

Concrete Anchorage


By Jason Oakley, P.E.

New Anchorage Design Requirements

- Why Cracked Concrete?
- Structural Requirements (2006 IBC)
- Anchorage Design Provision (ACI 318 – App. D)
- Design Example
- Software that helps
- Evolution of anchorage
- Code Reports

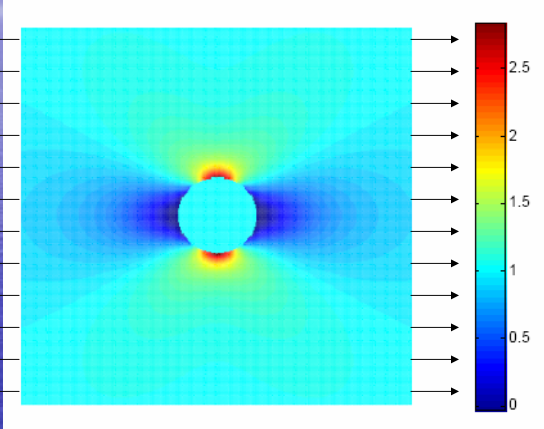
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Why Cracked Concrete?



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Stress Concentration



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Studies Show...

- Anchors lose capacity when in a crack
 - Ex: a crack width of 0.4 mm, losses are...

Crack Width (mm)	CIP=25% (Red)	expansion=40% (Green)	adhesives=50% (Black)
0.0	1.0	1.0	1.0
0.4	0.75	0.65	0.55
0.8	0.70	0.55	0.45
1.2	0.65	0.50	0.40
1.6	0.60	0.45	0.35

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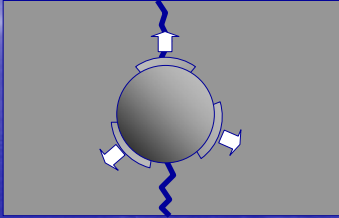
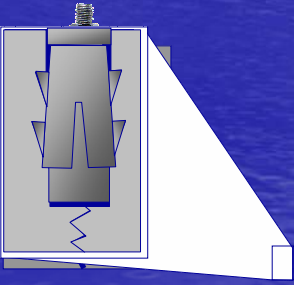
When & Where to Use "Cracked Concrete" Anchors

- "Tension Zone"
- Any application where seismic forces are considered
 - Regardless of location (moderate/severe regions)

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What makes an anchor work in CC?



- Tri-segmented clip design
 - Grabs at least 2 sides of crack
 - Distributes loads more uniformly
 - redundancy
- 2 Teeth per segment
 - Creates ledges when installed
 - Provides 'secondary' expansion as crack cycles

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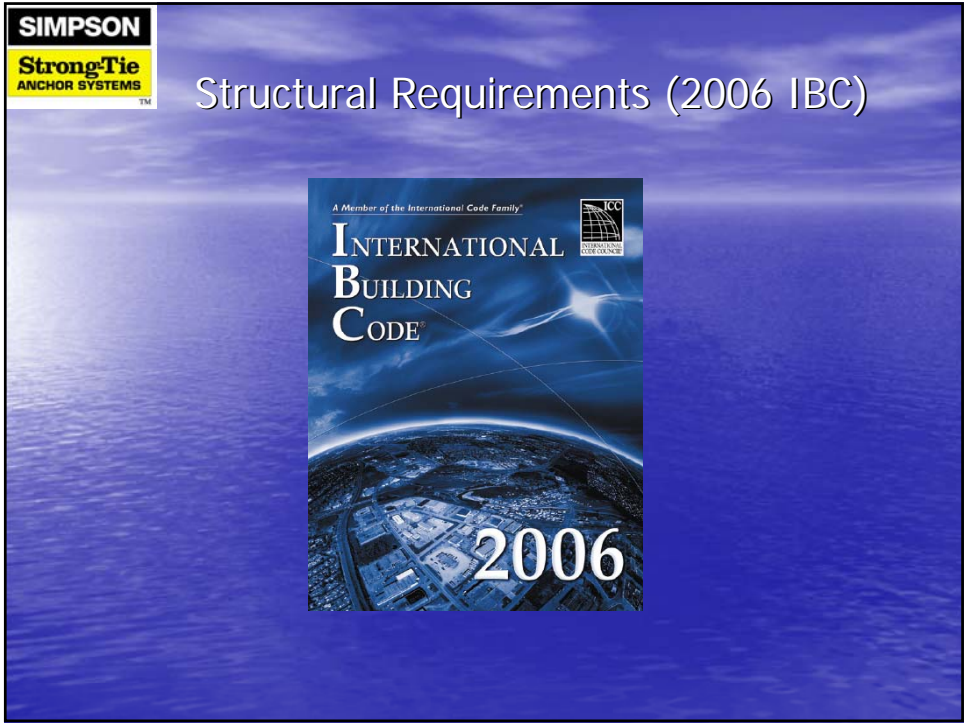
The code has changed

- New Codes have adopted new design provisions
- The new test standard addresses anchor performance in "cracked concrete"

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graph TD
    A['07 CBC'] --> B['06 IBC']
    B --> C[ACI 318 - App. D]
    C --> D[ACI 355.2]
    D --> E[AC 193a - mechanical/screw]
    D --> F[AC 308 - bonded]
  
```

The logo for SIMPSON Strong-Tie ANCHOR SYSTEMS is located in the top left corner of the slide.

CIP / Post-installed Mech. Anchors

- Per IBC 2006, Section 1911
 - Allowable Stress Design Approach
 - Applies to cast-in-place anchors only
 - Does not apply to post-installed anchors
 - Earthquake loads not permitted

**SECTION 1911
ANCHORAGE TO CONCRETE—
ALLOWABLE STRESS DESIGN**

1911.1 Scope. The provisions of this section shall govern the allowable stress design of headed bolts and headed stud anchors cast in normal-weight concrete for purposes of transmitting structural loads from one connected element to the other. These provisions do not apply to anchors installed in hardened concrete or where load combinations include earthquake loads or effects. The bearing area of headed anchors shall be not less than one and one-half times the shank area. Where strength design is used, or where load combinations include earthquake loads or effects, the design strength of anchors shall be determined in accordance with Section 1912. Bolts shall conform to ASTM A 307 or an approved equivalent.

CIP / Post-installed Mech. Anchors

- Per IBC 2006, Section 1912
 - Strength Design Approach
 - Covers CIP and post-installed *mechanical* anchor
 - Appendix D referenced
 - Does not cover screw and bonded type anchors

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SECTION 1912 ANCHORAGE TO CONCRETE—STRENGTH DESIGN

1912.1 Scope. 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 1908.1.16, provided they are within the scope of Appendix D.

CIP / Post-installed Mech. Anchors

--STRUCTURAL--

- Per 2006 IBC, Section 1908.1.16 – Concrete
 - Appendix D modified for SDC C/D/E/F:
 - Anchor steel must have ductile failure mode or
 - Fixture must yield at anchor nominal strength or
 - Design strength = **2.5** x factored forces

non-ductile overstrength factor

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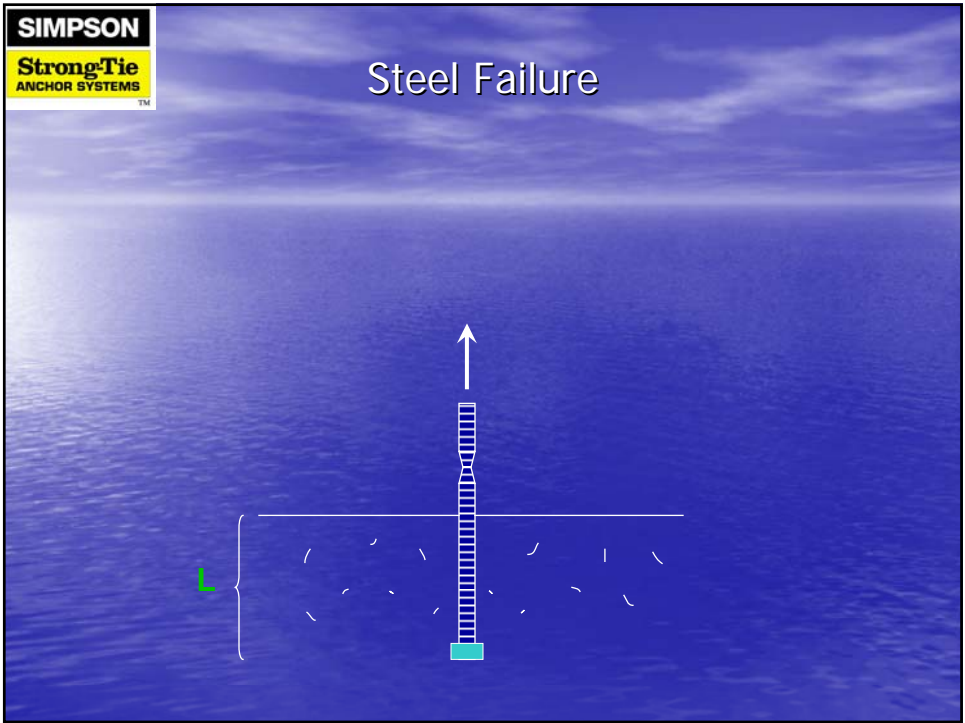
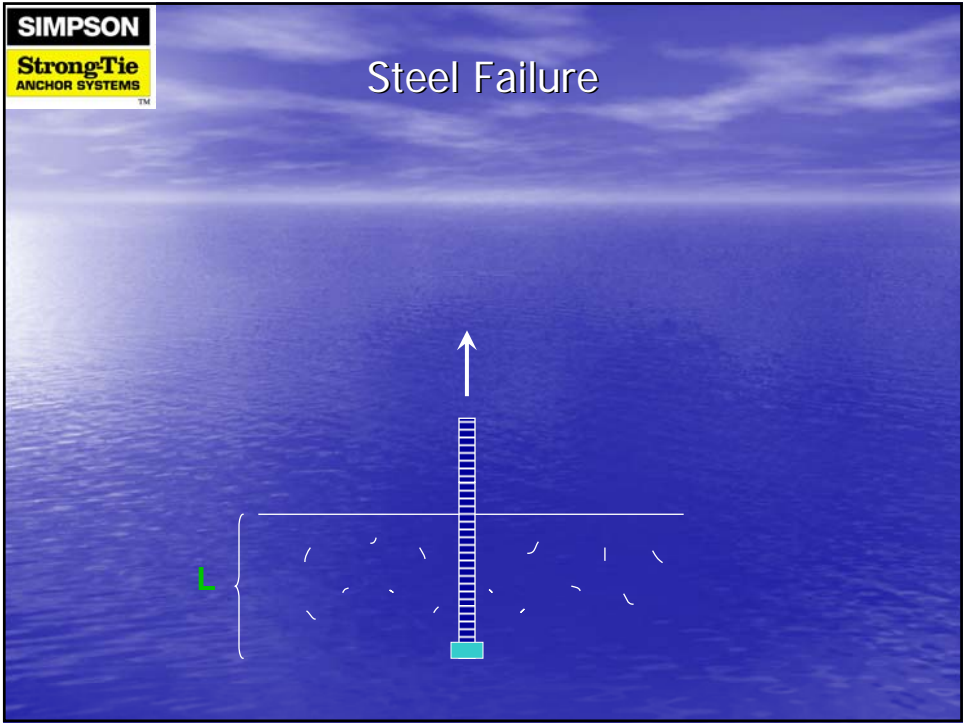
1908.1.16 ACI 318, Section D.3.3, Modify ACI 318, Sections D.3.3.2 through D.3.3.5, to read as follows:

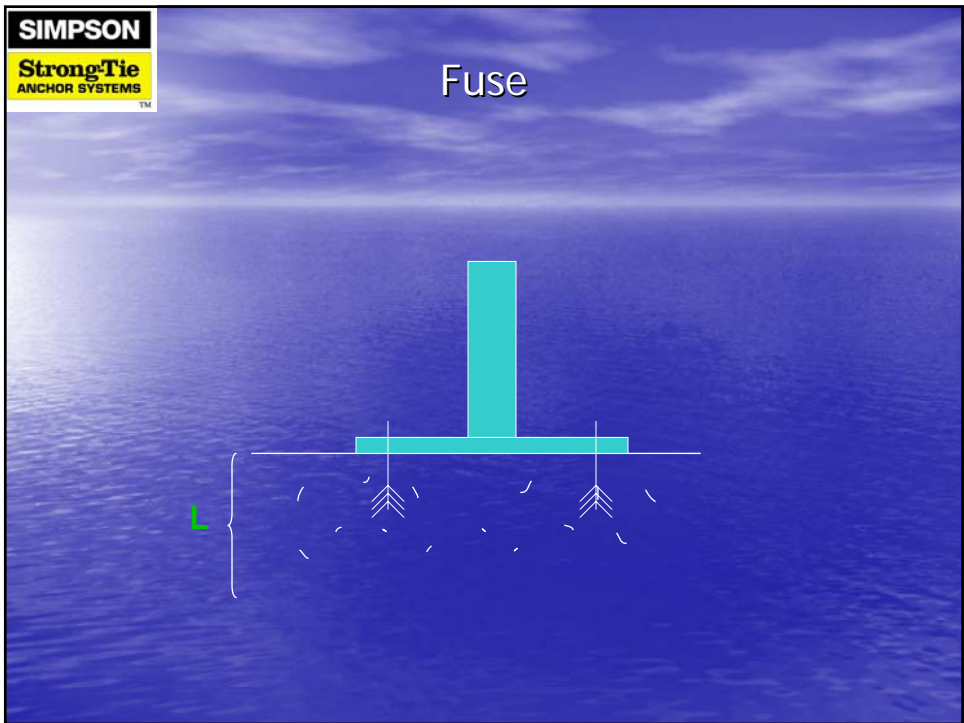
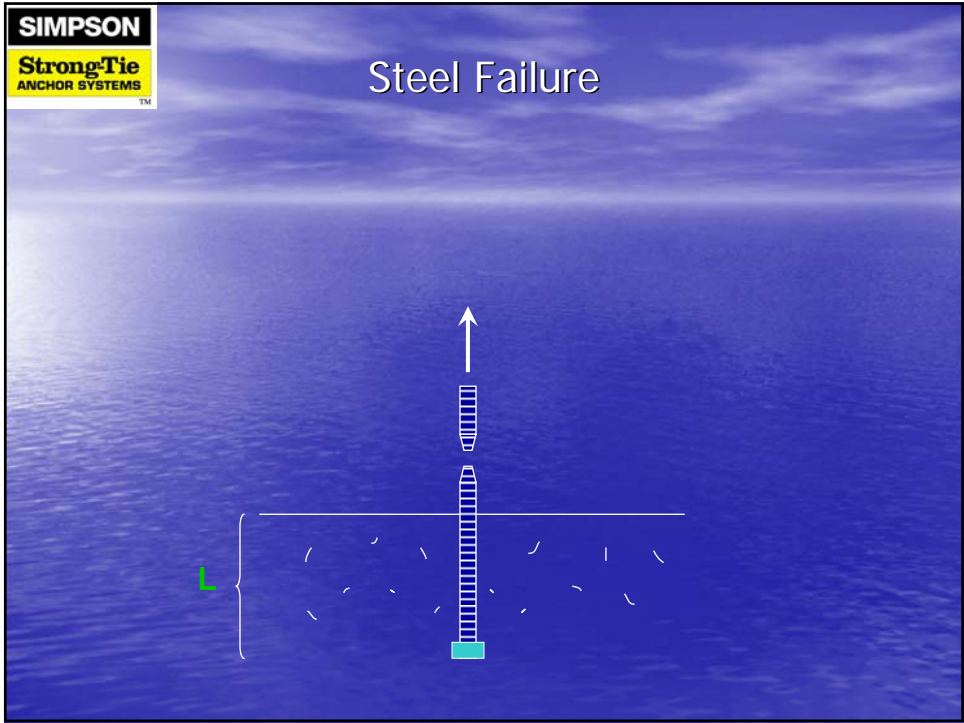
D.3.3.2 – In structures assigned to Seismic Design Categories C, D, E or F, post-installed anchors for use under D.2.3 shall have passed the Simulated Seismic Tests of ACI 355.2.

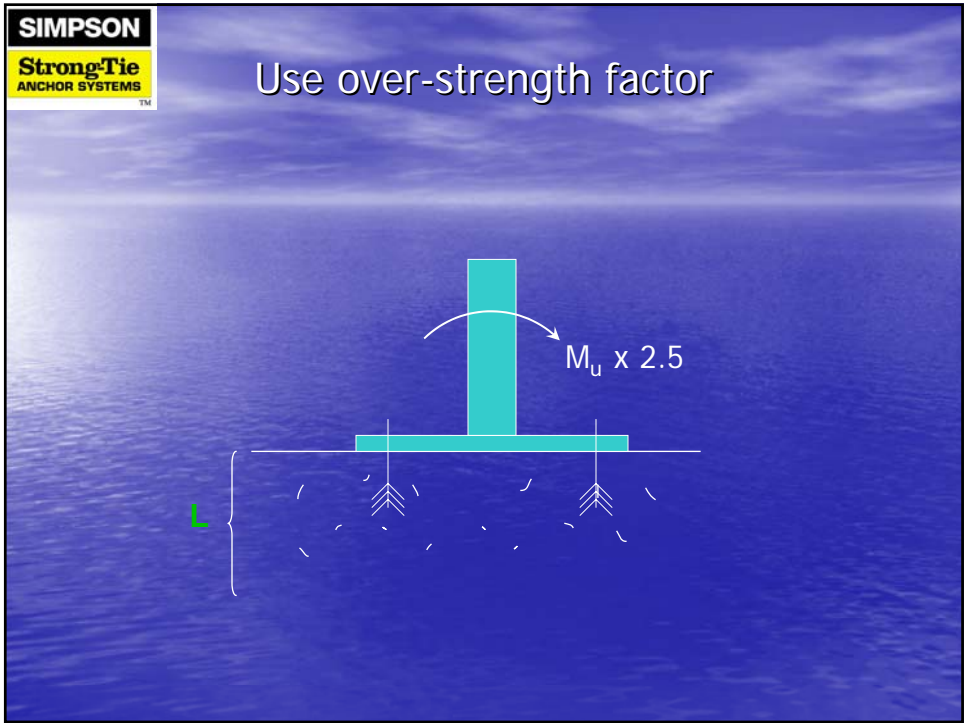
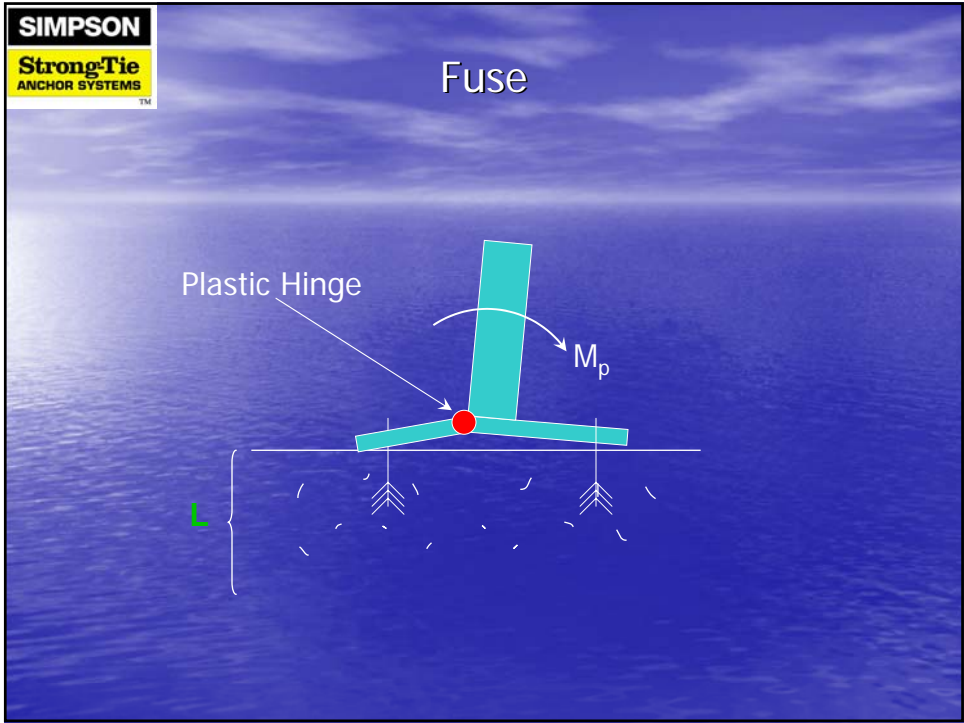
D.3.3.3 – In structures assigned to Seismic Design Categories C, D, E or F, the design strength of anchors shall be taken as $0.75\phi N_n$ and $0.75\phi V_n$, where ϕ is given in D.4.4 or D.4.3, and N_n and V_n are determined in accordance with D.4.1.

D.3.3.4 – In structures assigned to Seismic Design Categories C, D, E or F, anchors shall be designed to be governed by tensile or shear strength of a ductile steel element, unless D.3.3.5 is satisfied.

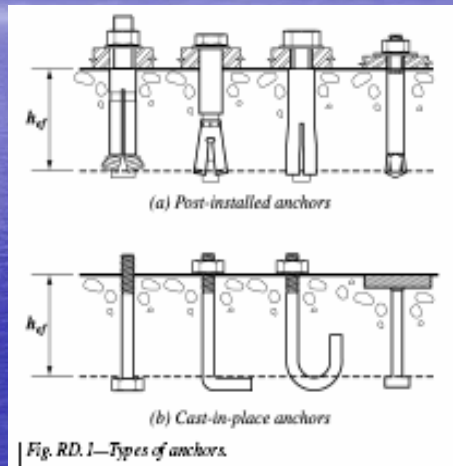
D.3.3.5 – Instead of D.3.3.4, the attachment that the anchor is connecting to the structure shall be designed so that the attachment will undergo ductile yielding at a load level corresponding to anchor forces no greater than the design strength of anchors specified in D.3.3.3, or the minimum design strength of the anchors shall be at least 2.5 times the factored forces transmitted by the attachment.







Anchorage Design Provision (ACI 318 – App. D)



Anchorage Design Provision (ACI 318 – App. D)

D.2.1 — This appendix provides design requirements for anchors in concrete used to transmit structural loads by means of tension, shear, or a combination of tension and shear between (a) connected structural elements; or (b) safety-related attachments and structural elements. Safety levels specified are intended for in-service conditions, rather than for short-term handling and construction conditions.

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Anchorage Design Provision (ACI 318 – App. D)

D.2.2 — This appendix applies to both cast-in anchors and post-installed anchors. Specialty inserts, through bolts, multiple anchors connected to a single steel plate at the embedded end of the anchors, **adhesive** or grouted anchors, and direct anchors such as powder or pneumatic actuated nails or bolts, are not included. Reinforcement used as part of the embedment shall be designed in accordance with other parts of this code.

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Appendix D

Strength Based Design Approach

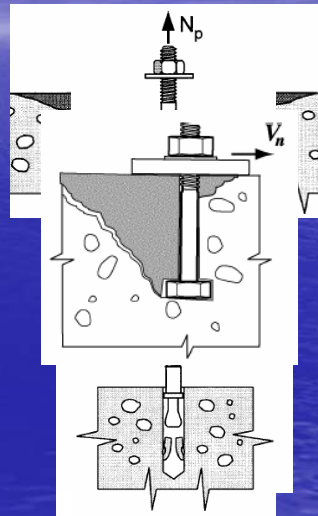
$$\phi N_n > N_u$$

$$\phi V_n > V_u$$

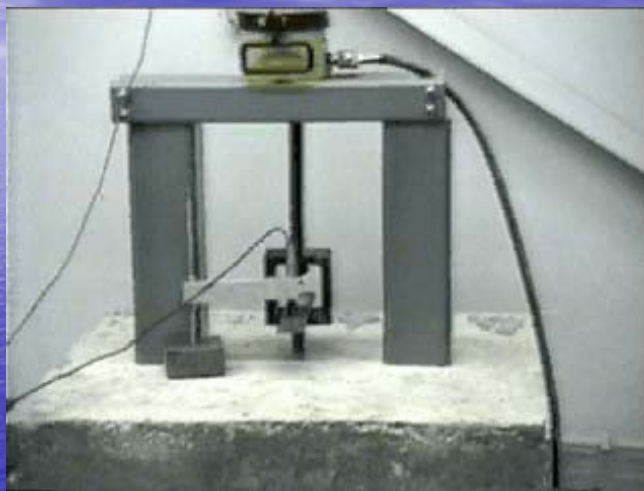
Design Strength > Factored load

ACI 318-05, Appendix D

- Design equations check 6 different failure modes
 - Steel capacity
 - Tension and Shear
 - Concrete breakout capacity
 - Tension and Shear
 - Pullout/Pull-through capacity
 - Tension only
 - Concrete Pryout
 - Shear only.

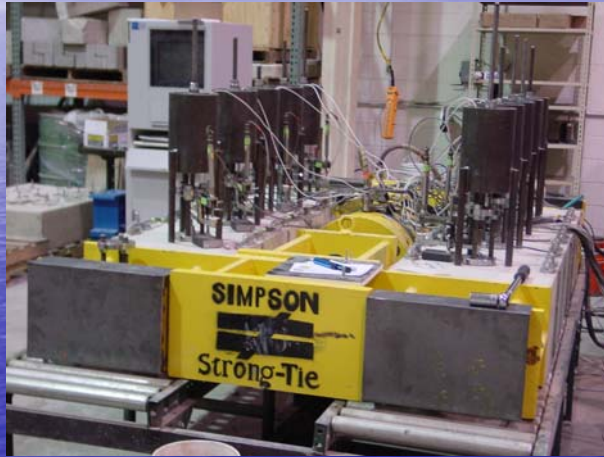


ASD method used safety factors

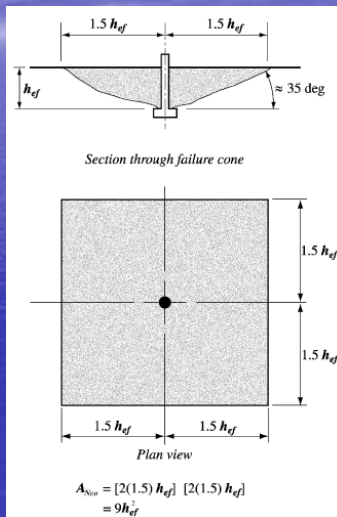




USD considers the spread of the data



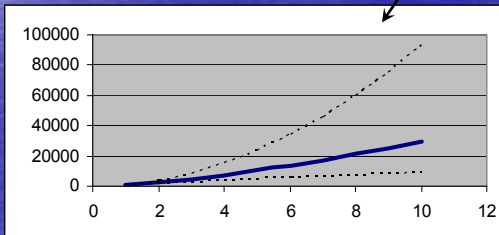
Concrete Breakout Strength (Tension)



Concrete Breakout Strength (Tension)

$$N_b = k_c \sqrt{f'_c} h_{ef}^{1.5} \quad (D-7)$$

where
 $k_c = 24$ for cast-in anchors; and
 $k_c = 17$ for post-installed anchors.



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Concrete Breakout Strength (Tension)

What happens when we get close to an edge?

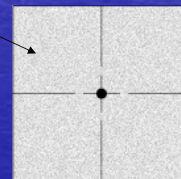
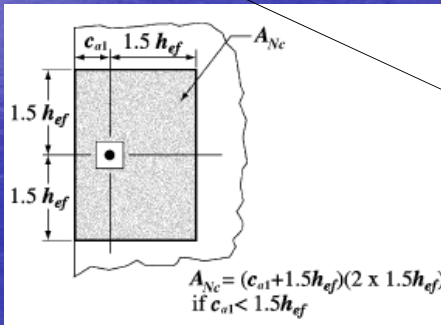


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Concrete Breakout Strength (Tension)

$$N_{cb} = \frac{A_{Nc}}{A_{Nco}} \psi_{ed, N} \psi_{c, N} \psi_{cp, N} N_b$$



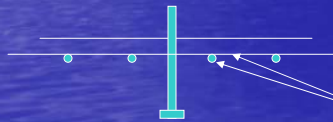
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Concrete Breakout Strength (Tension)

Condition A applies where the potential concrete failure surfaces are crossed by supplementary reinforcement proportioned to tie the potential concrete failure prism into the structural member.

Condition B applies where such supplementary reinforcement is not provided, or where pullout or pryout strength governs.



Not considered suppl. Reinf.!!

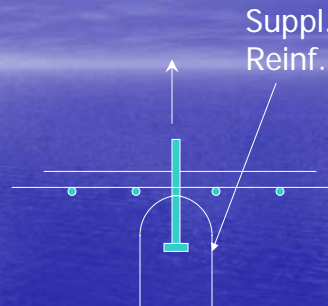
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Concrete Breakout Strength (Tension)

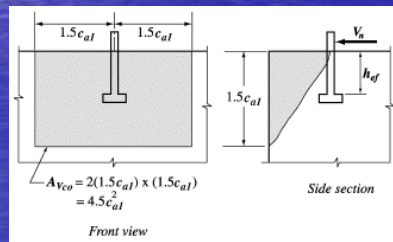
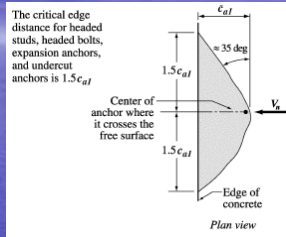
Condition A applies where the potential concrete failure surfaces are crossed by supplementary reinforcement proportioned to tie the potential concrete failure prism into the structural member.

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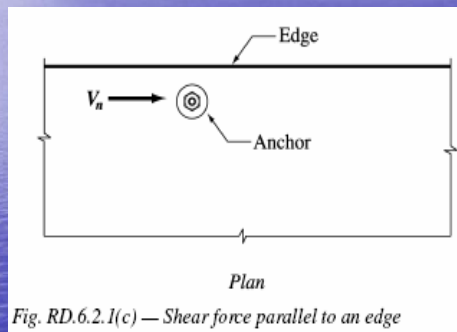


(CIP)
Only 7 to 20% increase in CBS!
(PI)

Concrete Breakout Strength (Shear)



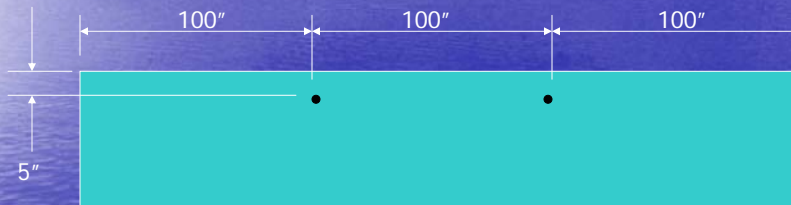
Concrete Breakout Strength (Shear)



Capacity doubles!

Concrete Breakout Strength (Shear)

Must use rational engineering judgment:



- (1) 5/8" x 5-1/8" emb. → Shear = 6,800 lbs
- (2) 5/8" x 5-1/8" emb. → Shear = 7,025 lbs!!

Treat as one anchor if adjacent anchor is greater than $3 \times h_{ef}$ away

Concrete Breakout Strength (Shear)

Flaw of '05 ACI-318 App. D.....

$\Psi_{h,V}$ (added in '08 ACI 318)

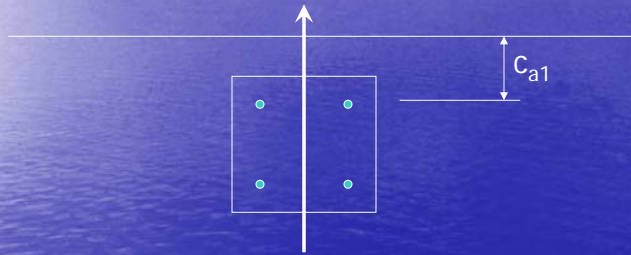
$$V_{cb} = \frac{A_{Vc}}{A_{Vco}} \psi_{ed,V} \psi_{c,V} V_b \quad (D-21)$$

See: "Shear Toward a Free Edge" paper by Burdette

Code fix: $\Psi_{h,V} = [1.5 \times c_{a1} / h_a]^{1/2}$

Concrete Breakout Strength (Shear)

$\Psi_{h,v}$ makes a big difference.....



No $\Psi_{h,v} \rightarrow c_{a1} = 160''$

Include $\Psi_{h,v} \rightarrow 37.5''$

} Big difference?

Concrete Breakout Strength (Shear)

Btw, lightweight concrete factor is not correct.....

D.3.4 — All provisions for anchor axial tension and shear strength apply to normalweight concrete. If lightweight concrete is used, provisions for N_n and V_n shall be modified by multiplying all values of $\sqrt{f'_c}$ affecting N_n and V_n , by 0.75 for all-lightweight concrete and 0.85 for sand-lightweight concrete. Linear interpolation shall be permitted when partial sand replacement is used.

Should be 0.6...software uses 0.6, not 0.85

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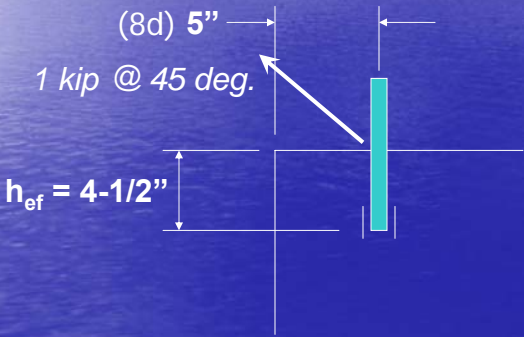
Simple Design Example

Strong Bolt
(ESR-1771)



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Example (STB)



(8d) 5"
1 kip @ 45 deg.
 $h_{ef} = 4-1/2"$

5/8" Strong-Bolt
CC / SDC F / STRUCTURAL

Example (Strong-Bolt) TENSION

- **Steel**
 - $N_s = 1 \times 0.167 \times 125,000 = \underline{21 \text{ kips}}$
- **Concrete**
 - $N_b = 17 \times (4,000)^{0.5} 4.5^{1.5} = 10.3 \text{ kips [basic]}$
 - $\Psi_{ed,N} = 0.7 + 0.3 \times 5 / (1.5 \times 4.5) = 0.92 \text{ [edge]}$
 - $\Psi_{c,N} = 1.0 \text{ [cracked]}$
 - $\Psi_{cp,N} = 1.0 \text{ [does not apply to CC]}$
 - $A_{nc} = (5 + 1.5 \times 4.5) \times (2 \times 1.5 \times 4.5) = 159 \text{ in}^2 \text{ [edge]}$
 - $A_{Nno} = 9 \times 4.5^2 = 182 \text{ in}^2 \text{ [1 anchor; no edge]}$
 - $N_{cb} = 159/182 \times 10.3 \times 0.92 \times 1.0 \times 1.0 = \underline{8.3 \text{ kips}}$
- **Pullout**
 - $N_{pn,cr} = 5,200 \times (4,000/2,500)^{0.7} = \underline{7.2 \text{ kips}}$

Example (Strong-Bolt) TENSION

- **Steel**
 - $\phi N_s = 0.75 \times 21 \text{ kips} = 16 \text{ kips [ductile steel]}$
- **Concrete**
 - $\phi N_{cb} = 0.65 \times 8.3 \text{ kips} = 5.4 \text{ kips [no supplementary reinf.]}$
- **Pullout**
 - $\phi N_p = 0.65 \times 7.2 \text{ kips} = \underline{4.7 \text{ kips}}$

Pullout governs

Anchor Categories

Example:

- Anchor A: Reference Test = 10000# → $w = 0.012''$
Reliability Test = 8600# → $w = 0.020''$

Table 10.1—Establishment of anchor categories

Smallest ratio of characteristic capacities	Anchor category	ϕ
$0.80 \leq \frac{N_{br}}{N_{b,o}}$	$8600\#/10000\# = 0.86$ 1	0.65
$0.70 \leq \frac{N_{br}}{N_{b,o}} < 0.80$	2	0.55
$0.60 \leq \frac{N_{br}}{N_{b,o}} < 0.70$	3	0.45
If $N_{br}/N_{b,o} < 0.60$	Anchor is unqualified	

Example (Strong-Bolt) SHEAR

- Steel
 - $V_{sa} = \underline{9.7 \text{ kips}}$
- Concrete
 - $V_b = 7(4.5/0.625)^{0.2}(0.625)^{0.5}(4,000)^{0.5}(5)^{1.5} = 5.8 \text{ kips}$
 - $\Psi_{ed,V} = 1.0$
 - $\Psi_{c,V} = 1.0$ [cracked]
 - $A_{vc} = 2 \times (1.5 \times 5) \times (1.5 \times 5) = 113 \text{ in}^2$ [edge]
 - $A_{vco} = 4.5 \times 5^2 = 113 \text{ in}^2$
 - $V_{cb} = 113 / 113 \times 1.0 \times 1.0 \times 5.8 = \underline{5.8 \text{ kips}}$
- Pryout
 - $V_{cp} = 2 \times 8.3 = \underline{16.6 \text{ kips}}$

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Example (Strong-Bolt) SHEAR

- Steel
 - $\phi V_s = 0.65 \times 9.7 \text{ kips} = 6.3 \text{ kips}$ [ductile steel]
- Concrete
 - $\phi V_{cb} = 0.70 \times 5.8 \text{ kips} = \mathbf{4.1 \text{ kips}}$ [no supplementary reinf.]
- Pryout
 - $\phi V_p = 0.70 \times 16.6 \text{ kips} = 11.6 \text{ kips}$

Concrete governs

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Example (Strong-Bolt)

$$0.75 \times \phi N_{cb} = 0.75 \times 4.7 \text{ k} = 3.5 \text{ kips}$$

$$0.75 \times \phi V_{cb} = 0.75 \times 4.1 \text{ k} = 3.1 \text{ kips}$$

NDOF

$$\frac{2.5 \times 0.707 \times P_{\max}}{3.5} + \frac{2.5 \times 0.707 \times P_{\max}}{3.1} = 1.2$$

$P_{\max} = 1.1 \text{ kips} > 1 \text{ kip} \dots \text{OK}$

D.3.3.3 — In regions of moderate or high seismic risk, or for structures assigned to intermediate or high seismic performance or design categories, the design strength of anchors shall be taken as $0.75\phi N_n$ and $0.75\phi V_n$, where ϕ is given in D.4.4 or D.4.5 and N_n and V_n are determined in accordance with D.4.1.


D.7.3 — If $V_{ua} > 0.2\phi V_n$ and $N_{ua} > 0.2\phi N_n$, then:

$$\frac{N_{ua}}{\phi N_n} + \frac{V_{ua}}{\phi V_n} \leq 1.2 \quad (\text{D-31})$$

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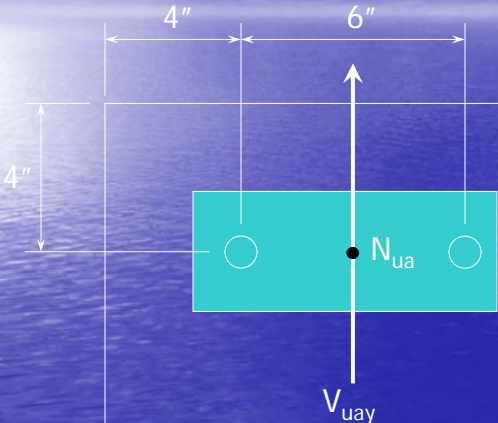
Reality Check Time

- CC/UCC = 0.65 to 0.8, call it 0.70
- Seismic: 0.75 factor (code: SDC C, D, E or F)
- Then you apply phi factor:
 - 0.65 (cat. 1)
- What is left?
 - $0.7 * 0.75 * 0.65 = 0.34$
- If we assume 15% COV for CC tests $N_{5\%} = 0.49 N_{avg_ult}$:
 - $0.34 / 1.1 * 0.49 = 0.15 * N_{avg_ult}$ (S.F. = 6.6)
 - Oh, and if it's not ductile, divide by 2.5! (S.F. = 16)



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Ultimate Strength Design (USD)



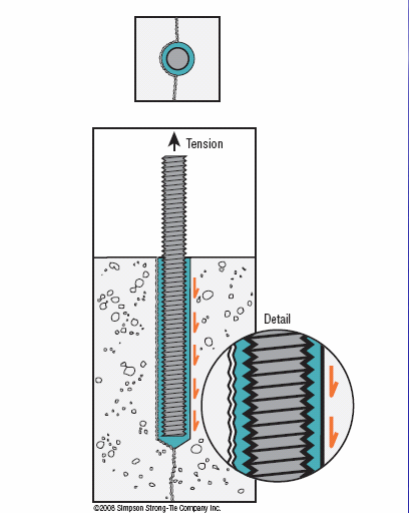
Anchor Software

	Tension (lbf)	Shear (lbf)
No Edge	3,000	1,900
4" single edge	3,000	900
4" double edge	3,000	550

1/2" x 3-7/8" emb. STB

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Evolution of Anchorage



The diagram illustrates the behavior of an adhesive anchor in cracked concrete under tension. At the top, a circular cross-section shows a central anchor surrounded by a ring of adhesive. Below, a vertical cross-section shows a threaded anchor being pulled upwards, with an arrow labeled 'Tension'. The concrete around the anchor is shown with a network of cracks. A circular 'Detail' inset shows a close-up of the anchor's threads and the surrounding concrete, with red arrows indicating the direction of crack propagation and the interaction between the adhesive and the concrete.

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Figure 1 – Adhesive Anchor Behavior in Cracked Concrete

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Bonded Anchors




The left photograph shows a construction site with a concrete wall and a large, rectangular concrete foundation. A worker is visible in the foreground, and the wall has several vertical anchors installed. The right photograph shows a worker in a blue shirt and white hard hat standing on a concrete slab. The slab has a grid of rebar and several vertical anchors installed. The worker is holding a clipboard and looking at the anchors.

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In the "old" days - ASD

****TENSION****

Dia.	Emb.	Edge	Bonded	TCA
5/8	5"	7-1/2"	6,700 lbs	2,100 lbs
5/8	5"	1-3/4"	3,300 lbs	-
	4-1/2"	2-1/2"	3,700 lbs	1,400 lbs



Bonded anchor was dominant!


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Bonded anchor evolution

(5/8" dia. x 5" emb. in 4 ksi NWC)

	Old adhesive		New adhesive	
<i>ASD</i> <i>TENSION</i>	"prev." ESR (UCC)	LARR (UCC)	New Code/ESR (CC) **	TCA (CC) **
Critical Edge	8.9 k @ 7.5"	6.4 k @ 7.5"	2.1 k @ 12.5"	1.3 k @ 9"
Min. Edge	4.3 k @ 1.75"	3.1 k @ 1-7/8"	750 lbs @ 3-1/8"	1.3 k @ 5"

50% loss 19-D or 1911.2

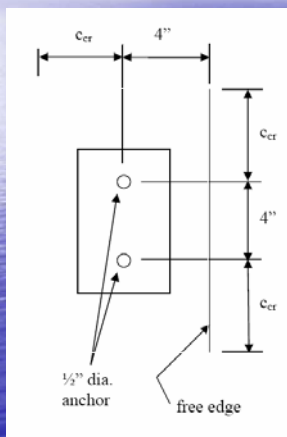


****2.5 NDOF included**

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Double anchor example (AC 308)



Cracked Concrete

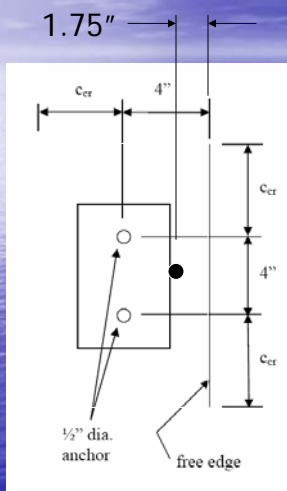
What's the ASD value for a "dry",
"structural" connection in CC and SDC C
– F for (2) 1/2" ATR x 9" emb.?

$$\begin{aligned} \text{ASD} &= 0.65 \times [(105 / 74) \times 0.98 \times 0.95 \times 1.0 \times \\ &0.19] \times 15,200 / 1.1 / 2.5 \\ &= 0.65 \times 0.25 \times 15,200 / 1.1 / 2.5 \\ &= 0.059 \times 15,200 \\ &= \mathbf{900 \text{ lbs}} \quad [\text{bond strength governs}] \end{aligned}$$

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Strong-Tie
ANCHOR SYSTEMS

.....compared with single anchor (AC 58)



Cracked Concrete

Take (1) 1/2" ATR x 6" emb. @ 1-3/4" –
What do we get?

Live pull test = 10 to 12 kips (steel fails 90% of
the time – witnessed by almost 1,000
eng./arch./plan checkers, contractors, etc.)

$$18,556 \times 0.59 = 11 \text{ kips (coincidence?)}$$

$$\text{ASD (old)} = 11 / 4 \times 1.33 = 3,650 \text{ lbs}$$

3650 lbs vs. 900 lbs.

@ 1/2 the edge

@ 3" less emb.

@ 1/2 the anchors

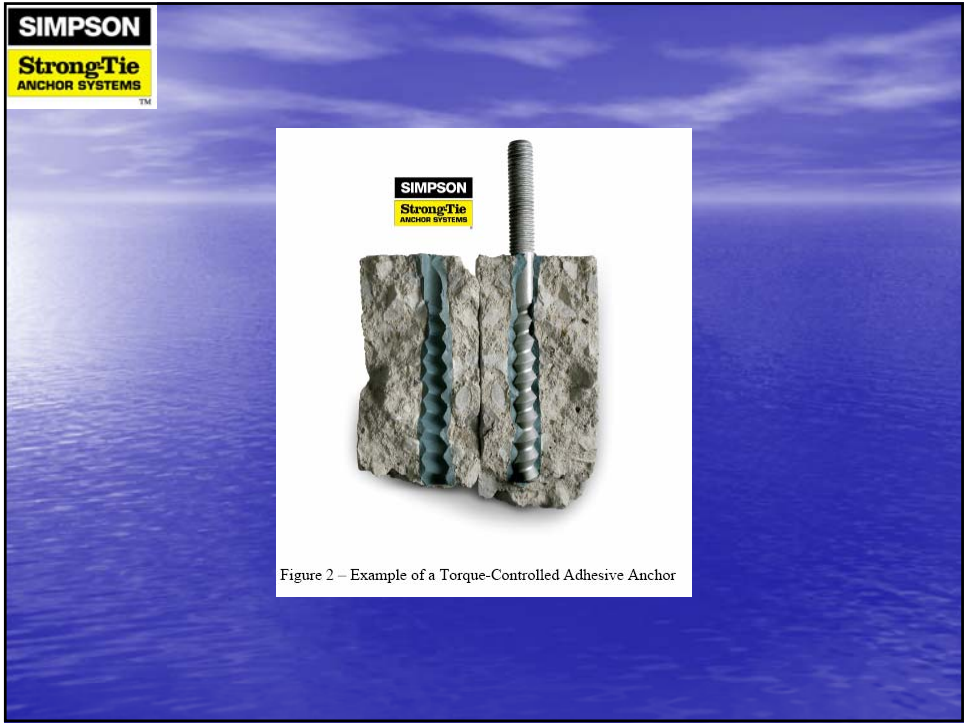


Figure 2 – Example of a Torque-Controlled Adhesive Anchor

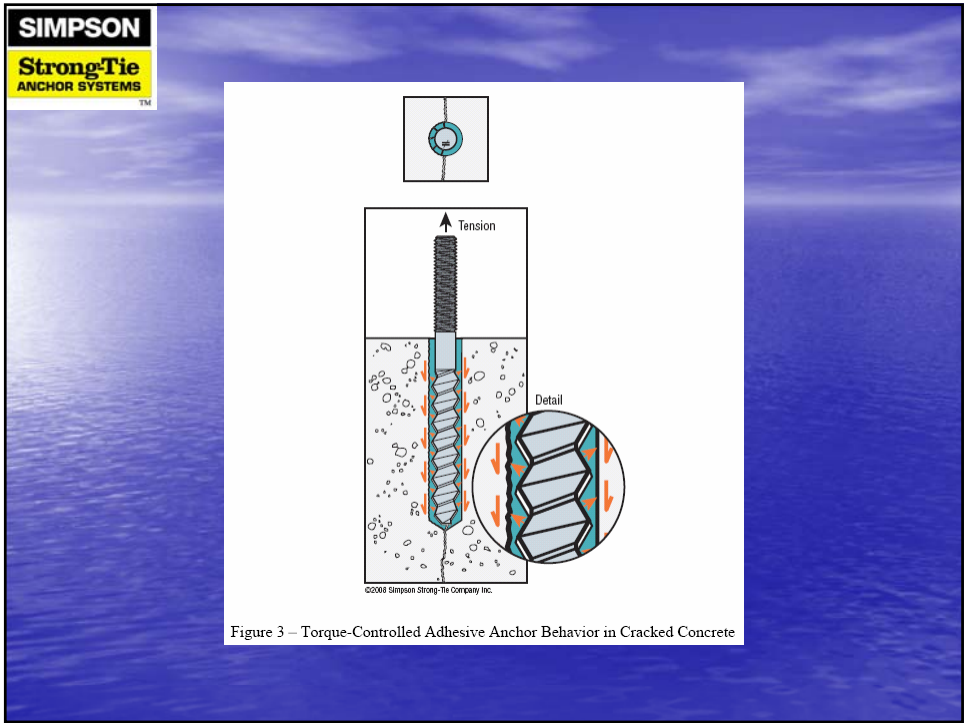


Figure 3 – Torque-Controlled Adhesive Anchor Behavior in Cracked Concrete

SIMPSON
Strong-Tie
ANCHOR SYSTEMS™

Shear walls (ASD / 2006 I.B.C.)

8'

4'

Wood

5/8" dia.

"a"

"b"

Max Tension

41.5"

	a	b	Tension
CIP	3-3/4"	8"	2.7 k
8" emb	12"	12"	8.9k **
SET-XP	1-3/4"	8"	1.2k
8" emb	10"	10"	2.7k
IXP	6-5/8"	8"	1.7k
6-5/8" emb	10"	10"	2.5k

**ductile

SIMPSON
Strong-Tie
ANCHOR SYSTEMS™

Shear walls (ASD / 2006 I.B.C.)

8'

4'

Wood

5/8" dia.

"a"

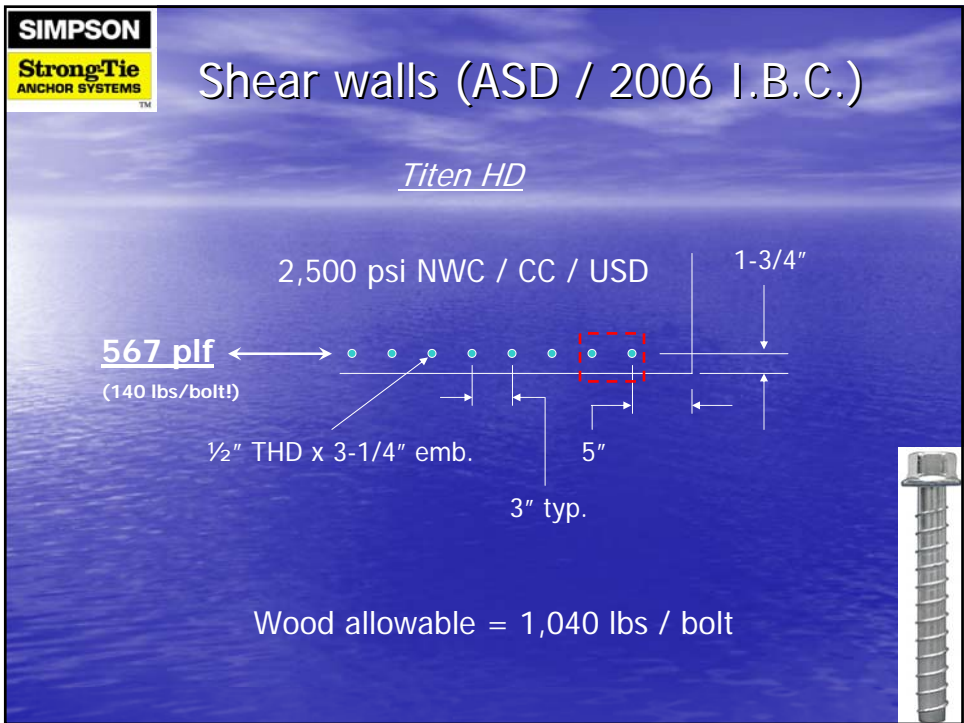
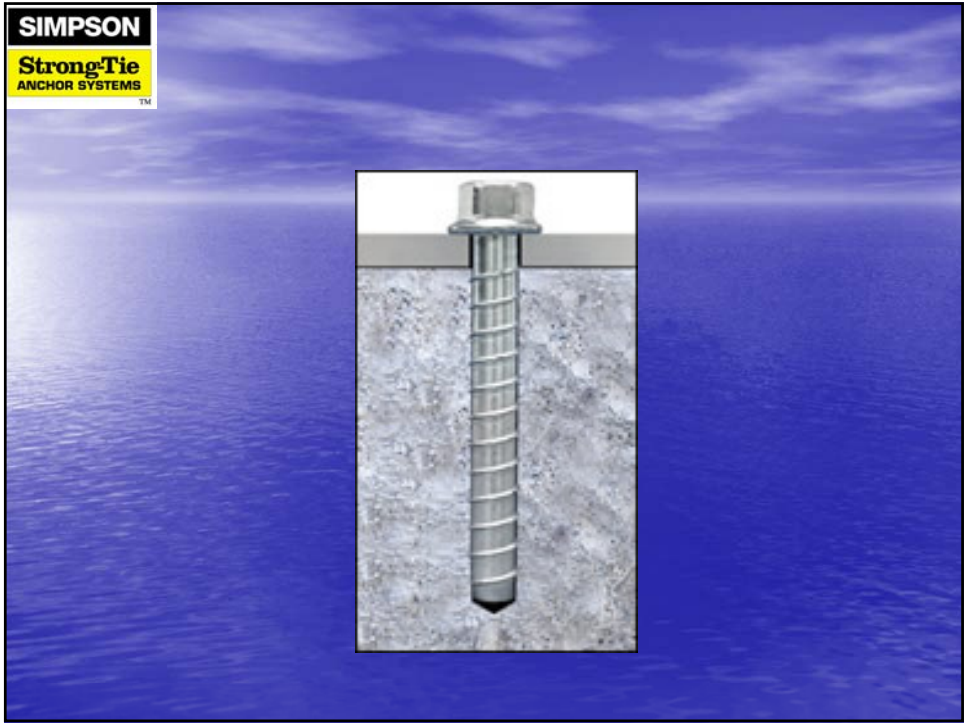
"b"

Max Tension

41.5"

	a	b	shear
CIP	3-3/4"	8"	290 plf
8" emb	12"	12"	960 plf **
SET-XP	1-3/4"	8"	130 plf
8" emb	10"	10"	295 plf
IXP	6-5/8"	8"	190 plf
6-5/8" emb	10"	10"	280 plf

**ductile





2006 IBC Compliant Code Reports

- Current
 - ESR 1771 (Strong-Bolt)
 - Concrete / LWCMD
 - ESR 2138 (pins)
 - Concrete / Steel / CMU / LWCMD
 - ESR 1772 (SET)
 - CMU / URM
 - ESR 1056 (Titen HD)
 - CMU
 - ESR 1396 (Wedge-All)
 - CMU
- Pending
 - SET XP
 - Concrete
 - Titen HD
 - Concrete
 - Torque Cut
 - Concrete



Questions