

A photograph of a construction site. In the foreground, a large, light-colored concrete beam is being positioned or moved. In the background, a tall, cylindrical concrete structure is under construction, with a worker visible on a high-rise section. The sky is blue with some light clouds.

Fastening to Concrete

3. Anchor Reinforcement

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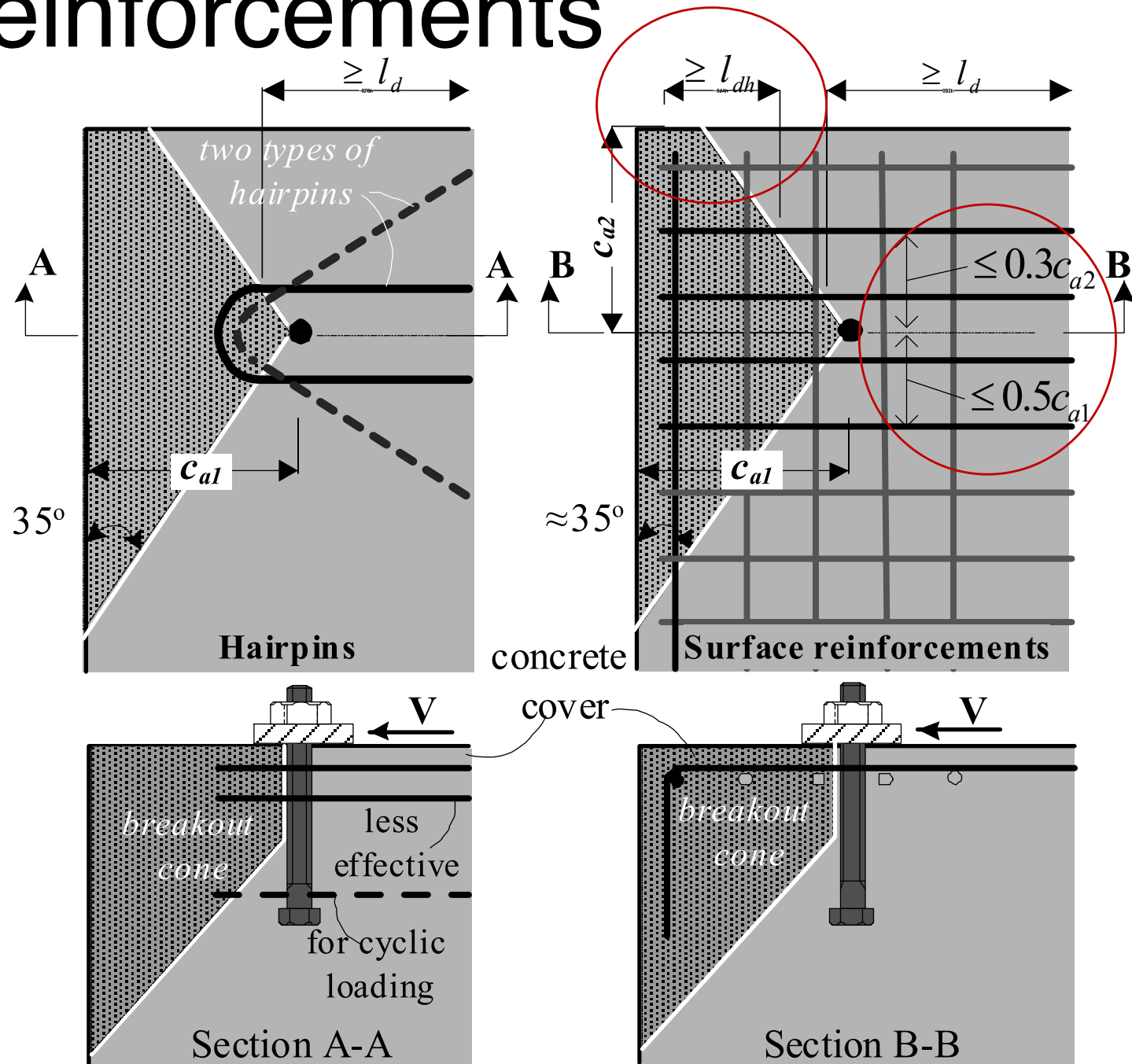
NEES-Anchor Tests

- Phase I: Unreinforced single anchors subjected to cyclic loading (UWM, Spring 2010)
- Phase II: Reinforced single anchors subjected to shear (UWM, Fall 2010)
- Phase III: Reinforced single anchors subjected to tension (UWM, Summer 2011)
- Phase IV: Anchor groups in plastic hinge zones of a concrete wall (NEES-UIUC, May 2012)
- Phase V: Reinforced single anchors in plastic hinge zones of columns (UWM, Spring 2012)

Phase II: Reinforced Anchor in Shear

Shear Reinforcements

- Breakout cone forms before anchor reinforcement in effect.
- Reinforcement fully developed at both sides of breakout crack.

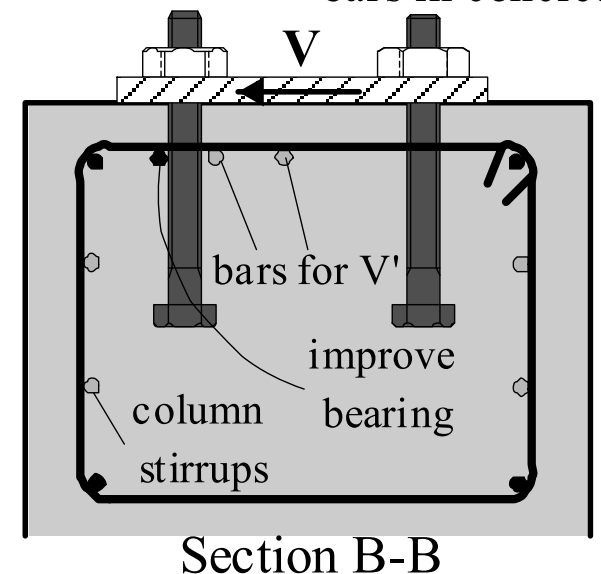
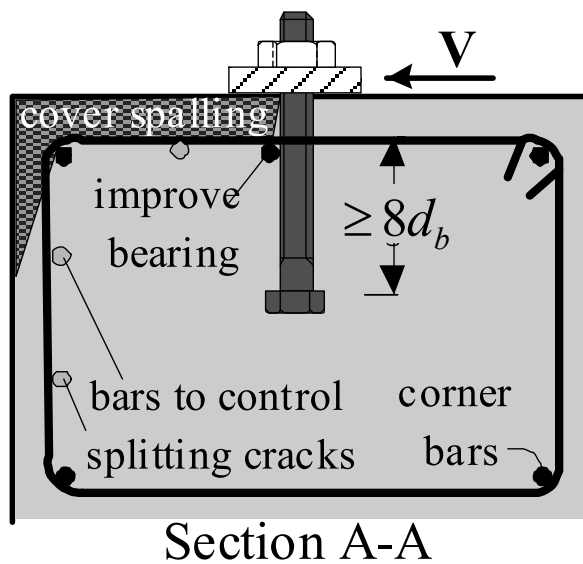
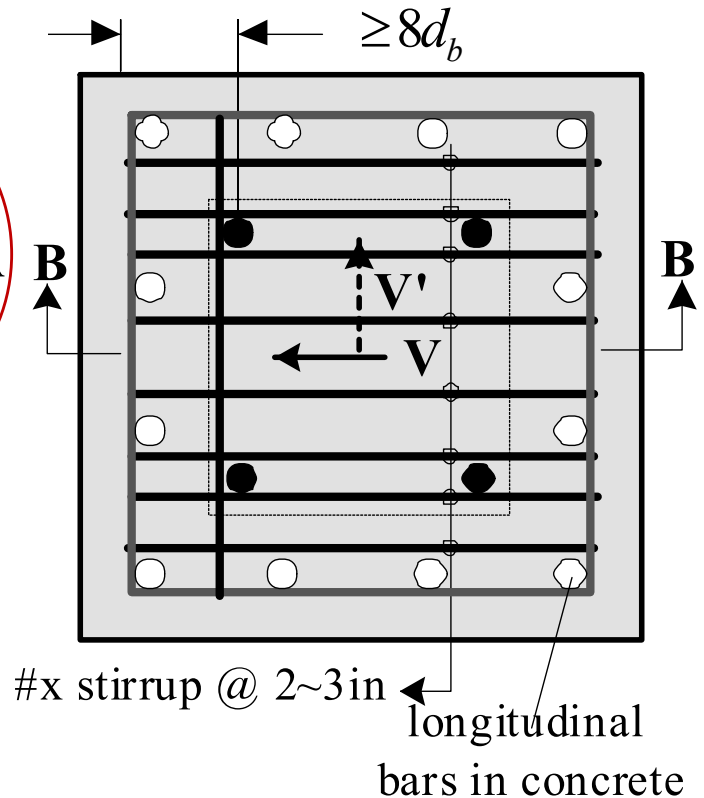
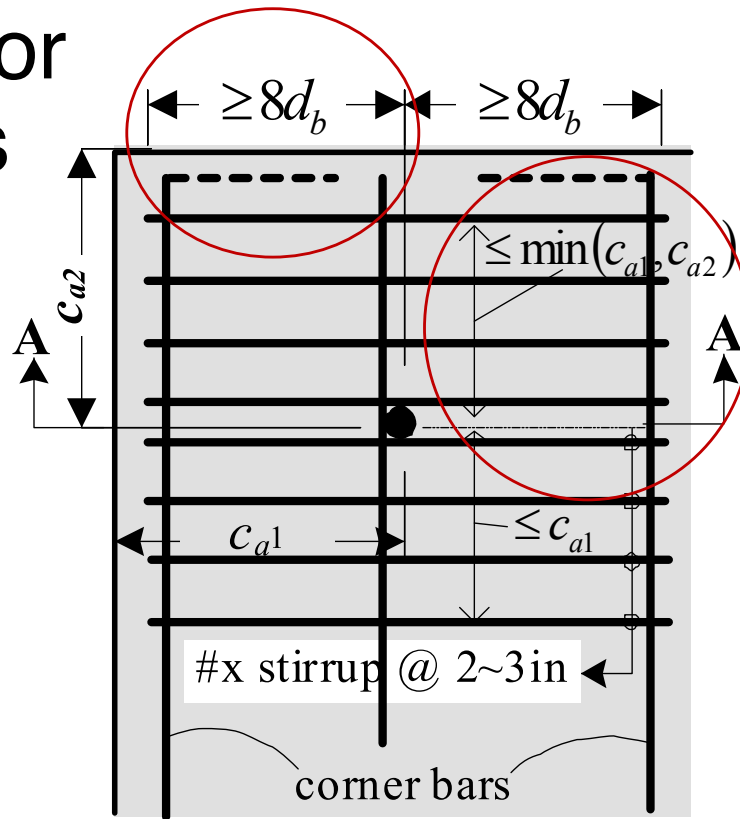


Design Method for Anchor in Shear

Reference	Design equation for A_{sa} given load V_{sd}	Development in cone	Actual shear capacity (V_s)	Notes
Shipp and Haninger (1983)	$F_{ys}A_{sa} = \frac{F_{uta}A_{se,N}}{1.85\cos 45^\circ}$	Not needed	Design based on equivalent tension	Hairpins
Klingner et al. (1983)	$F_{ys}A_{sa} = F_{uta}A_{se,V}$	Not needed	$V_s = 0.6F_{uta}A_{se,V}$	Hairpins
CEB (1997)	$0.5F_{ys}A_{sa} = 1.15V_{sd}$	Considered in capacity calculation	$V_s = \sum 2l_{dh} u f_{bd}$	Bars within $0.5c_{a1}$
ACI 318 (2008)	$0.75F_{ys}A_{sa} = V_{sd}$	$L_{dh} = \frac{0.02\psi F_{ys}}{\lambda \sqrt{f'_c}} d_b^*$	$V_s = F_{ys}A_{sa}$	Bars within $0.5c_{a1}$ or $0.3c_{a2}$
Widianto et al. (2010)	$\sigma_s A_{sa} = F_{uta}A_{se,V} \text{ or } 2.5V_{sd}$ σ_s reduced for not fully developed bars	Not considered in Strut-and-tie model	$V_s = V_{sd}$	Stirrups, ties and J-hooks
Fib design guide (to be published)	$0.5F_{ys}A_{sa} = V_{sd} \left(\frac{e_s}{z} + 1 \right)$	Considered in capacity calculation	$V_s = \sum l_{dh} u \frac{f_{bd}}{\alpha_{re}}$	Bars within $0.5c_{a1}$
Proposed	$F_{ys}A_{sa} = 0.6F_{uta}A_{se,V}$	$8d_b$ on both sides	$V_s = 0.45F_{uta}A_{se,V}$	Closed stirrups within c_{a1}

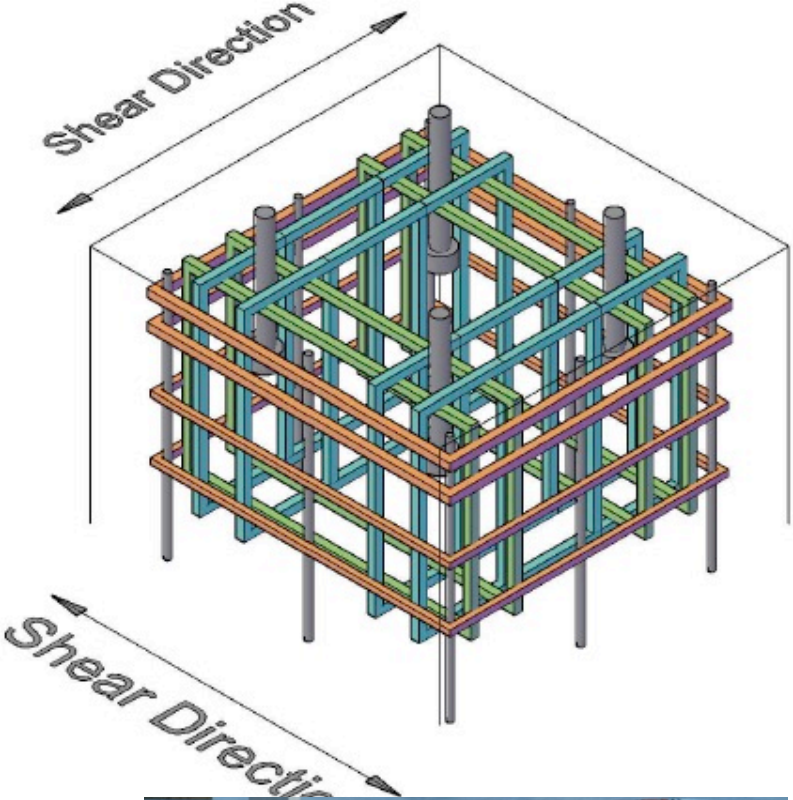
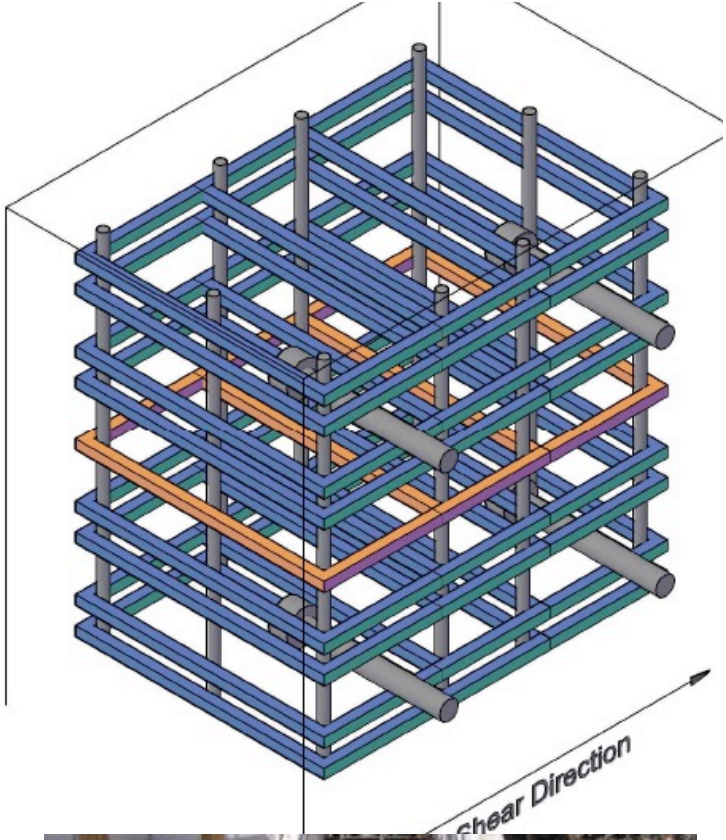
Proposed Anchor Reinforcements

- Breakout cone restrained by reinforcements
- Concrete provides shear and tension resistance
- Anchor yielding or fracture controls failure



Proposed Anchor Reinforcements

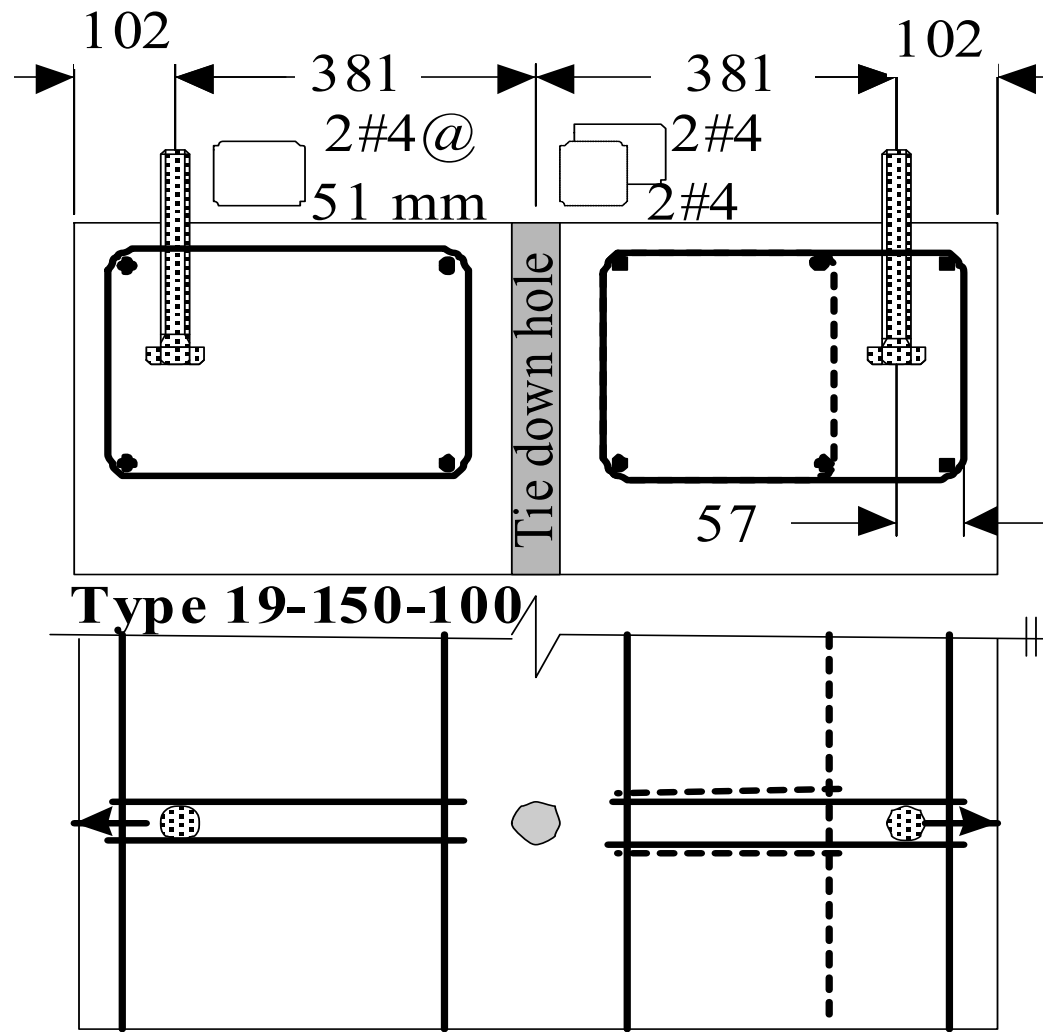
- Stirrups
- Ties
- J-hooks



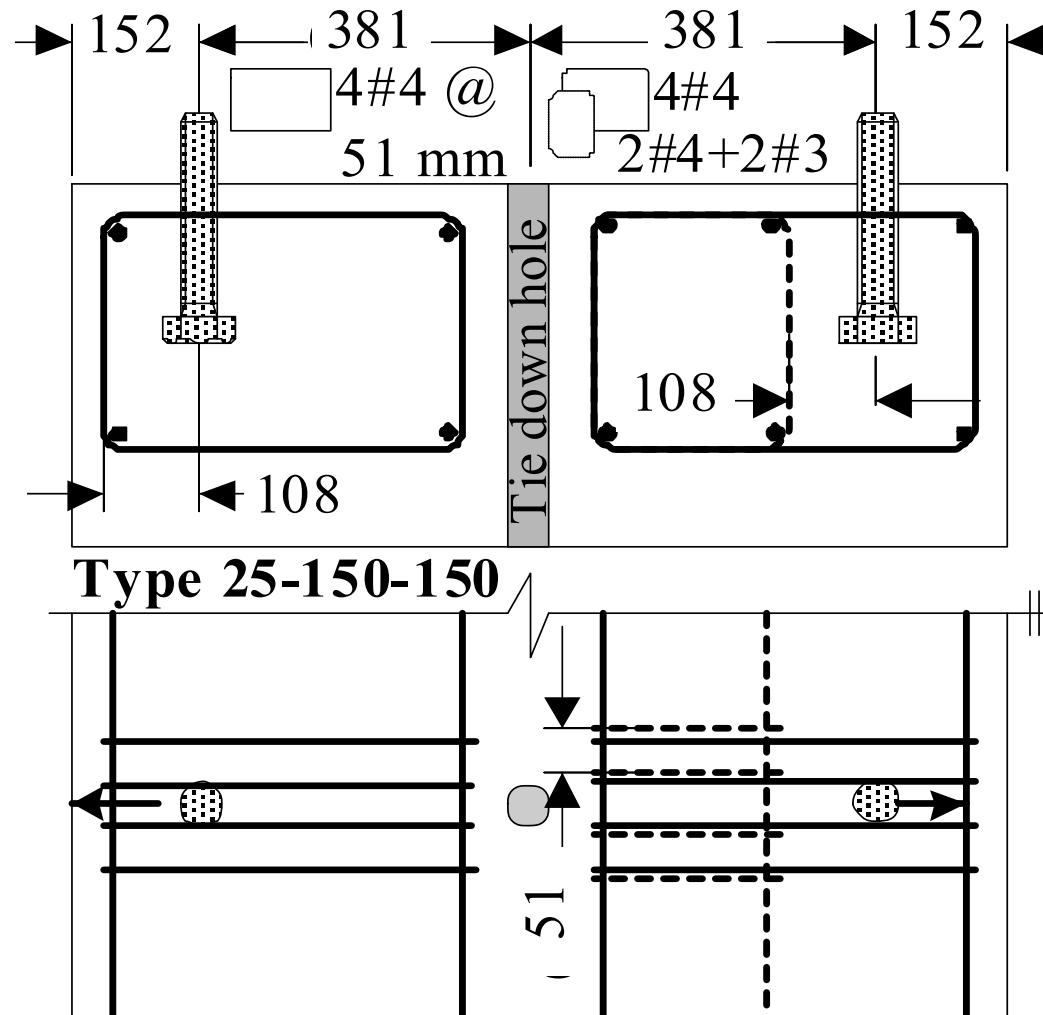
Phase II Test Matrix

Specimen ID	Block Type	d _a (in.)	C _{a1} (in.)	Load Type	Peak load (kips)
9132010	-	0.75	4	M	22.19
9132010_2	-	0.75	4	M	22.47
9172010	-	0.75	4	C1	16.69
9202010	-	0.75	4	C1	15.50
9282010	-	1.0	6	M	39.18
9292010	-	1.0	6	M	44.11
9302010	-	1.0	6	C1	38.71
10042010	-	1.0	6	C1	35.92
10052010	-	1.0	6	C1	34.35
10062010	H	1.0	6	M	38.40
10062010_2	H	1.0	6	M	34.71
10072010	H	1.0	6	M	33.40
10082010	H	1.0	6	C1	33.62
10082010_2	H	1.0	6	C1	31.77
10122010	H	1.0	6	C1	33.88
10132010	H	1.0	6	C2	-42.68*
10142010	H	1.0	6	C2	-47.79*
10292010	SG	1.0	6	M	36.13
11192010	SG	1.0	6	M	39.33

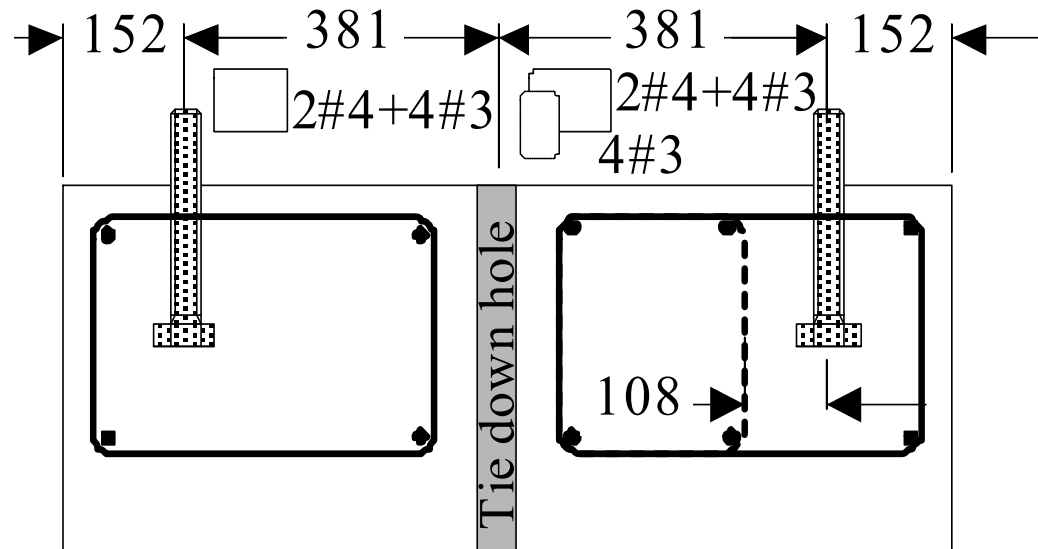
Specimen Design



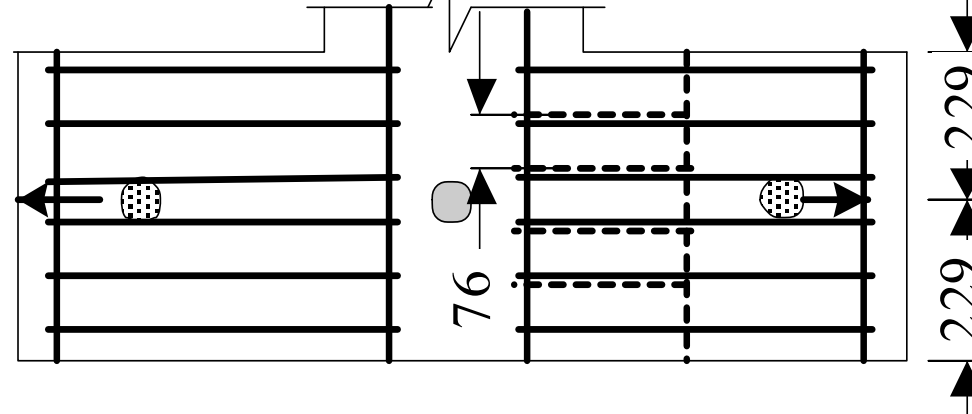
Specimen Design



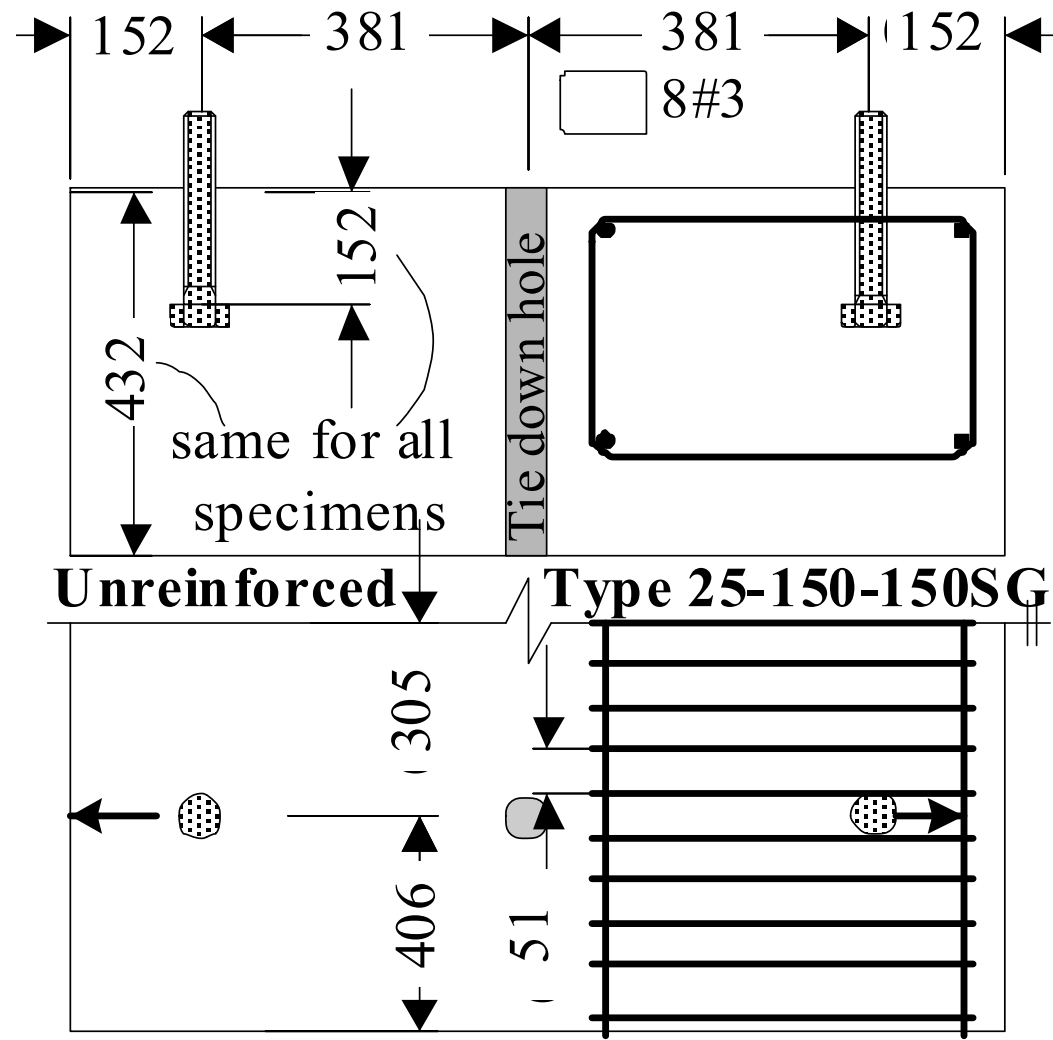
Specimen Design



Type 25-150-150H

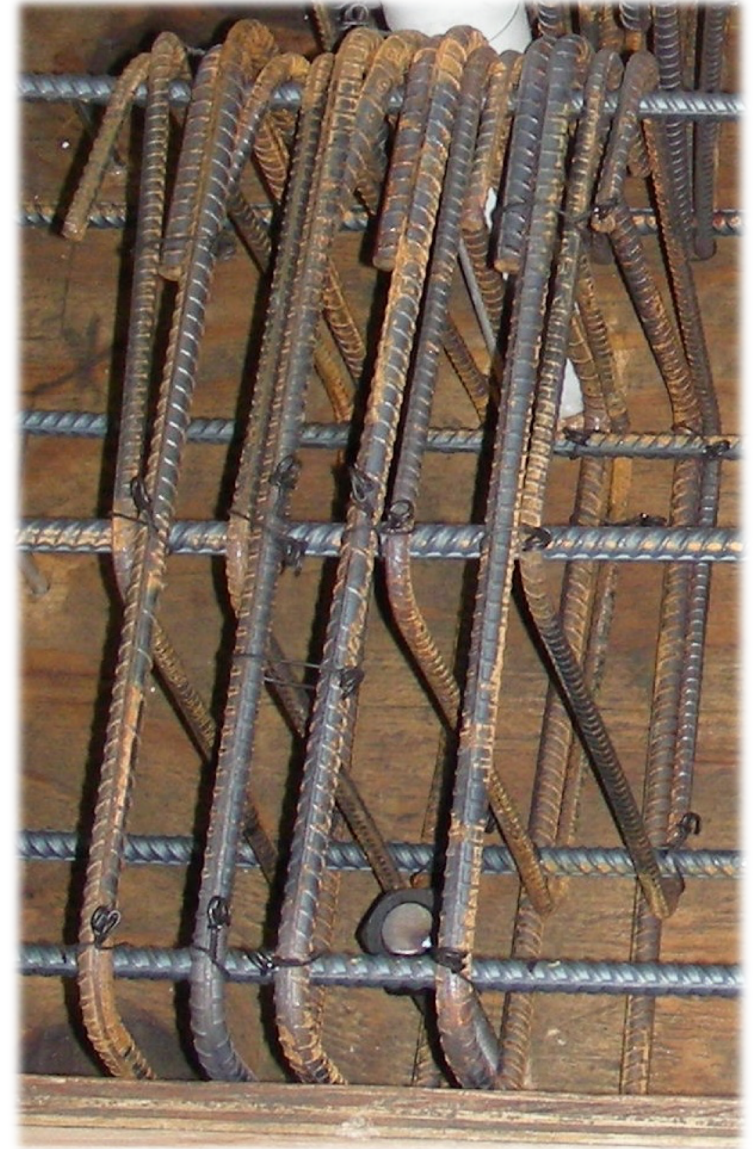


Specimen Design

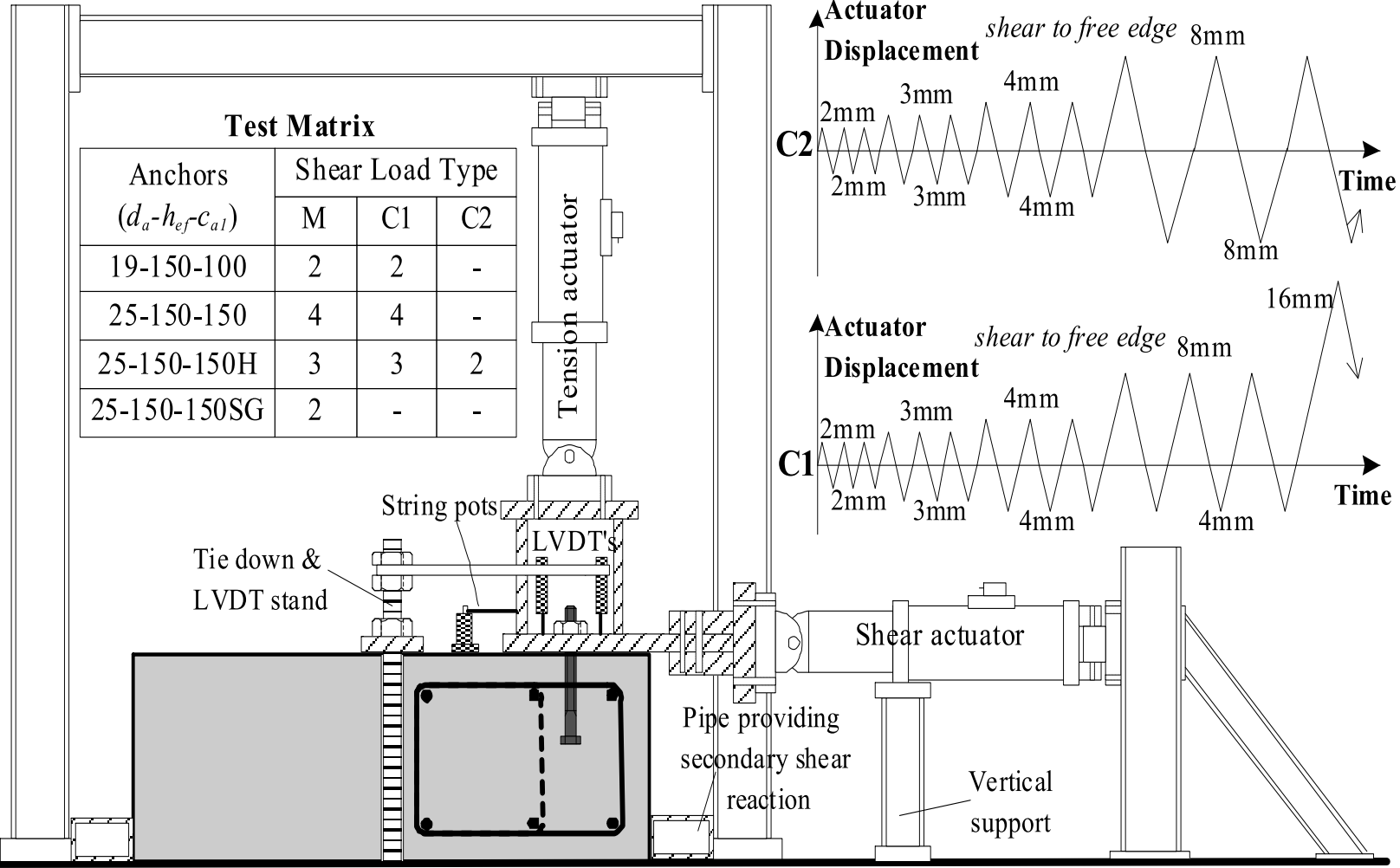


Reinforcement Design

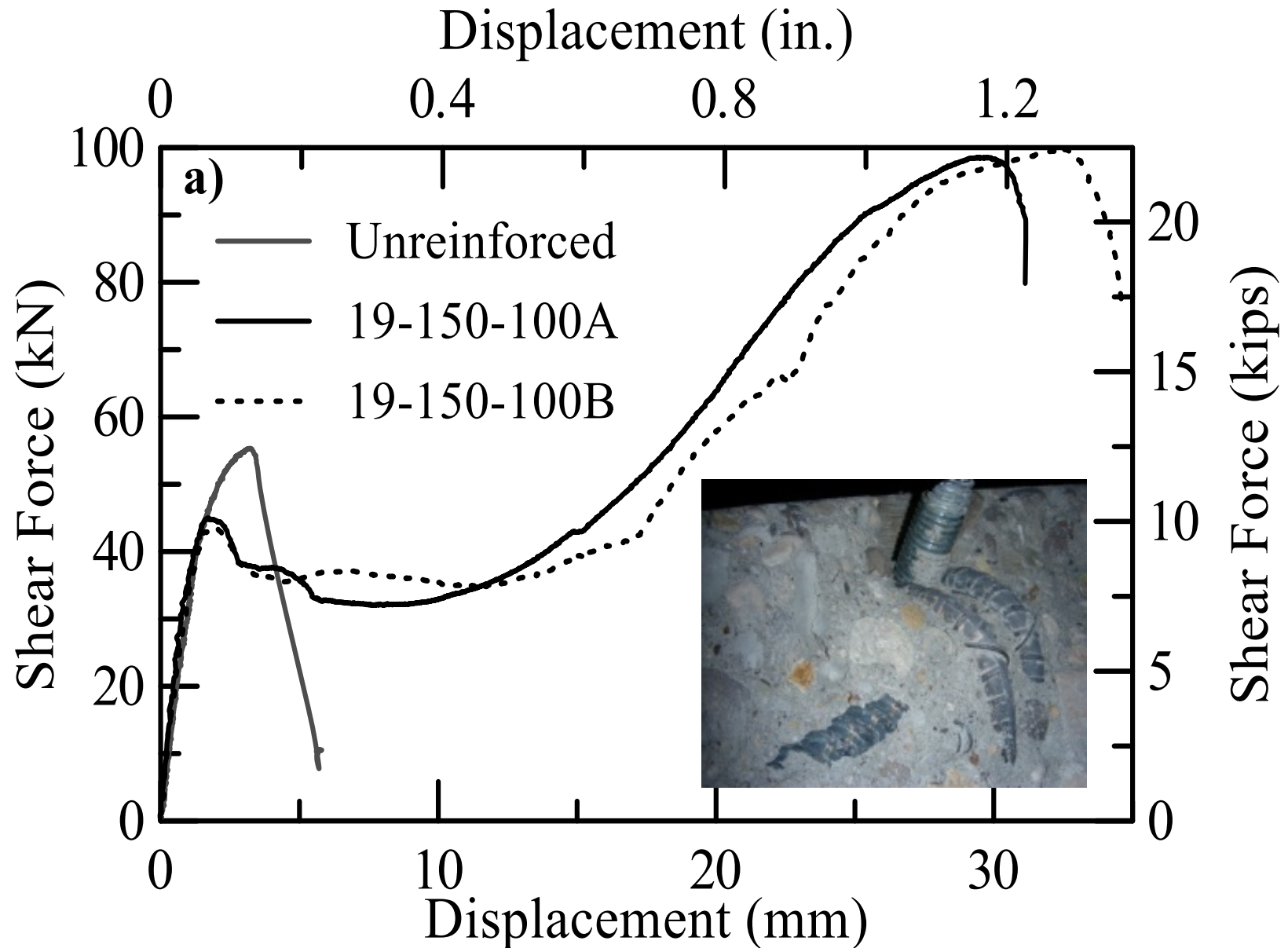
- Proportioned to resist full anchor steel capacity in tension or shear
- Development lengths inside assumed failure cone satisfied by interaction with corner bars
- Placed outside the limits of $0.5c_1$ and $0.5h_{ef}$
 - Limited side edge distance tests
 - Strain gauge tests



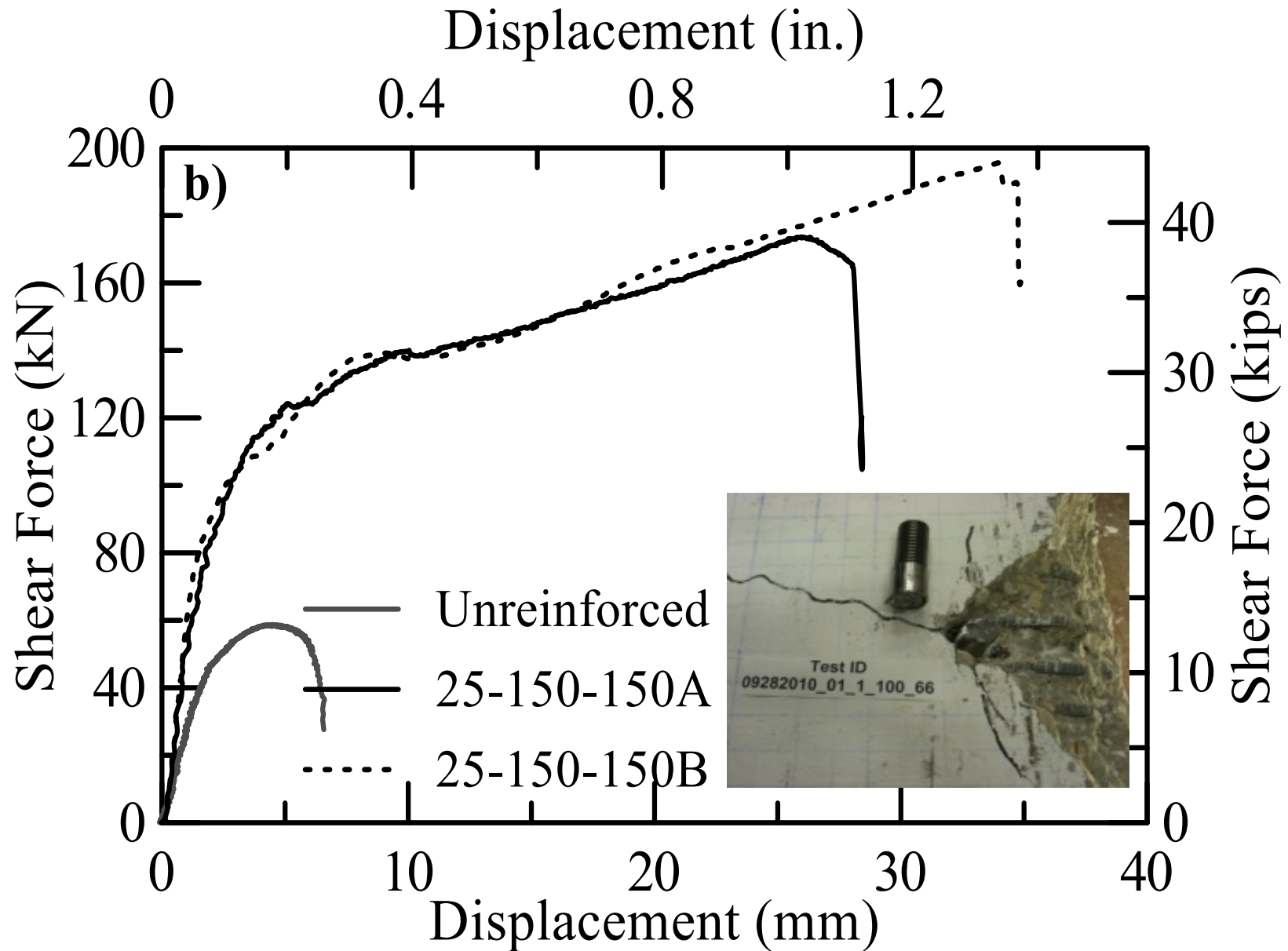
Test Setup



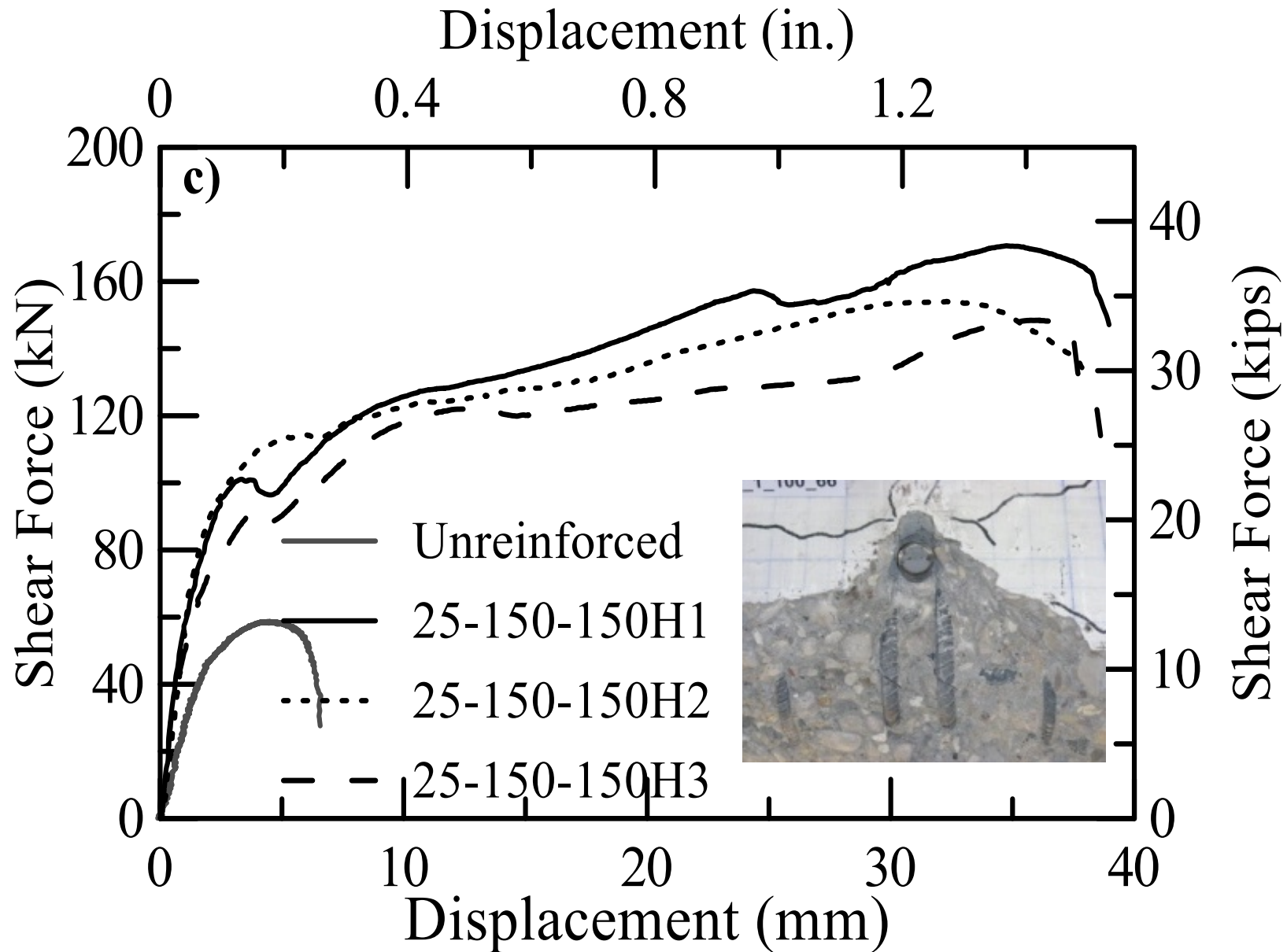
Reinforced Shear Tests



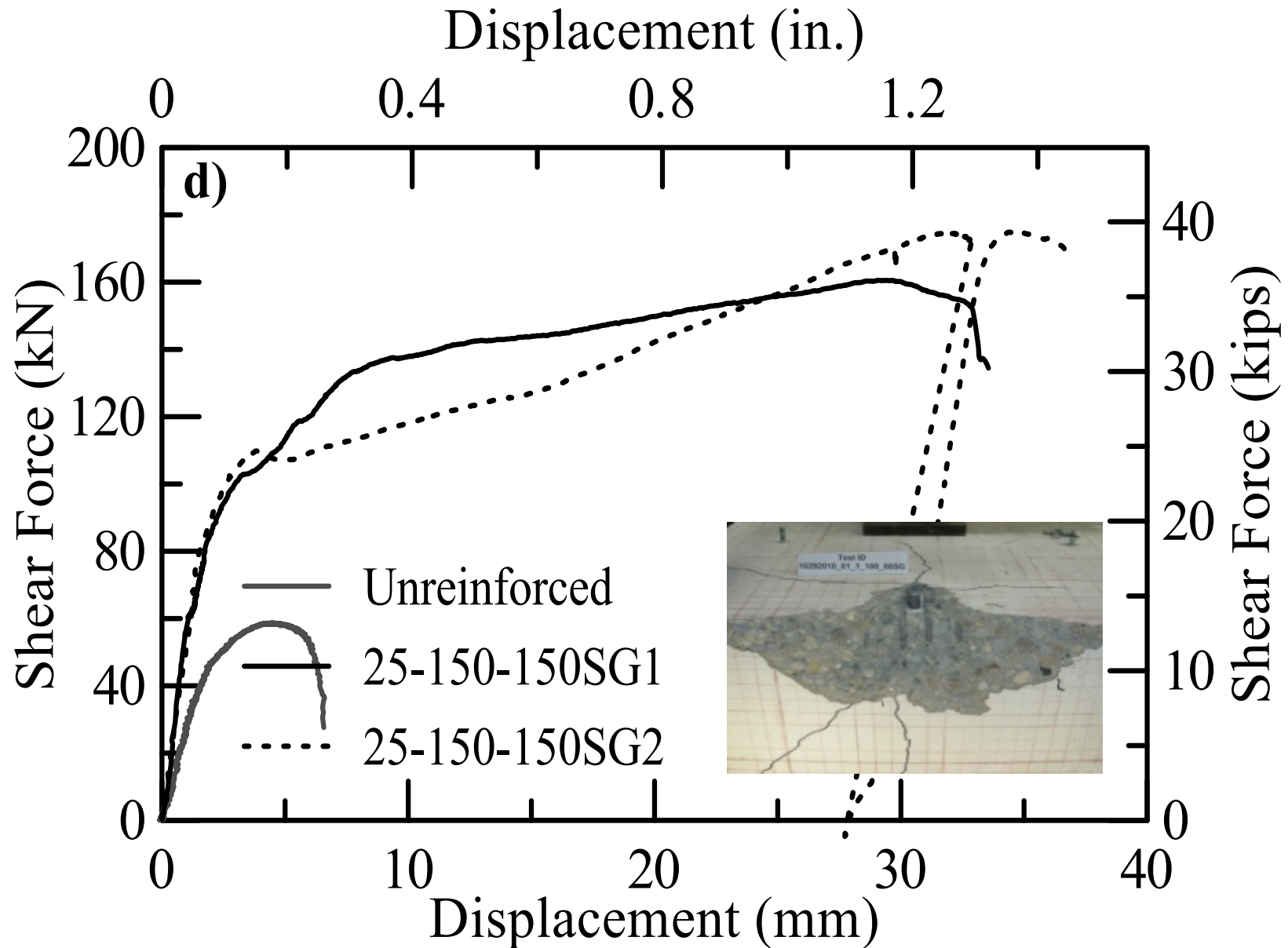
Reinforced Shear Tests



Reinforced Shear Tests



Reinforced Shear Tests



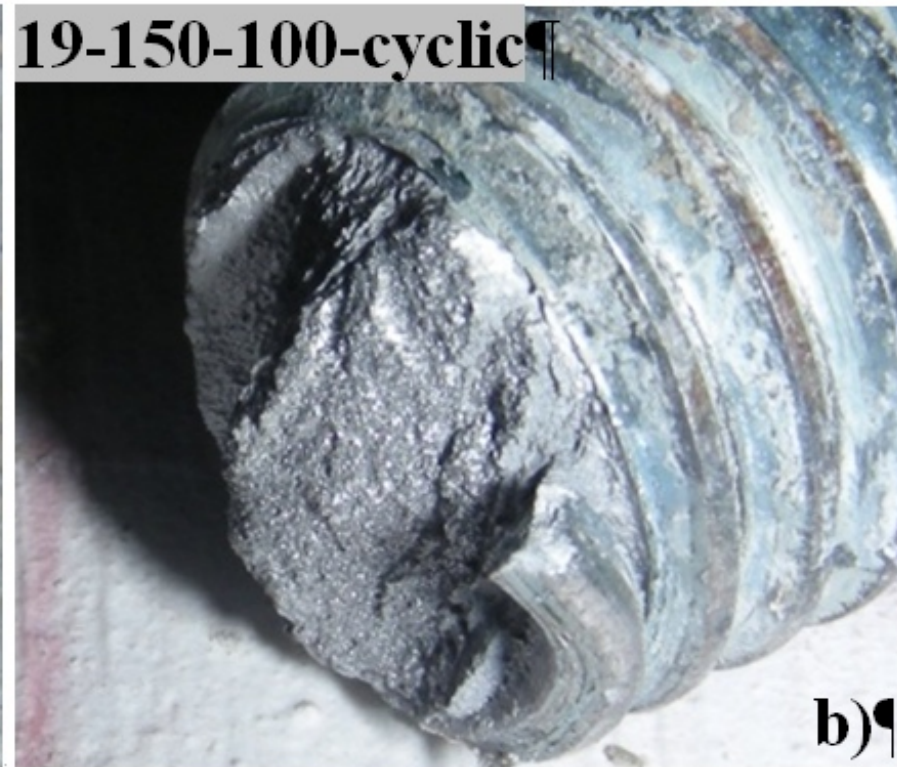
Confining reinforcement



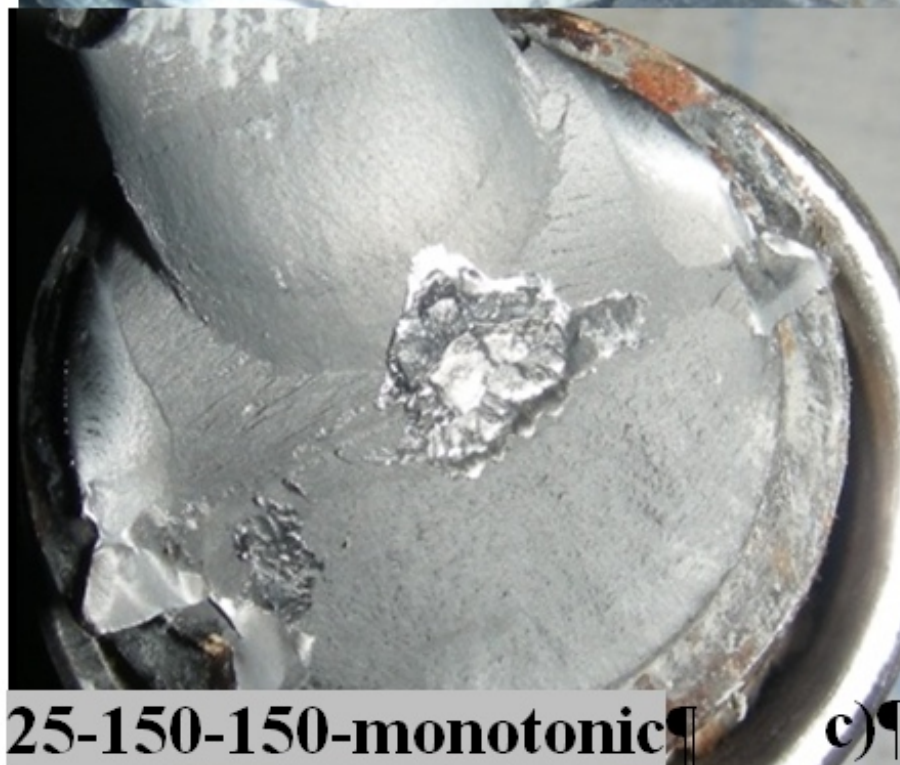
19-150-100-monotonic



19-150-100-cyclic

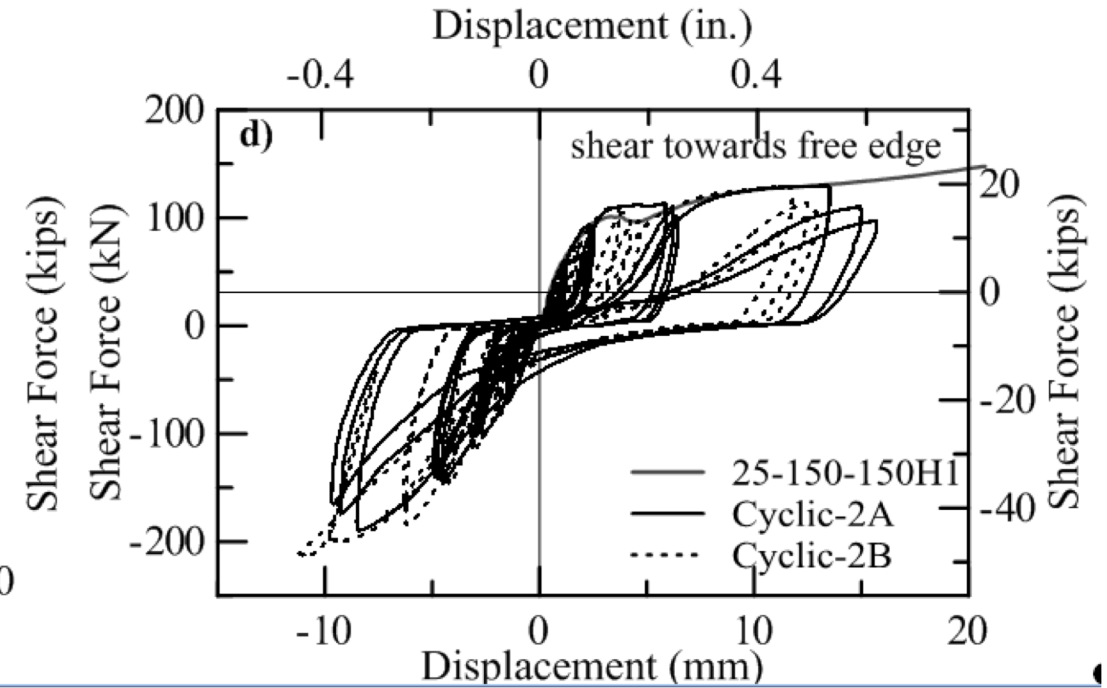
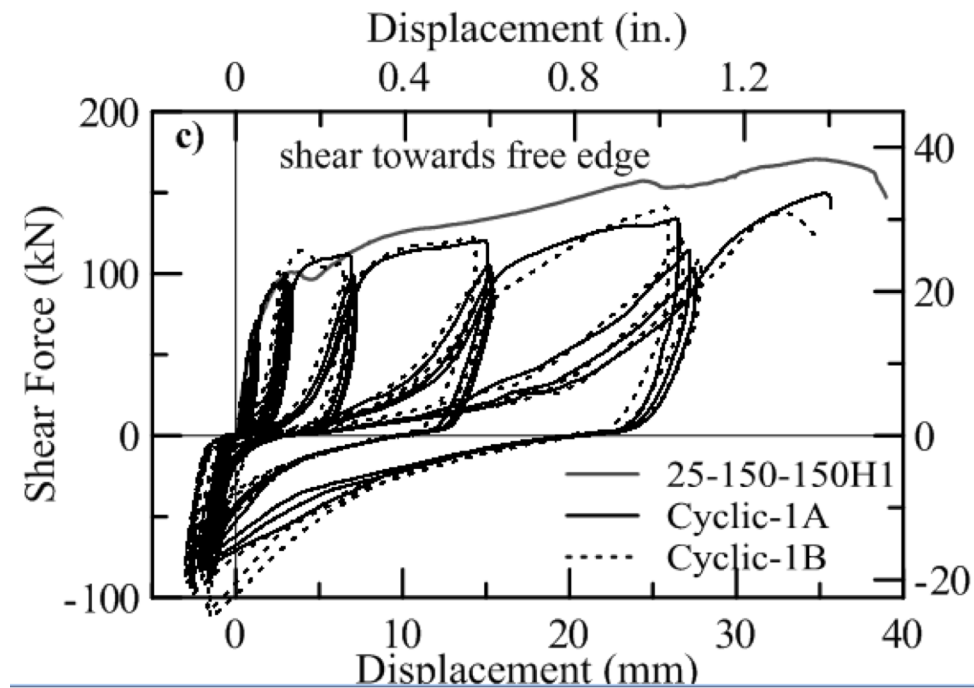
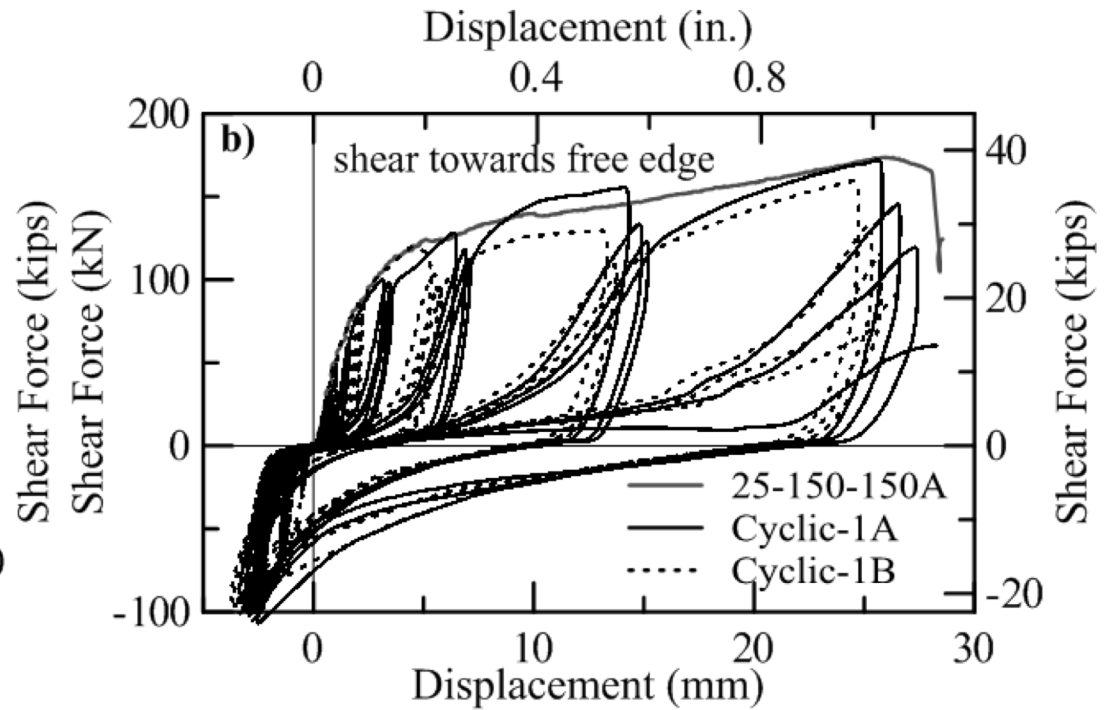
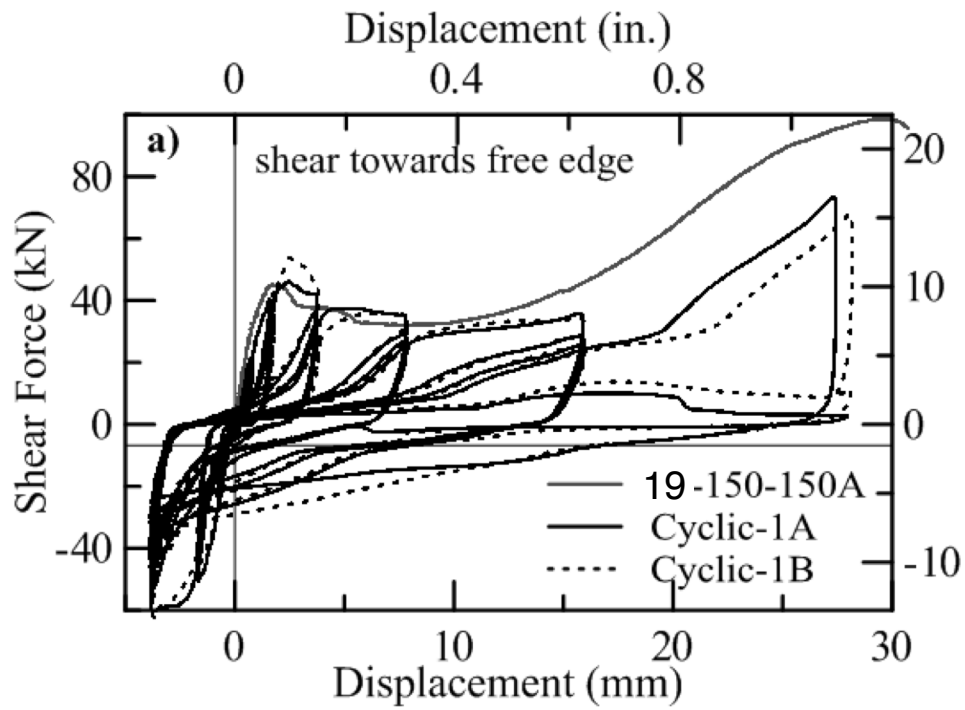


25-150-150-monotonic

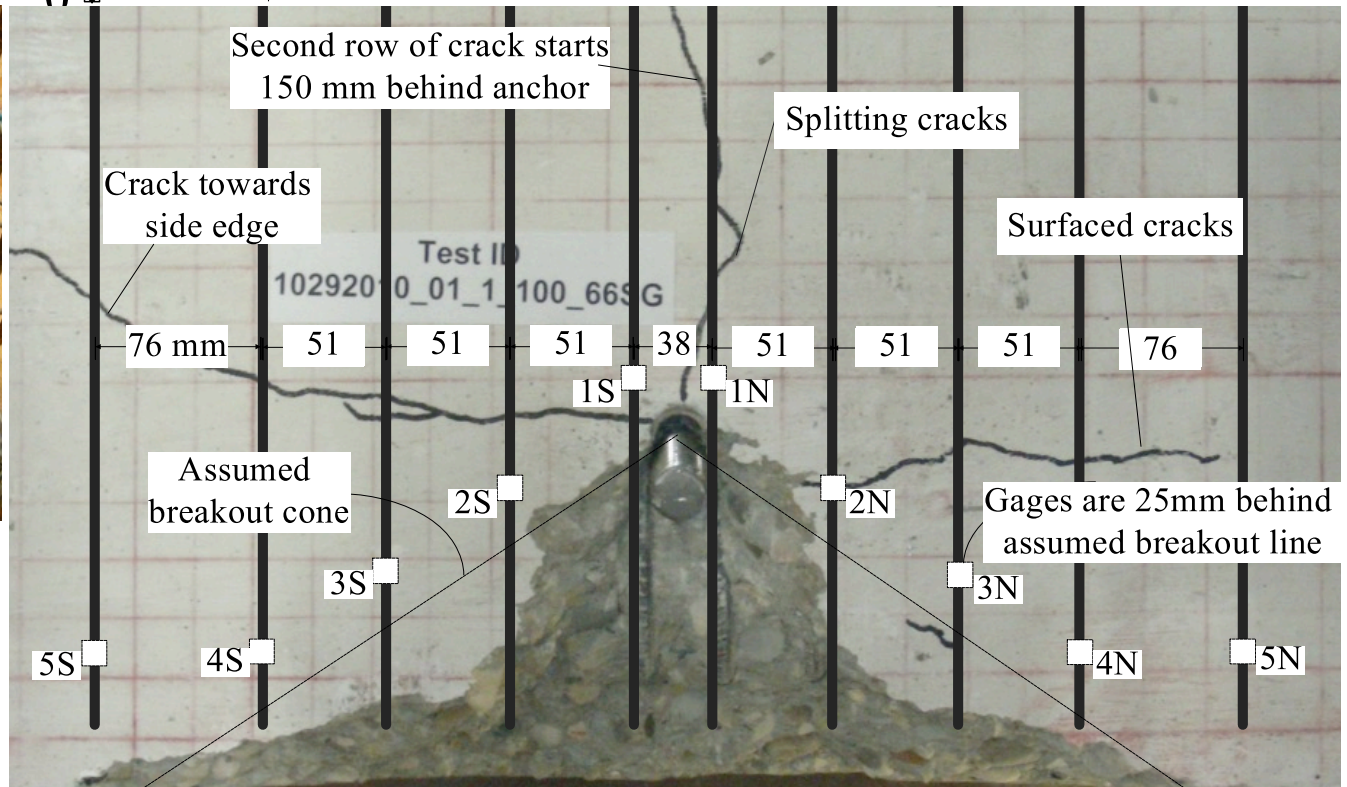
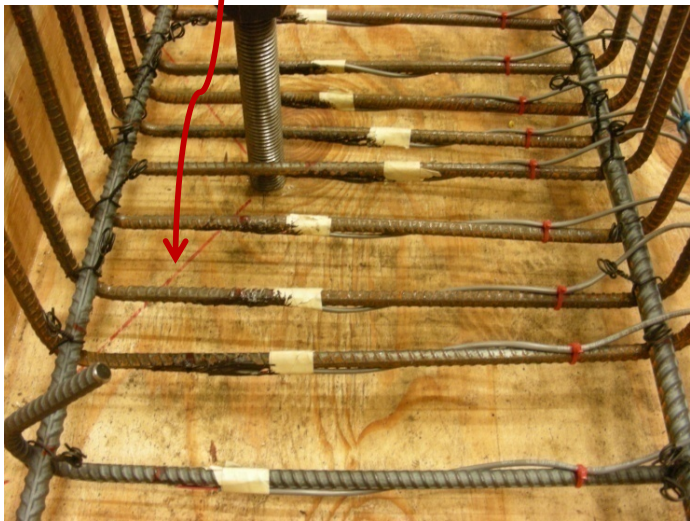
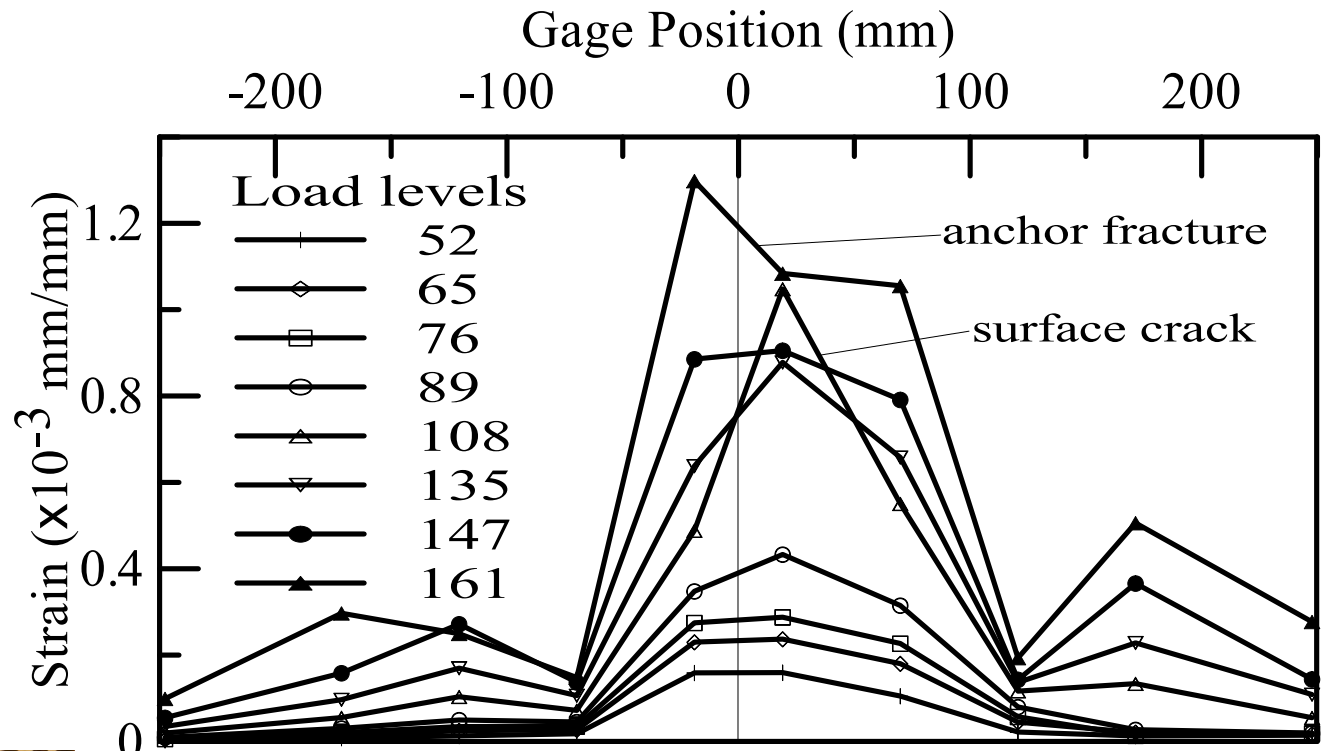


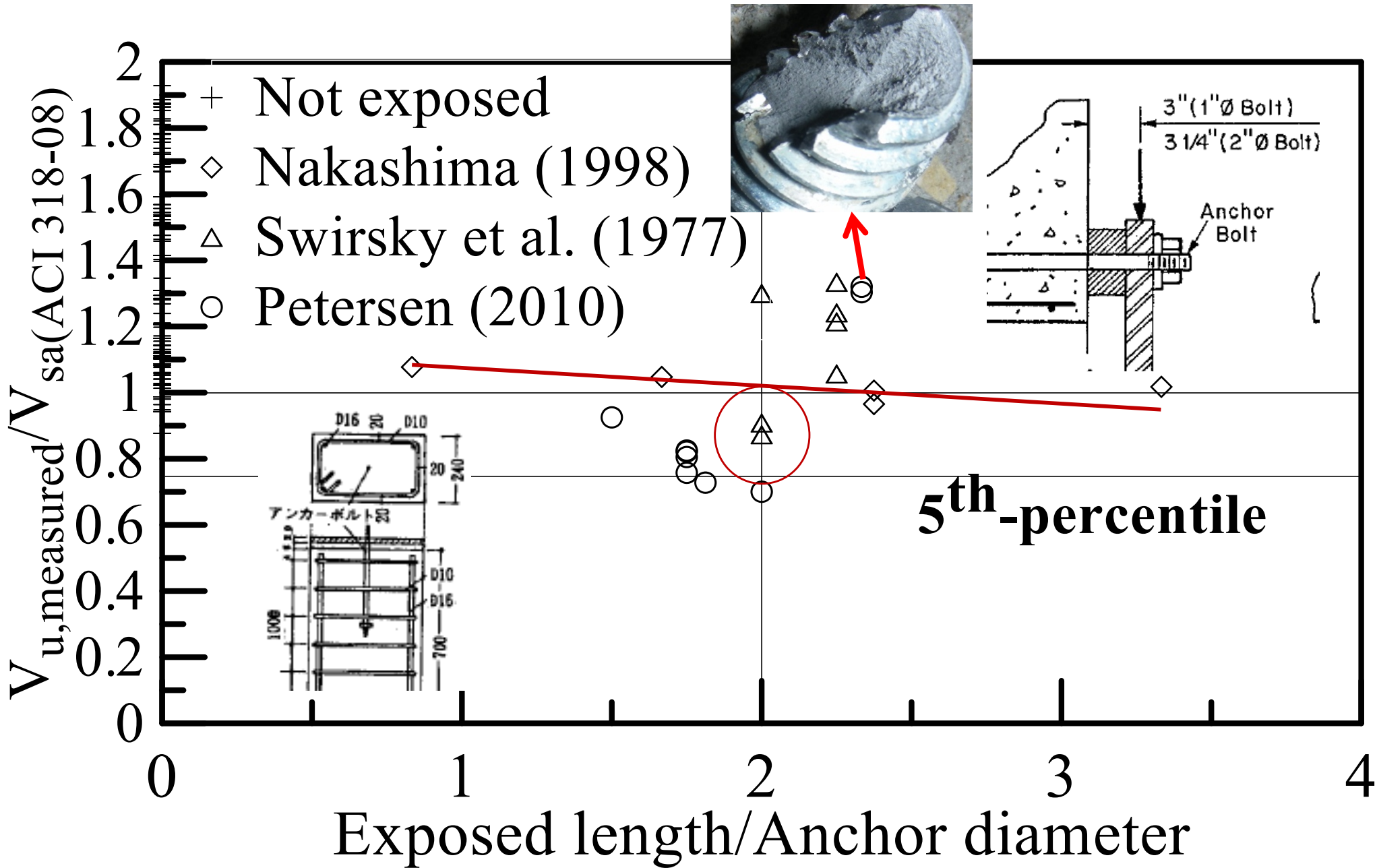
25-150-150-cyclic



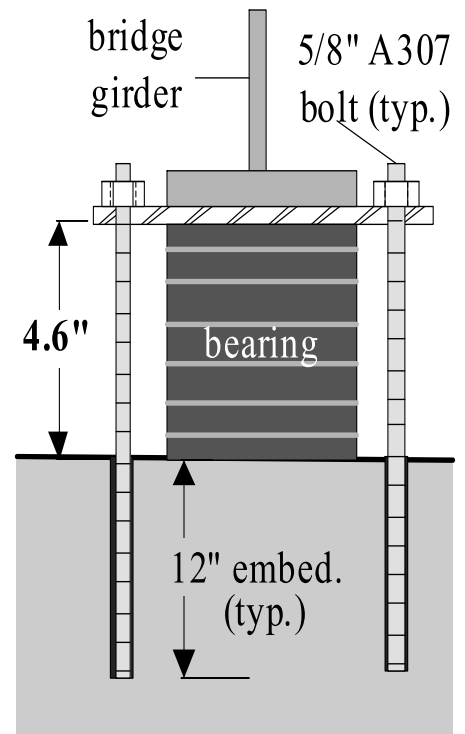
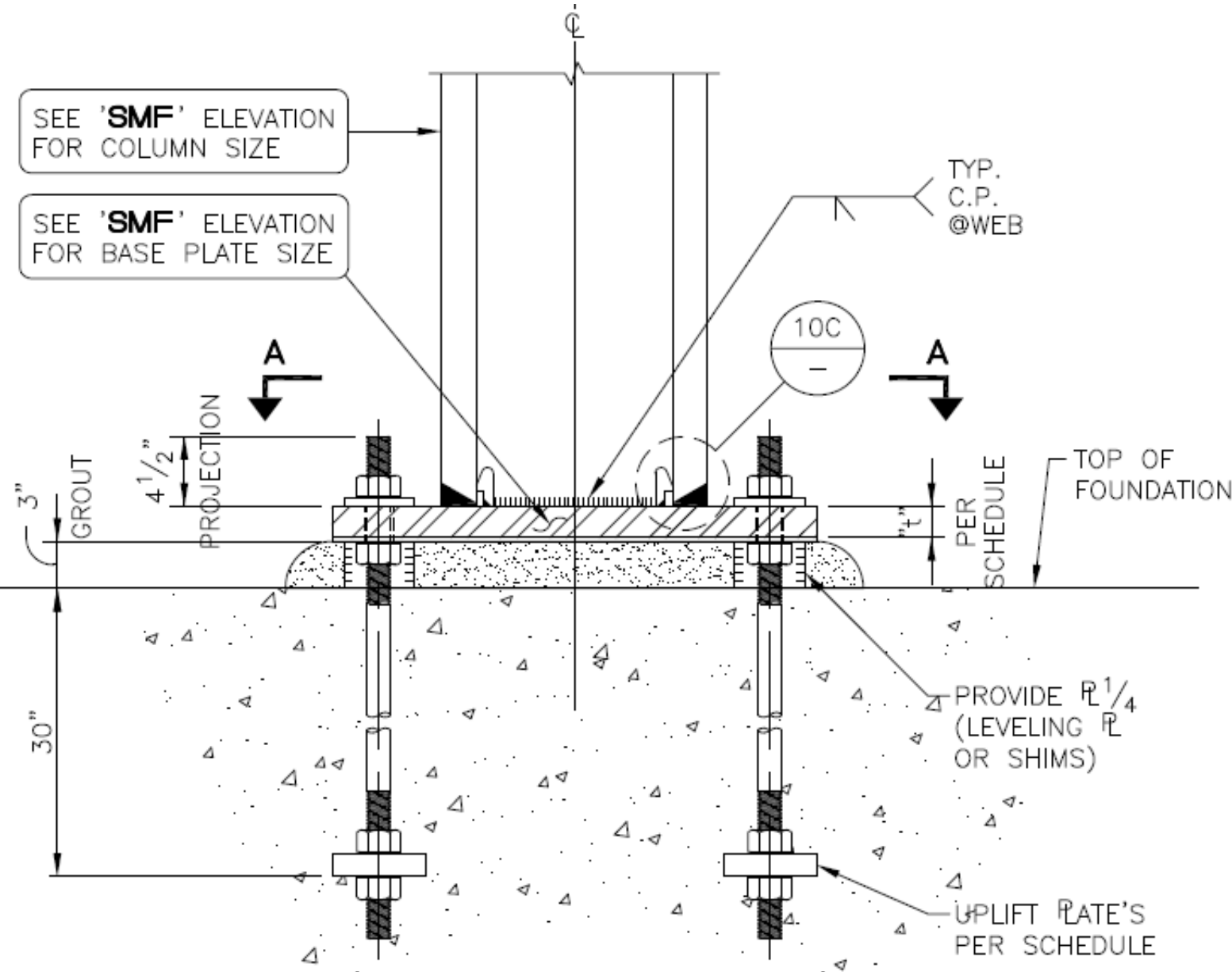


- Gages are 25 mm behind the assumed 35° cone



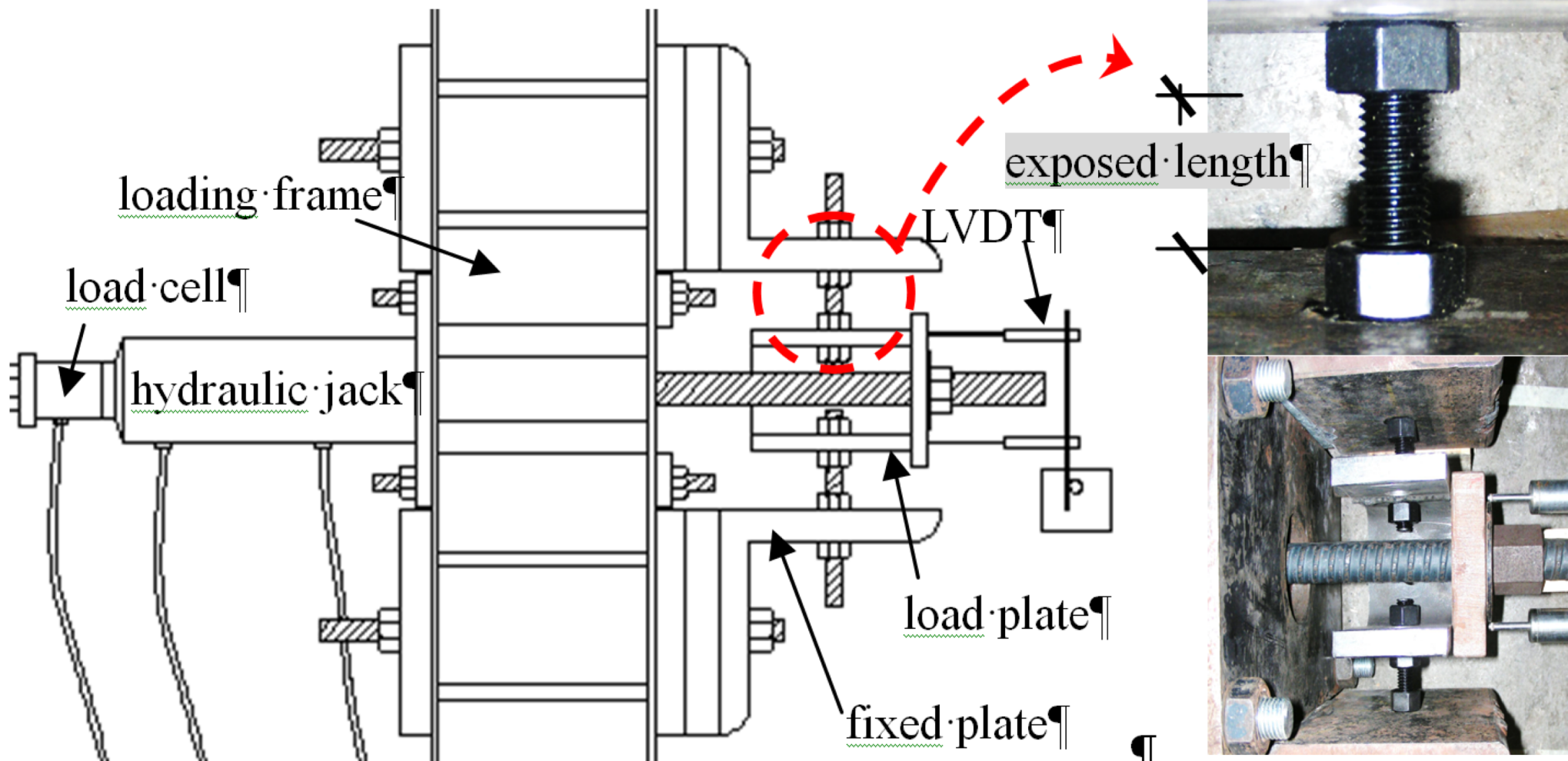


Exposed anchor bolts in various types of connections

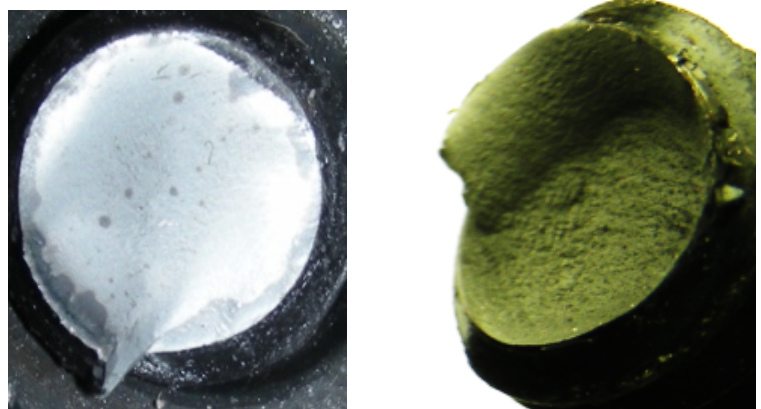
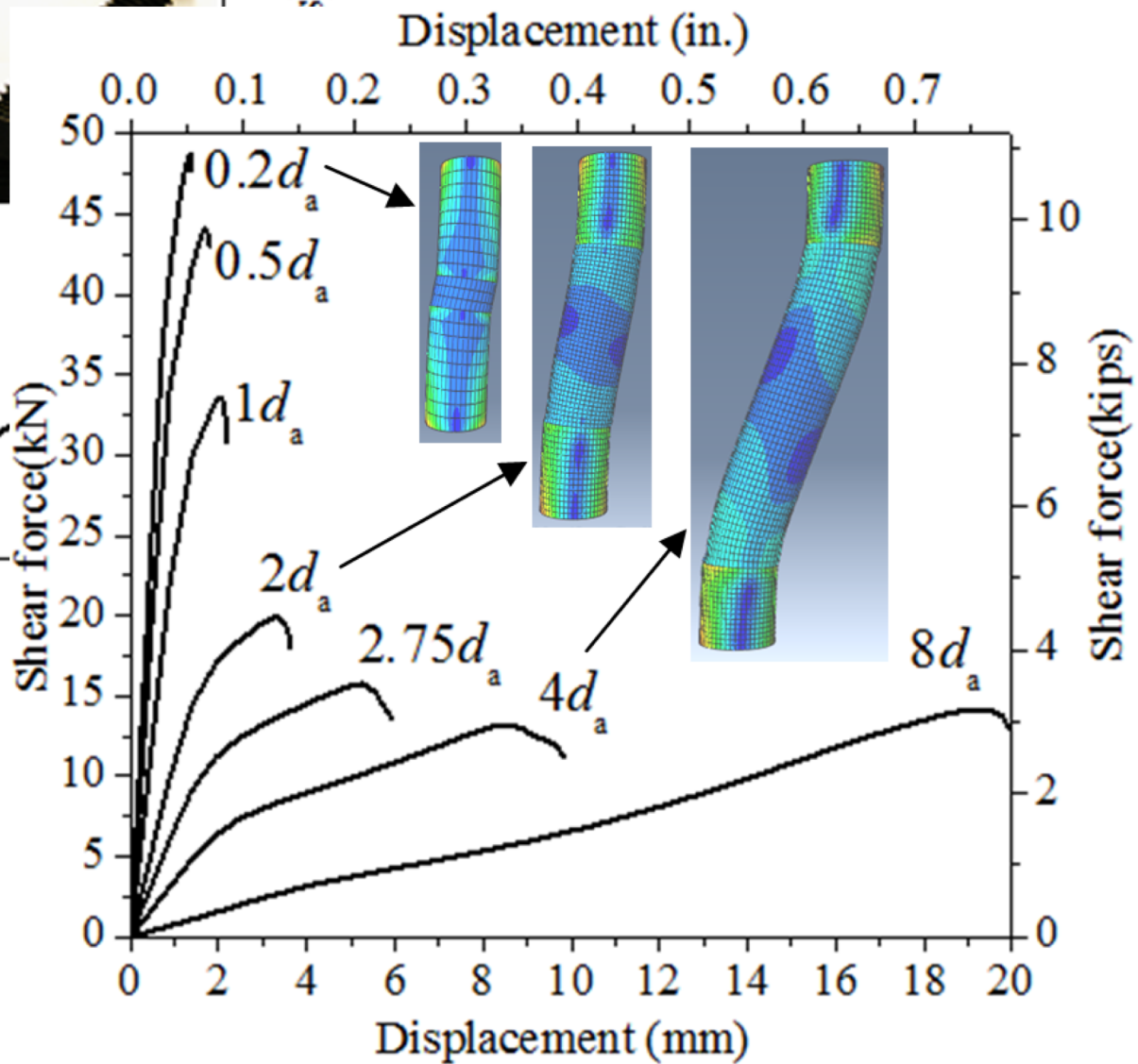
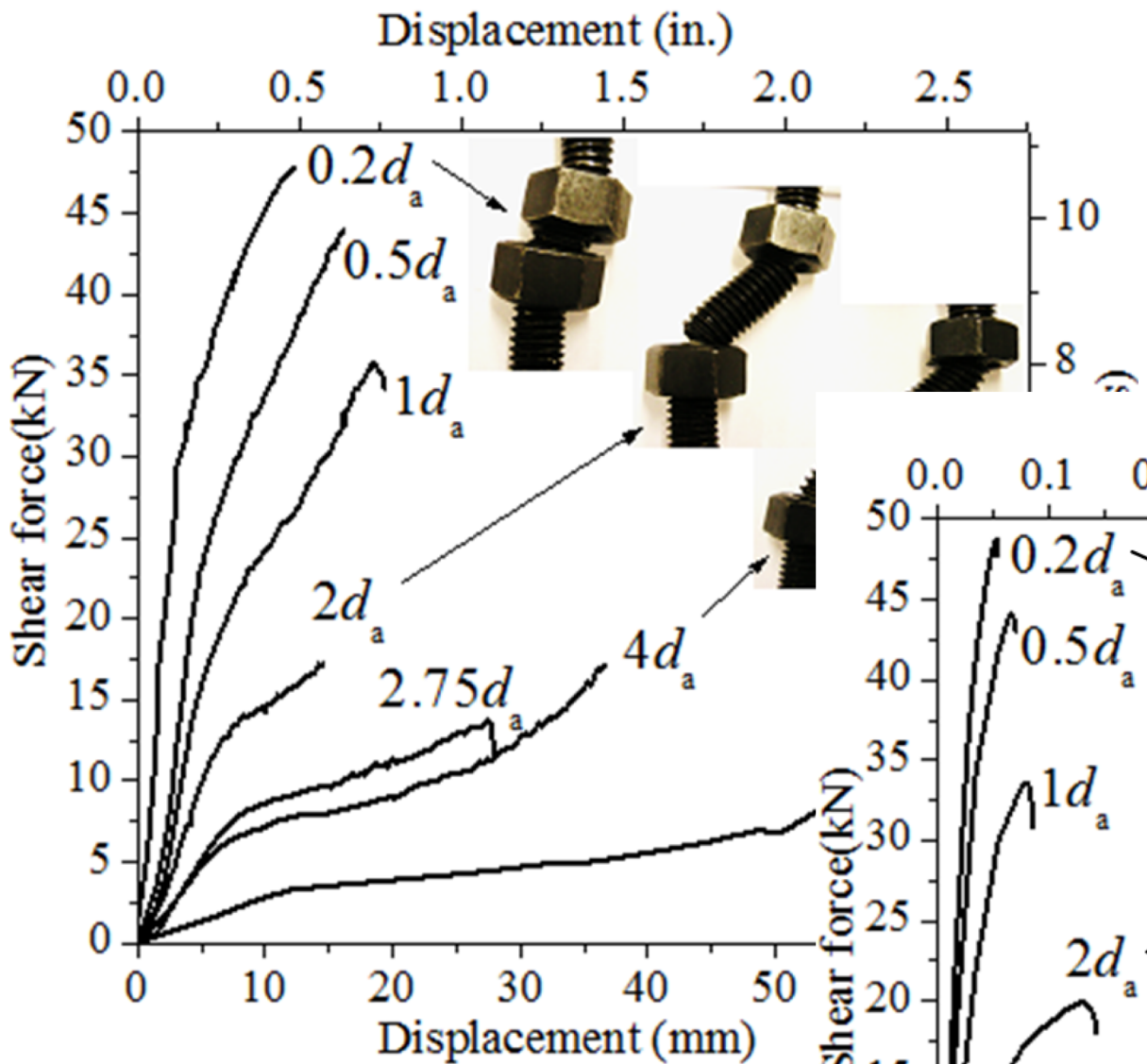


ing in bridge

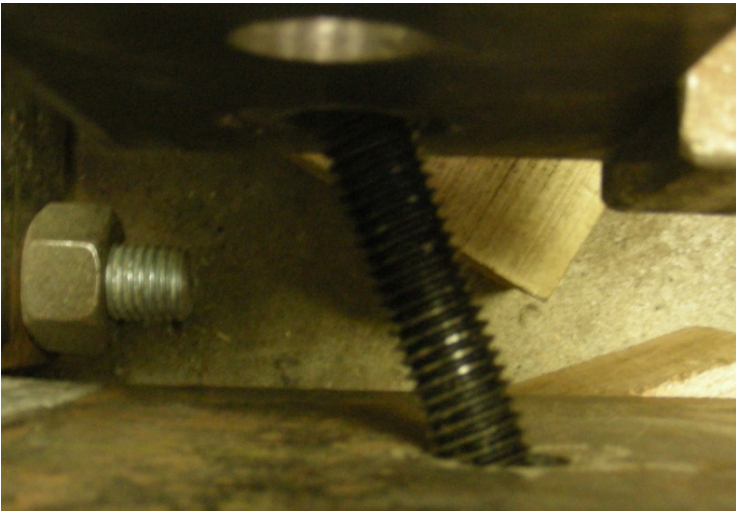
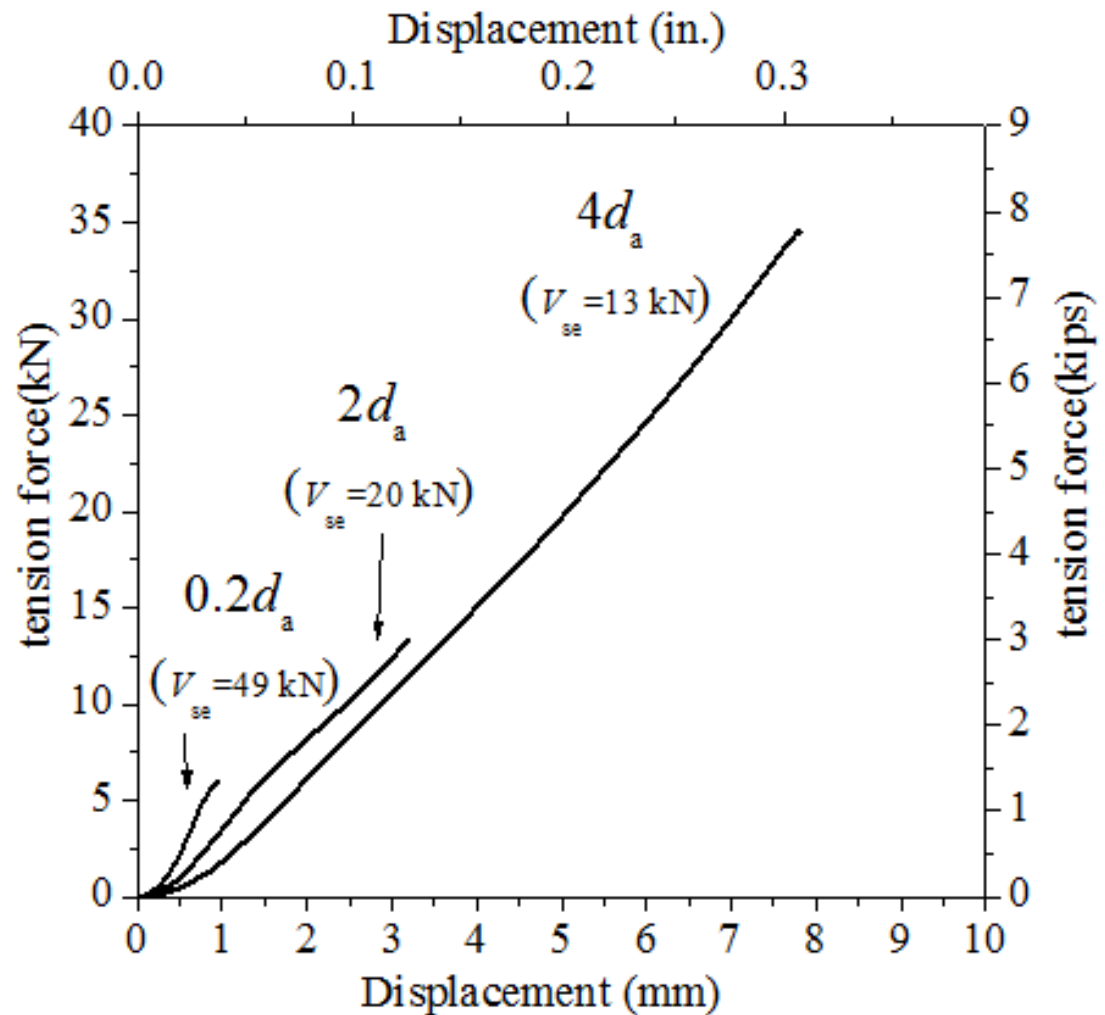
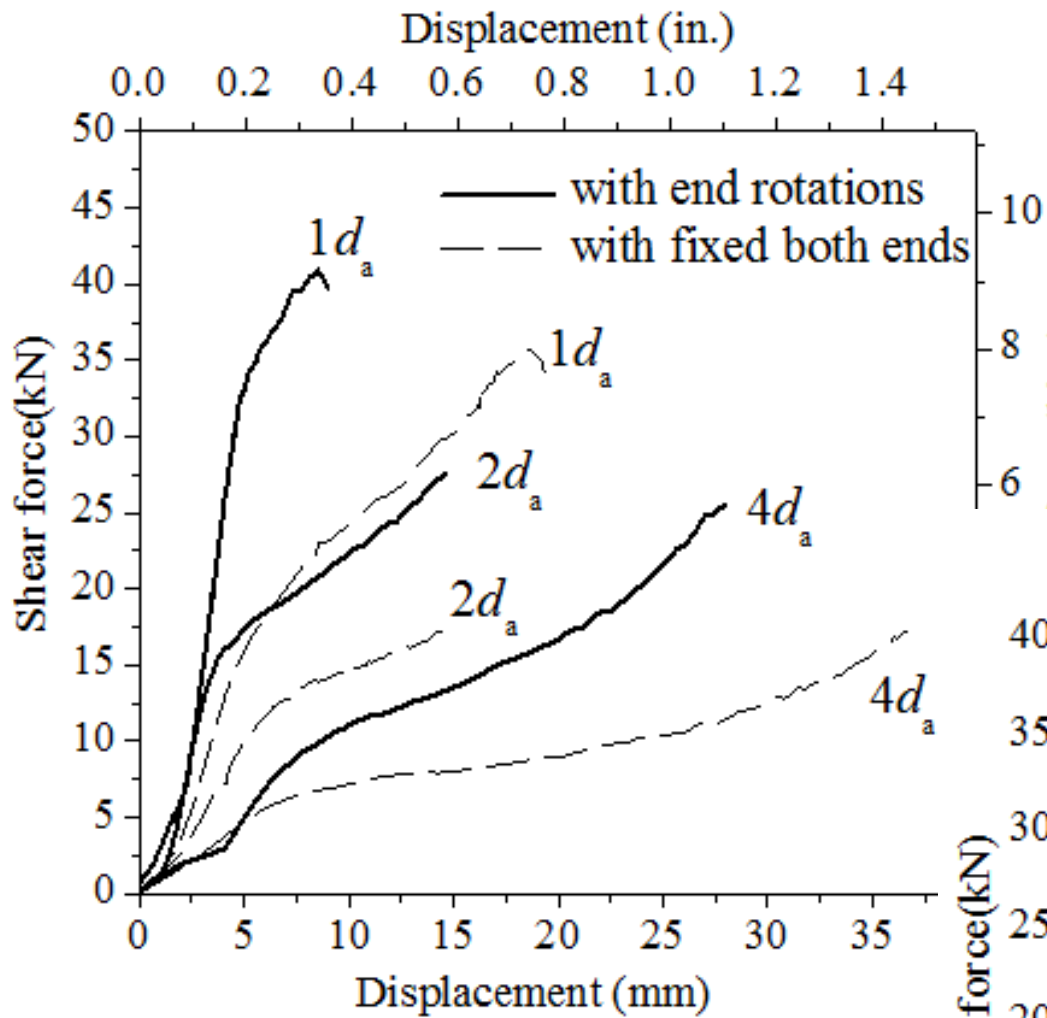
Exposed anchors in shear

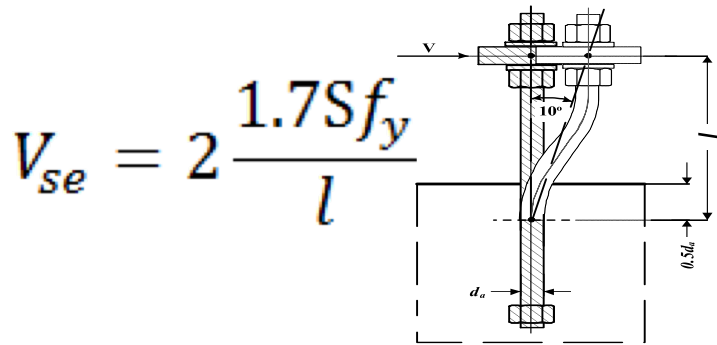
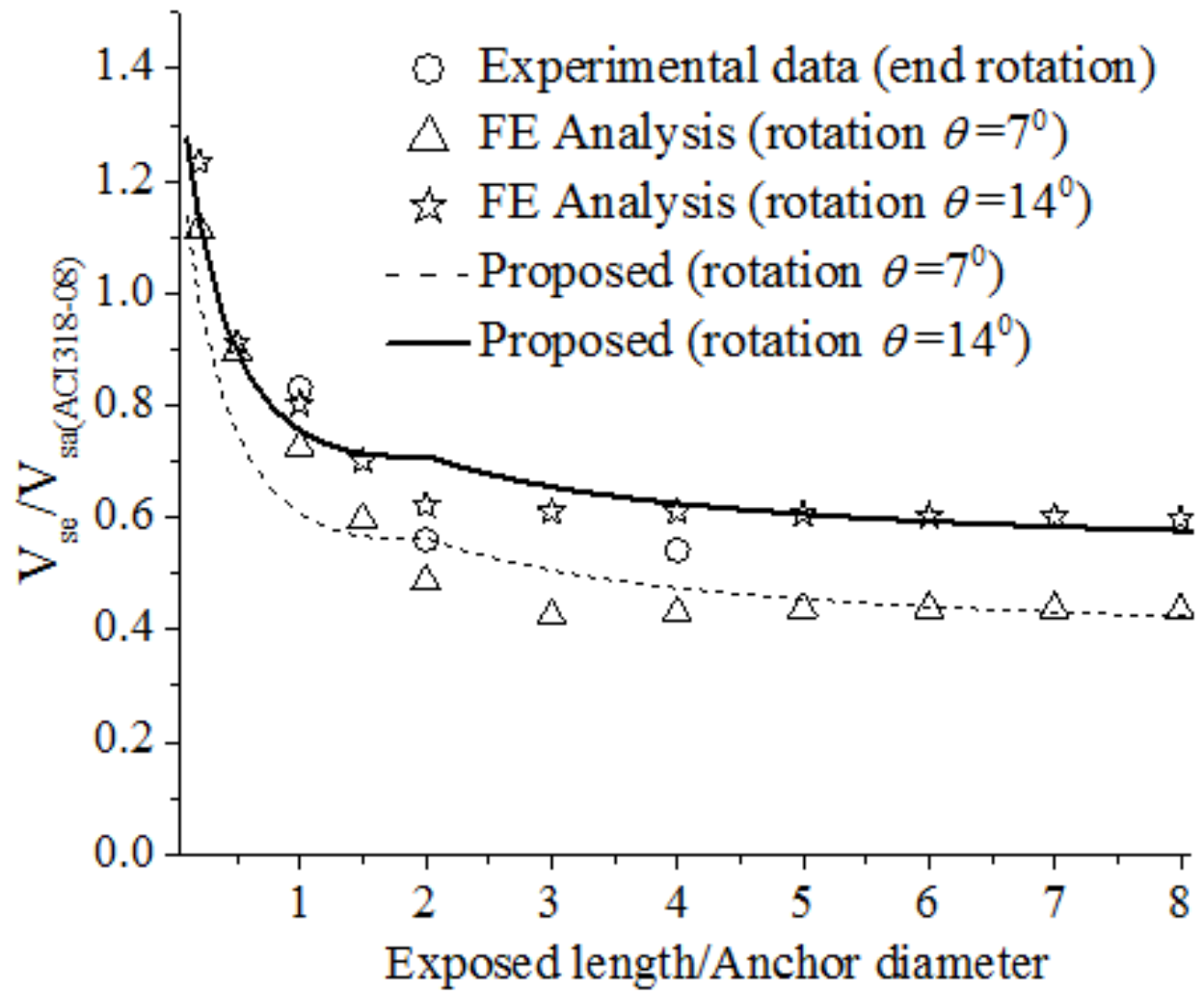
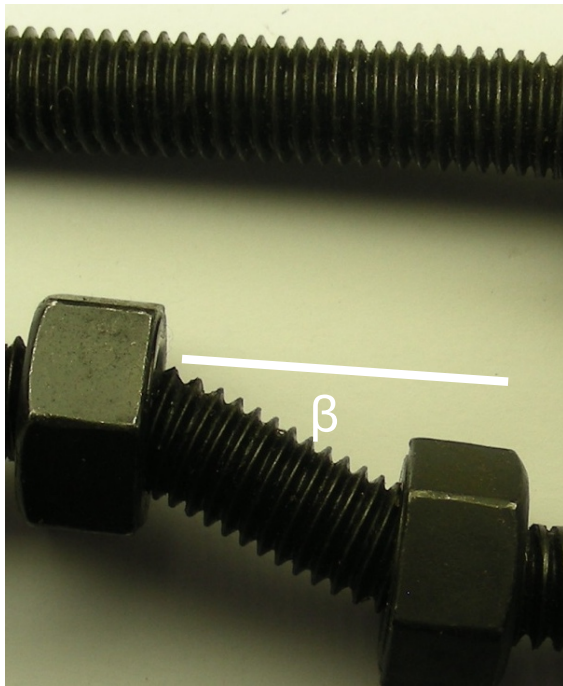


Exposed anchors in shear



End Rotation





$$V_{se} = 2 \frac{1.7Sf_y}{l}$$

$$V_{se} = f_y A_{se,v} \sin \beta + \frac{f_y \cos \beta}{\frac{1}{0.9A_{se,v}} + \frac{l}{3.4S}}$$

$$\beta = \theta + l_p \tan^{-1} \frac{\epsilon_{max}}{d_a}$$

Minimum elongation of anchor steel



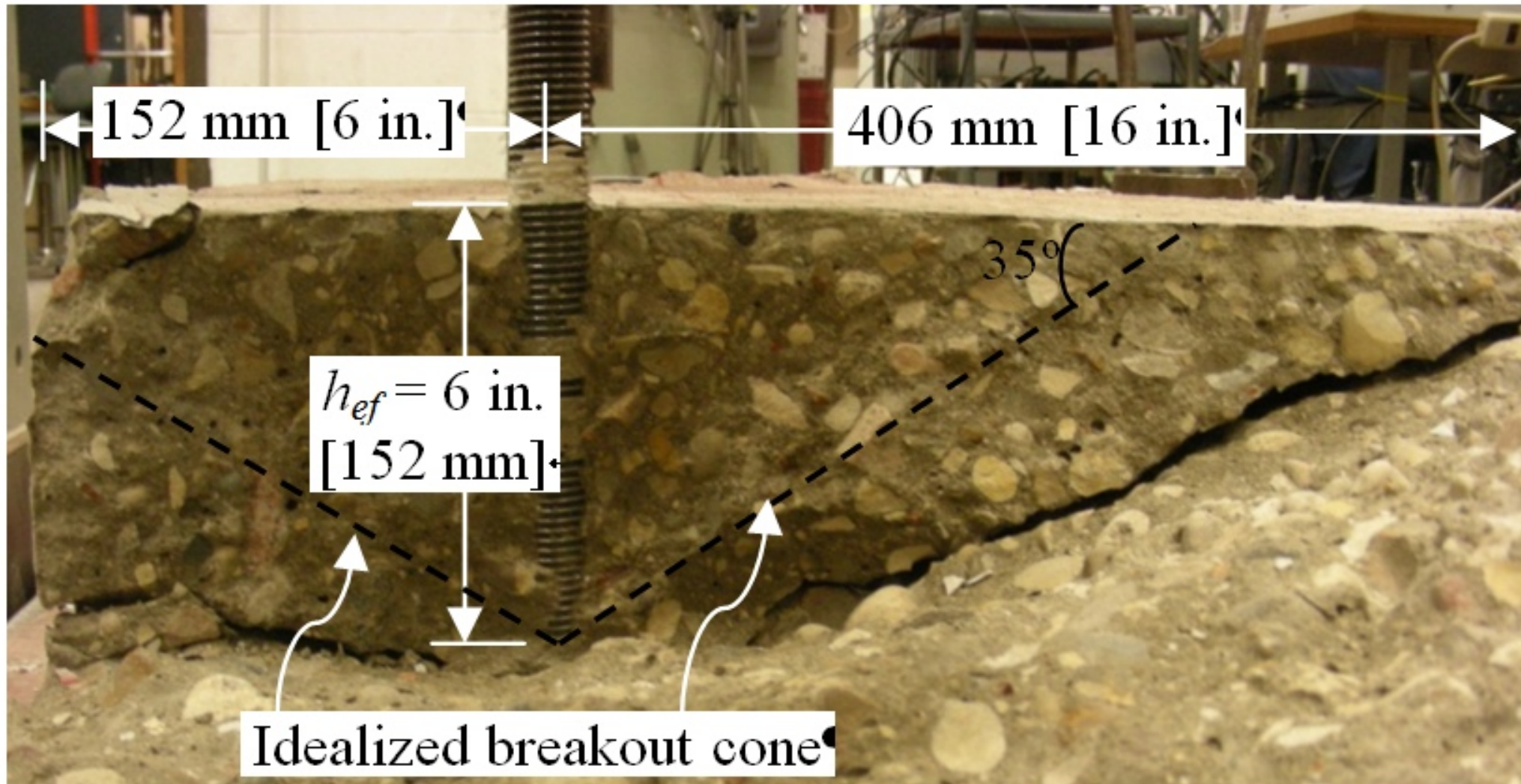
Conclusions From Phase II Tests

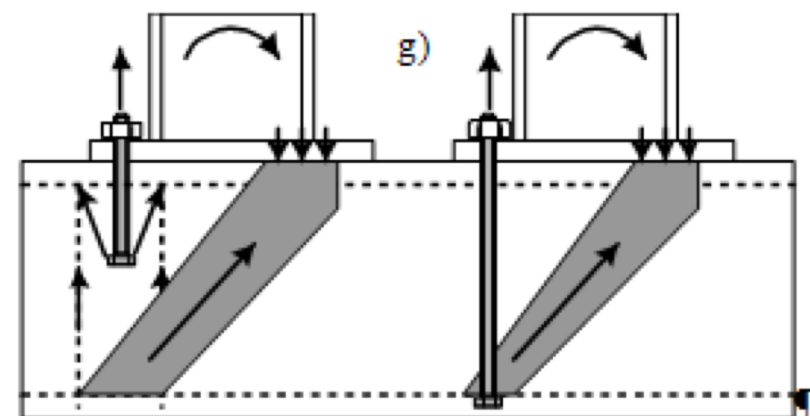
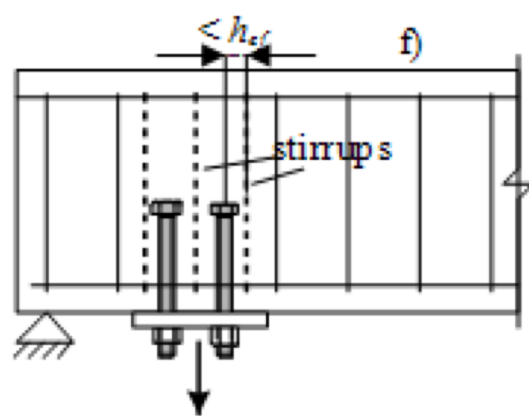
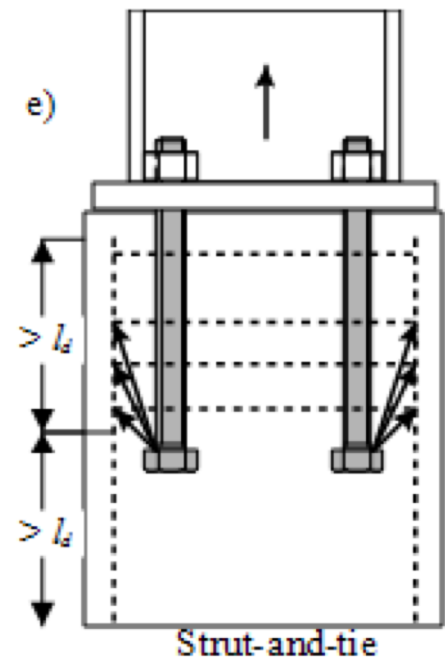
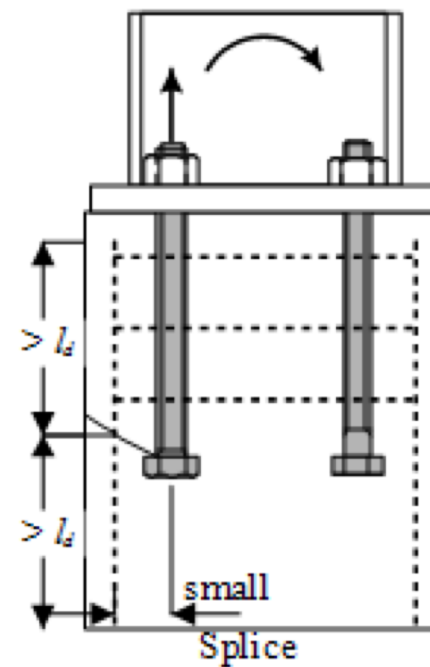
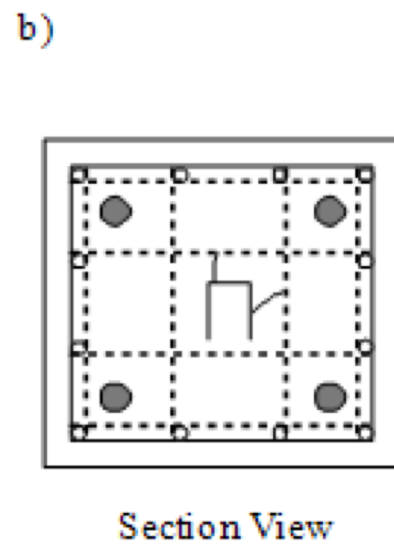
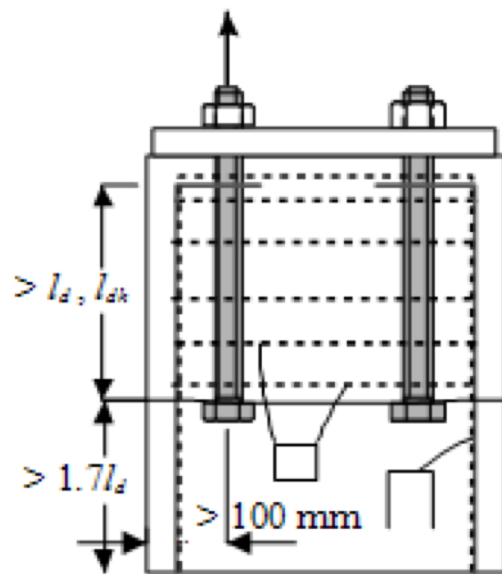
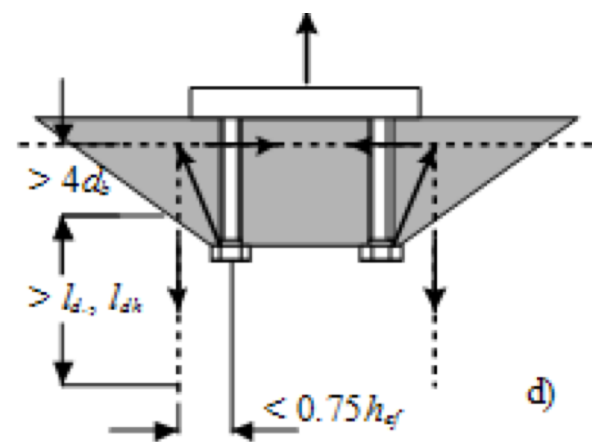
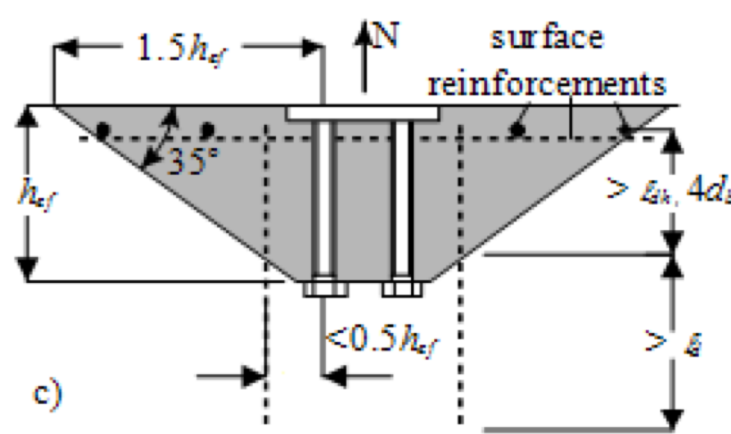
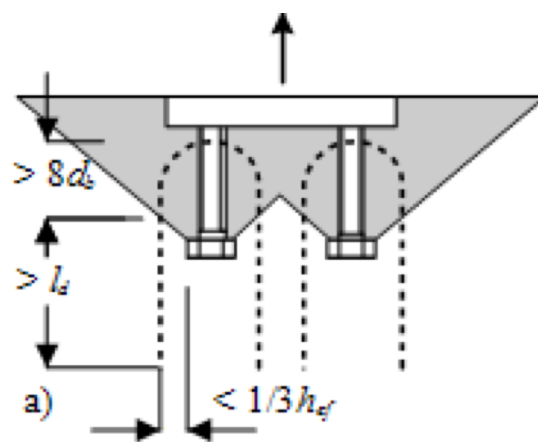
Anchor Reinforcements

- Properly placed reinforcements can restrain concrete breakout failure
- Some reinforcements should be placed next to anchors
- With closely placed rebars, the rest of the reinforcements can be placed further away.
- The code assumptions for calculating anchor capacities is not correct if breakout restrained
- Anchor rods with exposed length in shear
- Concrete crushing and pull out failure

Phase III: Reinforced Anchor in tension

Phase III Test

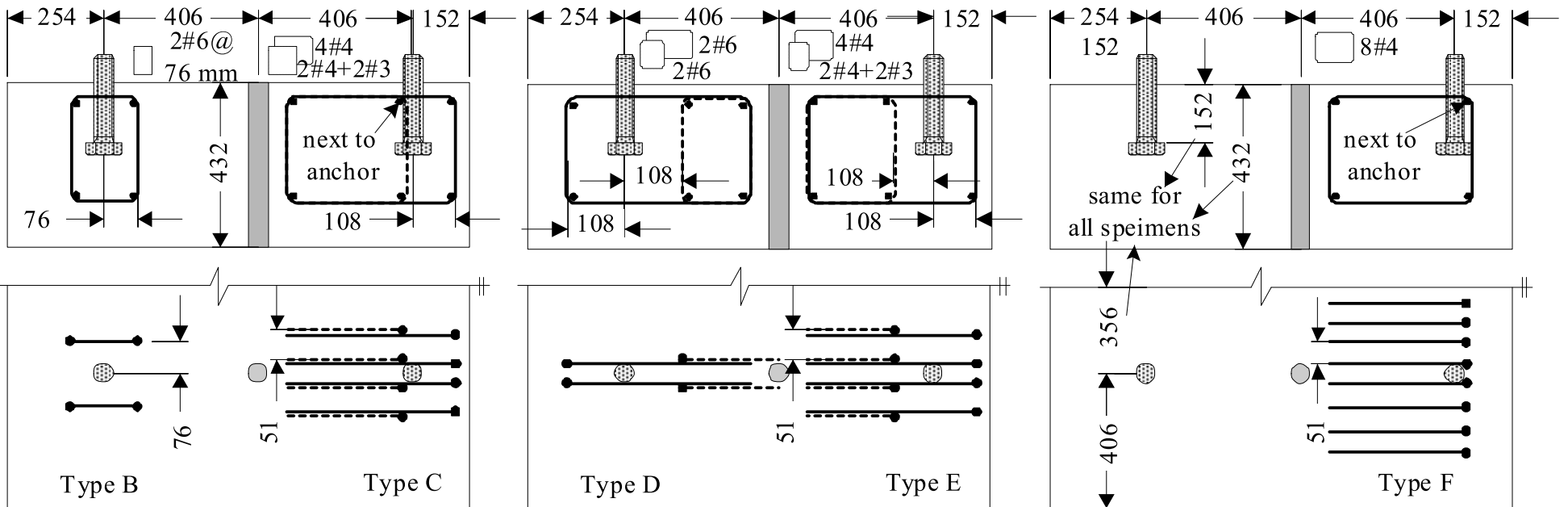
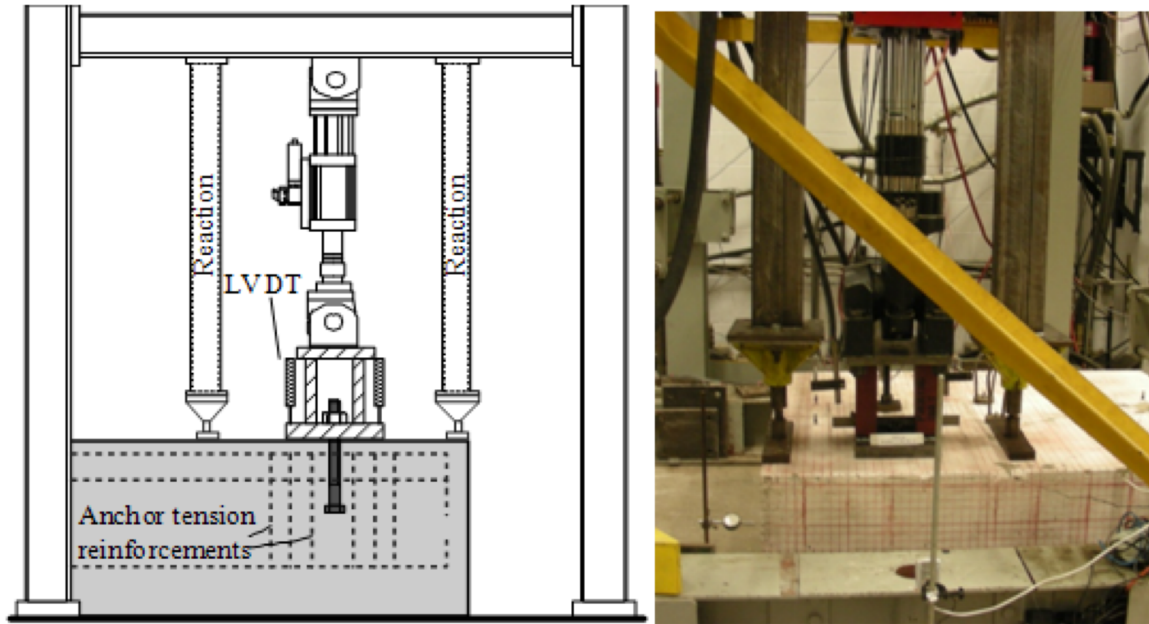




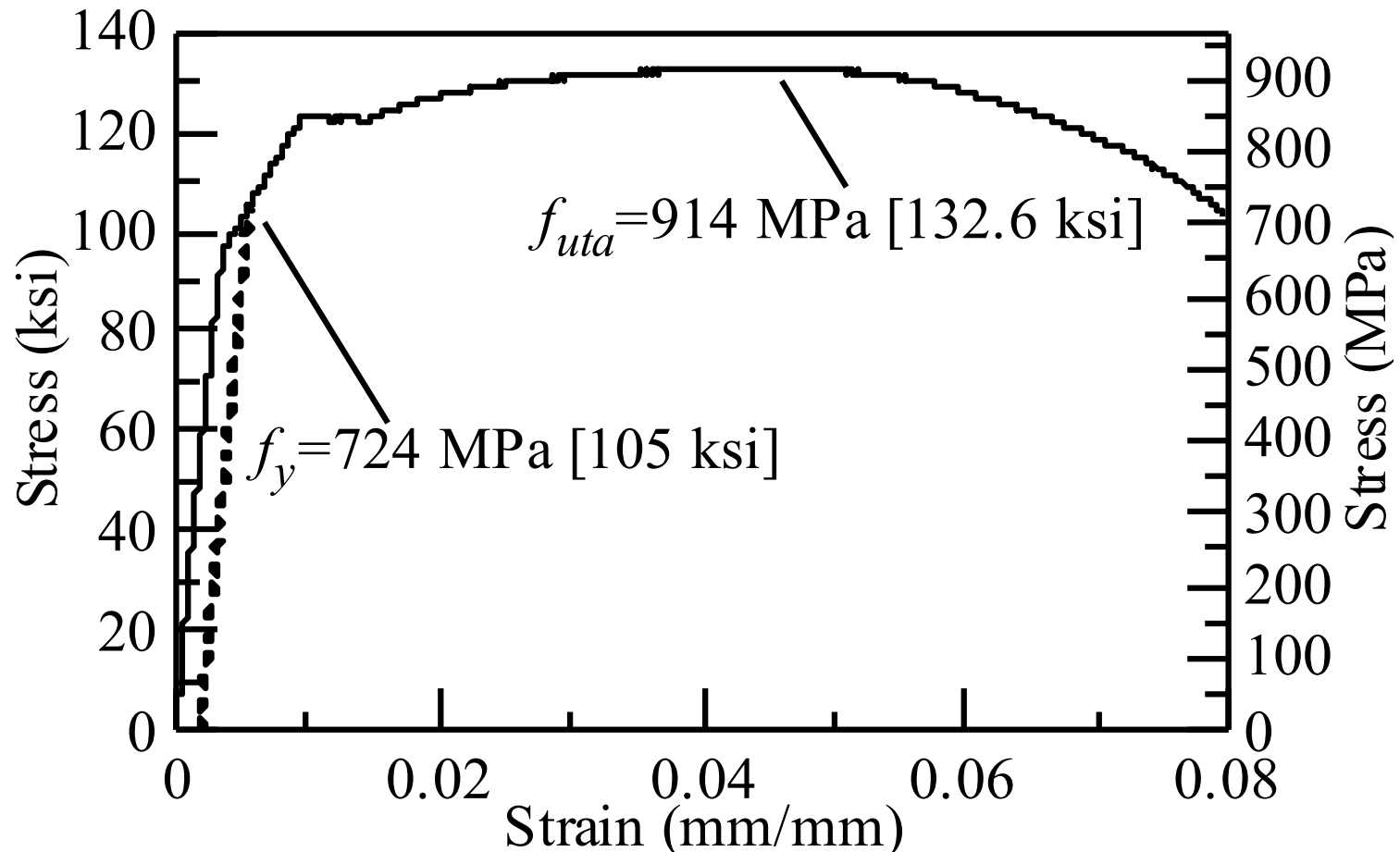
Phase III Test Matrix

Specimen ID	Reinf.Type	C _{a1} (in.)	Load Type	f _c (psi)	Peak load (kips)	Peak disp. (in.)
5132011-A1	-	10	M	5400	36.56	0.05
5162011-A2	-	10	C	5400	35.22	0.10
5162011-A3	-	6	M	5400	30.17	0.11
5162011-A4	-	6	C	5400	33.66	0.12
5172011-B1	B	10	M	5400	49.65	0.12
5172011-B2	B	10	C	5400	43.58	0.08
5202011-C1	B	10	C	5400	44.53	0.14
5202011-C2	B	10	C	5400	50.11	0.20
5182011-B3	C	6	M	5400	63.00	0.34
5182011-B4	C	6	C	5400	62.40	0.24
5232011-C3	C	6	C	5400	67.31	0.74
5232011-C4	C	6	C	5400	69.99	0.50
5252011-D1	D	10	M	5400	49.07	0.19
5252011-D2	D	10	C	5400	50.96	0.14
5272011-E1	D	10	C	5400	52.63	0.18
5272011-E2	D	10	C	5400	49.69	0.11
5252011-D3	E	6	M	5400	52.28	0.08
4252011-D4	E	6	M	5400	48.24	0.09
5262011-E3	E	6	C	5400	53.01	0.18
5252011-E4	E	6	C	5400	54.90	0.12
5282011-F1	F	6	M	5400	57.46	0.21
5282011-F4	F	6	M	5400	56.38	0.50
5282011-F2	F	6	C	5400	53.65	0.18
5282011-F3	F	6	C	5400	55.05	0.27
5122012-G1	G	10	M	6910	79.91	0.41
5152012-G2	G	10	C	6910	80.85	NA
5152012-G3	G	10	C	6910	80.86	0.45
5162012-G4	G	10	C	6910	80.54	0.49

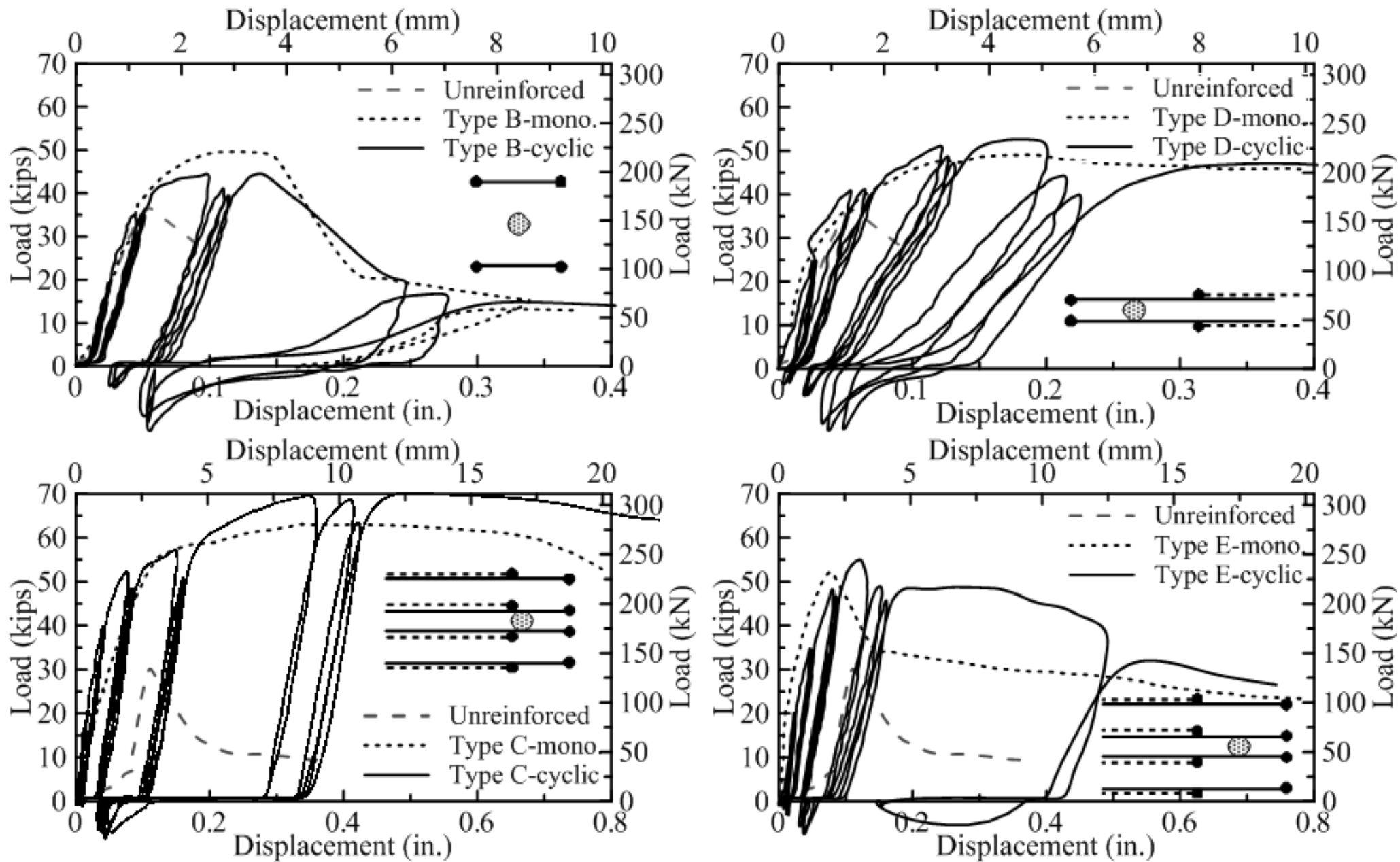
Phase III Tests



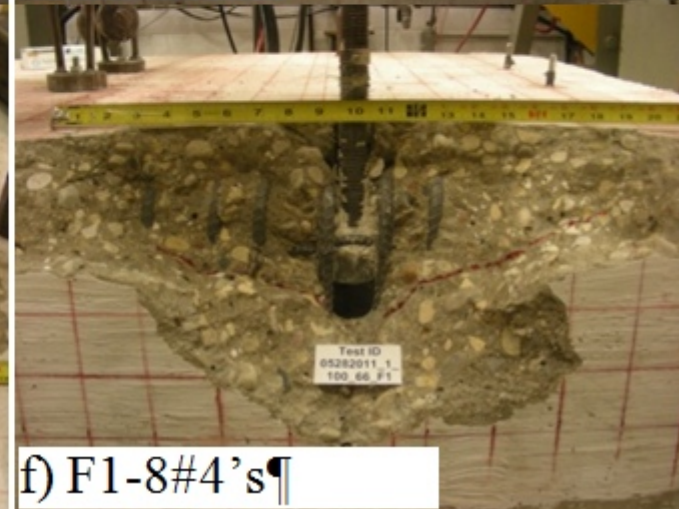
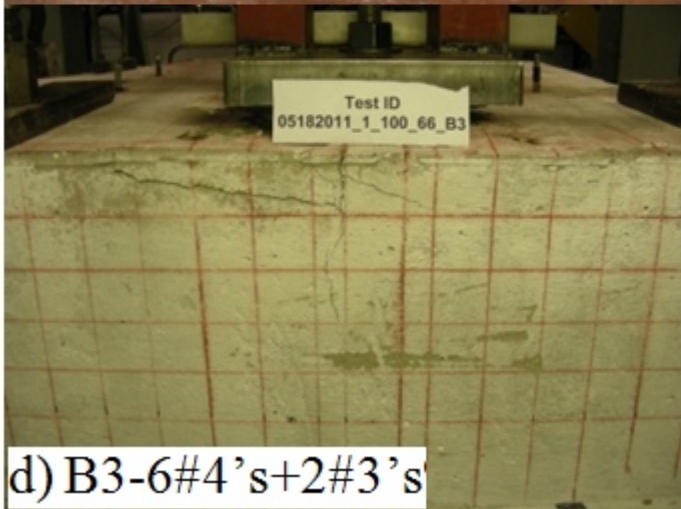
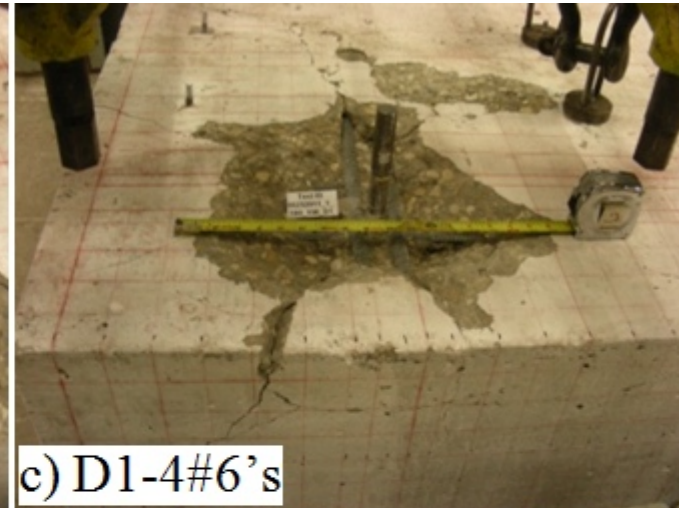
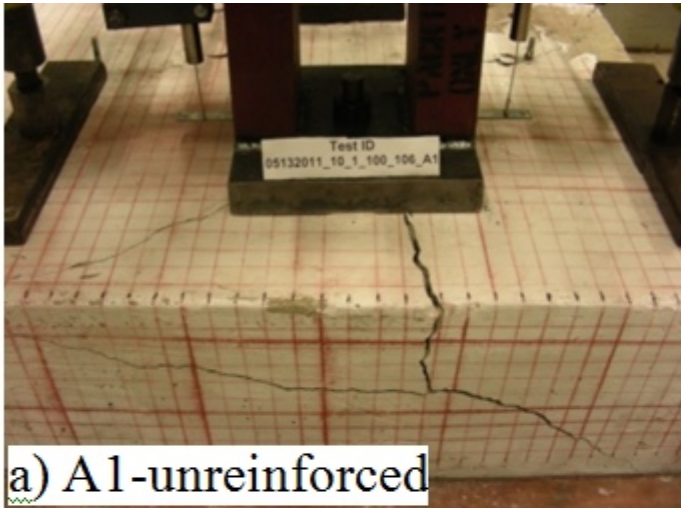
Phase III Anchor Material



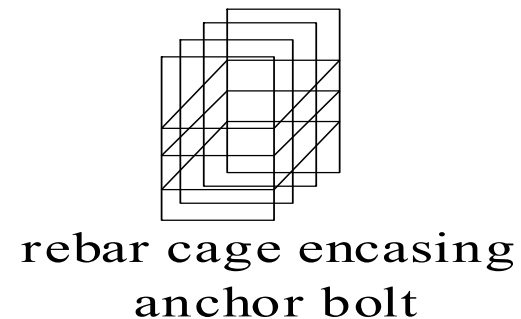
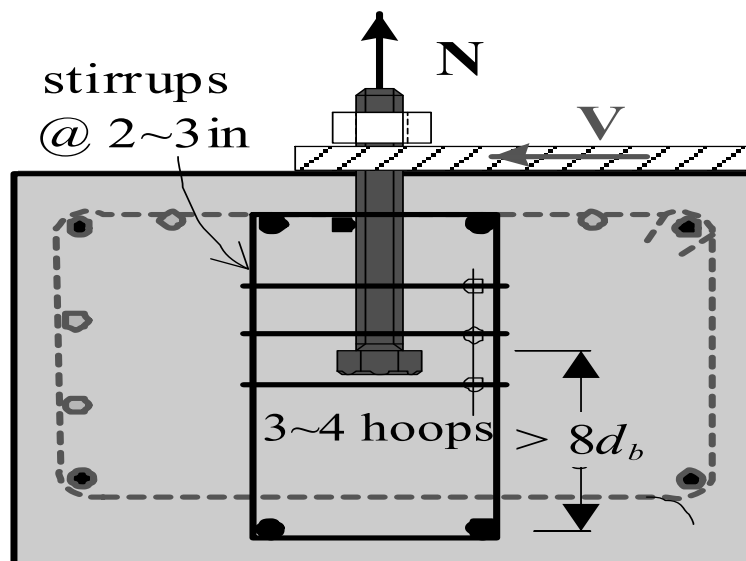
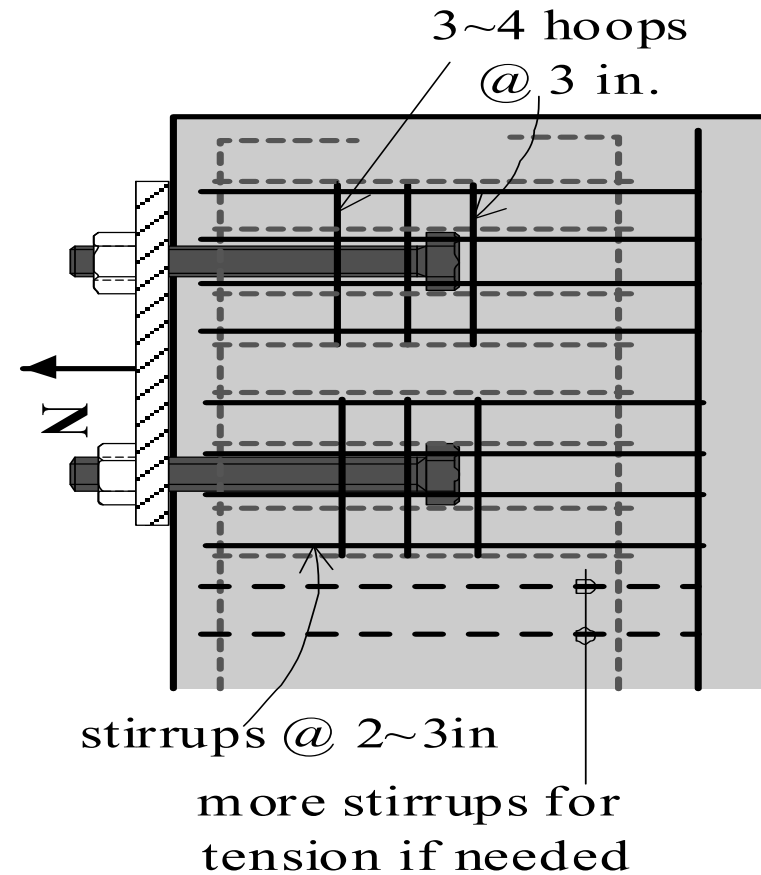
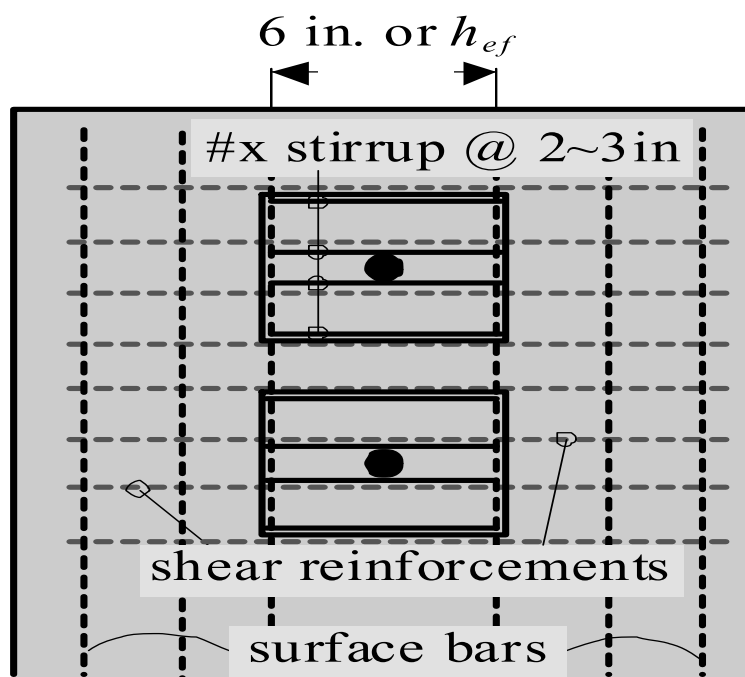
Summary of Phase III Tests



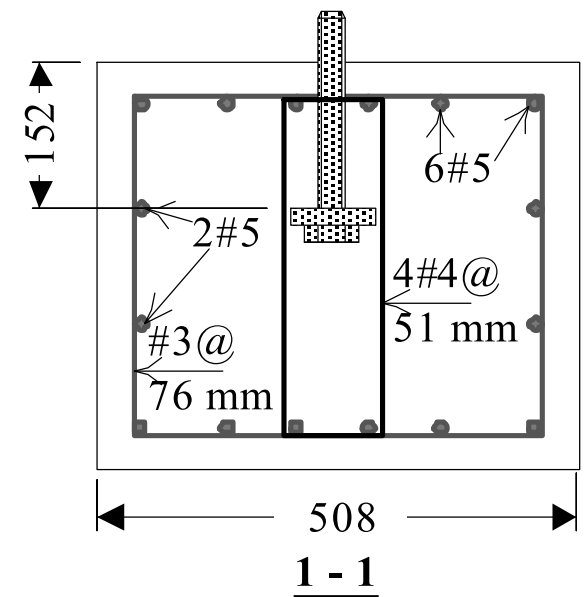
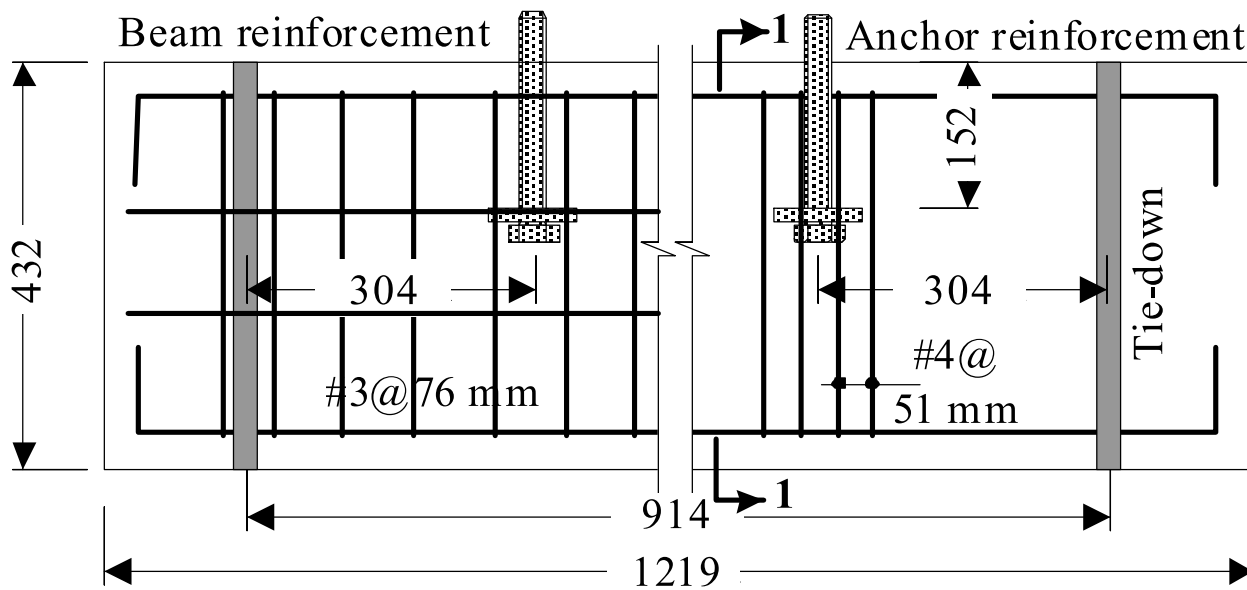
Phase III Tests ...



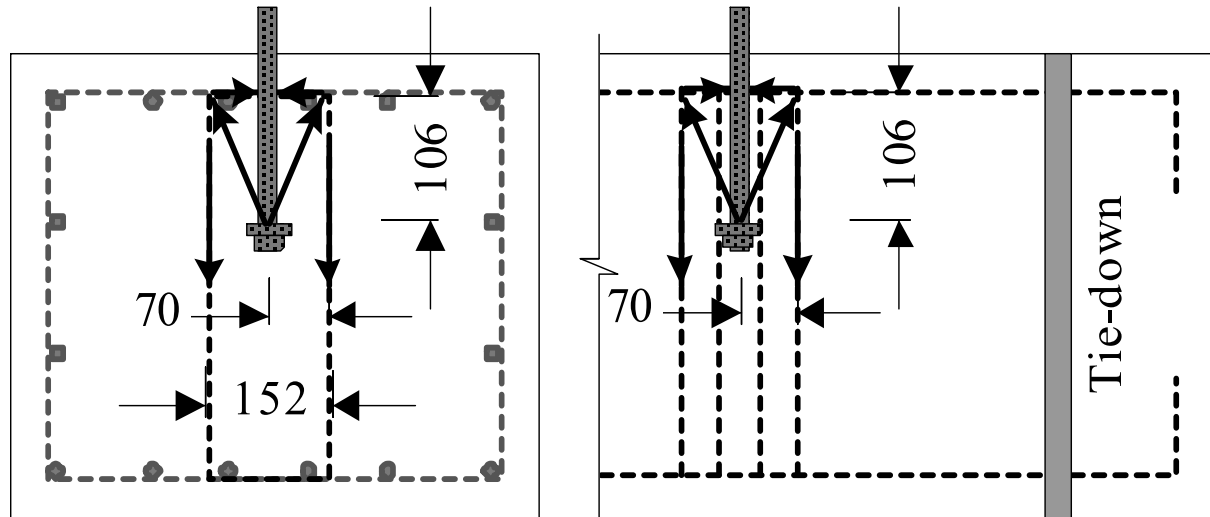
Proposed Anchor Reinforcement



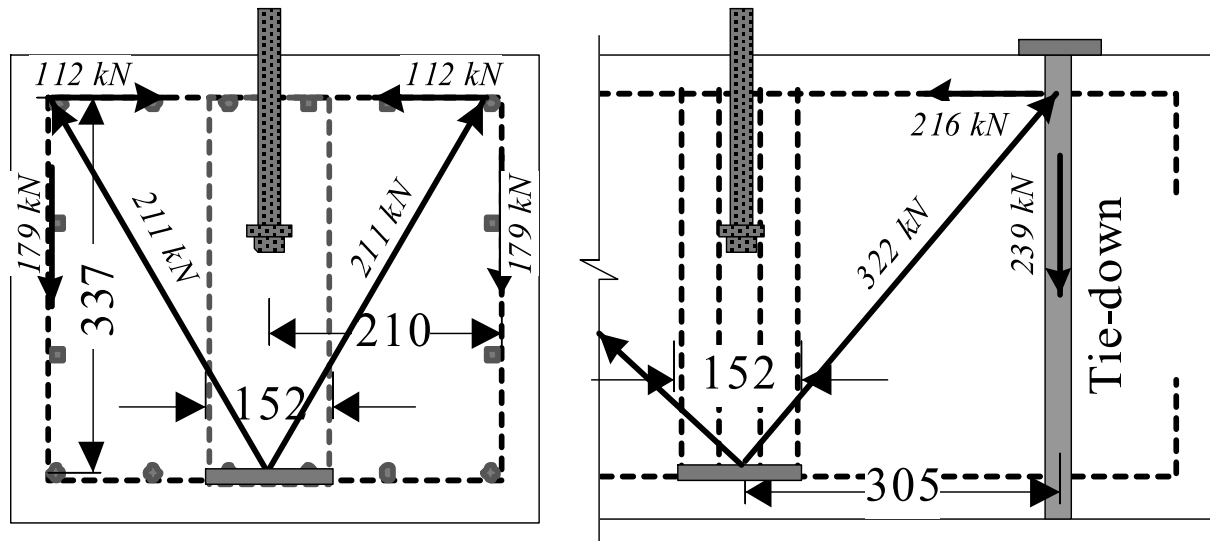
Specimen (Verification Tests)



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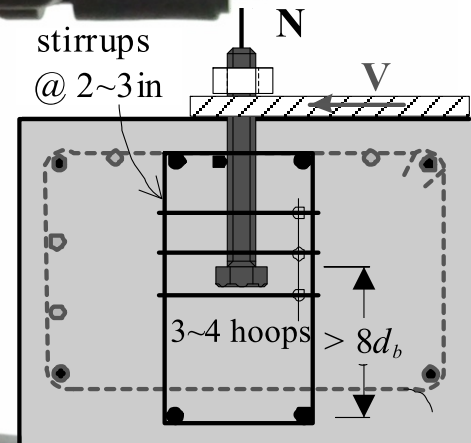
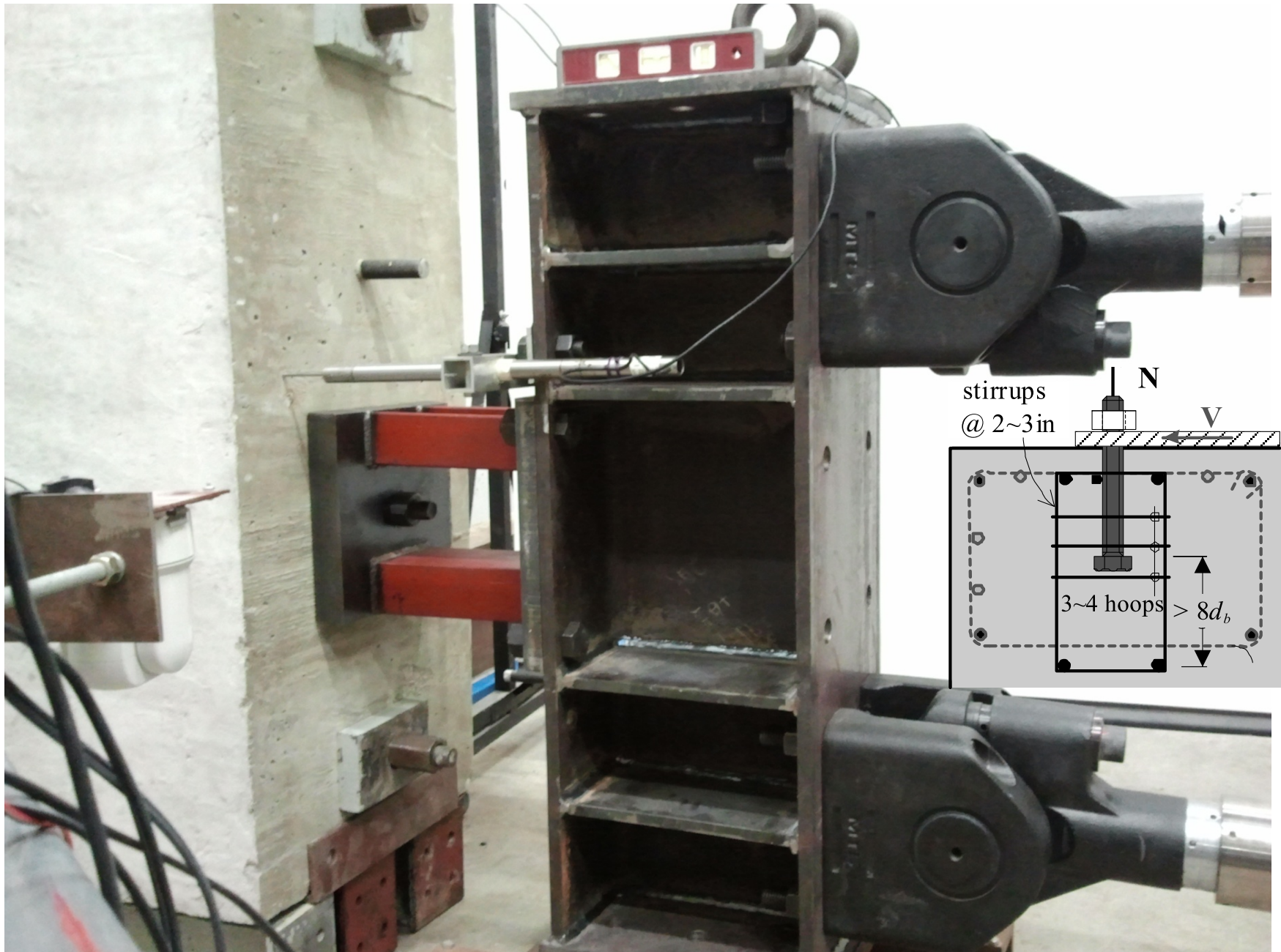


STMs for load transfer from anchor to reinforcement

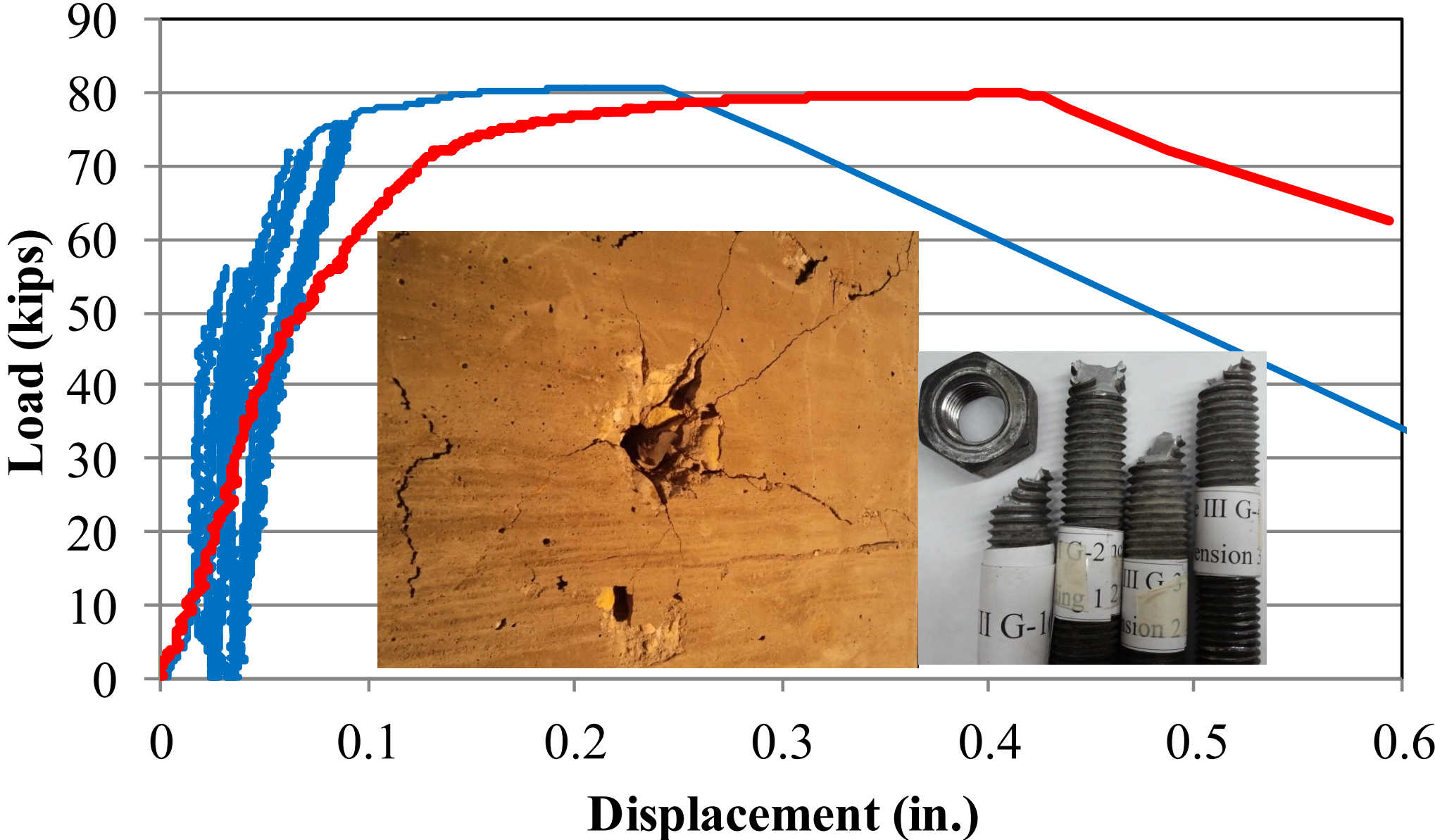


STMs for load transfer from reinforcement to structure

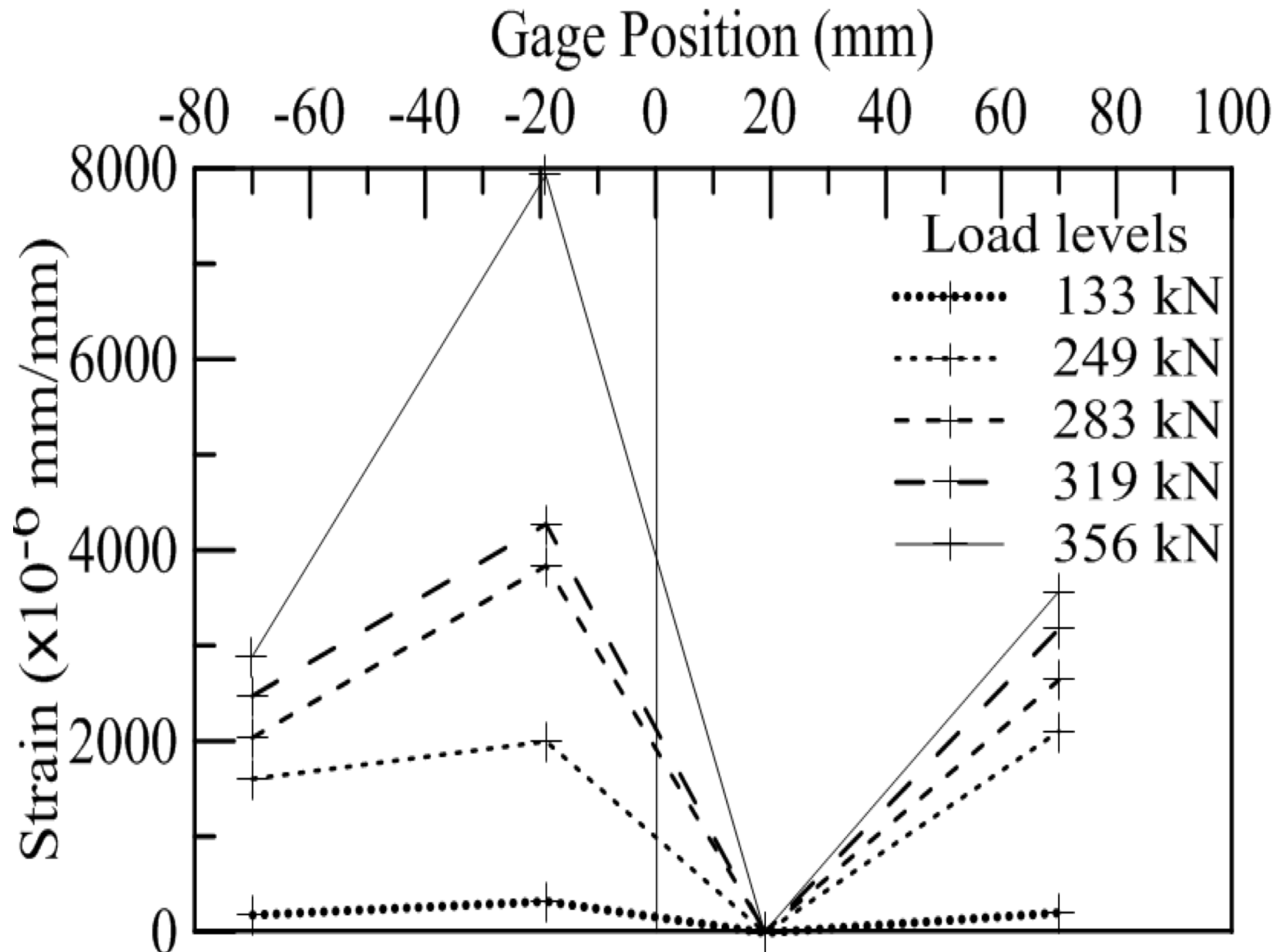
Verification Test Setup



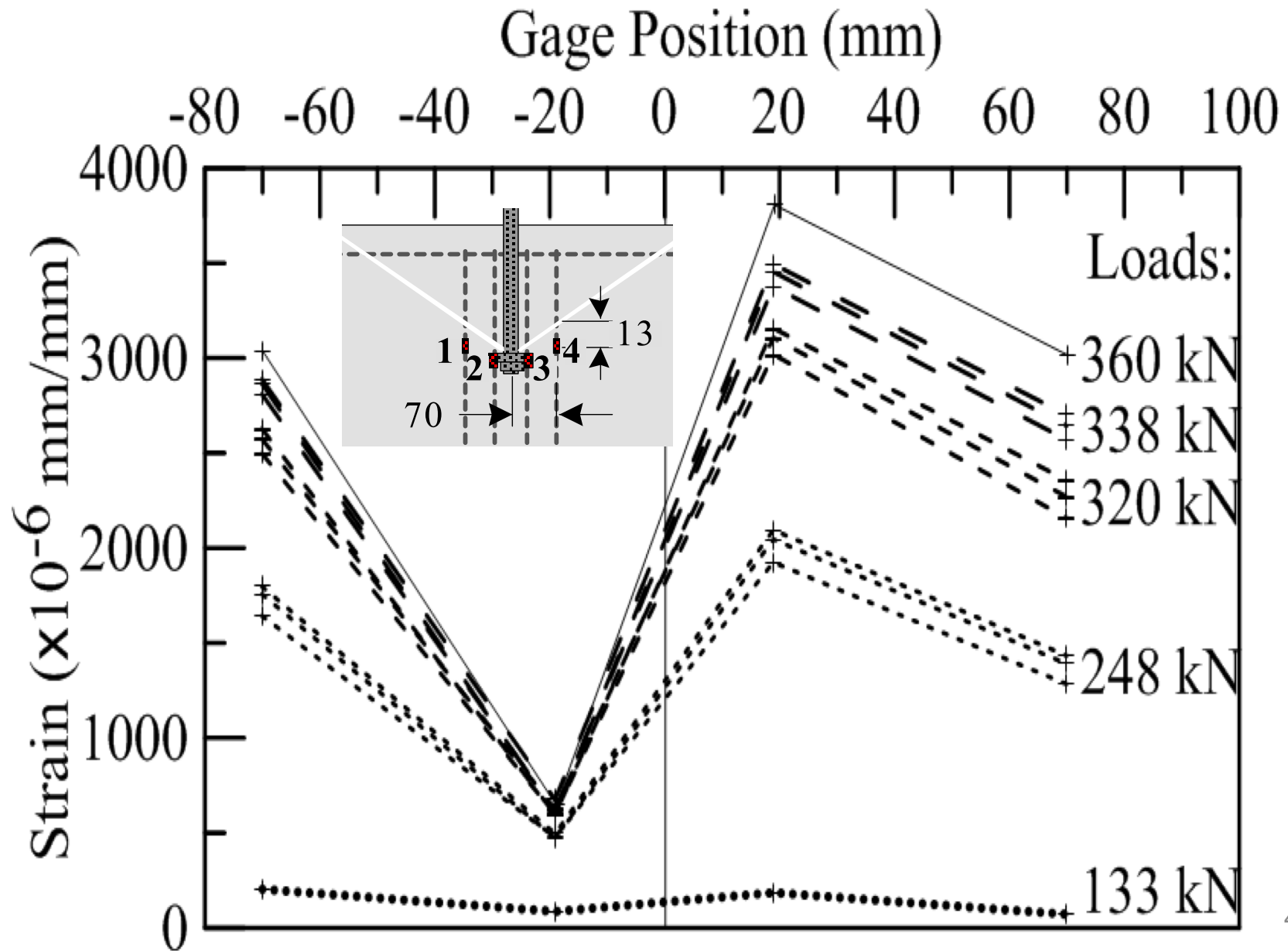
Verification Test Results



Anchor Reinforcement Strains



Anchor Reinforcement Strains



Conclusions from Phase III

- Current ACI recommendations on anchor reinforcement may need to be clarified
- Anchor reinforcement should
 - Restrain concrete from splitting and blowout
 - Transfer and distribute loads
 - Confine concrete struts
- Properly placed reinforcement can restrain concrete breakout failure

Light stands near Takada Matsubara building in Rikuzentakata, Japan, in Tohoku Tsunami, March 2011

Questions?

