Report on laboratory testing of anchor bolts connecting wood sill plates to concrete with minimum edge distances

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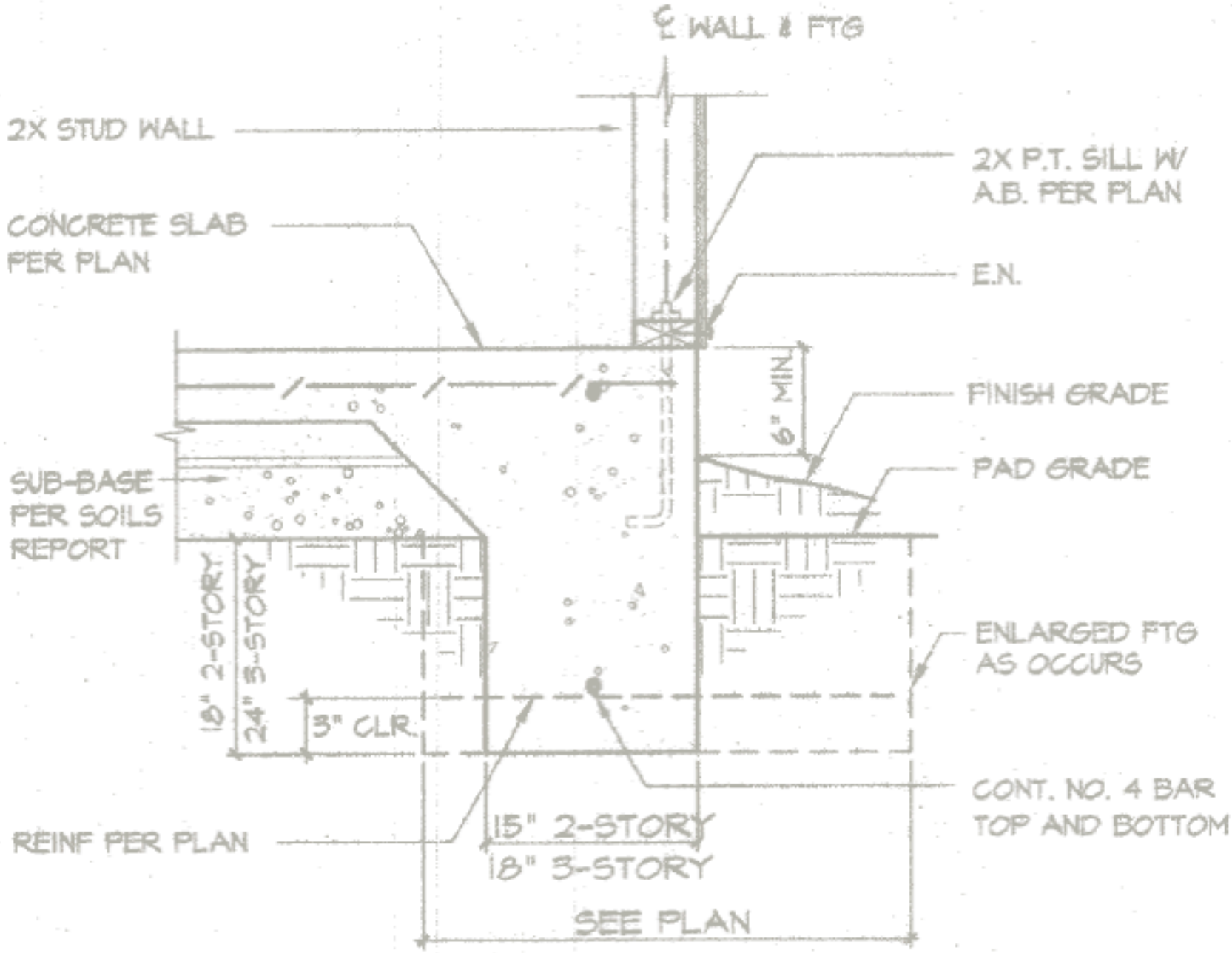
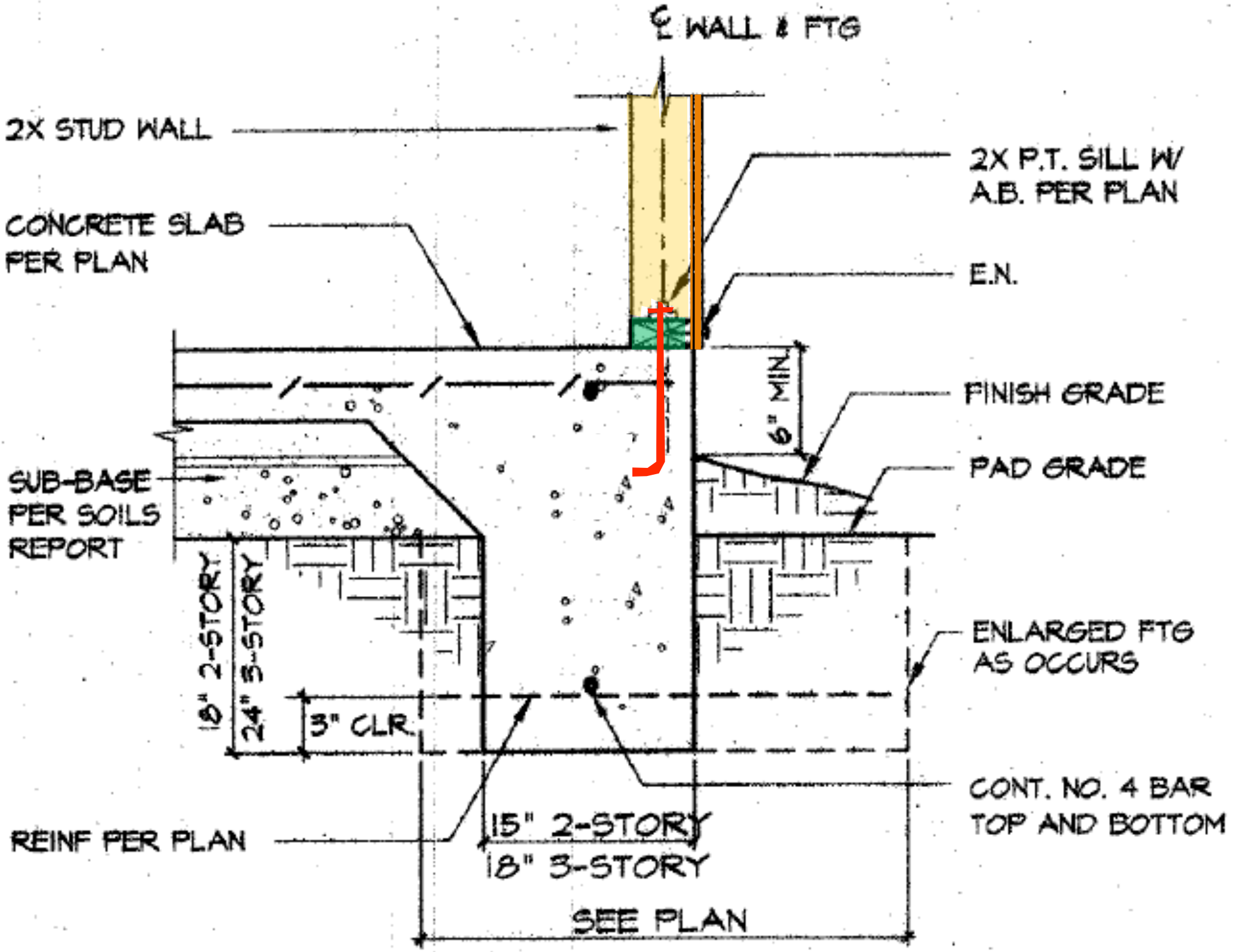
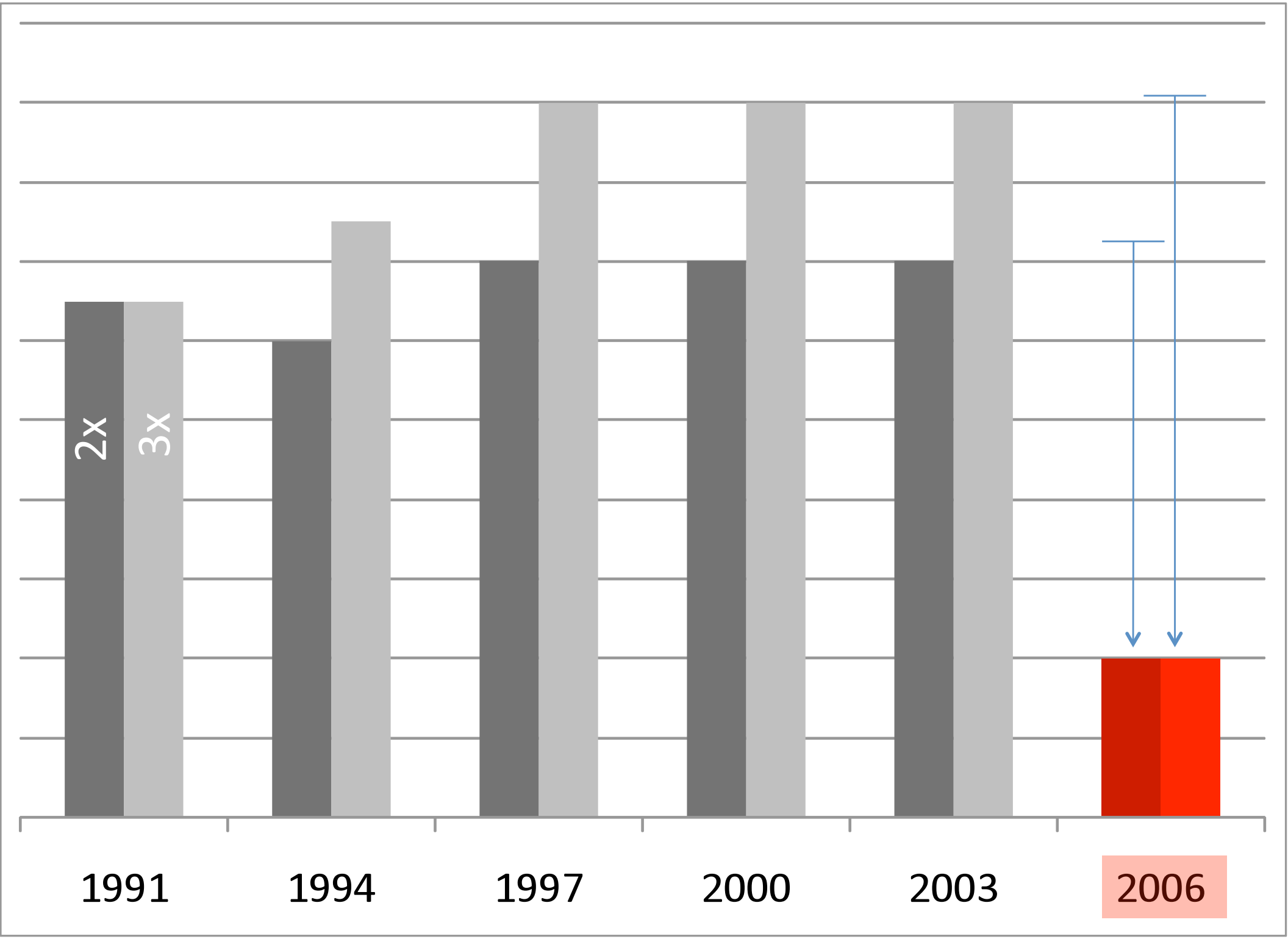
What we did

Anchor Bolt Testing in < 25 minutes




℄ WALL & FTG
2X STUD WALL
2X P.T. SILL W/ A.B. PER PLAN
CONCRETE SLAB PER PLAN
E.N.
6" MIN.
FINISH GRADE
PAD GRADE
SUB-BASE PER SOILS REPORT
18" 2-STORY
24" 3-STORY
3" CLR.
ENLARGED FTG AS OCCURS
CONT. NO. 4 BAR TOP AND BOTTOM
REINF PER PLAN
15" 2-STORY
18" 3-STORY
SEE PLAN


2x
3x
1991
1994
1997
2000
2003
2006

Structure Magazine
August 2008

InFocus thoughts from a member of the Editorial Board

For What Planet Is This Code Written?

By Richard L. Hess, A.E., S.E., SECB, F. ASCE, CSI, CCCA

Members of the SEAOC Code Committee (as well as others) are busy calculating. They are trying to come up with an allowable shear value for a wood sill plate anchor bolt that will facilitate construction of a single-story wood-frame house with anchor bolts greater than one foot apart or multi-story wood-frame buildings under any conditions. They are trying to figure out what approach will produce the best result from ACI 318 Appendix D, which is required by the 2006 International Building Code. Others, sensing the profit potential in this new complication, are developing software that solves the problem for you.

And then there is the question of ductility: How to make the steel

ing ⅝-inch bolts with 4-inch embedment being good for 1,000 pounds in shear with no edge distance restrictions.

The 6d (d = bolt diameter) minimum edge distance was not added until 1970. In 1979, after the 1971 San Fernando earthquake, the values for ⅝-inch anchor bolts were increased from 1,750 to 3,000 pounds. Subsequently, those values required a 12d edge distance with a 50% reduction allowed, which was maintained in the 1997 UBC three years after the Northridge earthquake. Section 1806.6 of that code required ⅝-inch anchor bolts to be used in seismic zone IV and specified an increased sill plate thickness and this was due to concerns about the bearing capacity of the because of the possibility of concrete breakout.

I remember participating in one of the

References

- Full **50-page** testing report available at www.SEAONC.org

- SEAOC Blue Book article

Structural Engineers Association of Northern California
2008-2009 Special Projects Initiative, (SPI).

2008-2009 SEAONC Board of Directors:
Reinhard Ludke (President), Rafael Sabelli (Vice-President), Kate Stillwell (Treasurer), Bret Lizundia (Past-Pres.), Greg Deierlein, Mark Ketchum, Karin Kuffel, John Osteraas.

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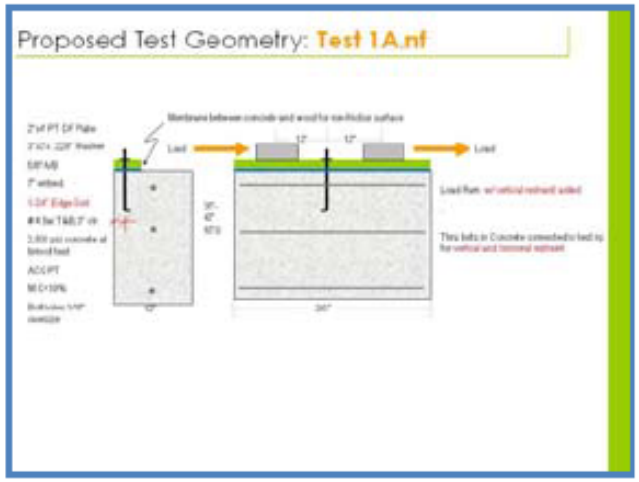
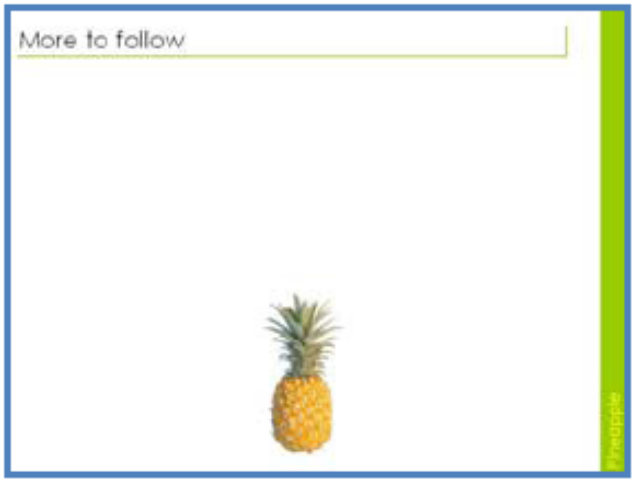
The Project Team gratefully acknowledges the following for their invaluable project support:
(Additional project acknowledgements are listed in the attached report)

Simpson Strong-Tie Company, Inc. (SSTC)
- Steve Pryor, CE, SE
- Ricardo Arevalo, CE, SE
- Tim Murphy, CE

American Forest & Paper Association (AF&PA)
- Phil Line, PE
- Brad Douglas, PE
- Shane Cochran





Preliminary Phase of Anchor Bolt Testing

Testing Specifications and Loading Protocols

October 9, 2008

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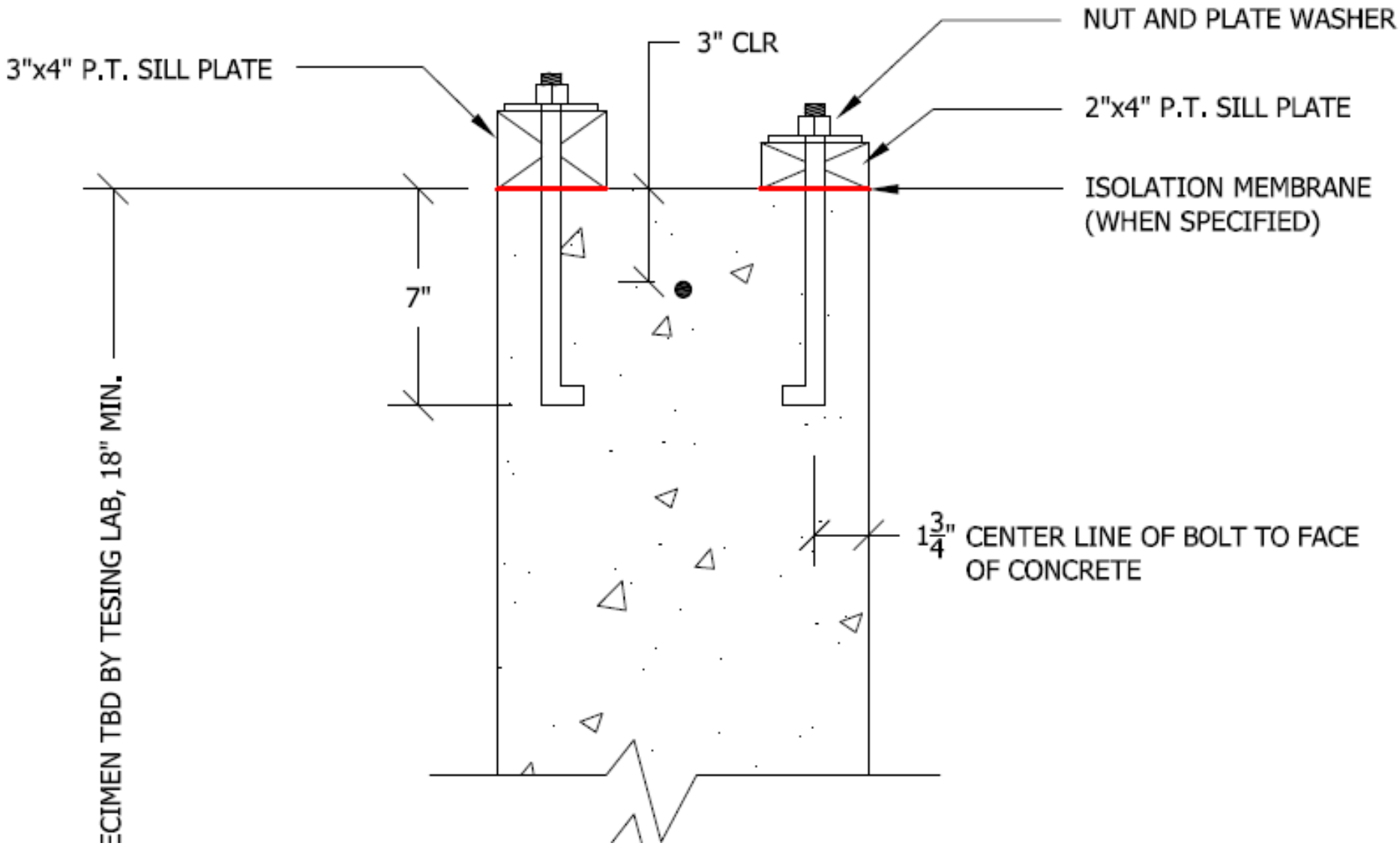

3"x4" P.T. SILL PLATE
3" CLR
NUT AND PLATE WASHER
2"x4" P.T. SILL PLATE
ISOLATION MEMBRANE
(WHEN SPECIFIED)
7"
ECIMEN TBD BY TESING LAB, 18" MIN.
1 3/4" CENTER LINE OF BOLT TO FACE
OF CONCRETE

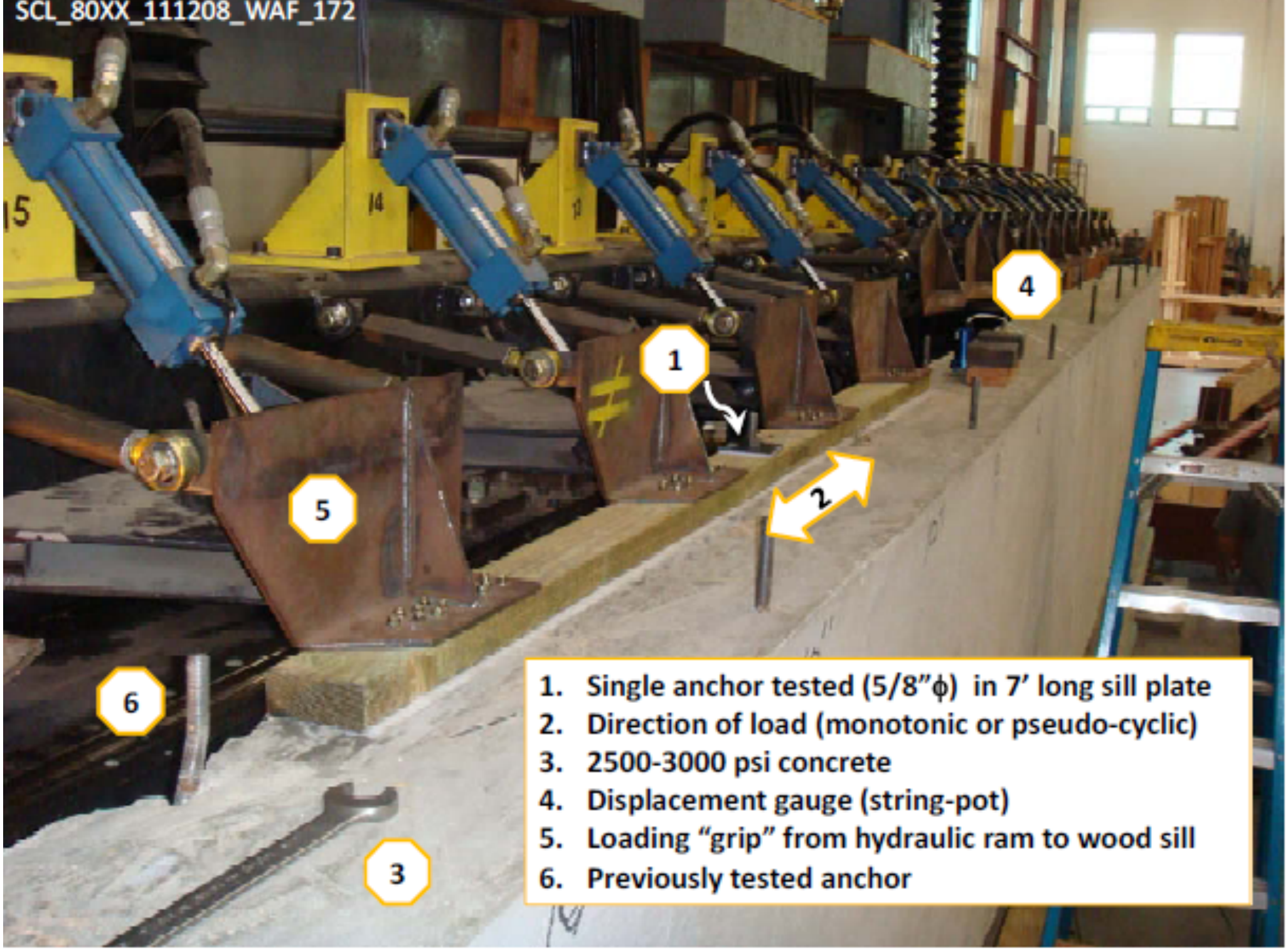


Image 2 – Typical set-up for anchor tests at Tyrell Gilb Research Laboratory in Stockton, CA.

What we found

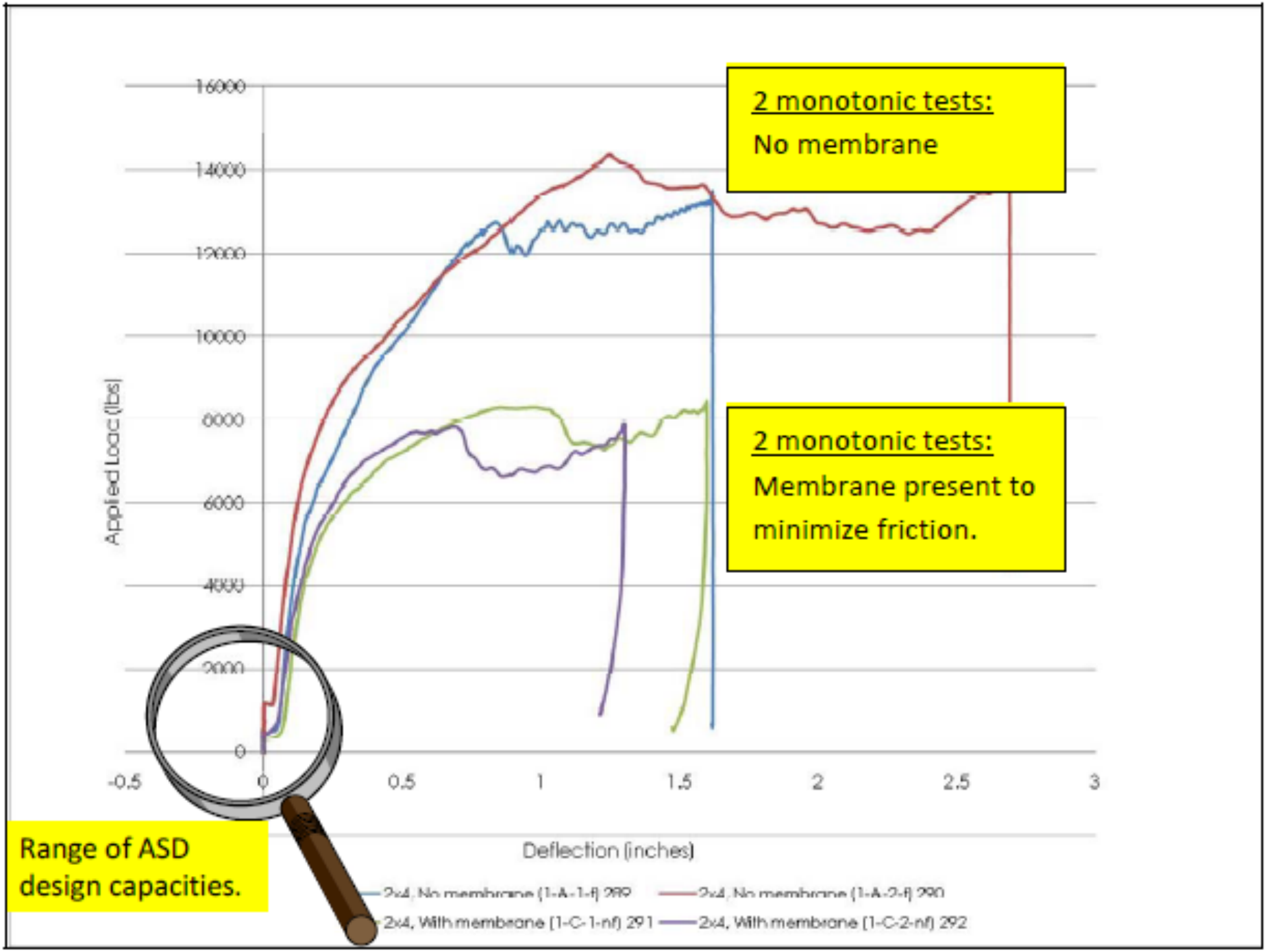


Chart 7 – Comparative plot of monotonic tests with (291, 292) & without (289, 290) membrane.


(E)
CHECK - TOP ONLY!
(E)
CHECK
TOP ONLY!
9.1
SEAOC A/B TESTS
11.14.08
C=1.6
2'D'2'nf
SCL
(WAF)

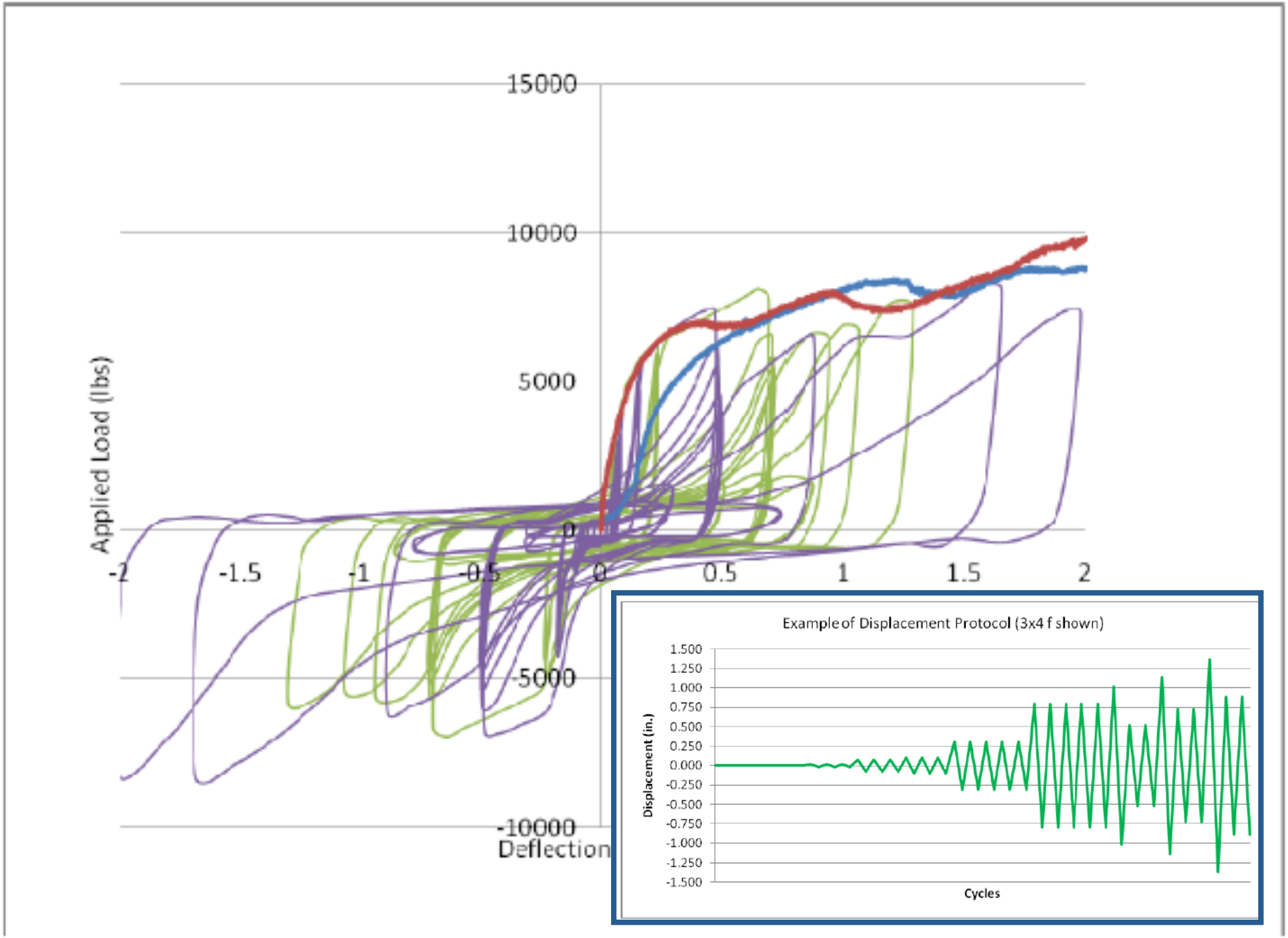
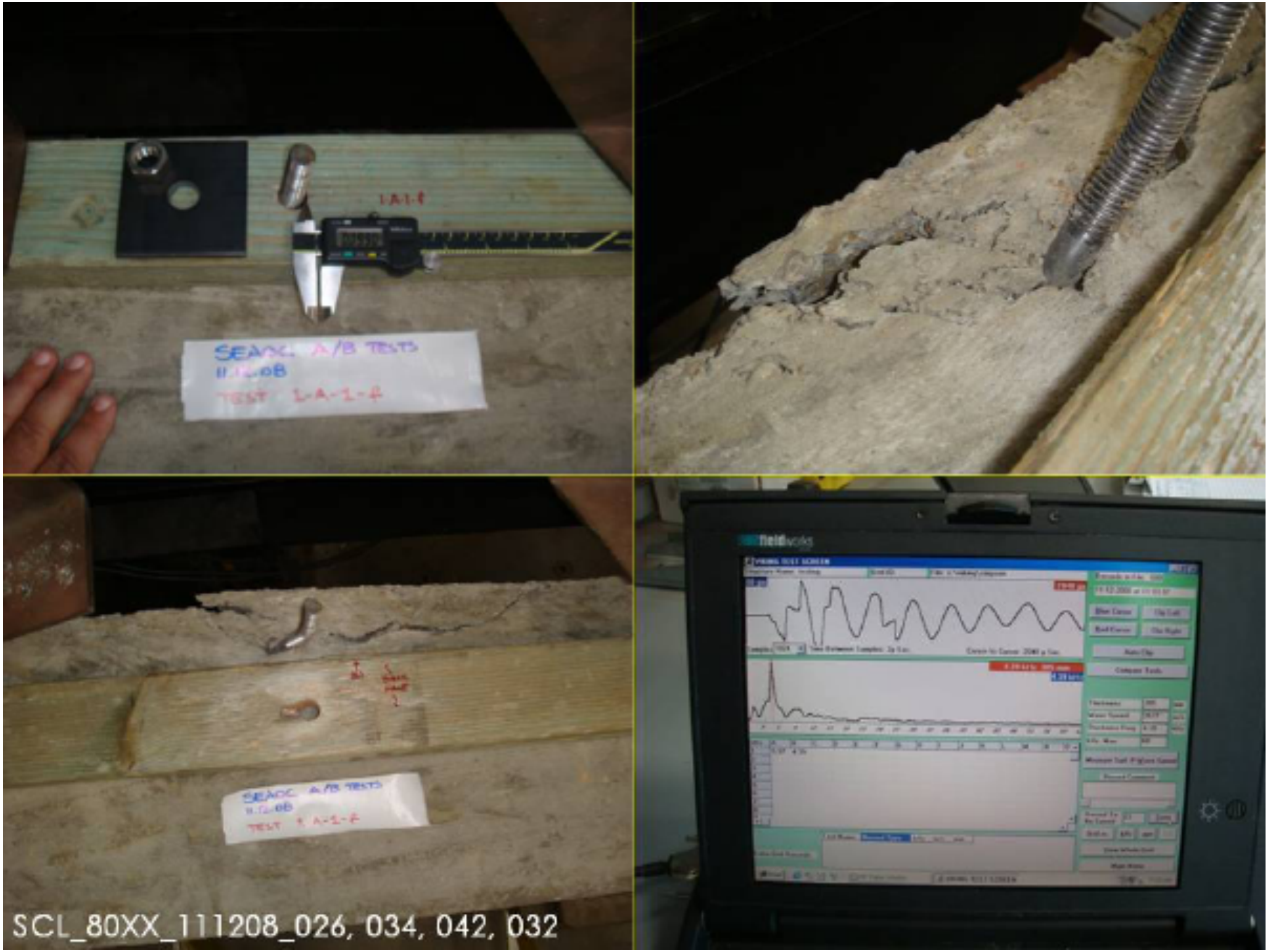
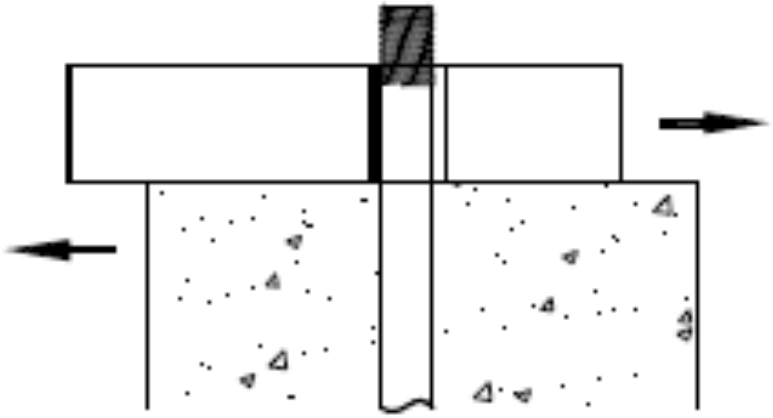


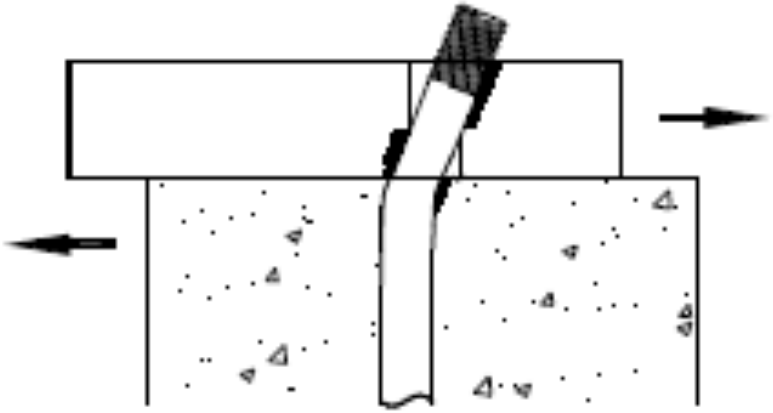
Chart 4 - Cyclic Tests (306, 307) vs Monotonic Tests (300, 301)


SEADC A/B TESTS
TEST 1-A-1-F
SEADC A/B TESTS
TEST 1-A-1-F
SCL_80XX_111208_026, 034, 042, 032



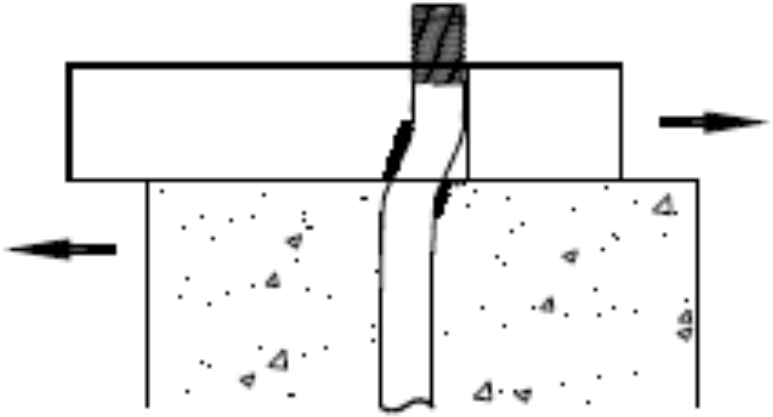
Mode I

(wood bearing deformation in side member)



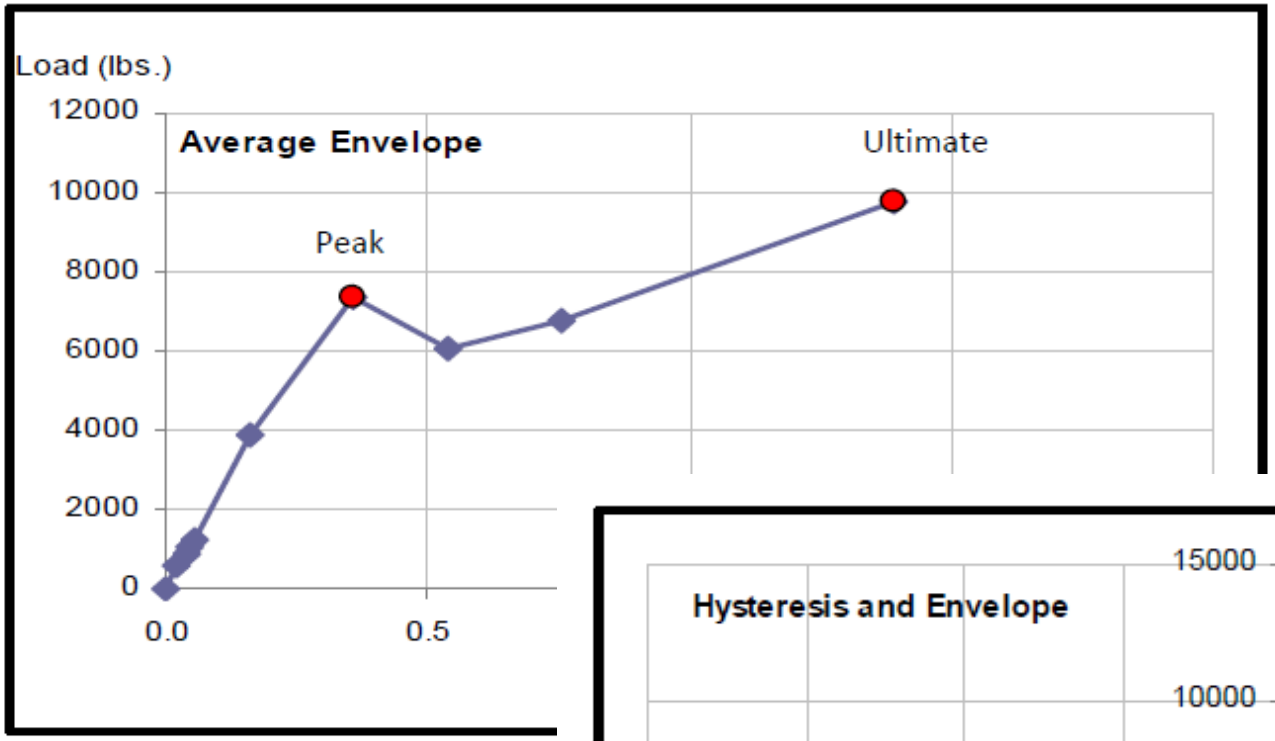
Mode III_s

Mode III_s (wood bearing deformation in side member and dowel bending in concrete)

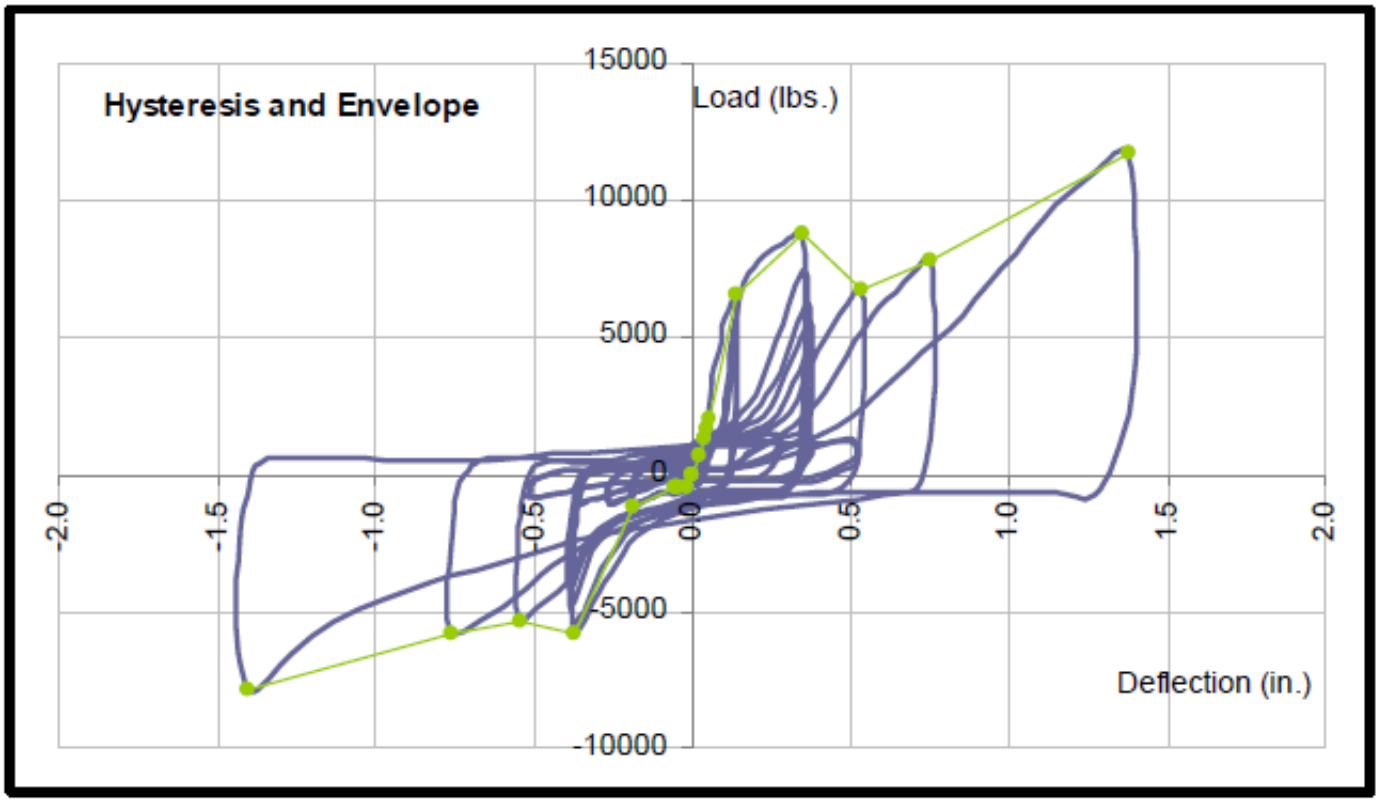


Mode IV

Mode IV (wood bearing deformation in side member and dowel bending in wood member and concrete)

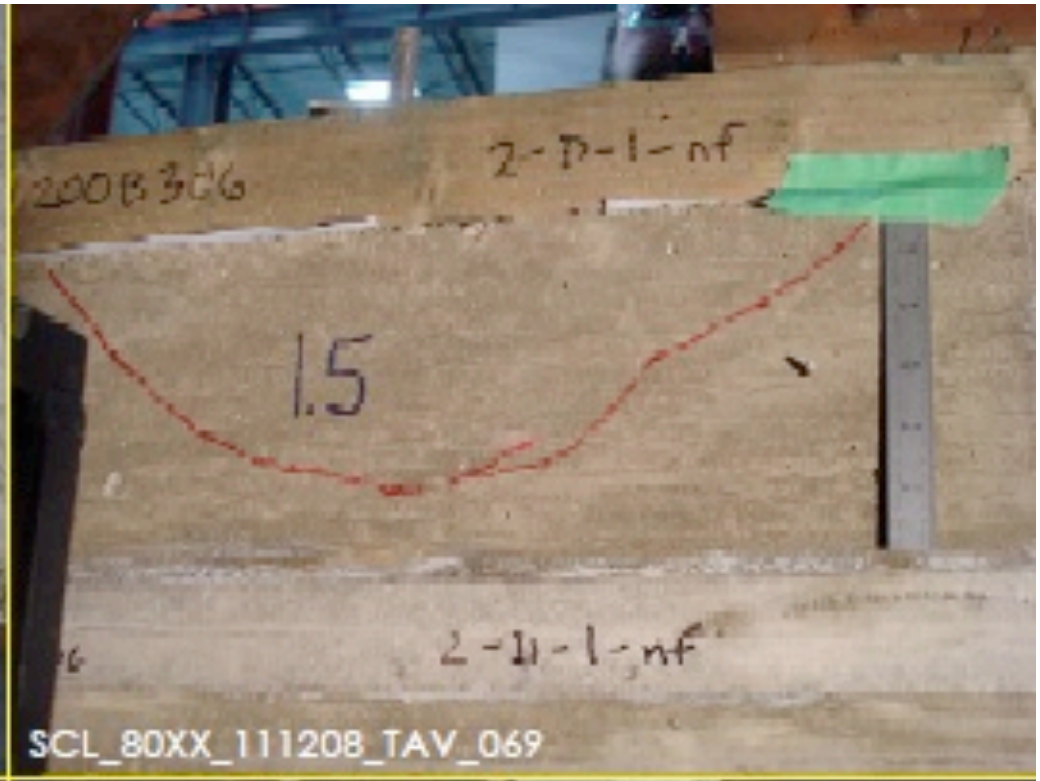


Test ID: 2



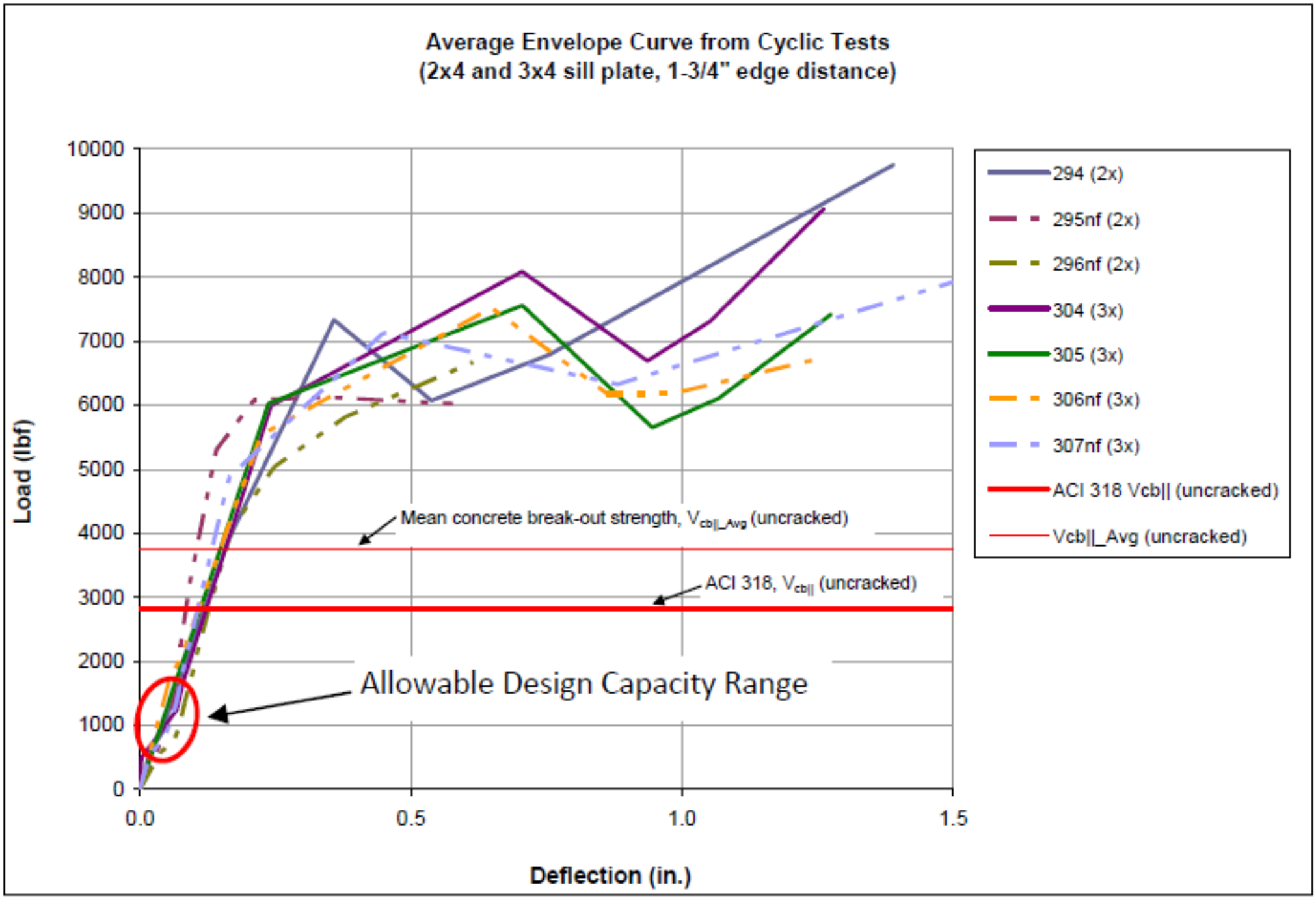
Test ID: 2-A-2-f-294, 2x4 Cyclic


SCL_80XX_060408_WAF_119


2-D-1-nf
1.5
2-U-1-nf
SCL_80XX_111208_TAV_069


2-A-2-f
4"
SCL_80XX_111208_TAV_027


SCL_80XX_111208_AAG_050 (cropped)


Average Envelope Curve from Cyclic Tests
(2x4 and 3x4 sill plate, 1-3/4" edge distance)
Load (lbf)
Deflection (in.)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0.0
0.5
1.0
1.5
Mean concrete break-out strength, $V_{cb||\_Avg}$ (uncracked)
ACI 318, $V_{cb||}$ (uncracked)
Allowable Design Capacity Range
294 (2x)
295nf (2x)
296nf (2x)
304 (3x)
305 (3x)
306nf (3x)
307nf (3x)
ACI 318 Vcb|| (uncracked)
Vcb||_Avg (uncracked)

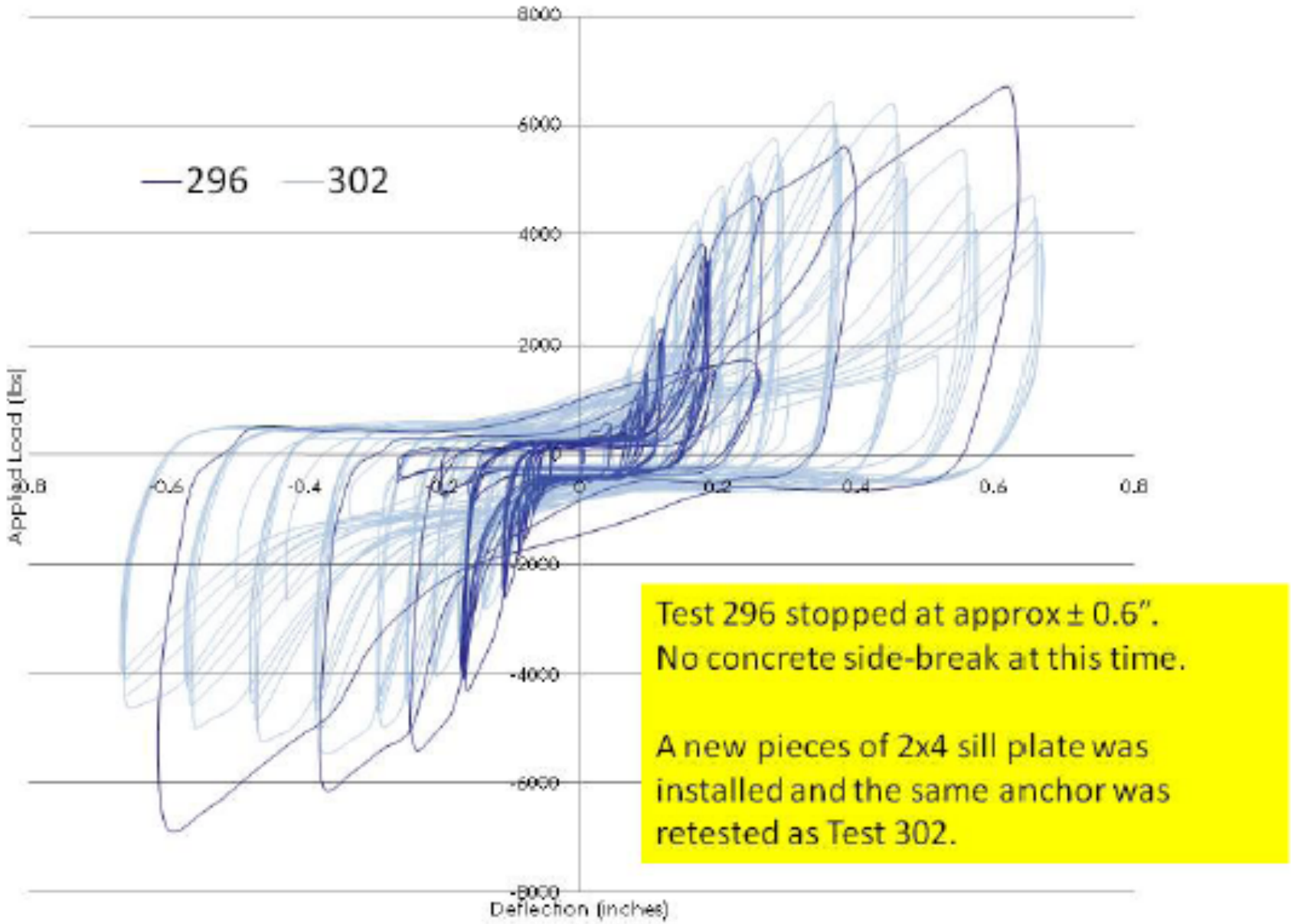


Chart 8 – Composite plot of Tests 296 and 302.


Test 296 stopped at ± 0.6". No delamination.
SCL_80XX_111308_WAF_10, 11, 08, 13

5/8" dia. bolt Code(s)	**ASD Design Capacity (#)** **2x4** DF-L (seasoned) (including C_D)	**ASD Design Capacity (#)** **3x4** DF-L (seasoned) (including C_D)	Comment
1991 UBC (NDS-86)	1306 # C_D = 1.33	1326 # C_D = 1.33	2510 (b), T-25-F
1994 UBC (NDS-91)	1173 # C_D = 1.33	1,492 # C_D = 1.33	2336.2.3, T-23-III-J NDS allows C_D=1.6.
1997 UBC (NDS-91)	1408 # C_D = 1.60	1790 # C_D = 1.60	2316, T-23-III-B-1
IBC-2003 (NDS-01)	1,424 # C_D = 1.60	1,824 # C_D = 1.60	NDS-01 Table 11E
IBC-2006 (NDS-05)	1,488 # C_D = 1.60	1,888 # C_D = 1.60	NDS-05 Table 11E
ACI-318-08 App. D, f'_c= 2500 psi.	Non ducti le: 500 # Ducti le: 1000 #	Non ducti le: 500 # Ducti le: 1000 #	0.5 factor used for non ducti le behavior. Values assume "uncracked" concrete.
ACI-318-05 App. D, f'_c= 2500 psi.	Non ducti le: 400 # Ducti le: 1000 #	Non ducti le: 400 # Ducti le: 1000 #	0.4 factor used for non ducti le behavior. Values assume "uncracked" concrete.
Peak values from average of Cyclic tests	Avg from test ID's: 294, 295-NF, 296-NF: **6710 # @ 0.44"**	Avg from test ID's; 304, 305, 306-NF & 307-NF: **7572 # @ 0.63"**	Peak cyclic test values are at least **4 ti mes** historic NDS wood design values.

Test Findings

- When loaded parallel to the concrete edge; the **wood governs the connection**. The wood sill plate "yields" well before any concrete limit state.

- The connection showed **excellent ductility**. Beyond the initial "peak" used for calculating capacities, tests often continued on to a second (and higher) peak.

Test Findings, Cont'd

- For 2x4 and 3x4 plates, the average peak loads:
  - were **more than 6 times higher** than ductile connection design strengths obtained from the equations from ACI 318-05 (&d 08), App. D, and
  - were **more than 4 times higher** than the allowable capacities obtained from IBC 2006 (NDS-05).

Conclusions

- Anchor bolts connecting wood sill plates to concrete with minimum edge distances have capacities much, much higher than those that would be obtained using the ACI Appendix D.

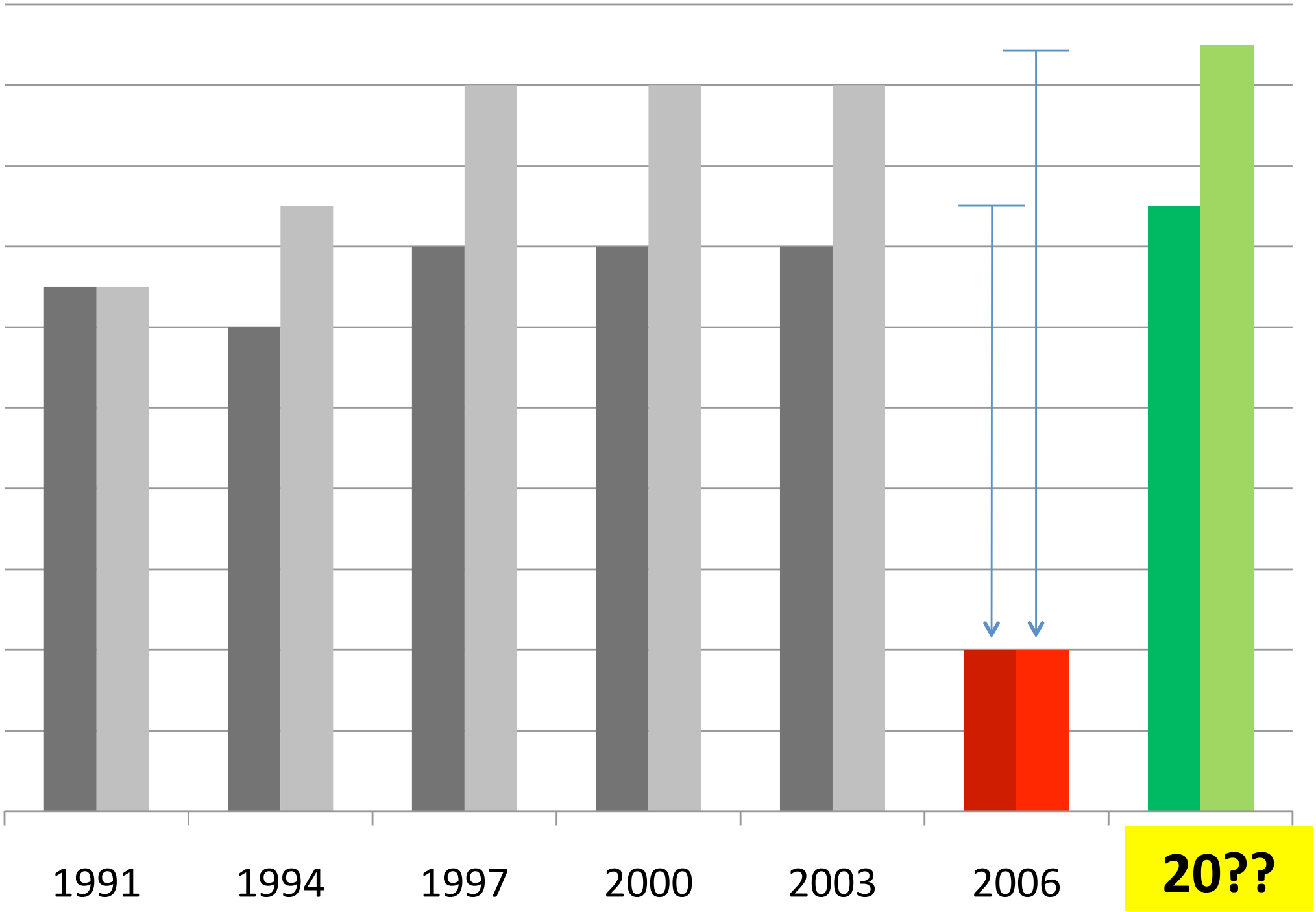
- Therefore code changes should be passed to allow for higher design values for these anchor bolts.

The next step

ICC Code Change Proposals

- At least **3 separate proposals**,
  - one authored by SEAOC Seismology Committee (submitted via NCSEA),
  - one by James Russell, City of Palo Alto, as an extension of SEAOC's proposal, and
  - one by SEAOC building code committee.

- ICC will hear the proposals in October 2009 for inclusion in the **2012 IBC (if accepted)**.


1991
1994
1997
2000
2003
2006
20??

THANK YOU