

Cast-in-place Anchors

- h_{ef} = Effective embedment depth



Post-Installed Anchors



h_{ef} = Effective embedment depth

KD.2.1 - Scope

- Anchors used to transmit tension, shear, or both
- Safety levels (LF & ϕ) for in-service conditions
- Not intended for short-term handling and construction loads

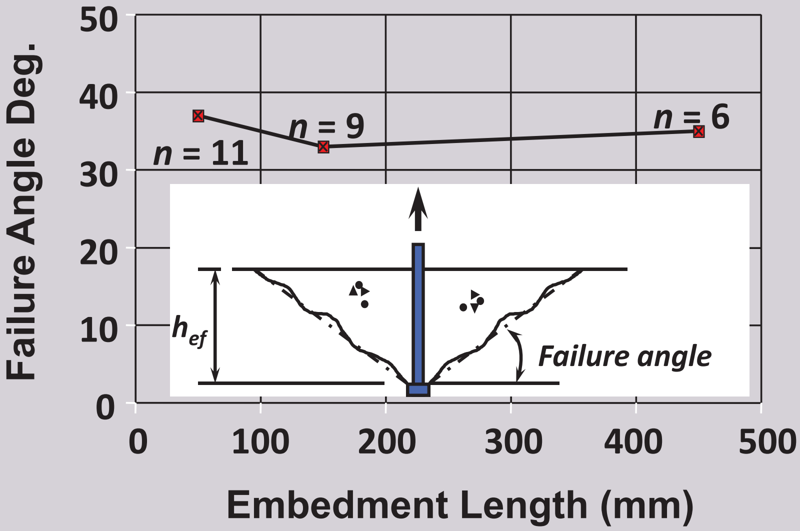
KD.2.2 - Scope

- Provisions for: Cast-in-place & post-installed mechanical anchors
- Excluded:
  - Specialty inserts
  - Through bolts
  - Multiple anchors connected to single plate at the embedded end of the anchors
  - Adhesive & grouted anchors
  - Powder/pneumatically actuated nails or bolts

The CCD Method (RD.4.2.2)

"… predicts the load capacity of an anchor or a group of anchors by using a basic equation for tension, or for shear for a single anchor in cracked concrete, and multiplied by factors that account for the number of anchors, edge distance, spacing, eccentricity and absence of cracking."

Failure Angle



KD.2.4 - Scope

- High-cycle fatigue or impact excluded
- Seismic load effects for SDC C or higher covered in KD.3.3

KD.3.1 – KD.3.2 - General Requirements

- Factored loads from elastic analysis
- Load combinations per 9.2 6.2.2 and ϕ per D.4.4
- Load combinations per C.2 and ϕ per D.4.5 [not an option in BNBC]

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KD.3.3.1 & KD.3.3.3 General Requirements

- Seismic Design Categories C, D, E, F
  - Anchors in plastic hinge zones excluded
  - Design strength associated with concrete failure: $0.75\phi N_n$ and $0.75\phi V_n$
  - Concrete assumed cracked unless demonstrated otherwise.

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KD.3.3.4 – KD.3.3.6 General Requirements

- Seismic Design Categories C, D, E, F
  - Anchor design governed by strength of ductile steel element, or
  - Attachment to undergo ductile yielding at a load ≤ minimum anchor design strength, or
  - Reduce design strength by a factor of 0.4 (0.5 for stud bearing walls)

KD.1 – Definition

- Brittle steel element
  - Elongation < 14%
  - Reduction in area < 30%
  - Or both
- Ductile Steel Element
  - Elongation ≥ 14%, and
  - Reduction in area ≥ 30%

A steel element meeting the requirements of ASTM A307 shall be considered ductile.

KD.1 – Definition

Attachment – The structural assembly, external to the surface of the concrete, that transmits loads to or receives loads from the anchor.

KD.3.4 - General Requirements

Modification factor λ for lightweight concrete in this Appendix shall be in accordance with 8.6.1 6.1.8.1 unless specifically noted otherwise.

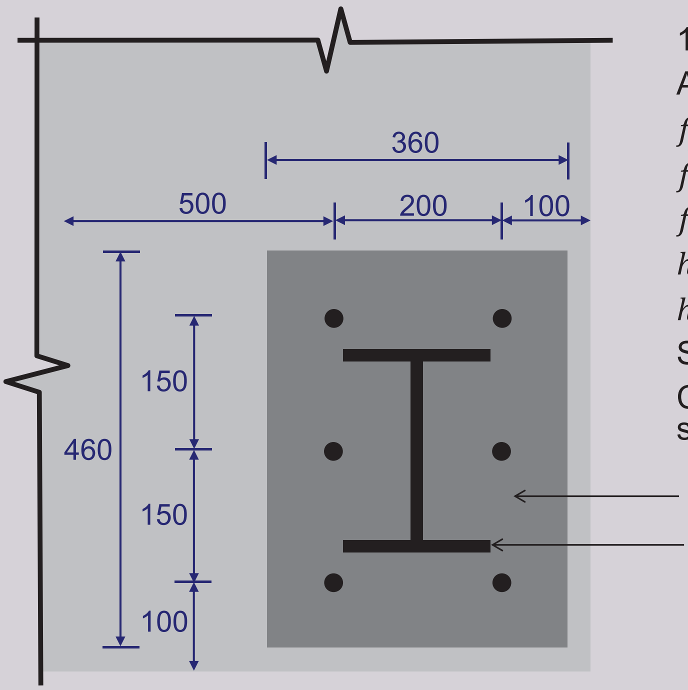
KD.4.1 – Strength of Anchors

$\phi N_n \geq N_{ua}$ (D-1) (6.K.1)

$\phi V_n \geq V_{ua}$ (D-2) (6.K.2)

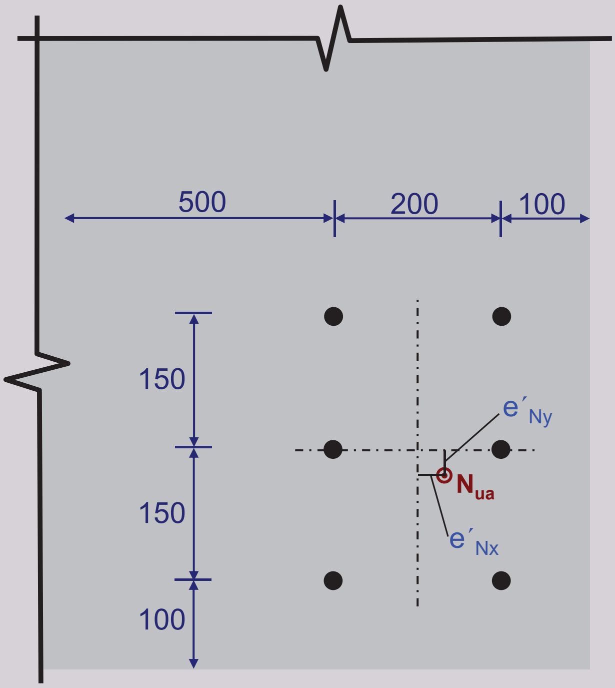
- Lowest ϕN_n and ϕV_n from applicable failure modes
- Interaction for combined N_{ua} and V_{ua}

Example Problem



12-mm. Headed bolts
ASTM F 1554 Grade 250
f_{ya} = 250 MPa
f_{uta} = 400 MPa
f_c' = 40 MPa
h_{ef} = 300 mm
h_a = 460 mm
SDC C
Concrete is assumed cracked at service load

Example Problem



e'_{Nx} = 25 mm

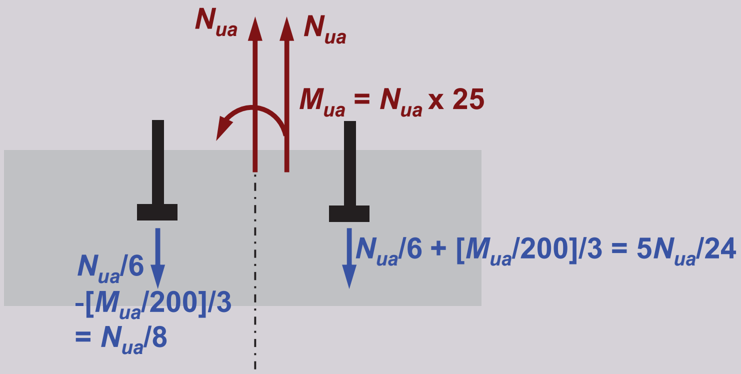
e'_{Ny} = 25 mm

KD.5 – Design Requirements for Tensile Loading

- KD.5.1 – Steel Strength
- KD.5.2 – Concrete Breakout Strength
- KD.5.3 – Pullout Strength
- KD.5.4 – Concrete Side-Face Blowout Strength of a Headed Anchor

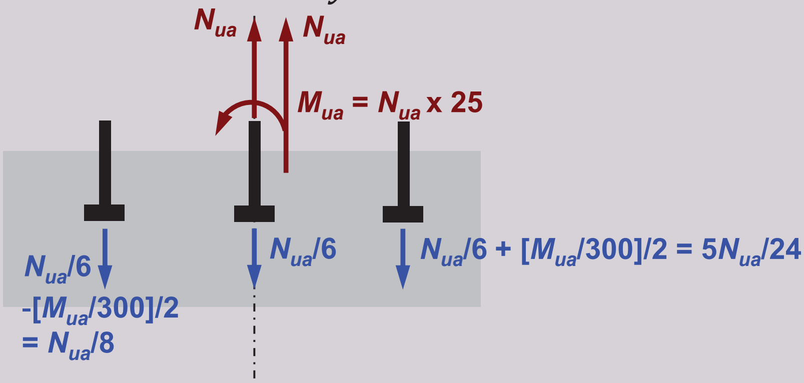
Tension Failure

Check for possible compression in anchor group due to load eccentricity e'_{Nx} :



Tension Failure

Check for possible compression in anchor group due to load eccentricity e'_{Ny} :



Tension Failure

Check for possible compression in anchor group due to load eccentricities:

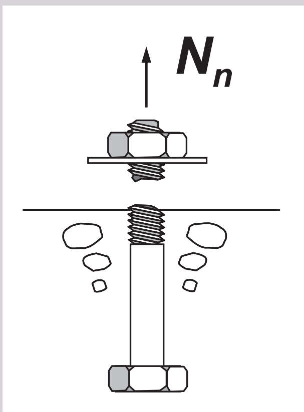
Maximum tension = $N_{ua}/6 + N_{ua}/24 + N_{ua}/24$

= $N_{ua}/4$

Minimum tension = $N_{ua}/6 - N_{ua}/24 - N_{ua}/24$

= $N_{ua}/12$ ....No compression

KD.5.1 – Steel Failure (Tension)



KD.5.1 – Steel Failure (Tension)

$N_{sa} = nA_{se,N}f_{uta}$ ....(D-3)

where $f_{uta} \leq 1.9\ f_{ya}$

≤ 860 Mpa

$A_{se,N}$ can be calculated as

$$A_{se,N} = \frac{\pi}{4}\left(d_a - \frac{0.9743}{n_t}\right)^2$$

where n_t is the number of threads per mm

KD.5.1 – Steel Failure (Tension)

Calculating for one bolt:

$A_{se,N}$ = 79.35 mm^2 [n_t = 0.5]

f_{uta} = 400 MPa < 1.9f_{ya} (= 475 MPa)...........OK

< 860 MPa....................OK

N_{sa} = 79.35 x 400/1000 = 31.74 kN

KD.5.1 – Steel Failure (Tension)

Strength reduction factor, ϕ:

ϕ = 0.75 for ductile steel elements under tension …….D.4.4(a)

KD.5.1 – Steel Failure (Tension)

Design strength of a single bolt for steel failure in tension:

$$\phi N_{sa} = 0.75 \times 31.74$$
$$= 23.81 \text{ kN}$$

KD.5.1 – Steel Failure (Tension)

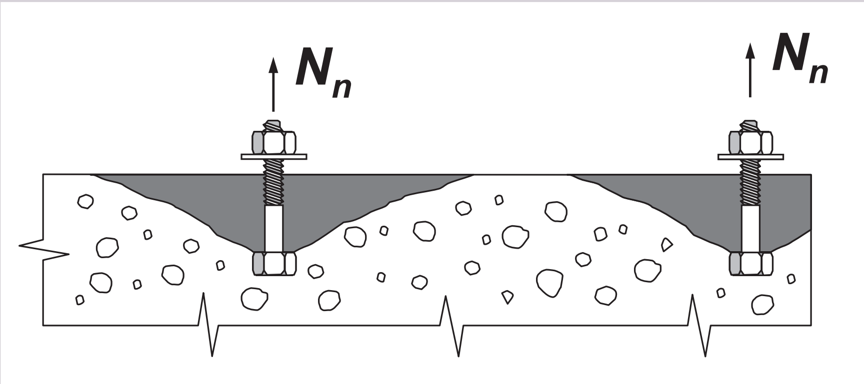
Equating with the maximum demand on a single bolt:

$N_{ua}/4 = 23.81$ kN

Thus maximum $N_{ua} = 95.24$ kN = ϕN_{sa} for the group of bolts

This is the maximum tension demand that the whole bolt formation can support for steel failure in tension

KD.5.2 – Concrete Breakout (Tension)



KD.1 – Definitions

Concrete Breakout Strength

The strength corresponding to a volume of concrete surrounding the anchor or group of anchors separating from the member.

KD.5.2.1 – Concrete Breakout Strength of Single Anchor (Tension)

$$N_{cb} = \frac{A_{Nc}}{A_{Nco}} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b \quad \ldots\text{(D-4)(6.K.4)}$$

- N_b: *Basic single anchor strength*
- $\psi_{cp,N}$: *Accounts for Post-Installed Anchor*
- $\psi_{c,N}$: *Accounts for cracking*
- $\psi_{ed,N}$: *Accounts for edge effects*
- $\frac{A_{Nc}}{A_{Nco}}$: *Accounts for projected area of failure surface*

KD.5.2.1 – Concrete Breakout Strength of Single Anchor (Tension)

$$N_{cbg} = \frac{A_{Nc}}{A_{Nco}} \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b \qquad \ldots\text{(D-5)(6.K.5)}$$

- N_b: Basic single anchor strength
- $\psi_{cp,N}$: Accounts for post-installed anchor
- $\psi_{c,N}$: Accounts for cracking
- $\psi_{ed,N}$: Accounts for edge effects
- $\psi_{ec,N}$: Accounts for eccentricity
- A_{Nc}/A_{Nco}: Accounts for projected area of failure surface

Consider only anchors in tension

KD.1 – Definitions

<u>Anchor Group</u>

A number of anchors of approximately equal effective embedment depth with each anchor spaced at less than $3h_{ef}$ from one or more adjacent anchors when subjected to tension……….. Only those anchors susceptible to the particular failure mode under investigation shall be included in the group.

KD.1 – Definitions

Anchor Group

h_{ef} = 300 mm

Spacing in X-direction = 200 mm < 3×300 mm ....OK

Spacing in Y-direction = 150 mm < 3×300 mm ....OK

The current bolt formation acts as a group in tension.

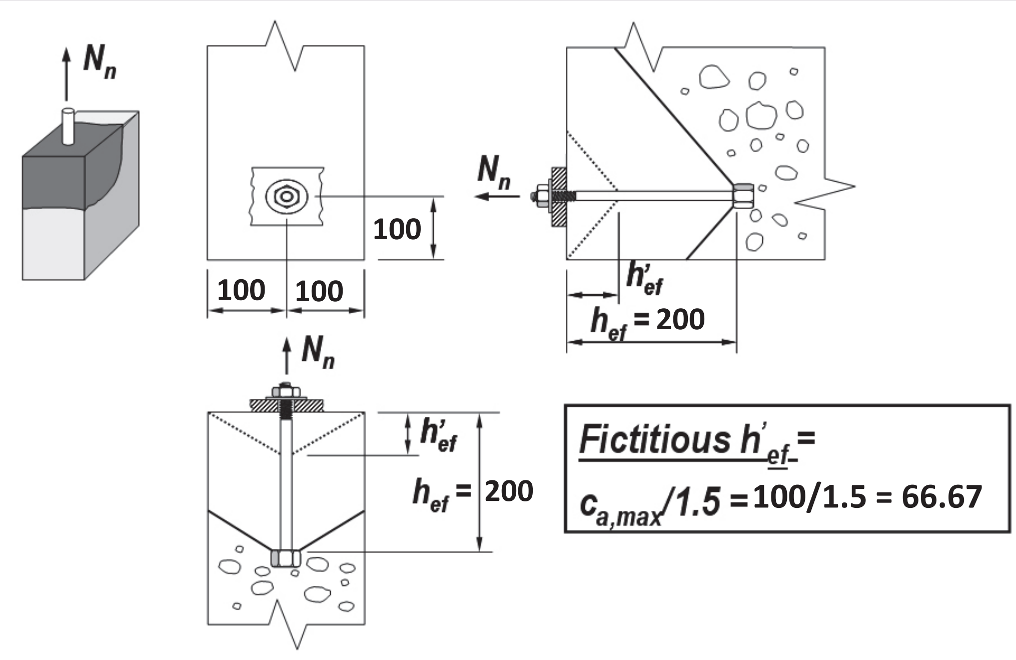
KD.5.2.3 – Anchor Close to 3 or 4 Edges

Where 3 or more edge distances < 1.5h_{ef} → Use h_{ef} in Eq.(D-4) through (D-11) equal to the larger of:

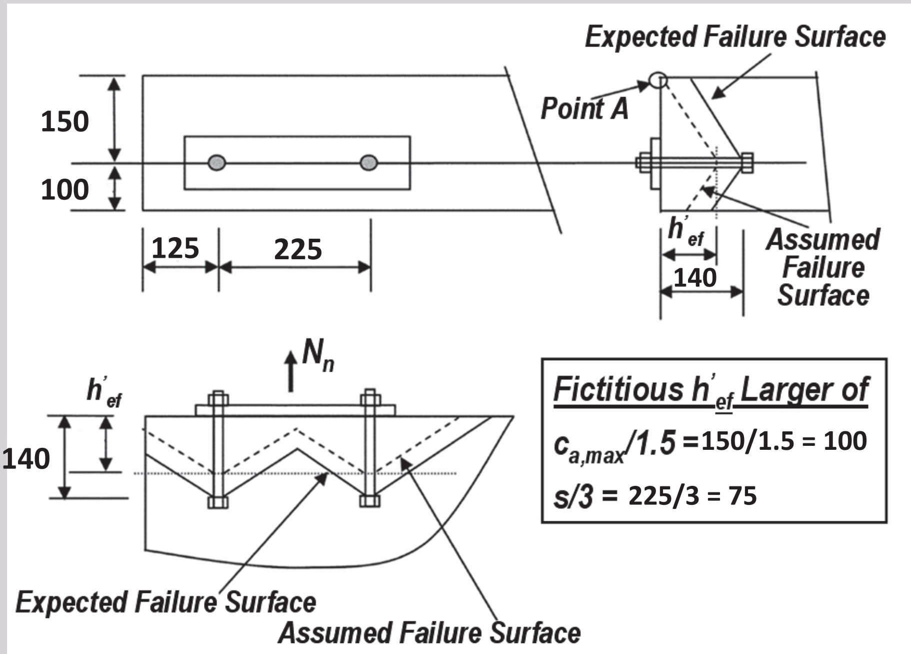
- $c_{a,max}$/1.5, and
- (1/3) maximum spacing between anchors

where $c_{a,max}$ = largest of the influencing edge distances that are less than 3h_{ef}

KD.5.2.3 – Anchor Close to 3 or 4 Edges



KD.5.2.3 – Anchor Close to 3 or 4 Edges



KD.5.2.3 – Anchor Close to 3 or 4 Edges

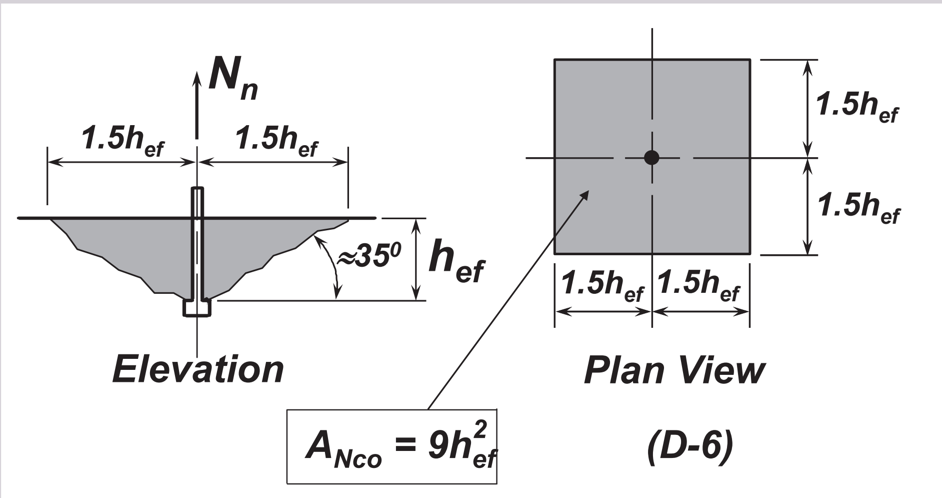
In the example problem, number of edge distances that are less than 1.5h_{ef} = 2

h_{ef} need not be modified

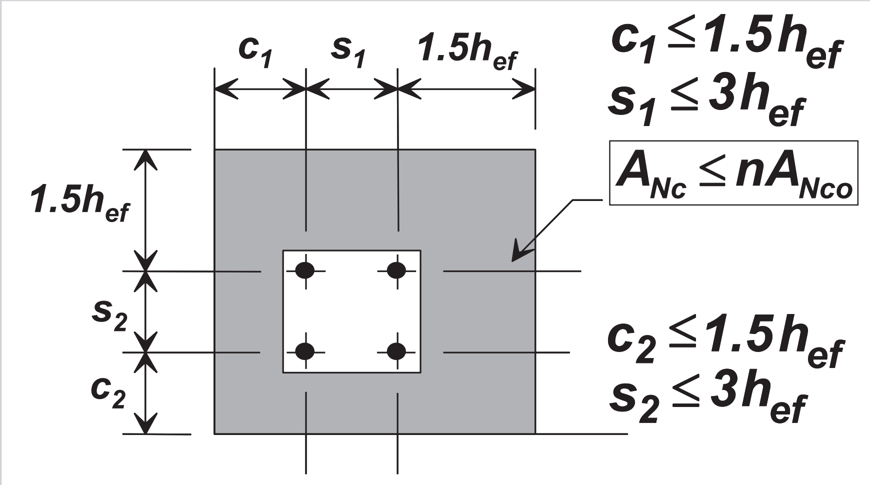
h_{ef} = 300 mm

KD.5.2.1 – Projected Area A_{Nco}

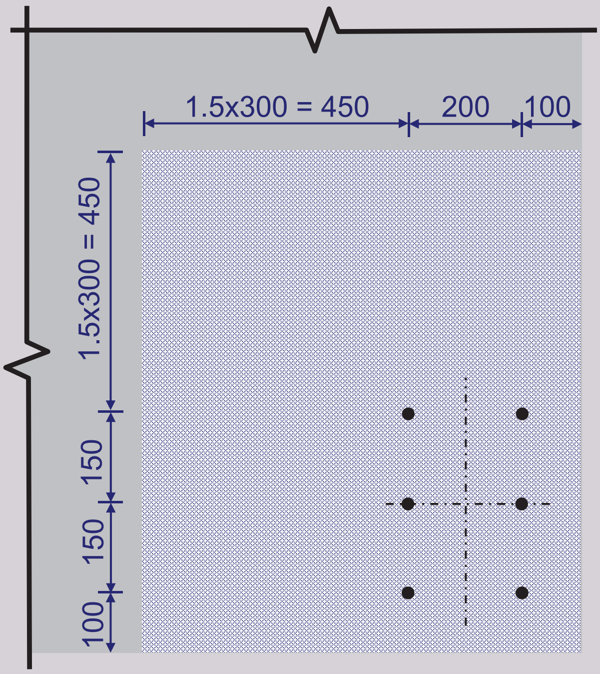
A_{Nco} = 9 × 300² = 810,000 mm²



KD.5.2.1 – Projected Area A_{NC}



KD.5.2.1 – Projected Area A_{NC}



A_{Nc} = [450+200+100] × [100+2x150+450]
= 637,500 mm^2

$A_{Nc} < nA_{Nco}$
(= 6 × 810,000)
................OK

KD.5.2.2 – Basic Concrete Breakout

Single anchor in tension in cracked concrete

$$N_b = k_c \lambda \sqrt{f'_c} h_{ef}^{1.5}$$

.........(D-7)(6.K.7)

- k_c = 10 for cast-in-place anchors

KD.5.2.2 – Basic Concrete Breakout

Alternatively, for cast-in headed studs/bolts with:

280 mm $\leq h_{ef} \leq$ 635 mm

$$N_b = 3.9 \lambda \sqrt{f'_c} h_{ef}^{5/3}$$

...........(D-8)(6.K.8)

KD.5.2.2 – Basic Concrete Breakout

$$N_b = 10 \times 1.0\sqrt{40}\;\; 300^{1.5}/1000$$
$$= 328.6 \text{ kN}$$

For cast-in headed bolts with 280 mm $\leq h_{ef} \leq$ 635 mm

$$N_b = 3.9\lambda\sqrt{f'_c}\,h_{ef}^{5/3} = 338 \text{ kN}$$

$\underline{N_b = 338 \text{ kN}}$

KD.5.2.4 – Eccentricity Effect

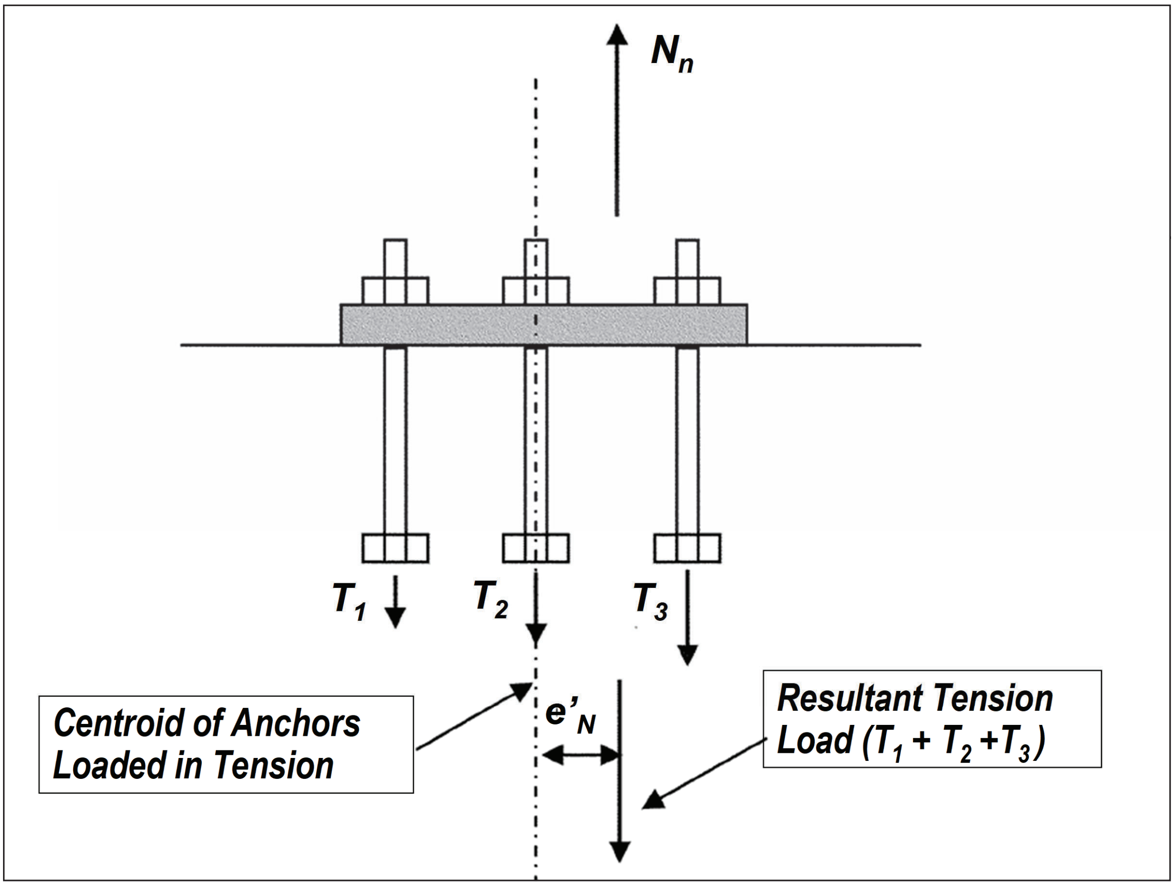
For anchor groups

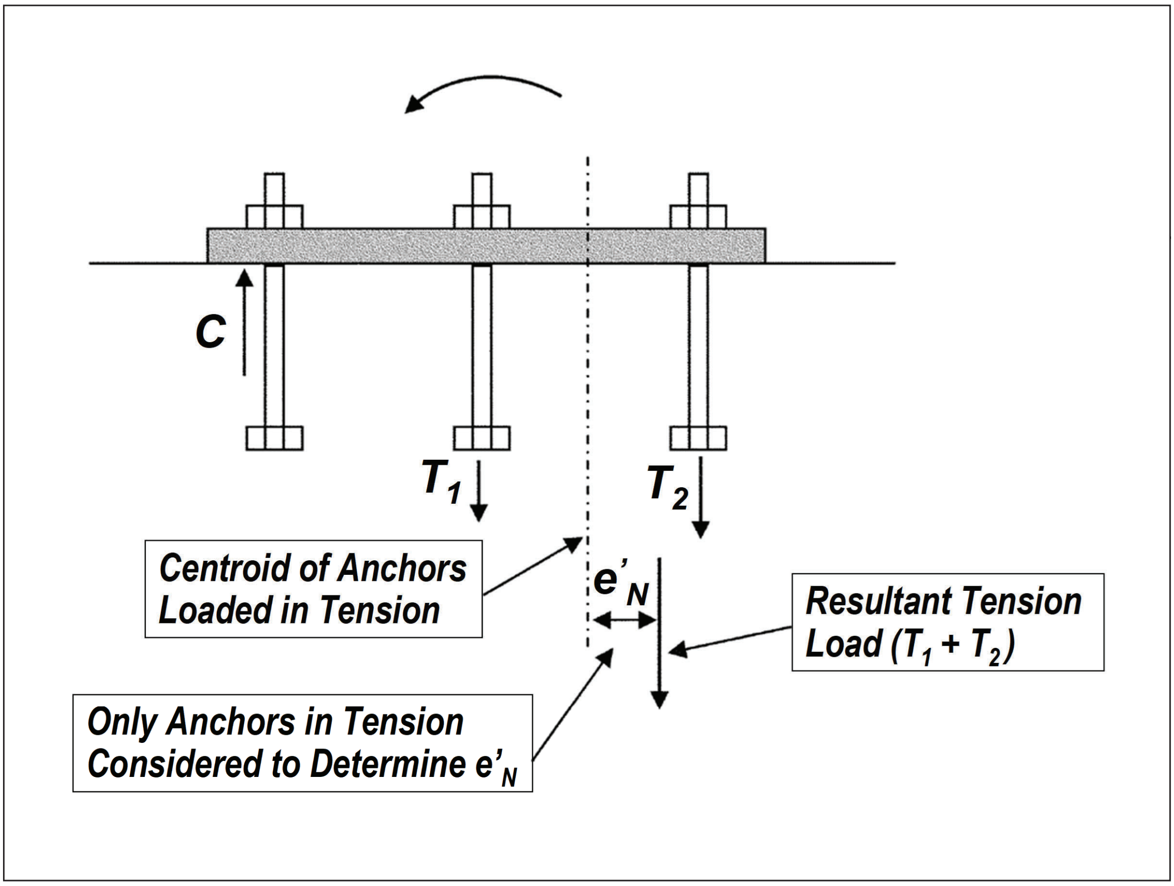
$$\psi_{ec,N} = \frac{1}{\left(1 + \frac{2e'_N}{3h_{ef}}\right)} \leq 1.0 \quad \text{.......... (D-9)}$$

where $e'_N \leq s/2$

Biaxial eccentricity?

→ $\psi_{ec,N} = \psi_{ec,Nx}\ \psi_{ec,Ny}$


N_n
T_1
T_2
T_3
Centroid of Anchors Loaded in Tension
e'_N
Resultant Tension Load ($T_1 + T_2 + T_3$)


C
T_1
T_2
Centroid of Anchors Loaded in Tension
e'_N
Resultant Tension Load ($T_1 + T_2$)
Only Anchors in Tension Considered to Determine e'_N

KD.5.2.4 – Eccentricity Effect

In the example problem:

h_{ef} =300 mm, e'_{Nx} = 25 mm, e'_{Ny} = 25 mm

$\psi_{ec,Nx}$ = 1 / [1 + 2x25/3x300] = 0.95 ≤ 1….OK

$\psi_{ec,Ny}$ = 1 / [1 + 2x25/3x300] = 0.95 ≤ 1….OK

$\psi_{ec,N} = \psi_{ec,Nx}\, \psi_{ec,Ny} = 0.90$

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KD.5.2.5 – Edge Effect

– If $c_{a,\min} \geq 1.5h_{ef}$

$\psi_{ed,N} = 1.0$ ………………… (D-10)

– If $c_{a,\min} < 1.5h_{ef}$

$\psi_{ed,N} = 0.7 + 0.3\dfrac{c_{a,\min}}{1.5h_{ef}}$ ………. (D-11)

$c_{a,min}$ = Minimum edge distance

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KD.5.2.5 – Edge Effect

In the example problem:

h_{ef} =300 mm, $c_{a,min}$ = 100 mm ≤ 1.5h_{ef}

$\psi_{ed,N}$ = 0.7 + 0.3x100/(1.5x300) = 0.77

KD.5.2.6 – Cracking Effect

For uncracked concrete ($f_t < f_r$ at service load)

Cast-in-place anchors $\psi_{c,N}$ = 1.25

For cracked concrete ($f_t \geq f_r$ at service load)

Cast-in-place anchors $\psi_{c,N}$ = 1.0

KD.5.2.6 – Cracking Effect

In the example problem:

Concrete is cracked at service load

$$\psi_{c,N} = 1.0$$

Provide crack control reinforcement per 10.6.4 6.3.6.4

KD.5.2.7 – Post-installed Anchors in Uncracked Concrete without Supplementary Reinforcement

In the example problem:

Anchors are cast-in place

$$\psi_{cp,N} = 1.0$$

KD.5.2.1 – Concrete Breakout Strength of Anchor Group (Tension)

In the example problem:

$$N_{cbg} = \frac{A_{Nc}}{A_{Nco}} \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b \quad \ldots\text{(D-5)(6.K.5)}$$

$$N_{cbg} = \frac{637{,}500}{810{,}000}\, 0.90 \times 0.77 \times 1.0 \times 1.0 \times 338$$

= 184.35 kN

KD.5.2.1 – Concrete Breakout Strength of Anchor Group (Tension)

Strength reduction factor, ϕ:

Condition A – Applies to concrete breakout and side-face blowout when supplementary reinforcement is present …….KD.4.4(c)

Condition B – Applies when supplementary reinforcement is not present OR to anchor pullout …….KD.4.4(c)

KD.1 – Definition

Supplementary reinforcement — Reinforcement that acts to restrain the potential concrete breakout but is not designed to transfer the full design load from the anchors into the structural member.

RD.1 – Supplementary Reinforcement

Supplementary reinforcement…… is not specifically designed to transfer loads from the anchors into the structural member. Stirrups, as used for shear reinforcement, may fall into this category.

KD.5.2.1 – Concrete Breakout Strength of Anchor Group (Tension)

Strength reduction factor, ϕ:

ϕ = 0.75 for cast-in headed bolts
(assuming Condition A) ....D.4.4(c)

For SDC C or above, a factor of 0.75 is applied D.3.3.3

$0.75\phi = 0.75 \times 0.75 = 0.56$

KD.5.2.1 – Concrete Breakout Strength of Anchor Group (Tension)

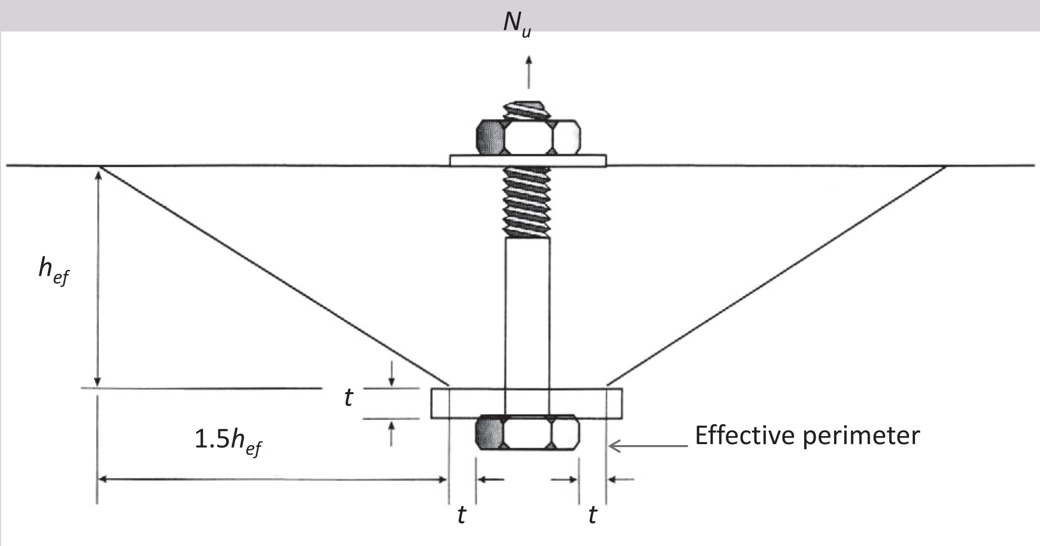
Design strength of the bolt group for concrete breakout in tension:

$$0.75\phi N_{cbg} = 0.56 \times 184.35 = 103.24 \text{ kN}$$

KD.5.2.8 Effect of Plate Washer

Where an additional plate or washer is added at the head of the anchor, it shall be permitted to calculate the projected area of the failure surface by projecting the failure surface outward from the effective perimeter of the plate or washer. The effective perimeter shall not exceed the value at a section projected outward more than the thickness of the washer or plate from the outer edge of the head of the anchor.

KD.5.2.8 Effect of Plate Washer



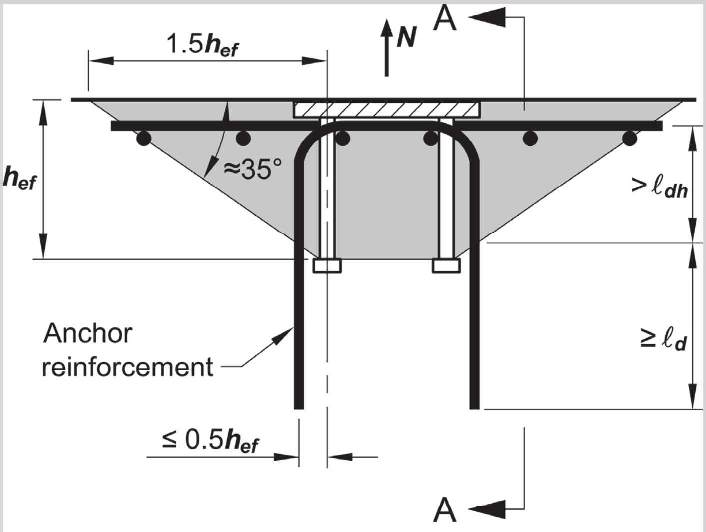
KD.5.2.9 Anchor Reinforcement for Tension

Where anchor reinforcement is developed in accordance with Chapter 12 Section 8.3 on both sides of the breakout surface, the design strength of the anchor reinforcement shall be permitted to be used instead of the concrete breakout strength in determining ϕN_n. A strength reduction factor of 0.75 shall be used in the design of the anchor reinforcement.

KD.1 Definition

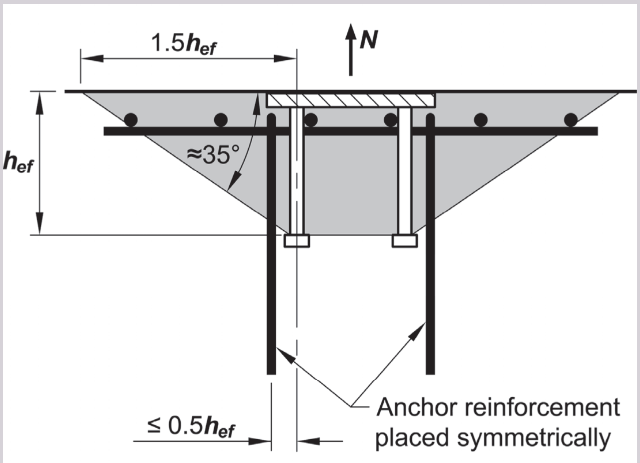
Anchor reinforcement — Reinforcement used to transfer the full design load from the anchors into the structural member. See KD.5.2.9 or KD.6.2.9.

KD.5.2.9 Anchor Reinforcement for Tension



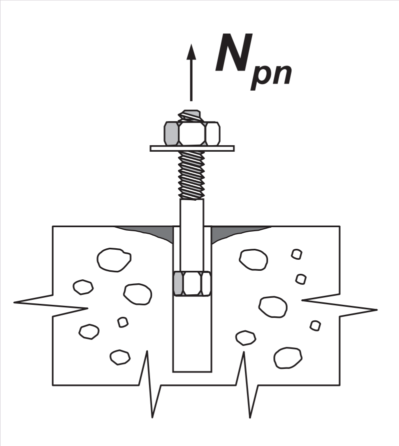
Elevation

KD.5.2.9 Anchor Reinforcement for Tension



Section A-A

KD.5.3 – Pullout Strength



KD.5.3 – Pullout Strength

$N_{pn} = \psi_{c,P} N_P$ ....(D-14)(6.K.14)

- Headed Stud/Bolt

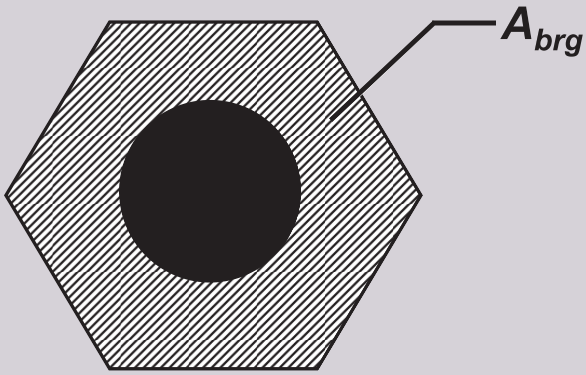
$N_P = 8A_{brg} f_c'$ ....(D-15)(6.K.15)

- J-Bolt or L-Bolt

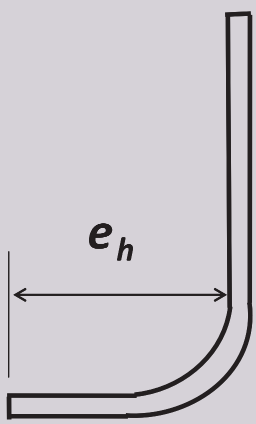
$N_P = 0.9 f_c' e_h d_a$ ....(D-16)(6.K.16)

where $3d_a \le e_h \le 4.5d_a$

Breaking Area



Distance e_h for L- and J-Bolts



KD.5.3.6 – Pullout Strength

For uncracked concrete ($f_t < f_r$ at service load)

$$\psi_{c,P} = 1.4$$

For cracked concrete

$$\psi_{c,P} = 1.0$$

KD.5.3.6 – Pullout Strength

In the example problem:

Anchors used – 12 mm cast-in headed bolts with Hex head

→ $A_{brg} = 187.74 \text{ mm}^2$

$N_P = 8 \times 187.74 \times 40 / 1000 = 60$ kN

For concrete cracked under service load, $\psi_{c,P} = 1.0$

$N_{pn} = 1.0 \times 60$
$= 60$ kN

This is the pullout strength of one anchor

KD.5.3.6 – Pullout Strength

Strength reduction factor, ϕ:

ϕ = 0.70 for cast-in headed studs (Condition B applies for pullout failure) .... KD.4.4(c)

For SDC C or above, a factor of 0.75 is applied KD.3.3.3

$$0.75\phi = 0.75 \times 0.70 = 0.53$$

KD.5.3.6 – Pullout Strength

Design strength of a single bolt for pullout in tension:

$$0.75\phi N_{pn} = 0.53 \times 60 = 31.8 \text{ kN}$$

KD.5.3.6 – Pullout Strength

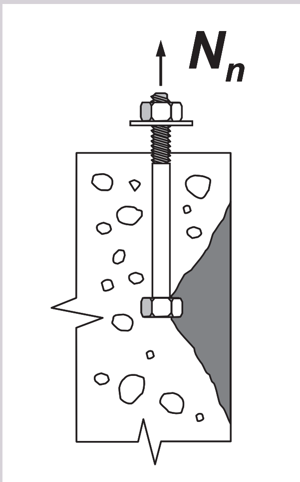
Equating with the maximum demand on a single bolt:

$N_{ua}/4$ = 31.8 kN

Thus max. N_{ua} = 127.2 kN = 0.75ϕN_{png} for the group of bolts

This is the maximum tension demand that the whole bolt formation can support for pullout failure in tension

KD.5.4 – Side-face Blowout



KD.1 – Definitions

Side-Face Blowout Strength

The strength of anchors with deep embedment but thin side cover corresponding to concrete spalling on the side face around the embedded head while no major breakout occurs near the top concrete surface.

KD.5.4.1 – Side-face Blowout

ACI 318-08 RD.5.4.2: In determining nominal side-face blowout strength for multiple headed anchors, only those anchors close to an edge ($h_{ef} > 2.5c_{a1}$) that are loaded in tension should be considered. Their strength should be compared to the proportion of the tensile load applied to those anchors.

KD.5.4.1 – Side-face Blowout

Single headed anchor with deep embedment, close to edge ($c_{a1} < 0.4h_{ef}$)

$$N_{sb} = \left(13c_{a1}\sqrt{A_{brg}}\right)\lambda\sqrt{f'_c} \quad \text{.......(D-17)(6.K.17)}$$

If perpendicular edge distance $c_{a2} < 3c_{a1}$, modify N_{sb} by:

$$(1 + c_{a2} / c_{a1}) / 4$$

where $1.0 \leq c_{a2} / c_{a1} \leq 3.0$

KD.5.4.2 – Side-face Blowout

- For multiple headed anchors with deep embedment, close to edge ($c_{a1} < 0.4h_{ef}$) and anchor spacing less than $6c_{a1}$

$$N_{sbg} = \left(1 + \frac{s}{6c_{a1}}\right)N_{sb} \quad \text{.........(D-18)(6.K.18)}$$

where

s = spacing of outer anchors along edge

N_{sb} is from Eq. (D-17) (6.K.17) without modification for perpendicular edge distance

KD.5.4.2 – Side-face Blowout

In the example problem:

Anchors used - Headed bolts

Minimum edge distance in X-direction = 100 mm < $h_{ef}/2.5$ (= 120 mm)

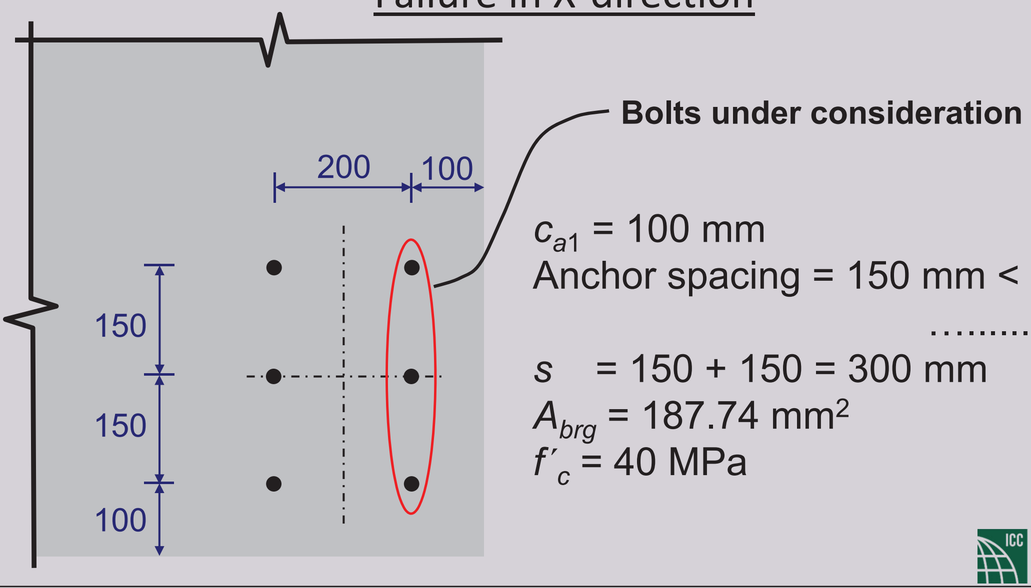
Minimum edge distance in Y-direction = 100 mm < $h_{ef}/2.5$ (= 120 mm)

Side-face blowout possible in both X- and Y-directions.

N_{sbg} needs to be calculated in both directions and the smaller strength would govern.

KD.5.4.2 – Side-face Blowout

Failure in X-direction



c_{a1} = 100 mm
Anchor spacing = 150 mm < $6c_{a1}$ ....OK

s = 150 + 150 = 300 mm
A_{brg} = 187.74 mm^2
f'_c = 40 MPa

KD.5.4.2 – Side-face Blowout

Failure in X-direction

$$N_{sbg} = \left(1 + \frac{s}{6c_{a1}}\right)\left(13c_{a1}\sqrt{A_{brg}}\right)\lambda\sqrt{f'_c}$$

$$= \left(1 + \frac{300}{6 \times 100}\right)\left(13 \times 100\sqrt{187.74}\right) \times 1.0 \times \sqrt{40}$$

= 168,983/1000 = 169 kN

KD.5.4.2 – Side-face Blowout

Strength reduction factor, ϕ:

ϕ = 0.75 for cast-in headed bolts

(assuming Condition A) ……. KD.4.4(c)

For SDC C or above, a factor of 0.75 is applied ……..KD.3.3.3

$0.75\phi = 0.75 \times 0.75 = 0.56$

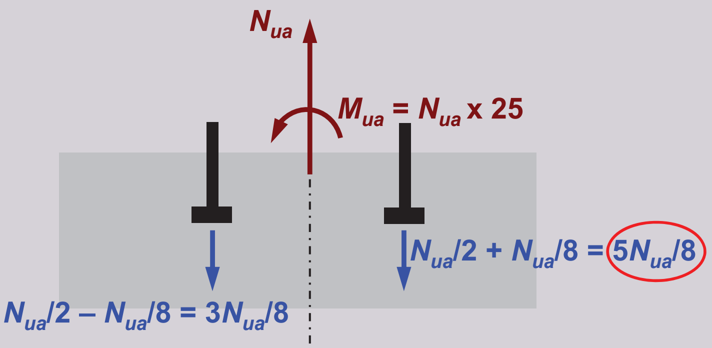
KD.5.4.2 – Side-face Blowout

Design strength of the bolt group in side-face blowout under tension:

$$0.75\phi N_{sbg} = 0.56 \text{ x } 169 = 94.64 \text{ kN}$$

KD.5.4.2 – Side-face Blowout

Failure in X-direction



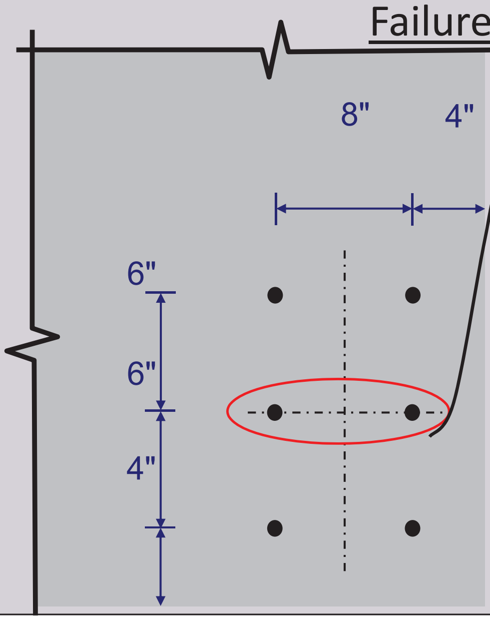
Proportion of tension demand carried by considered column of bolts = 5/8

The maximum tension demand that the whole bolt formation can support in side-face blowout

= 94.64x8/5 = 151.42 kN

KD.5.4.2 – Side-face Blowout

Failure in Y-direction



c_{a1} = 100 mm
Anchor spacing = 200 mm < $6c_{a1}$ ....OK

s = 200 mm
A_{brg} = 187.74 mm^2
f'_c = 40 MPa

KD.5.4.2 – Side-face Blowout

Failure in Y-direction

$$N_{sbg} = \left(1 + \frac{s}{6c_{a1}}\right)\left(13c_{a1}\sqrt{A_{brg}}\right)\lambda\sqrt{f'_c}$$

$$= \left(1 + \frac{200}{6 \times 100}\right)\left(13 \times 100\sqrt{187.74}\right) \times 1.0 \times \sqrt{40}$$

= 150,207/1000 = 150.21 kN

KD.5.4.2 – Side-face Blowout

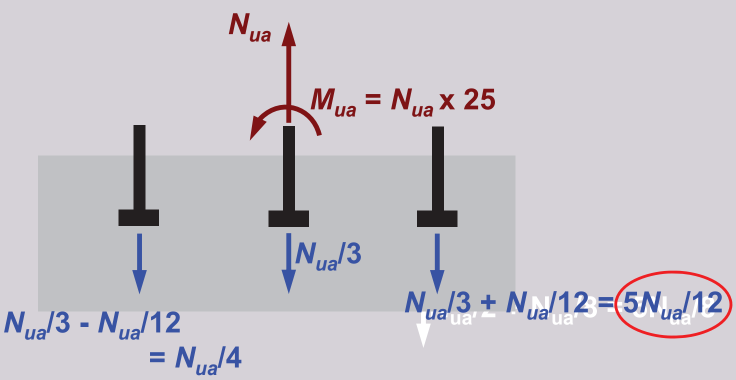
Failure in Y-direction

Design strength of the bolt group in side-face blowout under tension:

$$0.75\phi N_{sbg} = 0.56 \times 150.21 = 84.12 \text{ kN}$$

KD.5.4.2 – Side-face Blowout

Failure in Y-direction



Proportion of tension demand carried by considered row of bolts = 5/12

The maximum tension demand that the whole bolt formation can support in side-face blowout

= 84.12x12/5 = 202 kN

KD.5.4.2 – Side-face Blowout

Governing side-face blowout strength of the whole bolt formation is the smaller of those computed by considering failure in X-direction (151.42 kN) and in Y-direction (202 kN)

= 151.42 kN

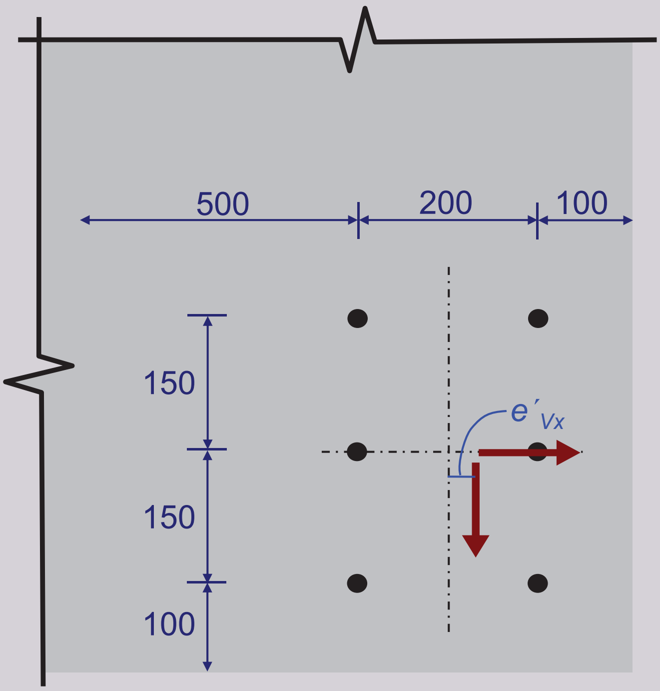
KD.5 – Design for Tensile Loading

- KD.5.1 – Steel Strength = 95.24 kN
- KD.5.2 – Concrete Breakout Strength = 103.24 kN
- KD.5.3 – Pullout Strength = 127.20 kN
- KD.5.4 – Concrete Side-Face Blowout Strength = 151.42 kN

- Group strength in tension = 95.24 kN, governed by steel strength
- Suitable for application in buildings assigned to SDC C or higher

KD.6 – Design for Shear Loading

- KD.6.1 – Steel Strength
- KD.6.2 – Concrete Breakout Strength
- KD.6.3 – Concrete Pryout Strength

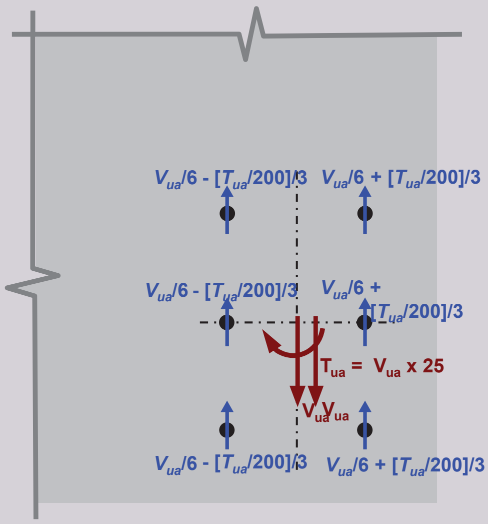


e'_{Vx} = 25 mm

e'_{Vy} = 0

Shear Failure

Check for possible reversal in direction of shear in anchor group due to load eccentricity e'_{Vx} :



Shear Failure

Check for possible reversal in direction of shear in anchor group due to load eccentricity e'_{Vx} :

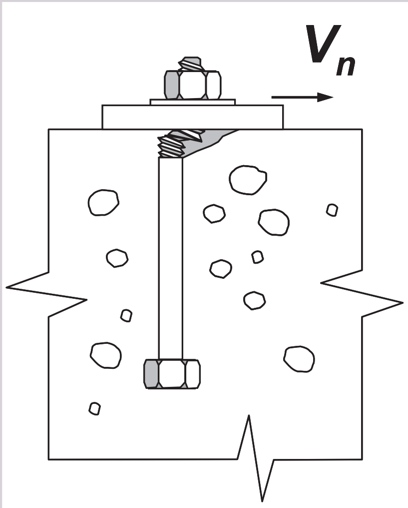
Maximum shear = $V_{ua}/6 + V_{ua}/24$

$= 5V_{ua}/24$

Minimum shear = $V_{ua}/6 - V_{ua}/24$

$= V_{ua}/8$ ……..No shear reversal

KD.6.1 – Steel Failure (Shear)



KD.6.1.2 – Steel Strength (Shear)

(a) Cast-in headed stud anchors

$$V_{sa} = nA_{se,V}f_{uta} \quad \text{..................(D-19)(6.K.19)}$$

(b) Cast-in-place headed and hooked bolts

$$V_{sa} = n0.6A_{se,V}f_{uta} \quad \text{...............(D-20)(6.K.20)}$$

- With built-up grout pads, use $0.8V_{sa}$ in both cases

KD.6.1.2 – Steel Strength (Shear)

where $f_{uta} \leq 1.9 f_{ya}$

≤ 860 MPa

$A_{se,V}$ can be calculated as

$$A_{se,V} = \frac{\pi}{4}\left(d_a - \frac{0.9743}{n_t}\right)^2$$

where n_t is the number of threads per mm

KD.6.1.2 – Steel Strength (Shear)

In the example problem, cast-in headed bolts are used

Calculating for one bolt:

$A_{se,V}$ = 79.35 mm^2 [n_t = 0.5]

f_{uta} = 400 MPa < 1.9f_{ya} (= 475 MPa)…………OK

< 860 MPa…………………OK

V_{sa} = 0.6 x 79.35 x 400/1000 = 19.0 kN

KD.6.1.2 – Steel Strength (Shear)

Strength reduction factor, ϕ:

ϕ = 0.65 for ductile steel elements under shear
…….KD.4.4(a)

KD.6.1.2 – Steel Strength (Shear)

Design strength of a single bolt for steel failure in shear:

ϕV_{sa}= 0.65 x 19.0 = 12.35 kN

KD.6.1.2 – Steel Strength (Shear)

Shear in Y-direction

Equating with the maximum demand on a single bolt:

$5V_{ua}/24 = 12.35$ kN

Thus max. $V_{ua} = \phi V_{sa} = 59.28$ kN for the group of bolts

This is the maximum shear demand that the whole bolt formation can support for steel failure in shear in Y-direction

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KD.6.1.2 – Steel Strength (Shear)

Shear in X-direction

Equating with the maximum demand on a single bolt:

$V_{ua}/6 = 12.35$ kN

Thus max. $V_{ua} = \phi V_{sa} = 74.10$ kN for the group of bolts

This is the maximum shear demand that the whole bolt formation can support for steel failure in shear in X-direction

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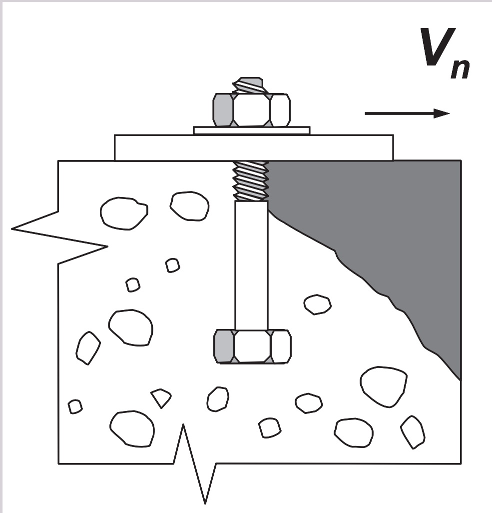
KD.6.2 – Concrete breakout (Shear)



KD.6.2.1(a) – Concrete Breakout Strength of Single Anchor (Shear)

$$V_{cb} = \frac{A_{Vc}}{A_{Vco}} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b \quad \text{.........(D-21)(6.K.1)}$$

- V_b: Basic single anchor strength
- $\psi_{h,V}$: Accounts for small concrete depth
- $\psi_{c,V}$: Accounts for cracking
- $\psi_{ed,V}$: Accounts for edge effects
- $\frac{A_{Vc}}{A_{Vco}}$: Accounts for projected area of failure surface

KD.6.2.1(b) – Concrete Breakout Strength of Anchor Group (Shear)

$$V_{cbg} = \frac{A_{Vc}}{A_{Vco}} \psi_{ec,V} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b \quad \text{...(D-22)(6.K.22)}$$

- V_b: Basic single anchor strength
- $\psi_{h,V}$: Accounts for small concrete depth
- $\psi_{c,V}$: Accounts for cracking
- $\psi_{ed,V}$: Accounts for edge effects
- $\psi_{ec,V}$: Accounts for eccentricity
- $\frac{A_{Vc}}{A_{Vco}}$: Accounts for projected area of failure surface

Section KD.1 - Definitions

Anchor Group

A number of anchors of approximately equal effective embedment depth with each anchor spaced at less than........ $3c_{a1}$ from one or more adjacent anchors when subjected to shear. Only those anchors susceptible to the particular failure mode under investigation shall be included in the group.

Section KD.1 - Definitions

Anchor Group

In the example problem:

In X-direction, c_{a1} = 100 mm

Row spacing = 150 mm < 3 x 100 mm ....OK

In Y-direction, c_{a1} = 100 mm

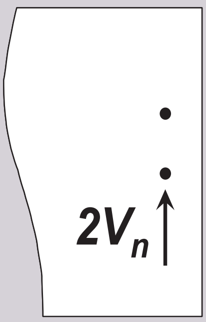
Column spacing = 200 mm < 3 x 100 mm ....OK

The example bolt formation acts as a group for shear acting in X- and in Y- directions.

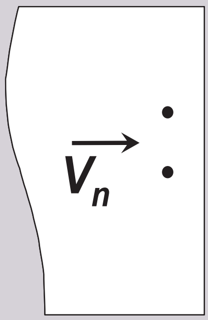
KD.6.2.1 (c) - (d) Shear Parallel to Edge

- Compute shear strength perpendicular to edge, V_n
- Based on testing, shear strength parallel to edge = $2V_n$ (where V_n is shear strength perpendicular to edge).

Actual



Compute



KD.6.2.1 (c)~(d) Shear Parallel to Edge

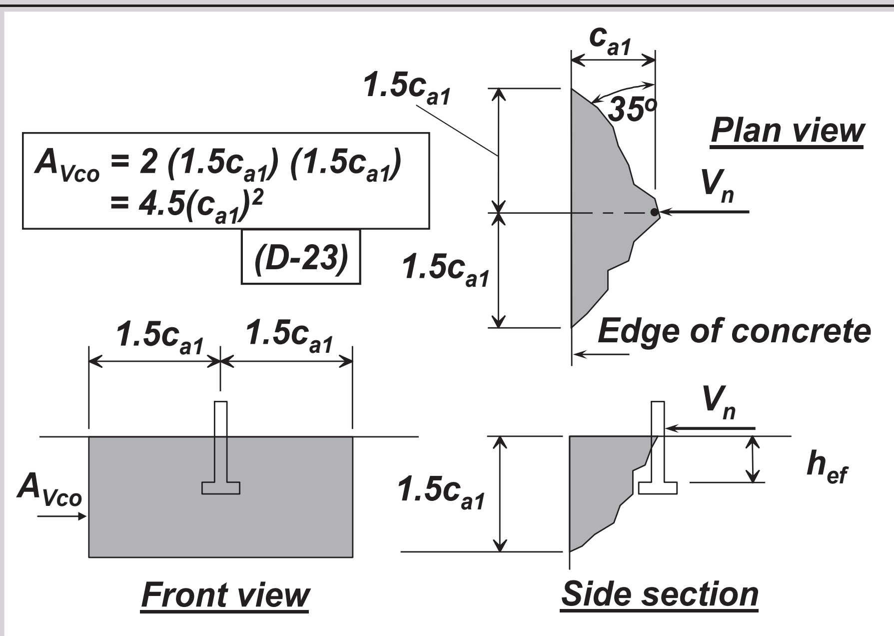
For shear force parallel to edge ($\psi_{ed,V} = 1$)

- V_{cb} = 2 [V_{cb} per Eq. (D-21)(6.K.21)]
- V_{cbg} = 2 [V_{cbg} per Eq. (D-22)(6.K.22)]

At corner, use smaller of:

- Strength perpendicular to edge
- Strength parallel to edge

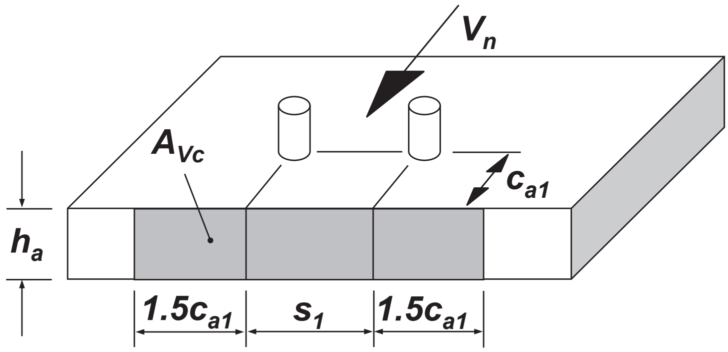
Projected Area of Concrete Breakout



Projected Area of Concrete Breakout

If $h_a < 1.5c_{a1}$ *and* $s_1 < 3c_{a1}$

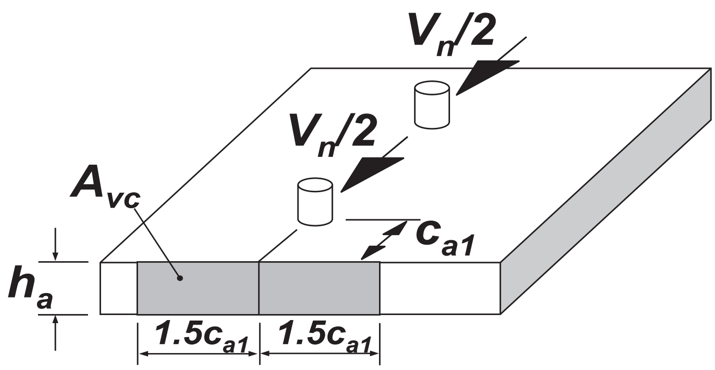
$$A_{Vc} = (2 \times 1.5c_{a1} + s_1)h_a$$



Projected Area of Concrete Breakout

If $h_a < 1.5c_{a1}$

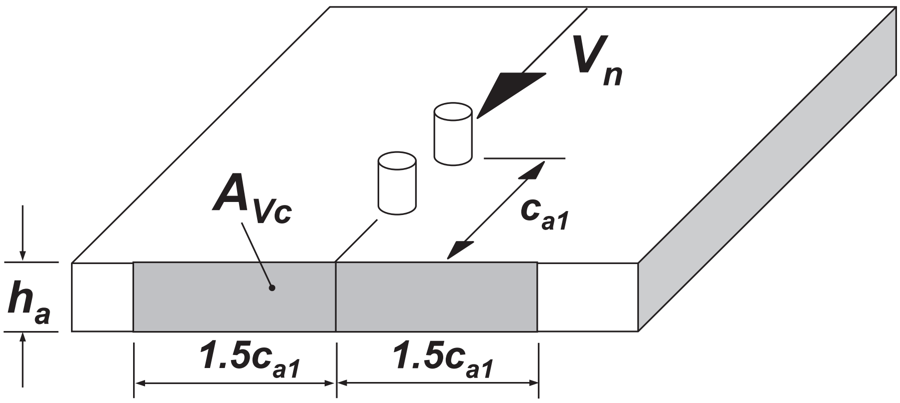
$$A_{Vc} = (2 \times 1.5c_{a1}) \times h_a$$



Projected Area of Concrete Breakout

If $h_a < 1.5c_{a1}$

$$A_{Vc} = (2 \times 1.5c_{a1})h_a$$



KD.6.2.2 – Basic Conc. Breakout (Shear)

- Single anchor in shear in cracked concrete

$$V_b = 0.6\left(\frac{\ell_e}{d_a}\right)^{0.2}\sqrt{d_a}\,\lambda\sqrt{f'_c}\,(c_{a1})^{1.5} \quad \text{...(D-24)(6.K.24)}$$

- $\ell_e = h_{ef}$ for anchors with constant stiffness
- $\ell_e \leq 8d_a$

KD.6.2.3 – Basic Conc. Breakout (Shear)

- Anchors rigidly welded to attachment, and
- minimum attachment thickness not less than
  a. 10 mm, and
  b. $d_a/2$
- For group of anchors welded to attachment, strength based on c_{a1} for row farthest from edge, and
- Center-to-center anchor spacing ≥ 65 mm, and
- If $c_{a2} \leq 1.5h_{ef}$, supplementary reinforcement is provided at corners

KD.6.2.3 – Basic Conc. Breakout (Shear)

When all conditions are satisfied, the basic concrete breakout strength is:

$$V_b = 0.66\left(\frac{\ell_e}{d_a}\right)^{0.2}\sqrt{d_a}\,\lambda\sqrt{f_c'}\,(c_{a1})^{1.5} \quad \ldots\text{(D-25)(6.K.25)}$$

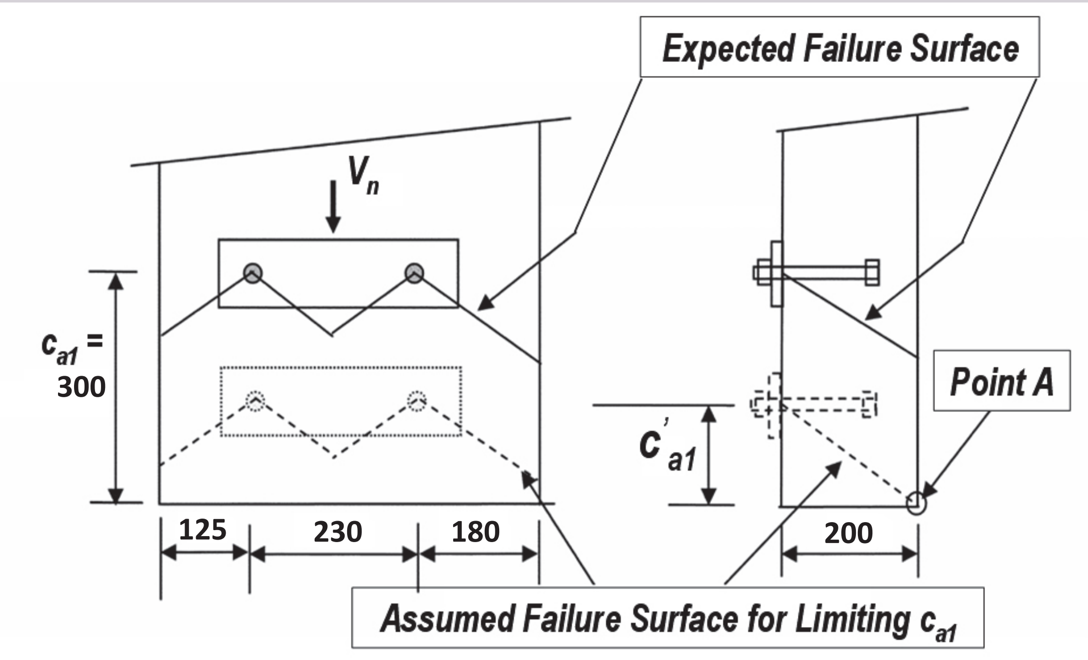
ℓ_e as defined in D.6.2.2

KD.6.2.4 – Anchors Close to 3 or 4 Edges

Where 3 or more edge distances ≤ $1.5c_{a1}$ → effective c_{a1} used in Eq.(D-23) (6.K.23) through (D-28) (6.K.28) not to exceed the largest of:

- c_{a2}/1.5 [in either direction]
- h_a/1.5
- (1/3) maximum spacing between anchors

KD.6.2.4 – Anchors Close to 3 or 4 Edges



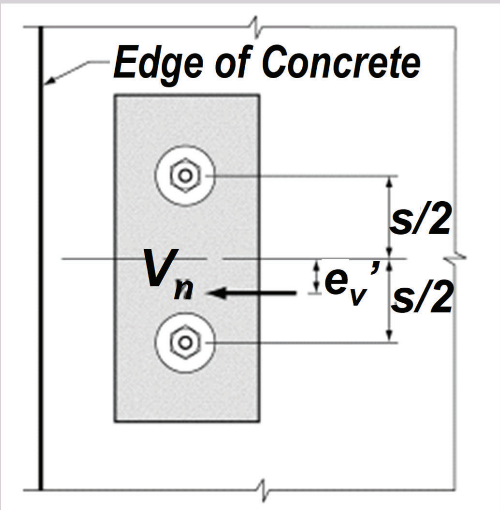
KD.6.2.5 – Eccentricity Effect

- For group of anchors

$$\psi_{ec,V} = \frac{1}{\left[1 + \frac{2e_V'}{3c_{a1}}\right]} \quad \text{..........(D-26)(6.K.26)}$$

Consider only anchors resisting shear in direction of load

KD.6.2.5 – Eccentricity Effect



KD.6.2.6 – Edge Effect

- If $c_{a2} \geq 1.5\ c_{a1}$

  $\psi_{ed,V} = 1.0$ ……………..(D-27)(6.K.27)

- If $c_{a2} < 1.5c_{a1}$

  $$\psi_{ed,V} = 0.7 + 0.3\frac{c_{a2}}{1.5c_{a1}}$$ …(D-28)(6.K.28)

KD.6.2.7 – Cracking Effect

For uncracked concrete ($f_t < f_r$) at service load

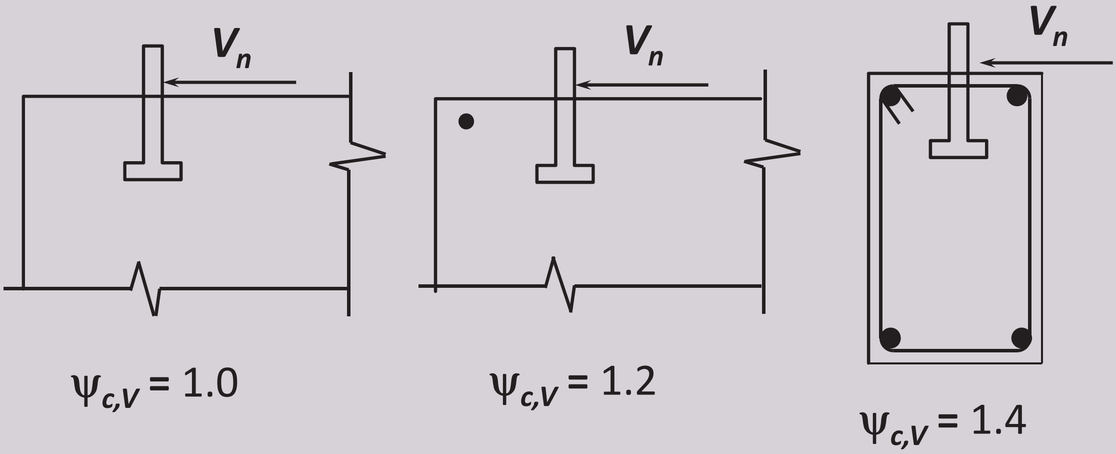
$\psi_{c,V} = 1.4$

For cracked concrete

- $\psi_{c,V} = 1.0$ No reinforcement* or < No. 13 bar
- $\psi_{c,V} = 1.2$ With reinforcement.* $\geq$ No. 13 bar
- $\psi_{c,V} = 1.4$ With reinforcement.* $\geq$ No. 13 bar (enclosed within stirrups w/spacing $\leq$100 mm)

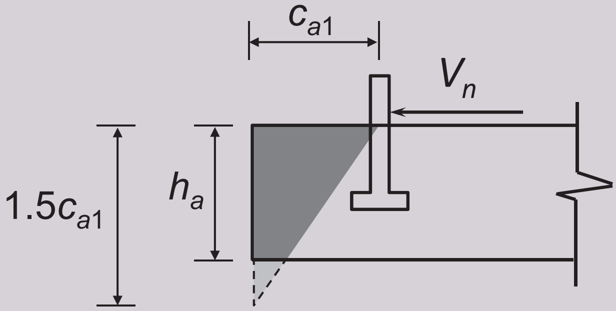
* Edge or supplementary reinforcement

KD.6.2.7 – Cracking Effect

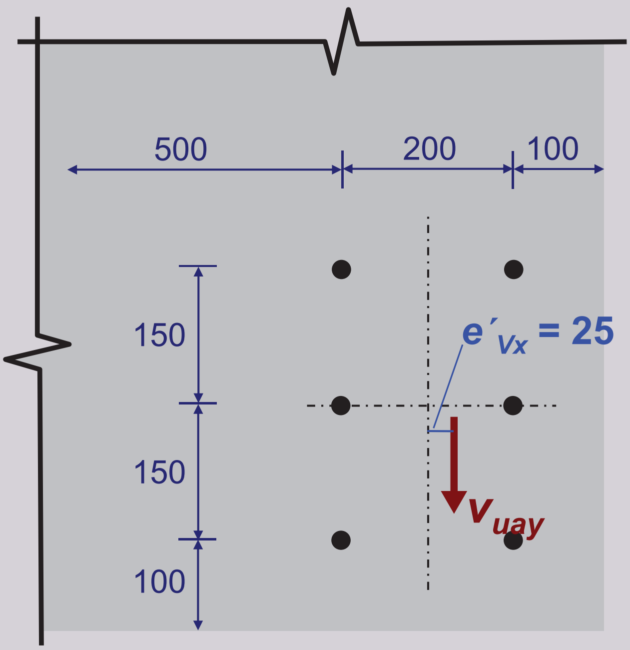


KD.6.2.8 – Concrete Depth Effect

$$\psi_{h,V} = \sqrt{\frac{1.5c_{a1}}{h_a}} \quad \text{for } h_a < 1.5c_{a1}$$

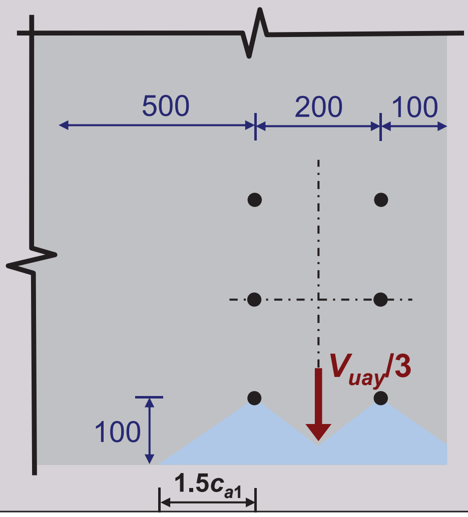


Shear in Y-Direction



Shear in Y-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge



c_{a1} = 100 mm

h_a = 460 mm > 1.5c_{a1} …….OK

$c_{a2,right}$ = 100 mm < 1.5c_{a1}

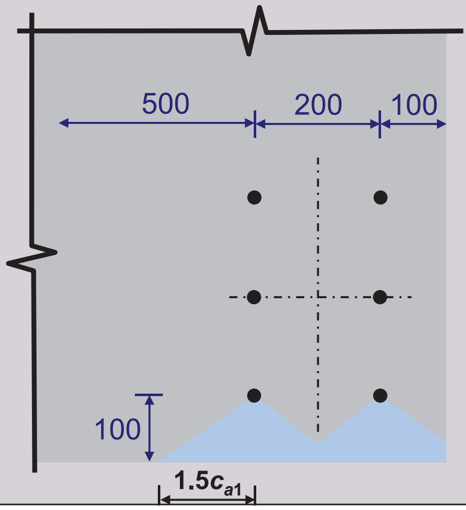
$c_{a2,left}$ = 500 mm > 1.5c_{a1} ……OK

Only one edge distance < 1.5c_{a1}

c_{a1} need not be revised

Shear in Y-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge



A_{Vc} = [1.5c_{a1} + 200 + 100][Min(h_a, 1.5c_{a1})]
= [1.5x100 + 200 + 100][1.5x100]
= 67,500 mm^2

A_{Vco} = 4.5c_{a1}^2 = 4.5x100^2 = 45,000 mm^2

Number of bolts involved, n = 2

$A_{Vc} < nA_{Vco}$

A_{Vc}/A_{Vco} = 1.5 ……………OK

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Shear in Y-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

<u>Basic concrete breakout strength</u>

$$V_b = 0.6\left(\frac{\ell_e}{d_a}\right)^{0.2}\sqrt{d_a}\lambda\sqrt{f_c'}(c_{a1})^{1.5}$$

ℓ_e = h$_{ef}$ = 300 mm > 8d$_a$ = 96 mm ➞ ℓ_e = 96 mm

$$V_b = 0.6\left(\frac{96}{12}\right)^{0.2}\sqrt{12}\times 1.0\times\sqrt{40}(100)^{1.5}$$

= 19,925 / 1000 = 20 kN

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Shear in Y-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Eccentricity factor

$$\psi_{ec,V} = \frac{1}{\left[1 + \frac{2e_V'}{3c_{a1}}\right]} = \frac{1}{\left[1 + \frac{2 \times 25}{3 \times 100}\right]} = 0.86$$

Shear in Y-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Edge factor

$c_{a2,\ right}$ = 100 mm < 1.5c_{a1} (= 150 mm)

$$\psi_{ed,V} = 0.7 + 0.3\frac{c_{a2}}{1.5c_{a1}}$$

$$= 0.7 + 0.3\frac{100}{1.5 \times 100}$$

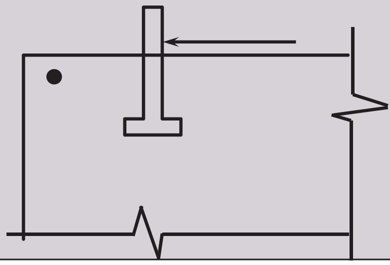
= 0.90

Shear in Y-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Cracking factor

Concrete is cracked at service load. It is assumed that supplementary reinforcement comprising of No. 13 bars is present between the anchors and the edges. No stirrup is used to enclose the reinforcement.



→ $\psi_{c,V} = 1.2$

Shear in Y-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Concrete depth factor

h_a = 460 mm > 1.5c_{a1} (= 150 mm)

$\psi_{h,V} = 1.0$

Shear in Y-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

$$V_{cbg} = \frac{A_{Vc}}{A_{Vco}} \psi_{ec,V} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b$$ …(D-22) (6.K.22)

$$V_{cbg} = \frac{67{,}500}{45{,}000} \, 0.86 \times 0.90 \times 1.2 \times 1.0 \times 20$$

= 27.86 kN

Shear in Y-Direction

Strength reduction factor, ϕ:

Condition A – Applies to concrete breakout when supplementary reinforcement is present
…….KD.4.4(c)

Condition B – Applies when supplementary reinforcement is not present OR to anchor pryout
…….KD.4.4(c)

Shear in Y-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Strength reduction factor, ϕ

ϕ = 0.75 for Condition A…….KD.4.4(c)

For SDC C or above, a factor of 0.75 is applied ……..KD.3.3.3

$0.75\phi = 0.75 \times 0.75 = 0.56$

Shear in Y-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Design strength of the first row for concrete breakout in shear:

$$0.75\phi V_{cbg} = 0.56 \times 27.86 = 15.60 \text{ kN}$$

This needs to be compared against the fraction of the total shear demand causing this failure

Shear in Y-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

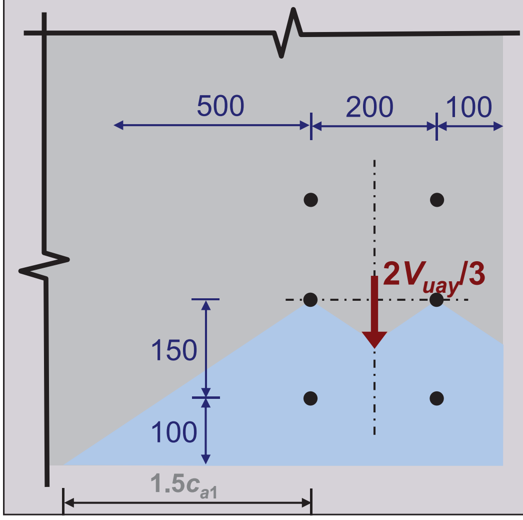
$V_{uay}/3$ = 15.60 kN

V_{uay} = 46.80 kN = $0.75\phi V_{cbg}$ for the whole group

This is the total shear demand that the whole group can support before Mode 1 failure takes place

Shear in Y-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd row from the edge



c_{a1} = 100 + 150 = 250 mm

h_a = 460 mm > $1.5c_{a1}$ …….OK

$c_{a2,right}$ = 100 mm < $1.5c_{a1}$

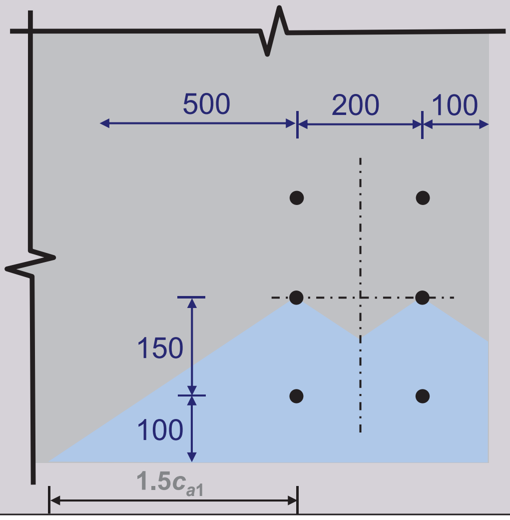
$c_{a2,left}$ = 500 mm > $1.5c_{a1}$ ……OK

Only one edge distance < $1.5c_{a1}$

c_{a1} need not be revised

Shear in Y-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd row from the edge



A_{Vc} = [1.5c_{a1} + 200 + 100][Min(h_a, 1.5c_{a1})]

= [1.5x250 + 200 + 100][1.5x250]

= 253,125 mm^2

$A_{Vco} = 4.5c_{a1}^2$ = 4.5x250^2 = 281,250 mm^2

Number of bolts involved, n = 2

$A_{Vc} < nA_{Vco}$

A_{Vc}/A_{Vco} = 0.9 ....OK

Shear in Y-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd row from the edge

Basic concrete breakout strength

$$V_b = 0.6\left(\frac{\ell_e}{d_a}\right)^{0.2}\sqrt{d_a}\lambda\sqrt{f'_c}(c_{a1})^{1.5}$$

$\ell_e = h_{ef}$ = 300 mm > $8d_a$ = 96 mm ➡ ℓ_e = 96 mm

$$V_b = 0.6\left(\frac{96}{12}\right)^{0.2}\sqrt{12}\times 1.0\times\sqrt{40}(250)^{1.5}$$

= 78,759 / 1000 = 78.76 kN

Shear in Y-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd row from the edge

Eccentricity factor

$$\psi_{ec,V} = \frac{1}{\left[1+\frac{2e_V'}{3c_{a1}}\right]} = \frac{1}{\left[1+\frac{2\times 25}{3\times 250}\right]} = 0.94$$

Shear in Y-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd row from the edge

Edge factor

$c_{a2,\ right}$ = 100 mm < 1.5c_{a1} (= 375 mm)

$$\psi_{ed,V} = 0.7 + 0.3\frac{c_{a2}}{1.5c_{a1}}$$

$$= 0.7 + 0.3\frac{100}{1.5\times 250}$$

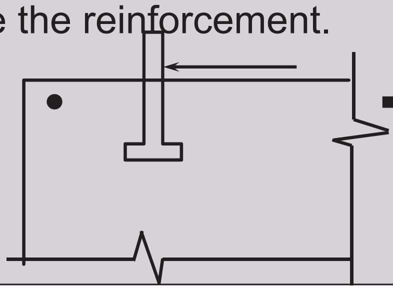
= 0.78

Shear in Y-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd row from the edge

Cracking factor

Concrete is cracked at service load. It is assumed that supplementary reinforcement comprising of No. 13 bars is present between the anchors and the edges. No stirrup is used to enclose the reinforcement.



→ $\psi_{c,V}$ = 1.2

Shear in Y-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd row from the edge

Concrete depth factor

h_a = 460 mm > 1.5c_{a1} (= 375 mm)

$\psi_{h,V}$ = 1.0

Shear in Y-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd row from the edge

$$V_{cbg} = \frac{A_{Vc}}{A_{Vco}} \psi_{ec,V} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b \quad \ldots\text{(D-22)(6.K.22)}$$

$$V_{cbg} = \frac{253{,}125}{281{,}250}\, 0.94 \text{ x } 0.78 \text{ x } 1.2 \text{ x } 1.0 \text{ x } 78.76$$

= 62.37 kN

Shear in Y-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd row from the edge

Strength reduction factor, ϕ

ϕ = 0.75 for Condition A
…….KD.4.4(c)

For SDC C or above, a factor of 0.75 is applied
……..KD.3.3.3

0.75ϕ = 0.75 x 0.75 = 0.56

Shear in Y-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd row from the edge

Design strength of the 2nd row for concrete breakout in shear:

$0.75\phi V_{cbg} = 0.56 \times 62.37 = 34.93$ kN

This needs to be compared against the fraction of the total shear demand causing this failure

Shear in Y-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd row from the edge

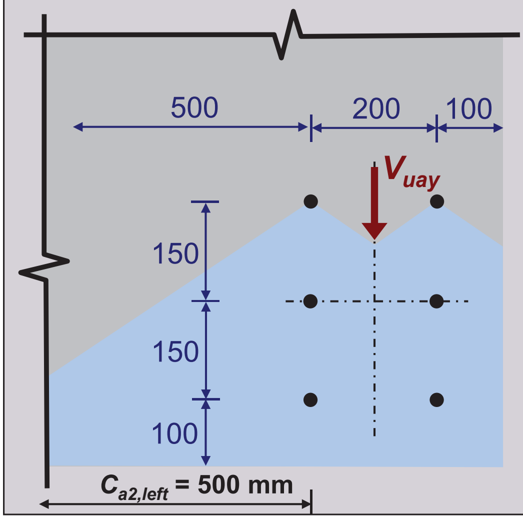
$2V_{uay}/3 = 34.93$ kN

$V_{uay} = 52.40$ kN $= 0.75\phi V_{cbg}$ for the whole group

This is the total shear demand that the whole group can support before Mode 2 failure takes place

Shear in Y-Direction

Failure Mode 3: Concrete breakout occurs from the anchors in the 3rd row from the edge



c_{a1} = 100 + 2x150 = 400 mm

h_a = 460 mm < 1.5c_{a1}

$c_{a2,right}$ = 100 mm < 1.5c_{a1}

$c_{a2,left}$ = 500 mm < 1.5c_{a1}

3 edge distances < 1.5c_{a1}

c_{a1} needs to be revised

Shear in Y-Direction

Failure Mode 3: Concrete breakout occurs from the anchors in the 3rd row from the edge

Revised c_{a1} = Greatest of -

$c_{a2,right}$ /1.5 = 100 / 1.5 = 66.67 mm

$c_{a2,left}$ /1.5 = 500 / 1.5 = 333.33 mm

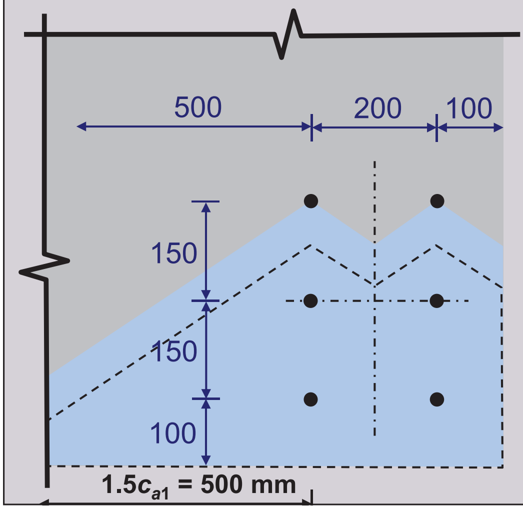
h_a /1.5 = 460 / 1.5 = 306.67 mm

(1/3) spacing between anchors = 200 / 3 = 66.67 mm

c_{a1} = 333.33 mm

Shear in Y-Direction

Failure Mode 3: Concrete breakout occurs from the anchors in the 3rd row from the edge



A_{Vc} = [1.5c_{a1} + 200 + 100][Min(h_a, 1.5c_{a1})]

= [1.5x333.33 + 200 + 100][460]

= 368,000 mm^2

A_{Vco} = 4.5c_{a1}^2 = 4.5x333.33^2 = 500,000 mm^2

Number of bolts involved, n = 2

$A_{Vc} < nA_{Vco}$ ....OK

A_{Vc}/A_{Vco} = 0.736

Shear in Y-Direction

Failure Mode 3: Concrete breakout occurs from the anchors in the 3rd row from the edge

Basic concrete breakout strength

$$V_b = 0.6\left(\frac{\ell_e}{d_a}\right)^{0.2}\sqrt{d_a}\,\lambda\sqrt{f'_c}\,(c_{a1})^{1.5}$$

$\ell_e = h_{ef}$ = 300 mm > 8d_a = 96 mm ➡ ℓ_e = 96 mm

$$V_b = 0.6\left(\frac{96}{12}\right)^{0.2}\sqrt{12}\times 1.0\times\sqrt{40}\,(333.33)^{1.5}$$

= 121256 / 1000 = 121.26 kN

Shear in Y-Direction

Failure Mode 3: Concrete breakout occurs from the anchors in the 3rd row from the edge

Eccentricity factor

$$\psi_{ec,V} = \frac{1}{\left[1+\frac{2e_V^{'}}{3c_{a1}}\right]} = \frac{1}{\left[1+\frac{2\times 25}{3\times 333.33}\right]} = 0.95$$

Shear in Y-Direction

Failure Mode 3: Concrete breakout occurs from the anchors in the 3rd row from the edge

Edge factor

$c_{a2,\ right}$ = 100 mm < $1.5c_{a1}$ (= 500 mm)

$$\psi_{ed,V} = 0.7 + 0.3\frac{c_{a2}}{1.5c_{a1}}$$

$$= 0.7 + 0.3\frac{100}{1.5\times 333.33}$$

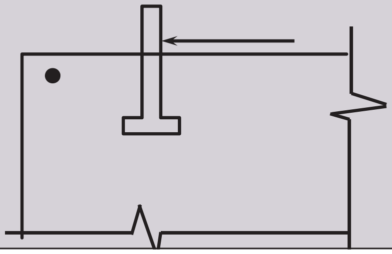
= 0.76

Shear in Y-Direction

Failure Mode 3: Concrete breakout occurs from the anchors in the 3rd row from the edge

Cracking factor

Concrete is cracked at service load. It is assumed that supplementary reinforcement comprising of No. 13 bars is present between the anchors and the edges. No stirrup is used to enclose the reinforcement.



$\rightarrow \psi_{c,V} = 1.2$

Shear in Y-Direction

Failure Mode 3: Concrete breakout occurs from the anchors in the 3rd row from the edge

Concrete depth factor

$h_a = 460 \text{ mm} < 1.5c_{a1}$ (= 500 mm)

$$\psi_{h,V} = \sqrt{\frac{1.5c_{a1}}{h_a}} = \sqrt{\frac{500}{460}} = 1.04$$

Shear in Y-Direction

Failure Mode 3: Concrete breakout occurs from the anchors in the 3rd row from the edge

$$V_{cbg} = \frac{A_{Vc}}{A_{Vco}} \psi_{ec,V} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b \quad \text{...(D-22)(6.K.22)}$$

$$V_{cbg} = \frac{368{,}000}{500{,}000} \; 0.95 \times 0.76 \times 1.2 \times 1.04 \times 121.26$$

= 80.42 kN

Shear in Y-Direction

Failure Mode 3: Concrete breakout occurs from the anchors in the 3rd row from the edge

Strength reduction factor, ϕ

ϕ = 0.75 for Condition A ......D.4.4(c)

For SDC C or above, a factor of 0.75 is applied D.3.3.3

$0.75\phi = 0.75 \times 0.75 = 0.56$

Shear in Y-Direction

Failure Mode 3: Concrete breakout occurs from the anchors in the 3rd row from the edge

Design strength of the 3rd row in concrete breakout in shear:

$$0.75\phi V_{cbg} = 0.56 \times 80.42 = 45.00 \text{ kN}$$

This needs to be compared against the fraction of the total shear demand causing this failure

Shear in Y-Direction

Failure Mode 3: Concrete breakout occurs from the anchors in the 3rd row from the edge

$$V_{uay} \equiv 45.00 \text{ kN } 0.75\phi V_{cbg} \text{ for the whole group}$$

This is the total shear demand that the whole group can support before Mode 3 failure takes place

Shear in Y-Direction

Design concrete breakout strength of the anchor group based on three failure modes:

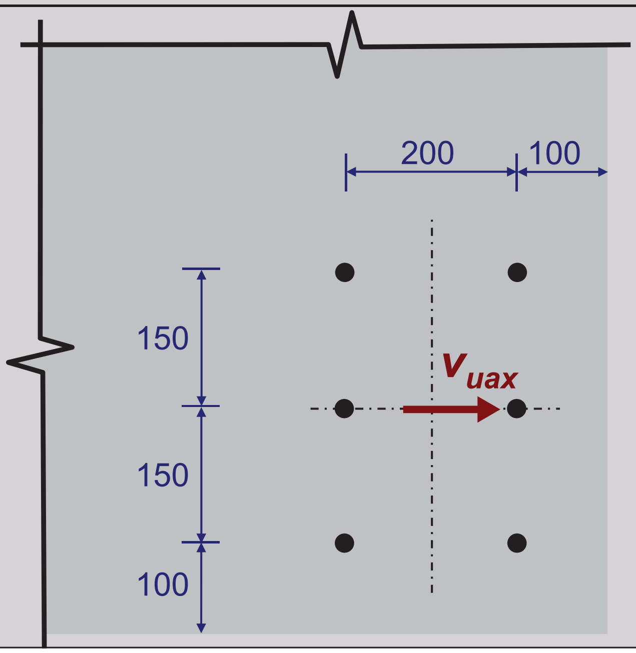
1st Mode: 46.80 kN

2nd Mode: 52.40 kN

3rd Mode: 45.00 kN

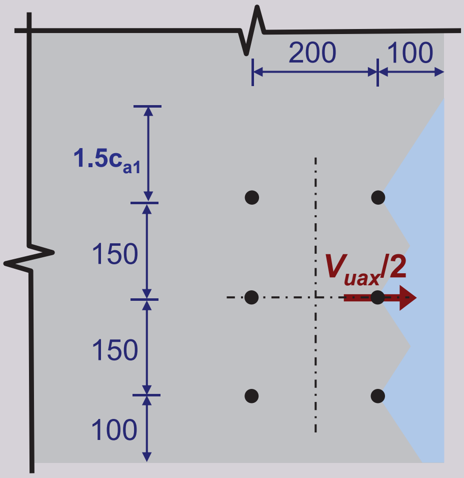
$$0.75\phi V_{cbg,y} = 45.00 \text{ kN}$$

Shear in X-Direction



Shear in X-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge



c_{a1} = 100 mm

h_a = 460 mm > $1.5c_{a1}$ (= 150 mm).....OK

$c_{a2,top}$ > $1.5c_{a1}$ ....OK

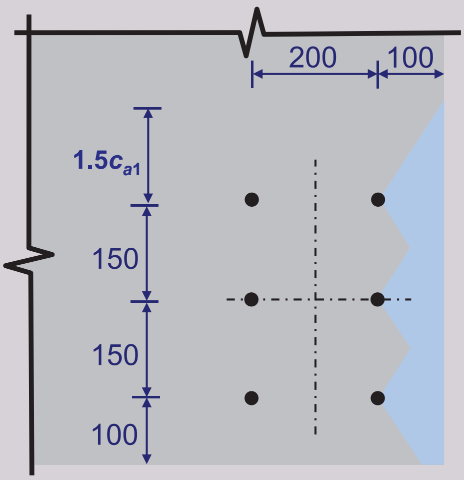
$c_{a2,bottom}$ < $1.5c_{a1}$

Only one edge distance < $1.5c_{a1}$

c_{a1} need not be revised

Shear in X-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge



A_{Vc} = [$1.5c_{a1}$+ 2x150 + 100][Min(h_a, $1.5c_{a1}$)]

= [1.5x100 + 2x150 + 100][1.5x100]

= 82,500 mm^2

$A_{Vco} = 4.5c_{a1}^2$ = 4.5x100^2 = 45,000 mm^2

Number of bolts involved, n = 3

$A_{Vc} < nA_{Vco}$ ....OK

A_{Vc}/A_{Vco} = 1.83

Shear in X-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Basic concrete breakout strength

$$V_b = 0.6\left(\frac{\ell_e}{d_a}\right)^{0.2}\sqrt{d_a}\lambda\sqrt{f_c^{'}}(c_{a1})^{1.5}$$

$\ell_e = h_{ef} = 300$ mm > $8d_a = 96$ mm ➡ $\ell_e = 96$ mm

$$V_b = 0.6\left(\frac{96}{12}\right)^{0.2}\sqrt{12}\times 1.0\times\sqrt{40}(100)^{1.5}$$

= 19925 / 1000 = 20 kN

Shear in X-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Eccentricity factor

$$\psi_{ec,V} = \frac{1}{\left[1+\frac{2e_V^{'}}{3c_{a1}}\right]} = \frac{1}{\left[1+\frac{2\times 0}{3\times 100}\right]} = 1$$

Shear in X-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Edge factor

$c_{a2,\ bottom}$ = 100 mm < $1.5c_{a1}$ (= 150 mm)

$$\psi_{ed,V} = 0.7 + 0.3\frac{c_{a2}}{1.5c_{a1}}$$

$$= 0.7 + 0.3\frac{100}{1.5 \times 100}$$

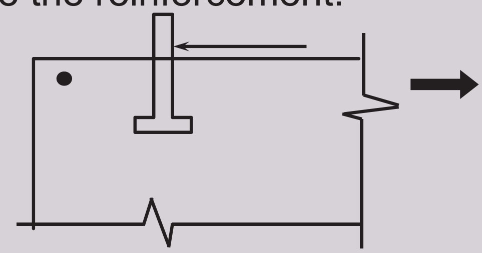
= 0.90

Shear in X-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Cracking factor

Concrete is cracked at service load. It is assumed that supplementary reinforcement comprising of No. 13 bars is present between the anchors and the edges. No stirrup is used to enclose the reinforcement.



$\psi_{c,V}$ = 1.2

Shear in X-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Concrete depth factor

h_a = 460 mm > 1.5c_{a1} (= 150 mm)

$\psi_{h,V}$ = 1.0

Shear in X-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

$$V_{cbg} = \frac{A_{Vc}}{A_{Vco}} \psi_{ec,V} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b \quad \ldots\text{(D-22)(6.K.22)}$$

$$V_{cbg} = \frac{82{,}500}{45{,}000} 1.0 \times 0.90 \times 1.2 \times 1.0 \times 20$$

$$= 39.6 \text{ kN}$$

Shear in X-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Strength reduction factor, ϕ

ϕ = 0.75 for Condition A ....D.4.4(c)

For SDC C or above, a factor of 0.75 is applied D.3.3.3

$0.75\phi = 0.75 \times 0.75 = 0.56$

Shear in X-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

Design strength of the first row in concrete breakout in shear:

$0.75\phi V_{cbg} = 0.56 \times 39.6 = 22.18$ kN

This needs to be compared against the fraction of the total shear demand causing this failure

Shear in X-Direction

Failure Mode 1: Concrete breakout occurs from the anchors closest to the edge

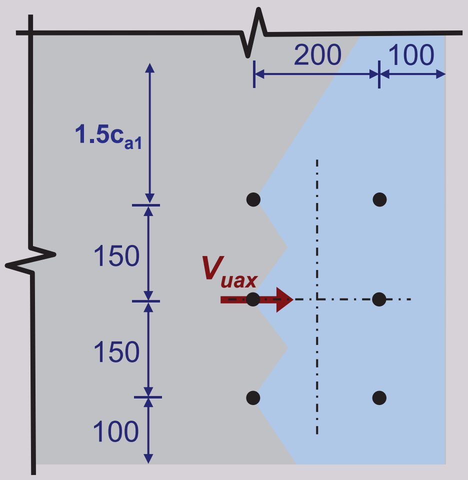
$V_{uax}/2 = 22.18$ kN

$V_{uax} = 44.36$ kN $= 0.75\phi V_{cbg}$ for the whole group

This is the total shear demand that the whole group can support before Mode 1 failure takes place

Shear in X-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd column from the edge



$c_{a1} = 200 + 100 = 300$ mm

$h_a = 460$ mm $> 1.5c_{a1}$ ....OK

$c_{a2,top} > 1.5c_{a1}$ ....OK

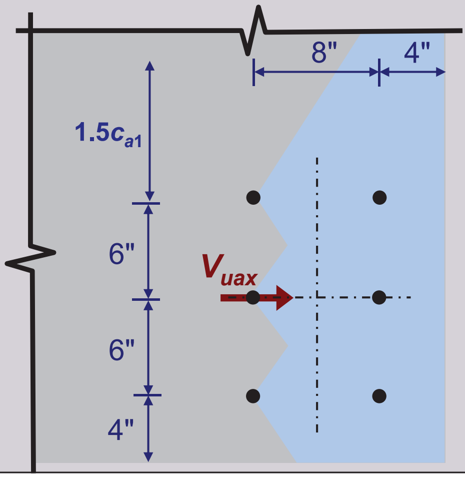
$c_{a2,bottom} < 1.5c_{a1}$

Only one edge distance $< 1.5c_{a1}$

c_{a1} need not be revised

Shear in X-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd column from the edge



A_{Vc} = [1.5c_{a1} + 2x150 + 100][Min(h_a, 1.5c_{a1})]

= [1.5x300 + 2x150 + 100][1.5x300]

= 382,500 mm^2

$A_{Vco} = 4.5c_{a1}^2 = 4.5\text{x}300^2$ = 405,000 mm^2

Number of bolts involved, n = 3

$A_{Vc} < nA_{Vco}$ ....OK

$A_{Vc}/A_{Vco} = 0.94$

Shear in X-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd column from the edge

Basic concrete breakout strength

$$V_b = 0.6\left(\frac{\ell_e}{d_a}\right)^{0.2}\sqrt{d_a}\lambda\sqrt{f'_c}(c_{a1})^{1.5}$$

$\ell_e = h_{ef}$ = 300 mm > $8d_a$ = 96 mm ➡ ℓ_e = 96 mm

$$V_b = 0.6\left(\frac{96}{12}\right)^{0.2}\sqrt{12}\times 1.0\times\sqrt{40}(300)^{1.5}$$

= 103,531 / 1000 = 103.53 kN

Shear in X-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd column from the edge

Eccentricity factor

$$\psi_{ec,V} = \frac{1}{\left[1+\frac{2e_V^{'}}{3c_{a1}}\right]} = \frac{1}{\left[1+\frac{2\times 0}{3\times 300}\right]} = 1$$

Shear in X-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd column from the edge

Edge factor

$c_{a2,\ bottom}$ = 100 < 1.5c_{a1} (= 450 mm)

$$\psi_{ed,V} = 0.7 + 0.3\frac{c_{a2}}{1.5c_{a1}}$$

$$= 0.7 + 0.3\frac{100}{1.5\times 300}$$

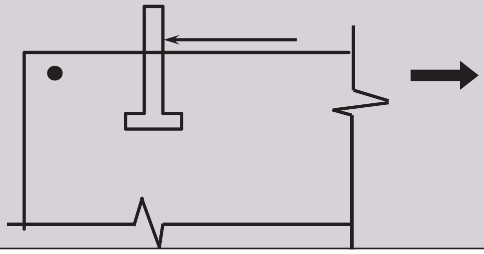
= 0.77

Shear in X-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd column from the edge

Cracking factor

Concrete is cracked at service load. It is assumed that supplementary reinforcement comprising of No. 13 bars is present between the anchors and the edges. No stirrup is used to enclose the reinforcement.



$\psi_{c,V} = 1.2$

Shear in X-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd column from the edge

Concrete depth factor

h_a = 460 mm > $1.5c_{a1}$ (= 450 mm)

$\psi_{h,V} = 1.0$

Shear in X-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd column from the edge

$$V_{cbg} = \frac{A_{Vc}}{A_{Vco}} \psi_{ec,V} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b$$ …(D-22)(6.K.22)

$$V_{cbg} = \frac{382{,}500}{405{,}000} 1.0 \times 0.77 \times 1.2 \times 1.0 \times 103.53$$

= 90.35 kN

Shear in X-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd column from the edge

Strength reduction factor, ϕ

ϕ = 0.75 for Condition A ……. KD.4.4(c)

For SDC C or above, a factor of 0.75 is applied ……..KD.3.3.3

$0.75\phi = 0.75 \times 0.75 = 0.56$

Shear in X-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd column from the edge

Design strength of the first row in concrete breakout in shear:

$$0.75\phi V_{cbg} = 0.56 \times 90.35 = 50.60 \text{ kN}$$

This needs to be compared against the fraction of the total shear demand causing this failure

Shear in X-Direction

Failure Mode 2: Concrete breakout occurs from the anchors in the 2nd column from the edge

$$V_{uax} = 50.60 \text{ kN} = 0.75\phi V_{cbg}$$

This is the total shear demand that the whole group can support before Mode 2 failure takes place

Shear in X-Direction

Design concrete breakout strength of the anchor group based on two failure modes:

1st Mode: 44.36 kN

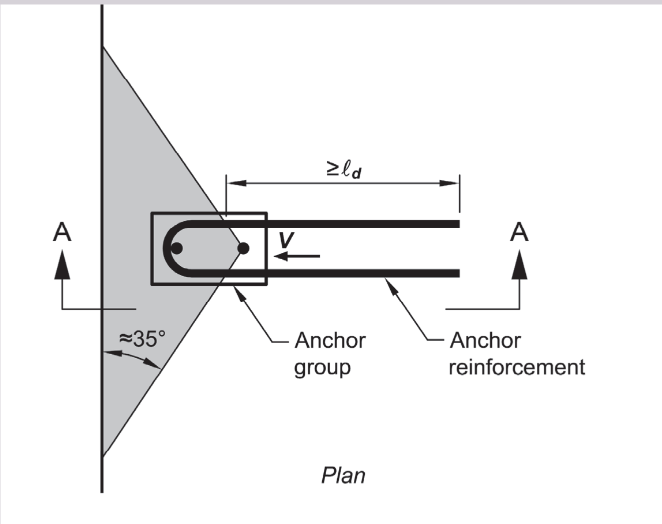
2nd Mode: 50.60 kN

$$0.75\phi V_{cbg,x} = 44.36 \text{ kN}$$

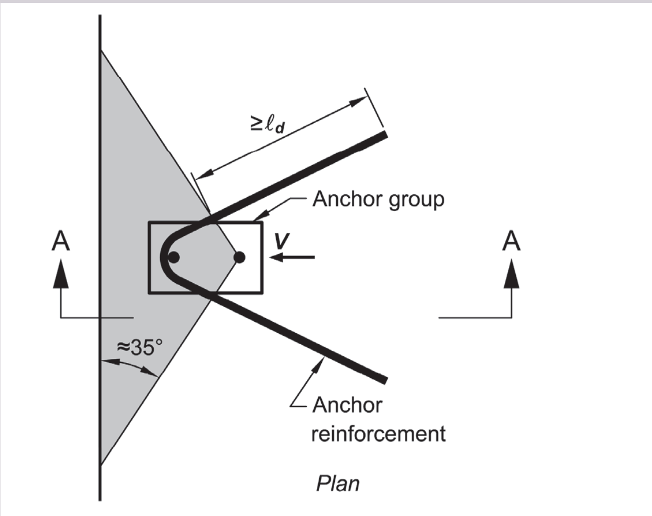
KD.6.2.9 Anchor Reinforcement for Shear

Where anchor reinforcement is either developed in accordance with Chapter 12 Section 8.3 on both sides of the breakout surface, or encloses the anchor and is developed beyond the breakout surface, the design strength of the anchor reinforcement shall be permitted to be used instead of the concrete breakout strength in determining ϕV_n. A strength reduction factor of 0.75 shall be used in the design of the anchor reinforcement.

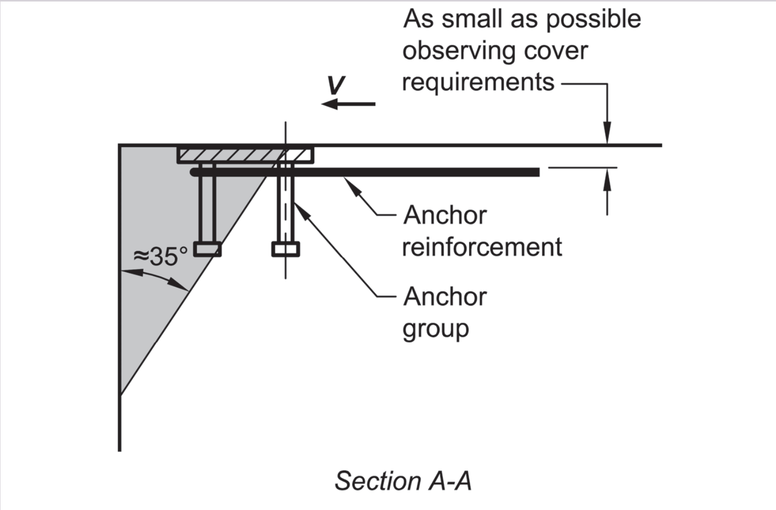
KD.6.2.9 Anchor Reinforcement for Shear



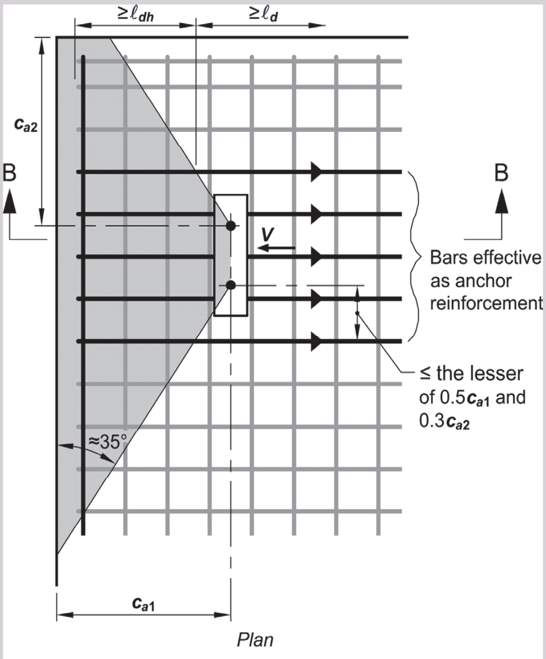
KD.6.2.9 Anchor Reinforcement for Shear



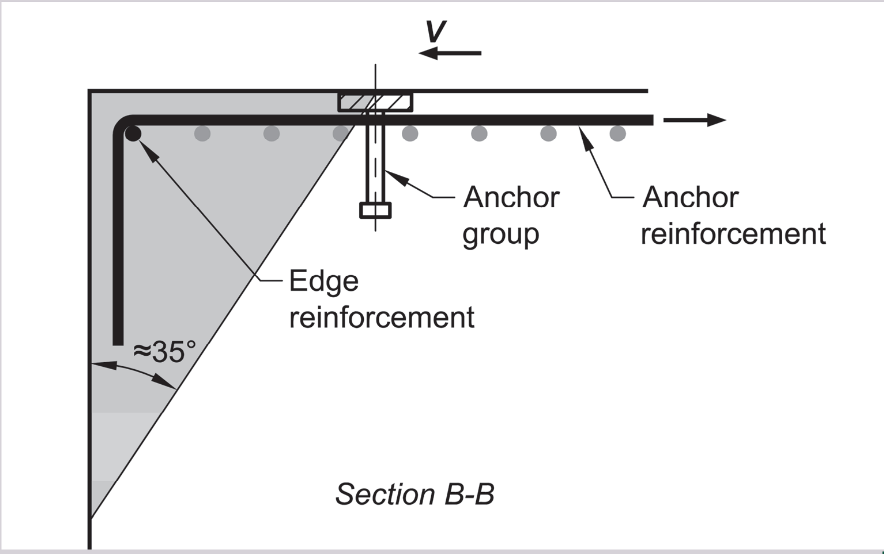
KD.6.2.9 Anchor Reinforcement for Shear



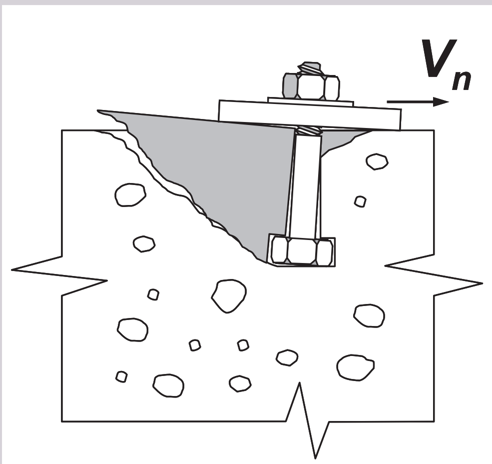
KD.6.2.9 Anchor Reinforcement for Shear



KD.6.2.9 Anchor Reinforcement for Shear



KD.6.3 – Concrete Pryout



KD.1 - Definitions

Concrete Pryout Strength

The strength corresponding to formation of a concrete spall behind a short, stiff anchor with an embedded base that is displaced in the direction opposite to the applied shear force.

KD.6.3 – Concrete Pryout

Single anchor $V_{cp} = k_{cp}N_{cb}$ ……(D-29)(6.K.29)

Group of anchors $V_{cpg} = k_{cp}N_{cbg}$ ….(D-30)(6.K.30)

where

- k_{cp} = 1.0 for h_{ef} < 65 mm
- k_{cp} = 2.0 for $h_{ef} \geq$ 65 mm
- N_{cb} computed from Eq. (D-4)(6.K.4)
- N_{cbg} computed from Eq. (D-5)(6.K.5)

KD.6.3 – Concrete Pryout

In the current problem:

h_{ef} = 300 mm > 65 mm → k_{cp} = 2.0

N_{cbg} = 184.35 kN

V_{cpg} = 2 x 184.35 = 368.7 kN

KD.6.3 – Concrete Pryout

Strength reduction factor, ϕ:

ϕ = 0.70 (Condition B applies for pryout failure)

……. KD.4.4(c)

For SDC C or above, a factor of 0.75 is applied

……..KD.3.3.3

$0.75\phi = 0.75 \times 0.70 = 0.53$

KD.6.3 – Concrete Pryout

Design strength of the anchor group in concrete pryout

$$0.75\phi N_{cpg} = 0.53 \times 368.7 = 195.41 \text{ kN}$$

KD.6 – Design for Shear Loading

KD.6.1 – Steel Strength = 74.10 kN for shear in X-direction

= 59.28 kN for shear in Y-direction

KD.6.2 – Concrete Breakout Strength = 44.36 kN for shear in X-direction

= 45.00 kN for shear in Y-direction

KD.6.3 – Concrete Pryout Strength = 195.41 kN for shear in both directions

Group strength for shear in X-direction = 44.36 kN, governed by concrete breakout strength

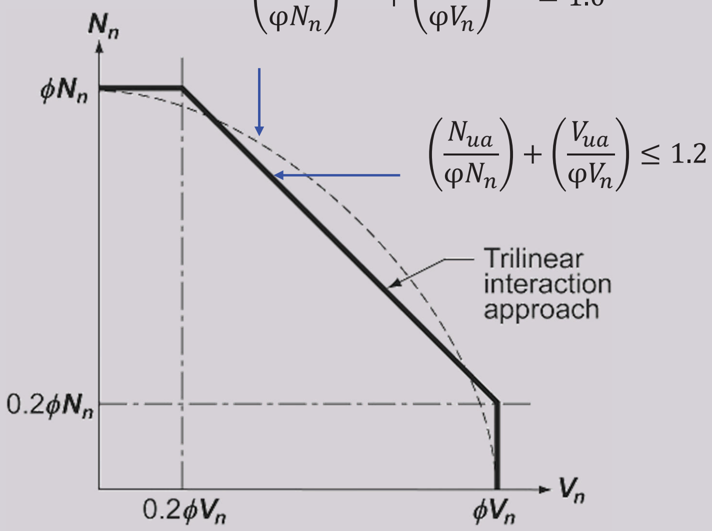
Group strength for shear in Y-direction = 45.00 kN, governed by concrete breakout strength

Not suitable for application in buildings assigned to SDC C or higher

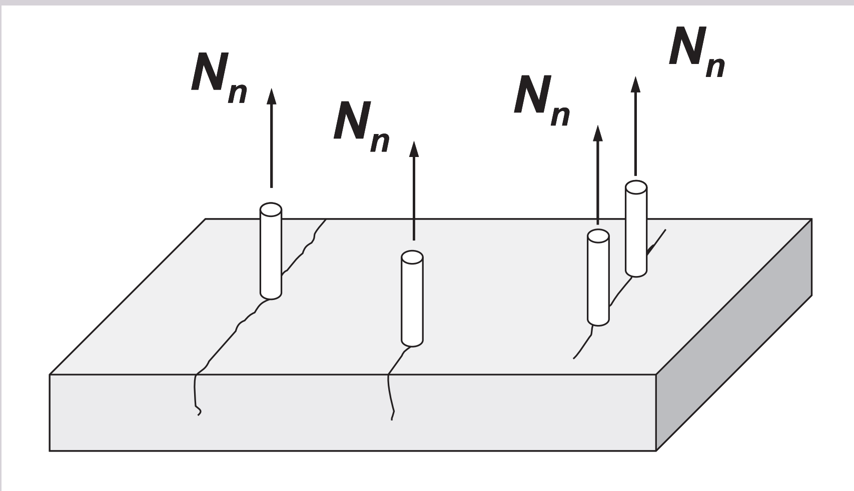
KD.7 – Tension/Shear Interaction

$$\left(\frac{N_{ua}}{\varphi N_n}\right)^{5/3} + \left(\frac{V_{ua}}{\varphi V_n}\right)^{5/3} = 1.0$$

$$\left(\frac{N_{ua}}{\varphi N_n}\right) + \left(\frac{V_{ua}}{\varphi V_n}\right) \leq 1.2$$



KD.8 – Preclude Splitting Failure



KD.8 – Preclude Splitting Failure

- At design stage, specific products may not be known
- In absence of supplementary reinforcement for crack control, KD.8 sets minimum cover, spacing, member thickness

KD.4.4.2 Anchor Size Limits

For anchors with diameters not exceeding 50 mm, and tensile embedments not exceeding 635 mm in depth, the concrete breakout strength requirements shall be considered satisfied by the design procedure of KD.5.2 and KD.6.2.

Questions?
Thank you