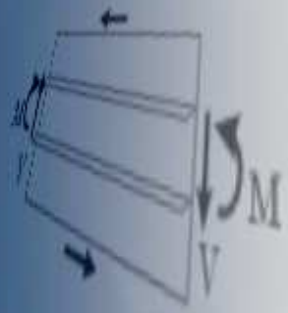
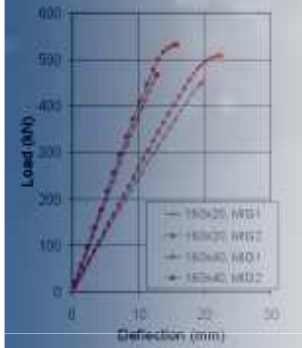


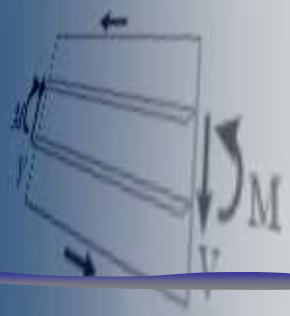
Seismic performance quantification of steel corrugated shear wall system



Laszlo Gergely Vigh, *(Geri)*
Visiting scholar, Stanford, CA
Asst. Prof., Budapest University of Technology and Economics,
Dept. Of Structural Engineering, Hungary

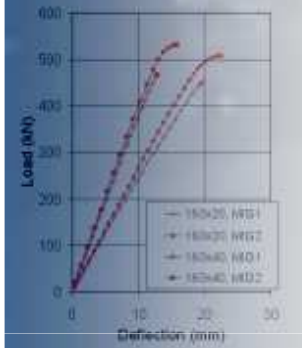
and
Professor Gregory Deierlein,
Professor Eduardo Miranda,
Abbie Liel (Stanford)
Stephen Tipping (Tipping Mar + Associates)

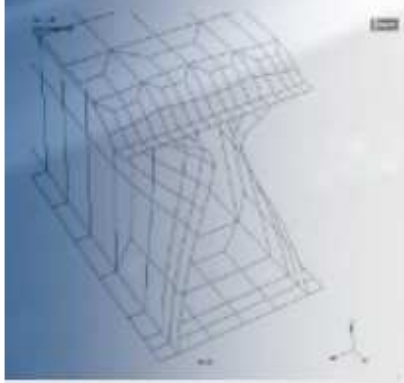
Thanks are due to:
The Thomas Cholnoky Foundation, Inc.



Little background…

- **Hard to work at Dept. of Structural Engineering**





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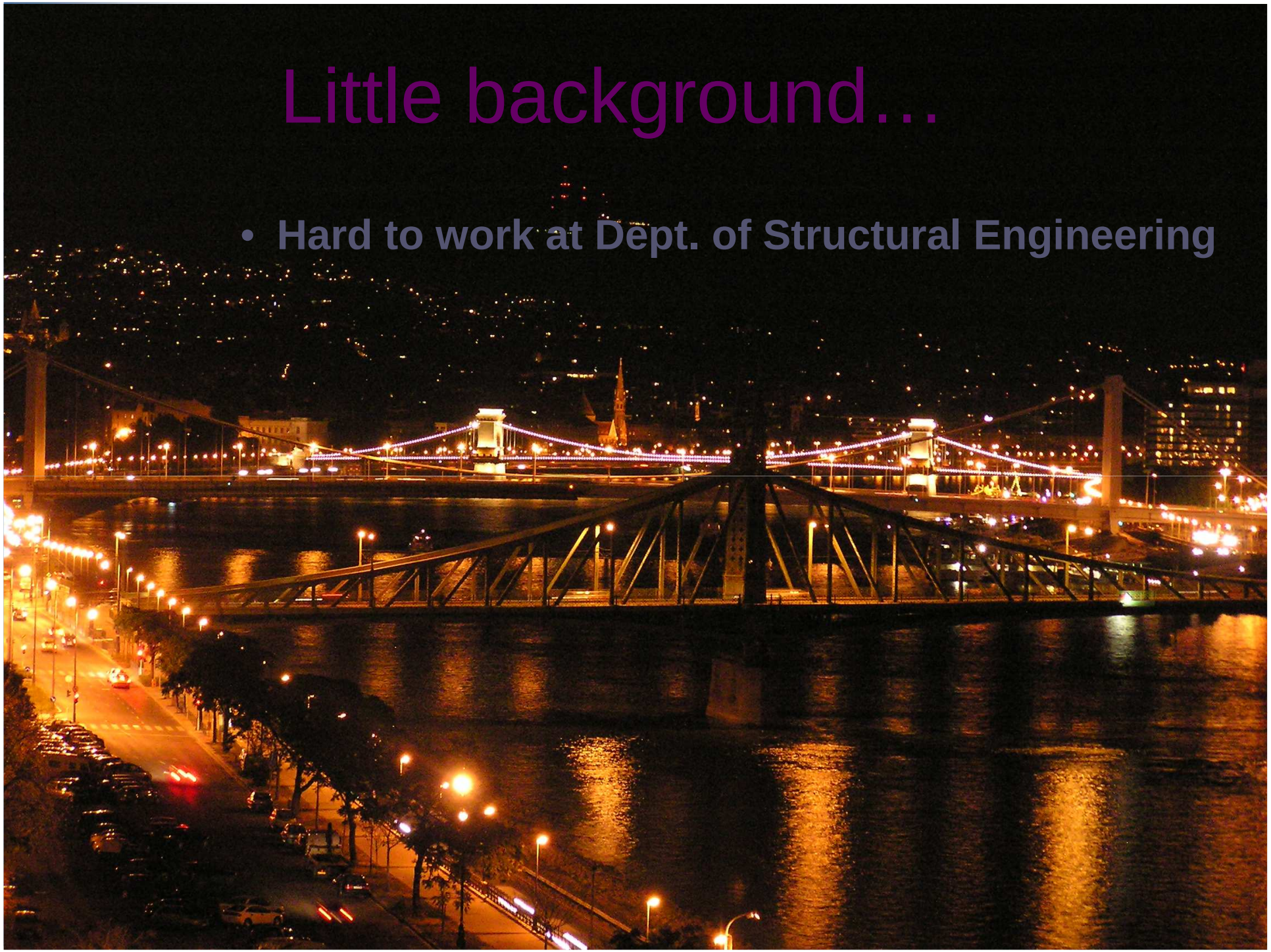
Little background…

- **Hard to work at Dept. of Structural Engineering**

Little background…

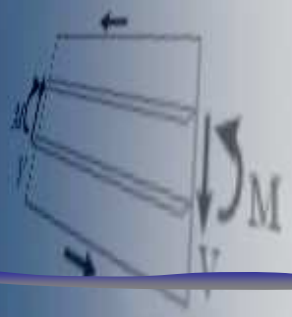
- **Hard to work at Dept. of Structural Engineering**



Little background…

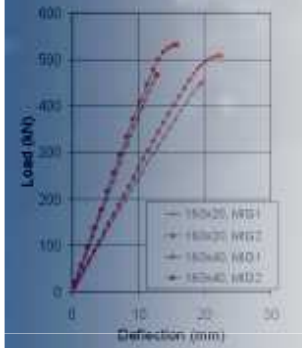
- **Budapest University of Technology and Economics**

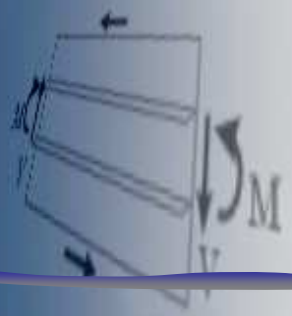
Source: www.bme.hu



Little background…

- **Budapest University of Technology and Economics**





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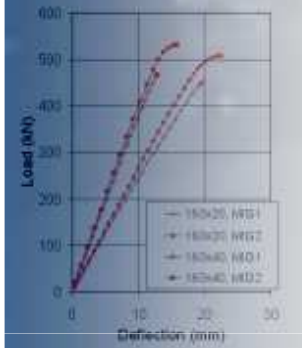
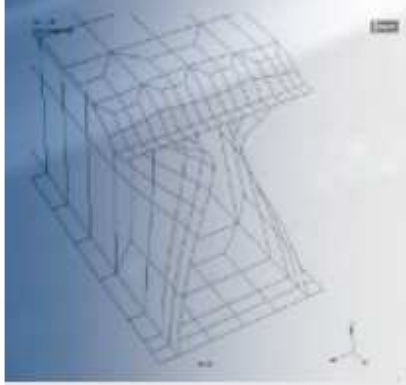


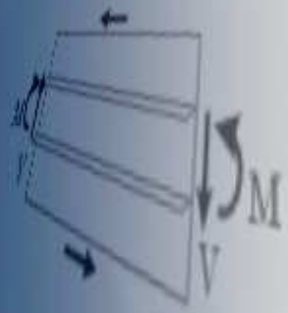
- **Budapest University of Technology and Economics:**
  - **8 faculties and several innovation centers**
  - **Faculty of Civil Engineering:**
    - **10 departments**
    - **Dept. of Structural Engineering:**
      - **staffs: 57 (incl. appr. 25 of asst. prof – prof)**
      - **22 BSc, 16 MSc courses + optionals**

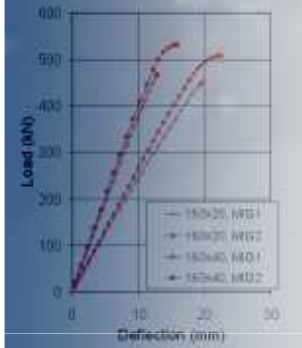


Little background…

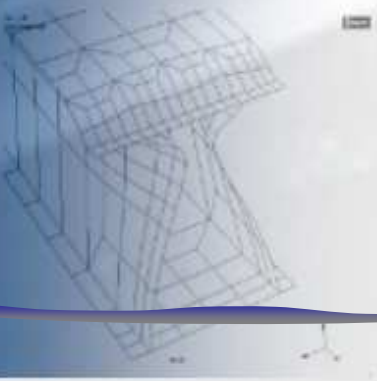
- **Dept. of Structural Engineering**

1. **Education**
2. **Research – national research funds, and ‘selfish’ researches**
3. **Industry & University**
   - **R&D**
   - **Co-designer**
   - **Expert**
   - **Independent checks**
   - **Laboratory and site testing – Accredited laboratory**
4. **Student life…**





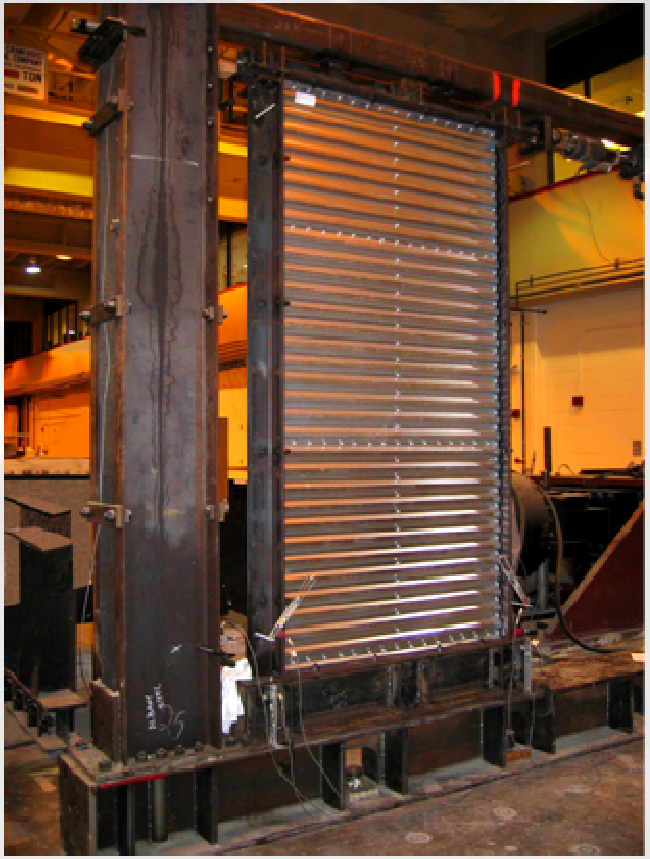
Seismic performance quantification of steel corrugated shear wall systems

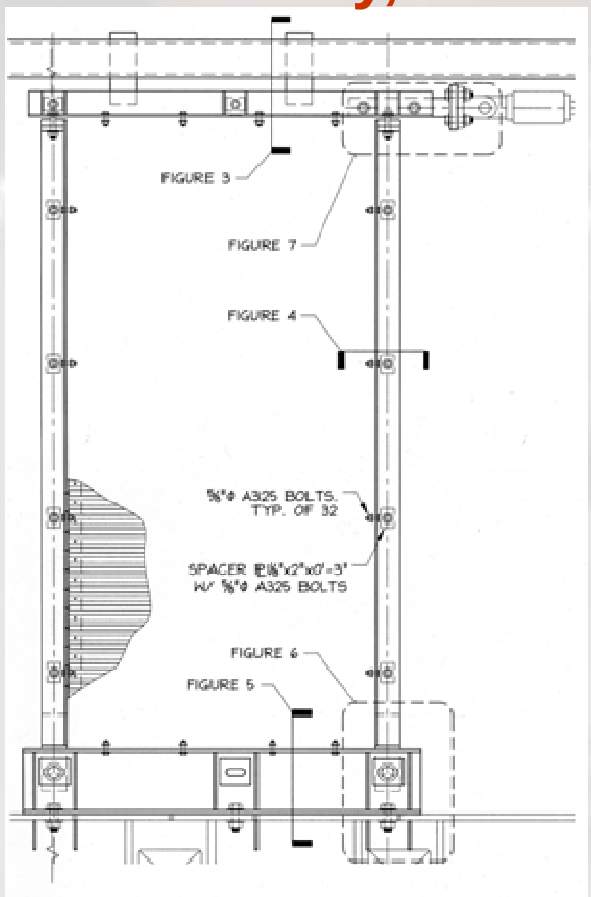


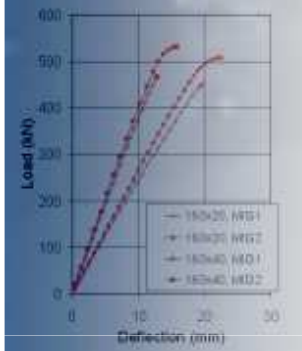
Shear wall system

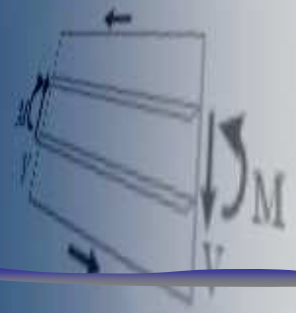
- corrugated sheet
- boundary elements
- screwed connection

Tipping Mar and Associates, Berkeley, CA









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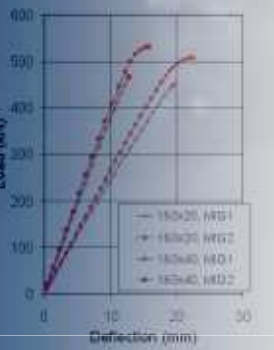
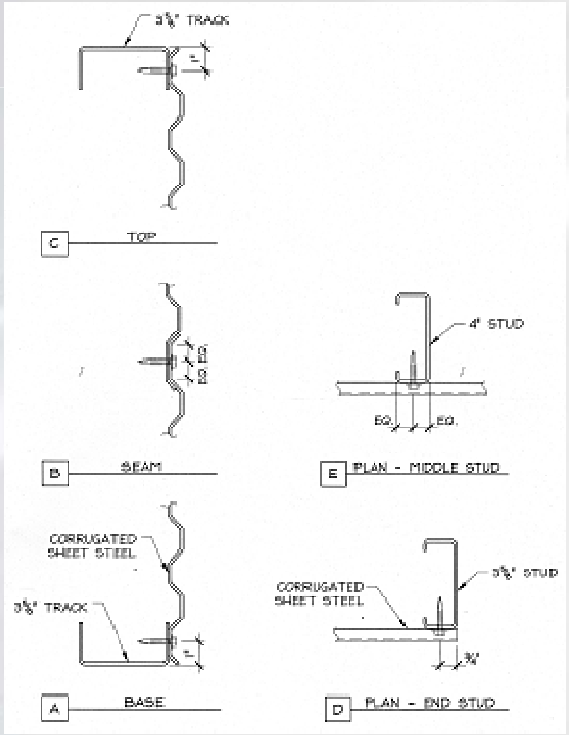
Shear wall system

- corrugated sheet
- boundary elements
- screwed connection

Assembly	stud gauge	20	18	16	16
	screw size	12	12	12	14
sheathing	screw spacing	Group #			
22	6"	1	25	7	
22	3"	3	6	8	
18	3"		13	14	16





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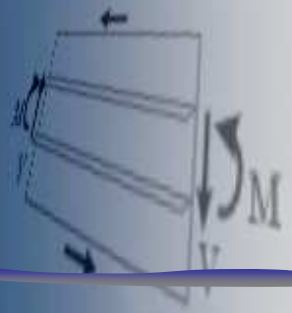
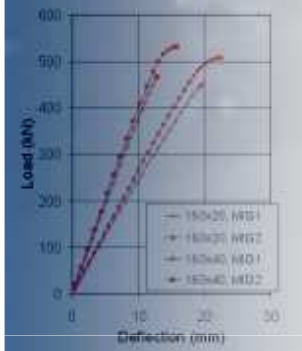


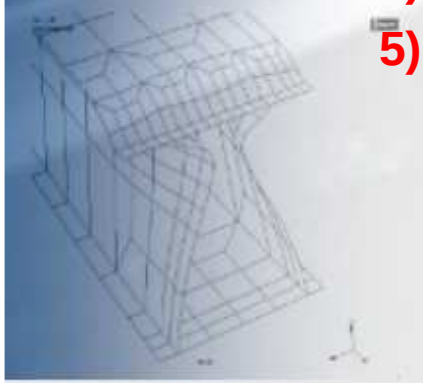
Seismic performance quantification by ATC-63



- performance quantification by cyclic tests

  or

- Applied Technology Council, Project 63
- achieves primary life safety performance objective by requiring an acceptably low probability of collapse
- R, Ω_0, C_d factors



1) idealized archetypical systems: realization, design (assume R)
2) analytical model development and calibration
3) nonlinear static (pushover) analysis → Ω_0
4) nonlinear incremental dynamic analysis (IDA)
5) fragility curves;
   adjusted collapse margin ratio (ACMR) vs. acceptable ACMR

↓

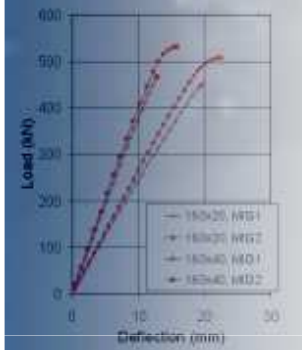
R, C_d

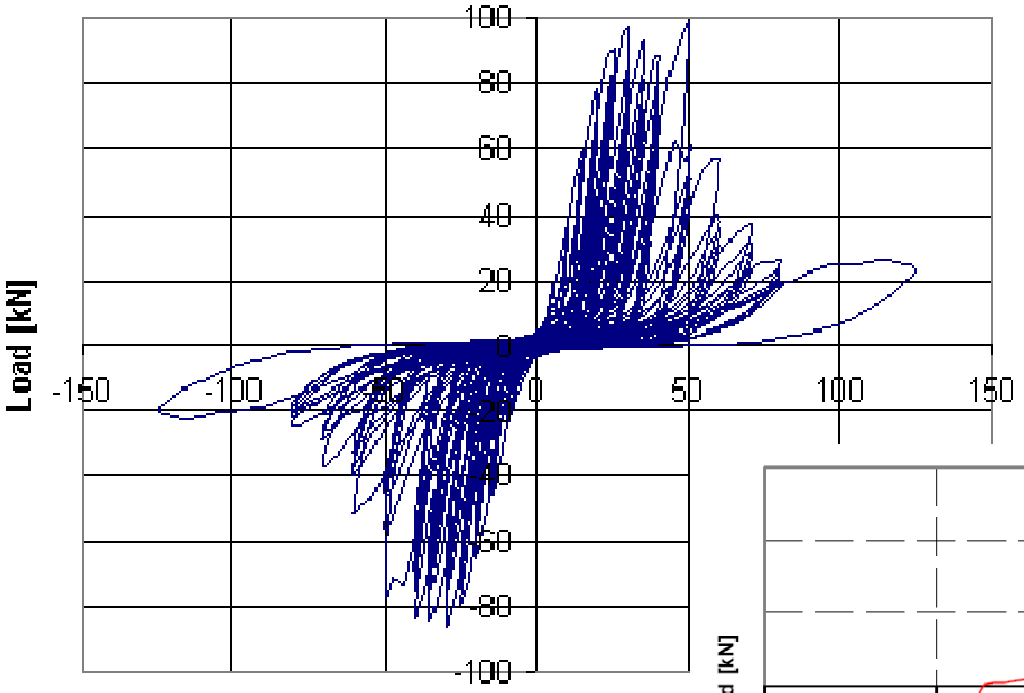
Experimental results

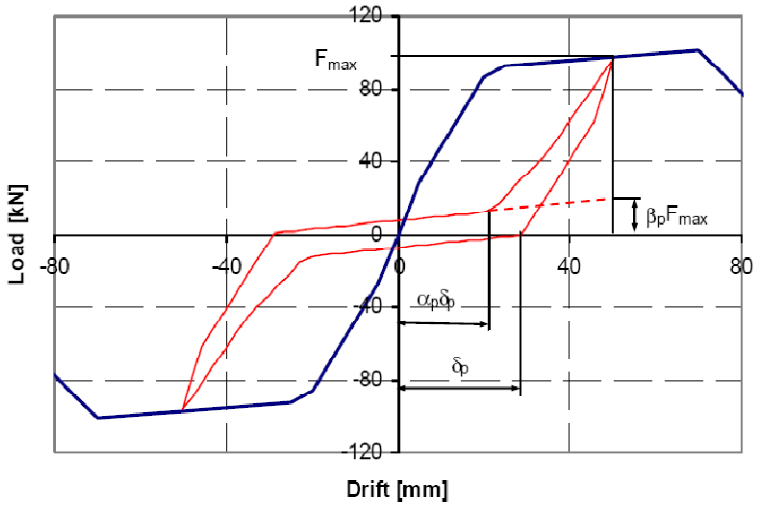
- **Stojadinovic et al. at UC Berkeley**
- **44 specimens**

Experimental results

- pinching hysteresis behavior







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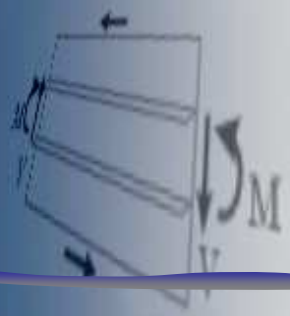
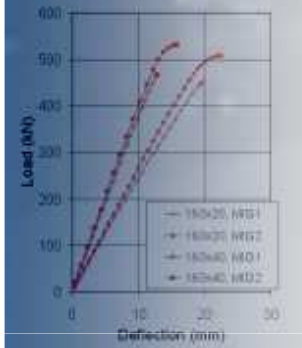


Experimental results

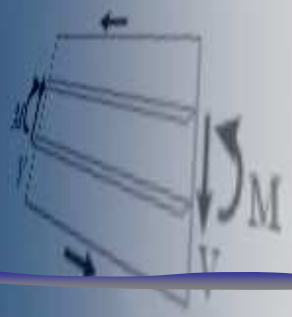
- **failure modes**



a) bearing

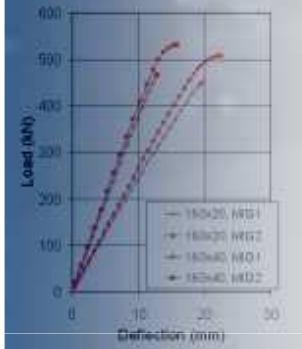
b) screw pull-out / tilt

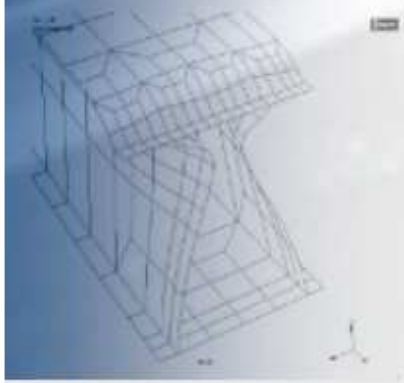
c) buckling and warping of corrugated sheet after screw pull-out

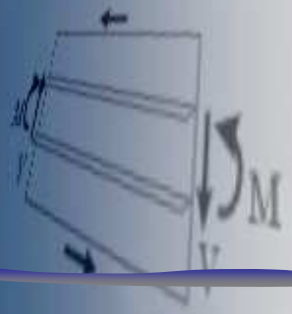


Experimental results

- **failure modes**

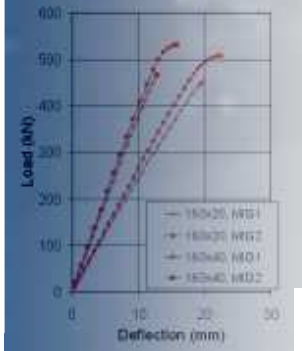


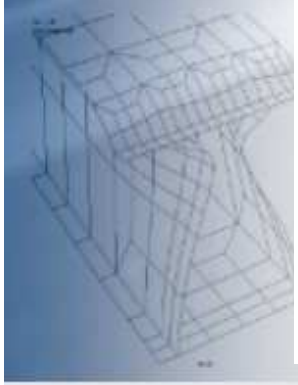




Shear wall behavior –
estimation of monotonic backbone curve

- **challenge:**
  - **- cyclic behavior is path-dependent**
  - **- calibration to test results – we should know the monotonic behavior**





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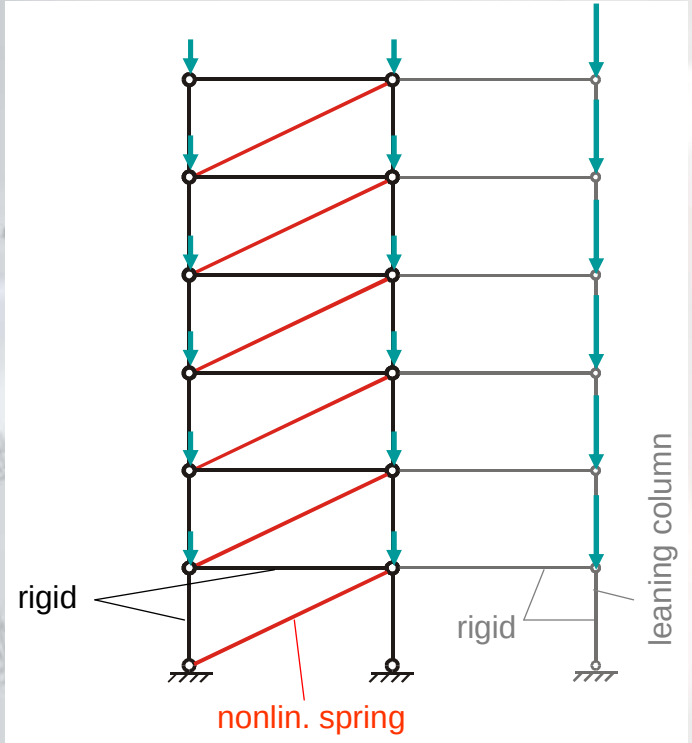
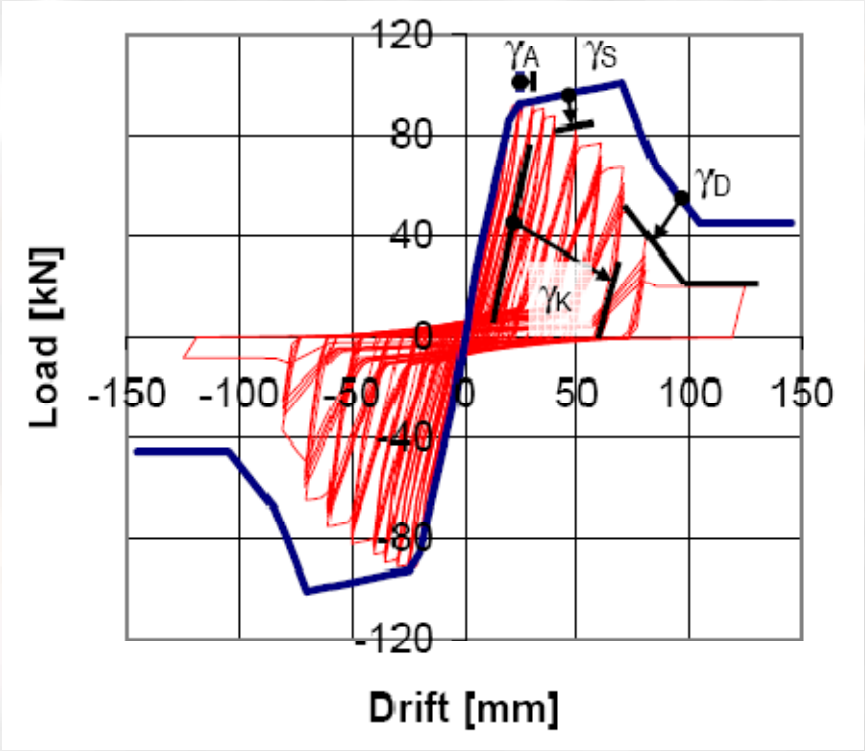
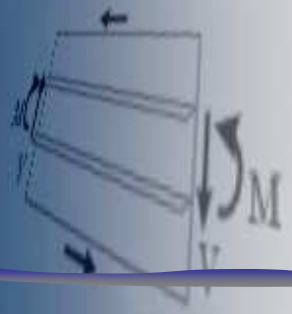
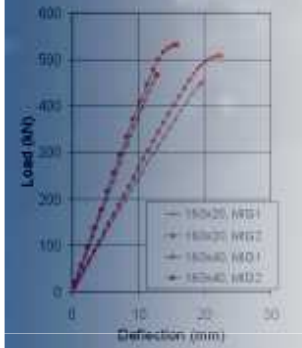


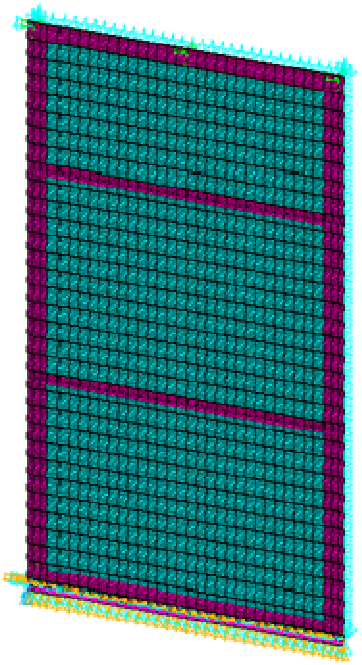


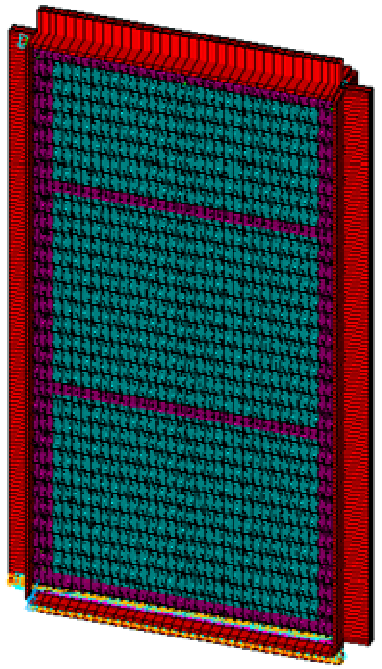


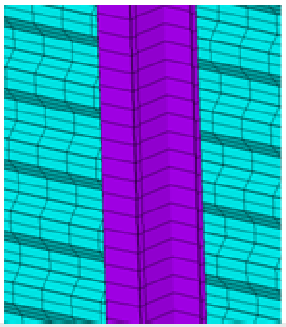
Shear wall behavior –
estimation of monotonic backbone curve

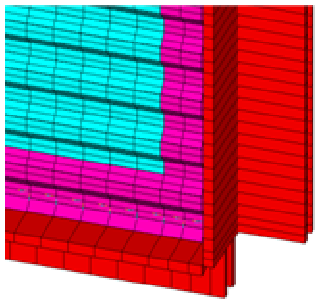
- **modelling technique**

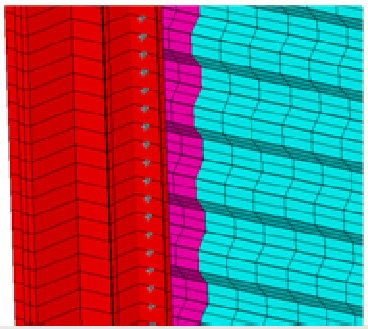




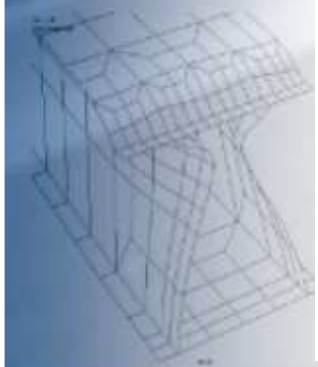


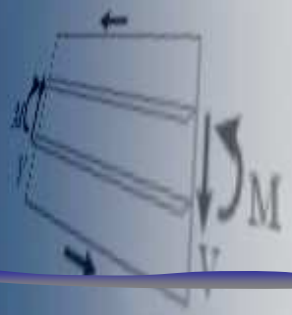






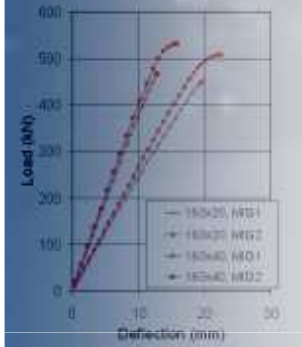
ANSYS
shell, beam & spring elements

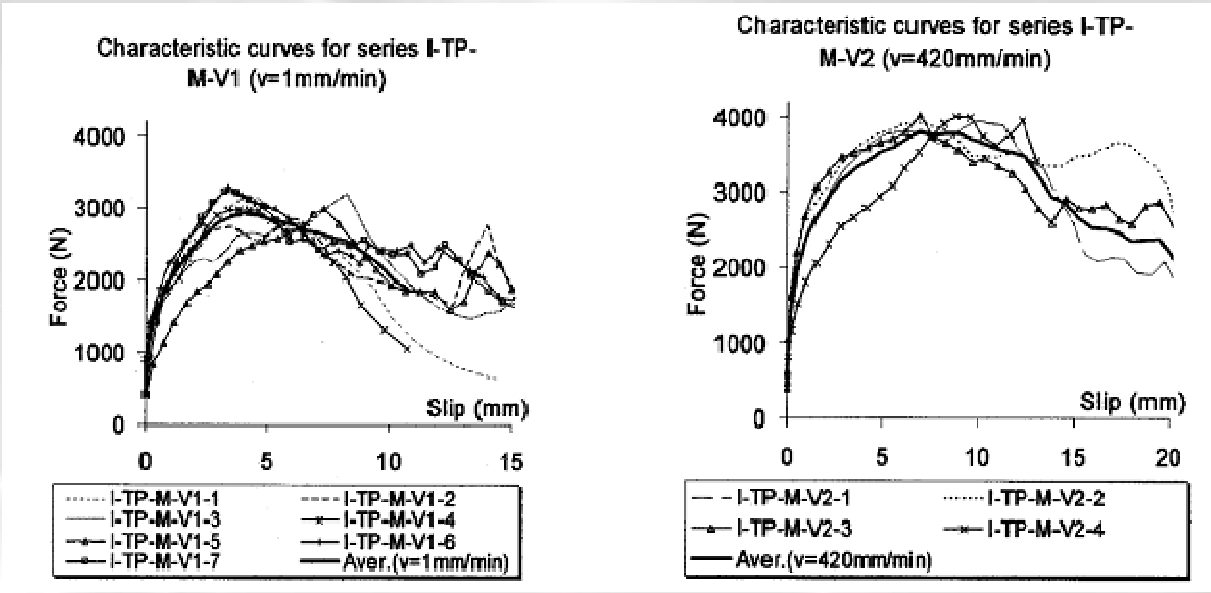




Shear wall behavior –
estimation of monotonic backbone curve

- **single screw connection behavior**





Source: Dubina et al.

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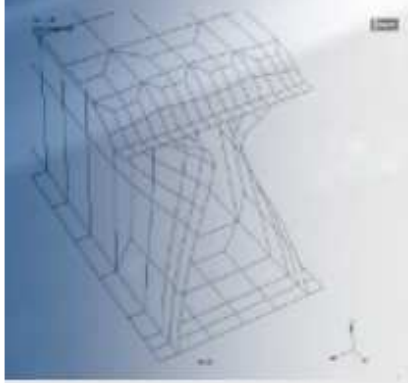
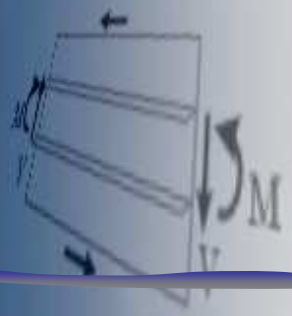
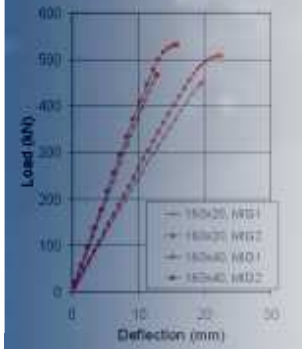


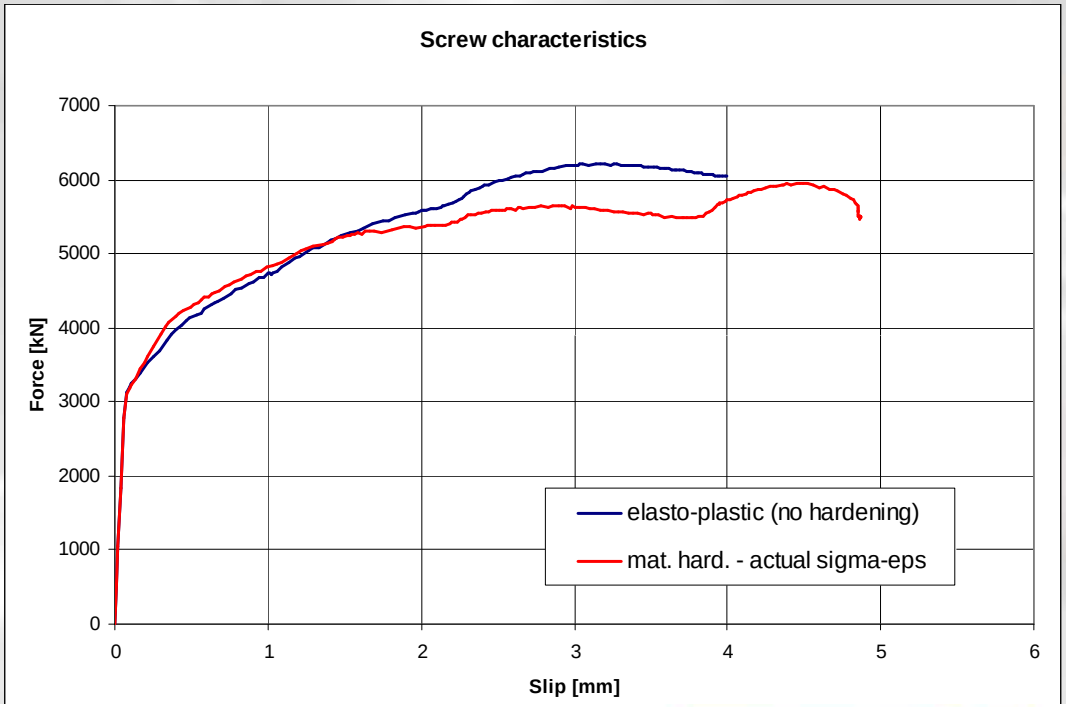
- **literature**
- **EC3**
- **published experimental data**



Shear wall behavior –
estimation of monotonic backbone curve

- **single screw connection behavior**





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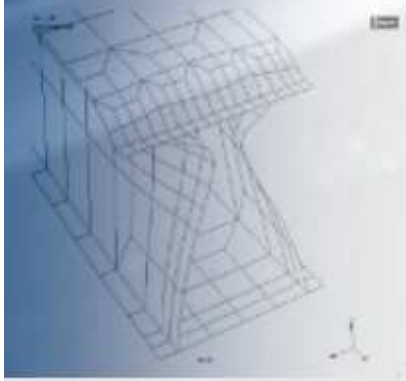
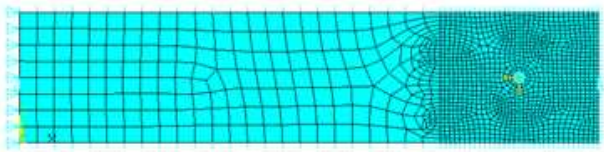
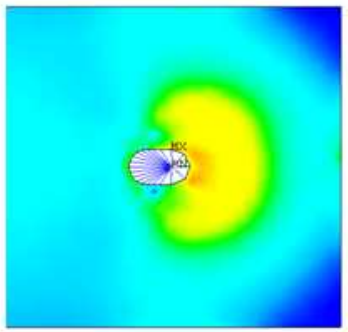
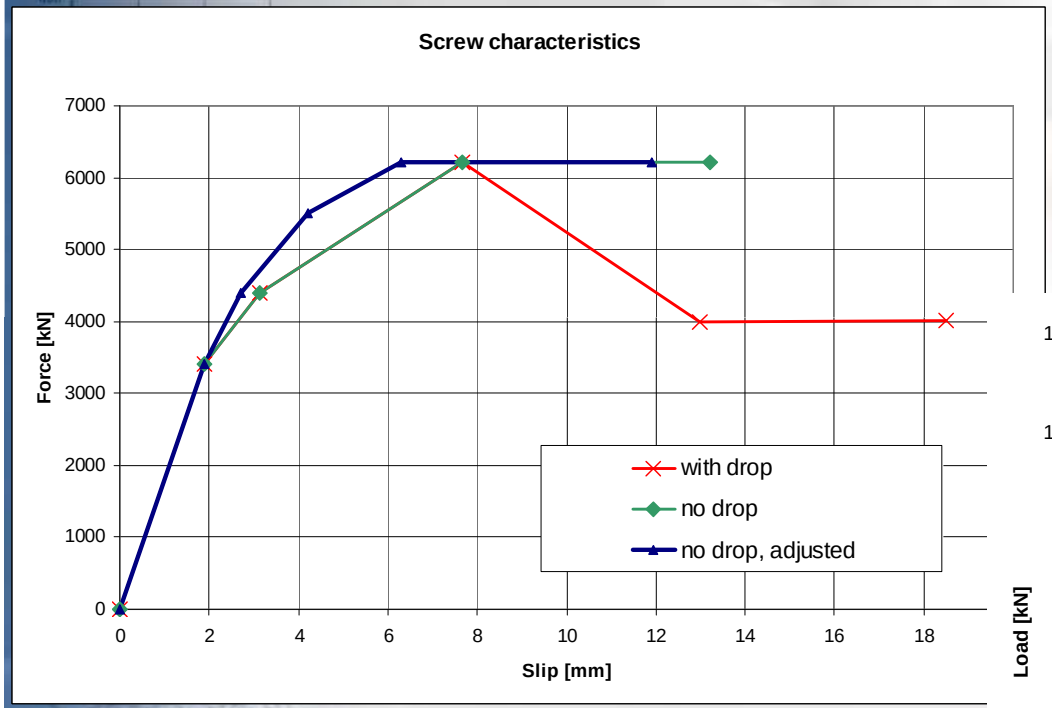


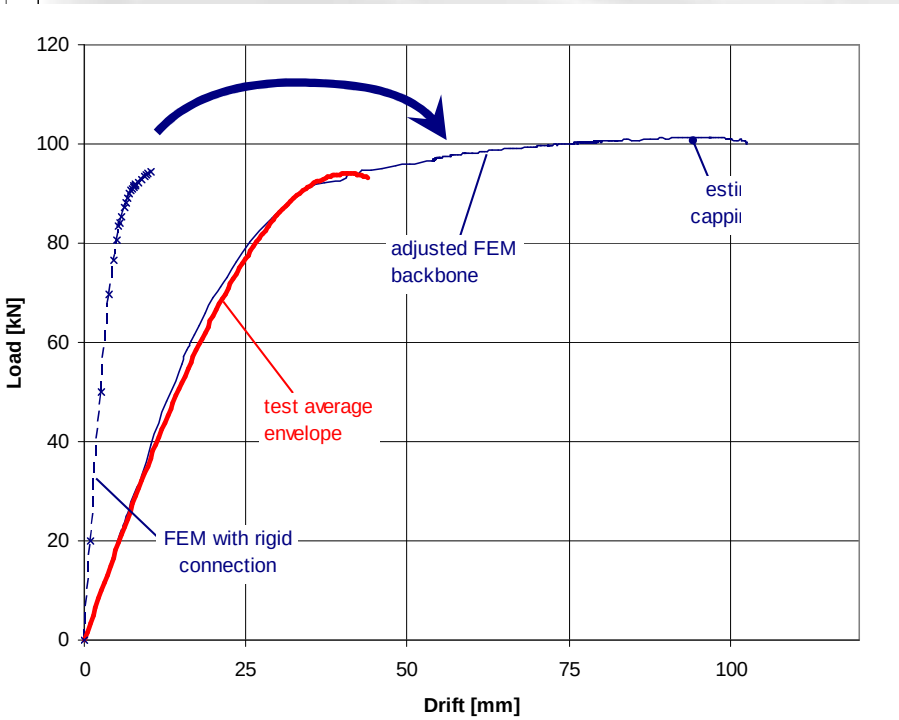


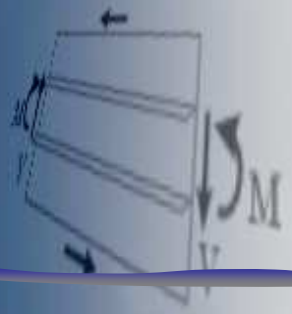


Shear wall behavior –
estimation of monotonic backbone curve

- **single screw connection behavior**

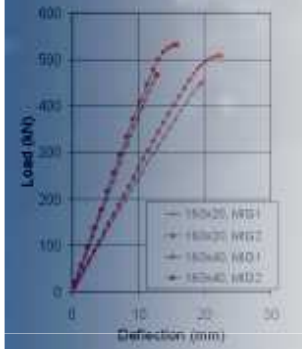


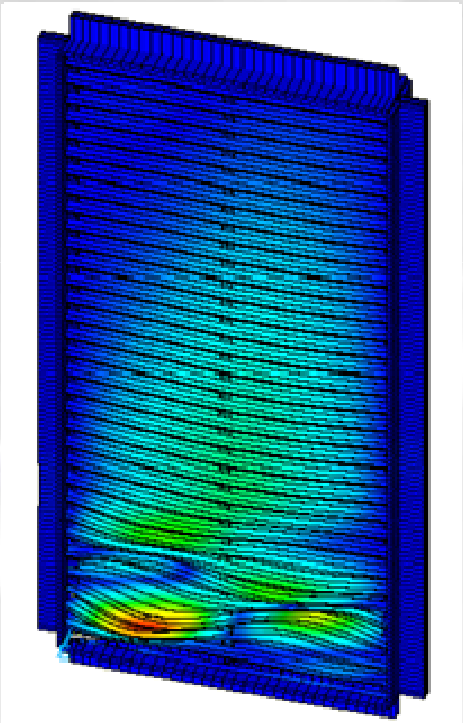


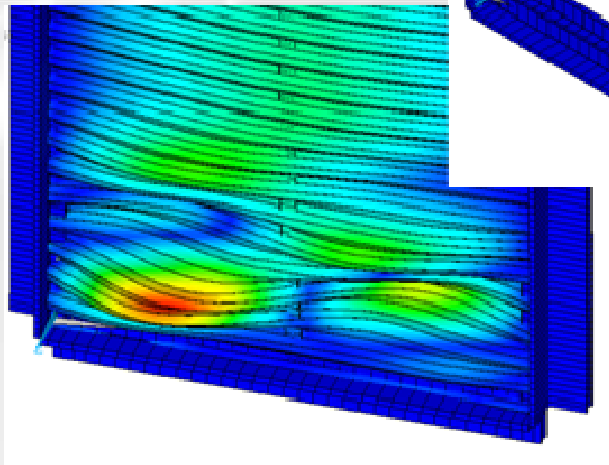


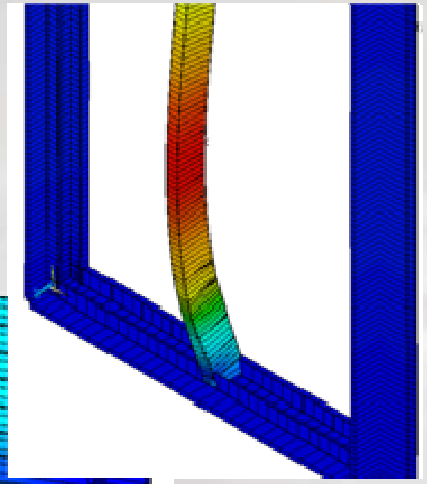
Shear wall behavior –
estimation of monotonic backbone curve

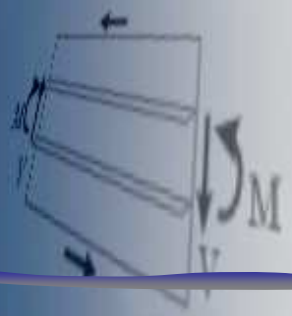
- **analysis of tested shear walls**





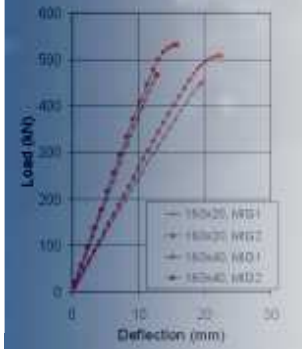


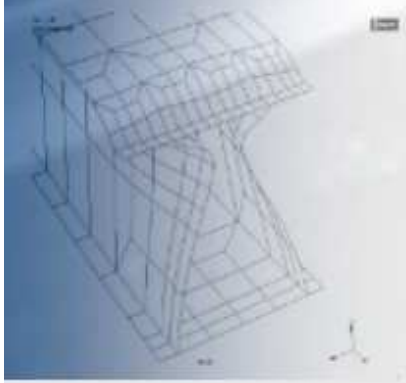




Shear wall behavior –
estimation of monotonic backbone curve

- **extension to longer walls**





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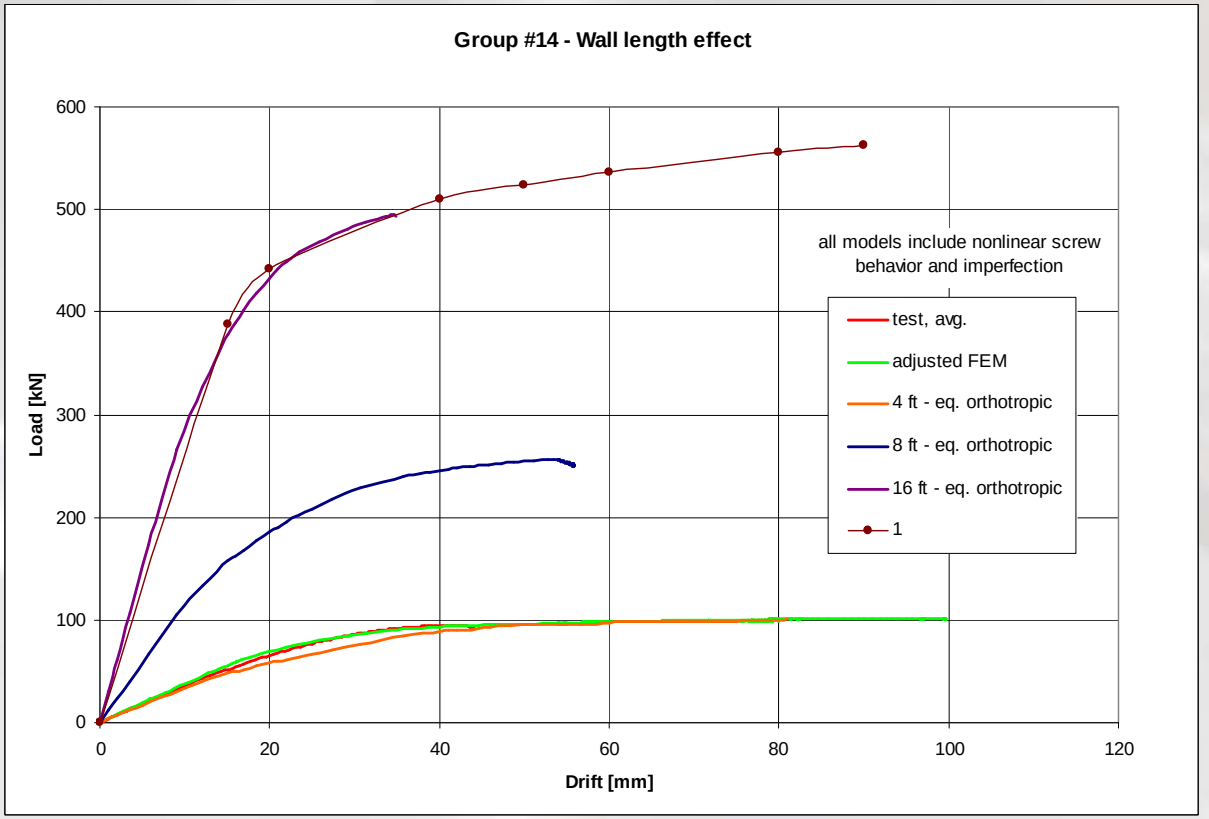
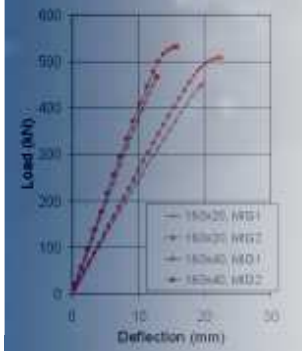


Model calibration

- OpenSees
- Ibarra – Medina – Krawinkler model



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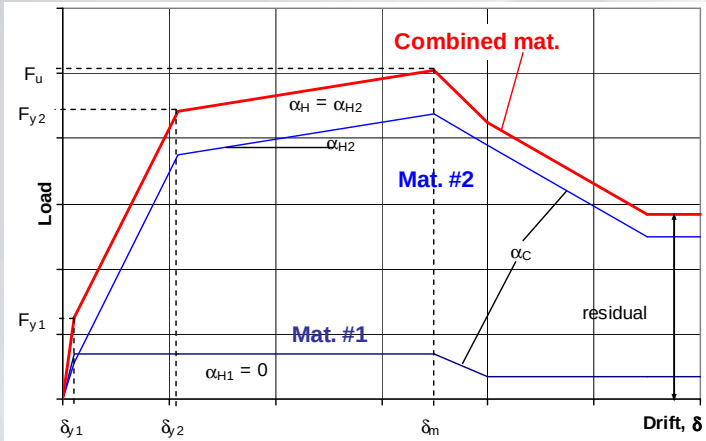
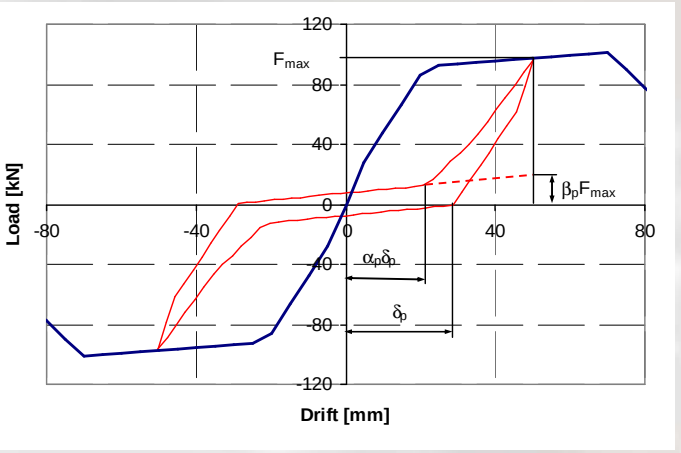
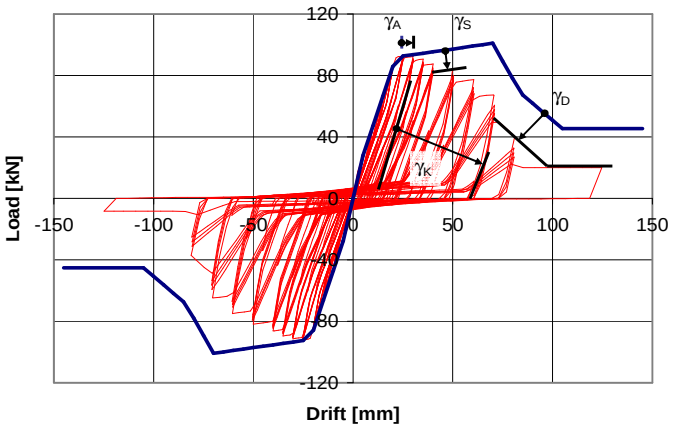
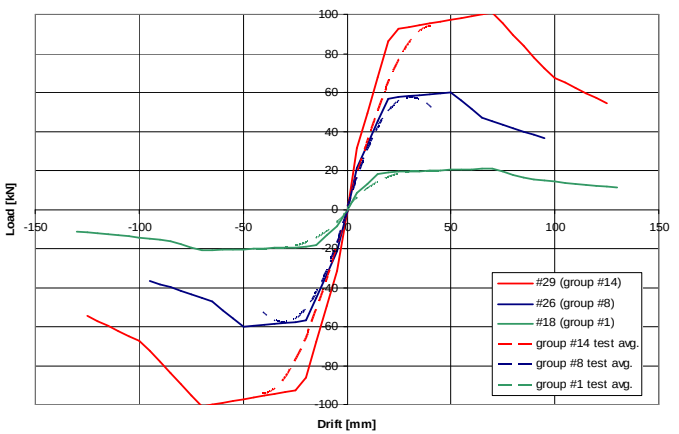
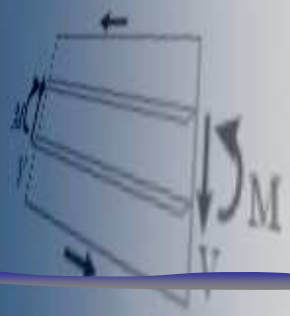




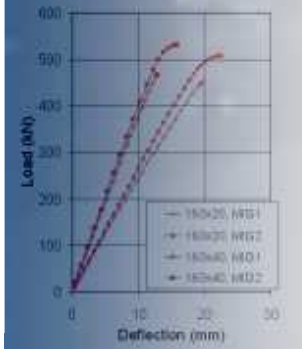


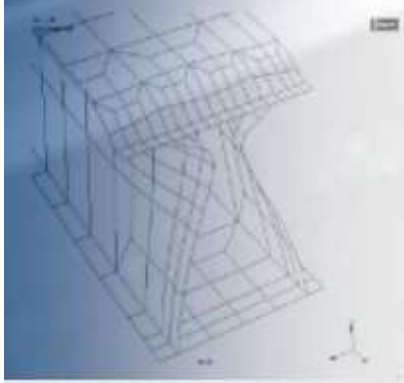




Model calibration

- **calibration: GA**





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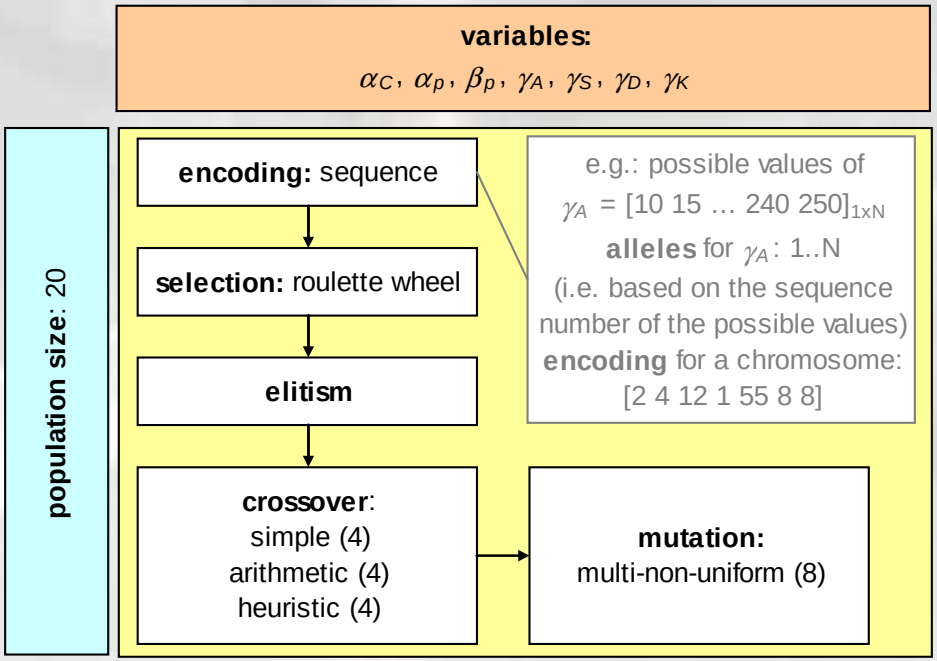
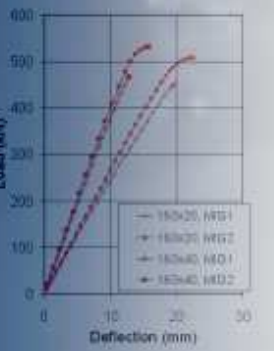
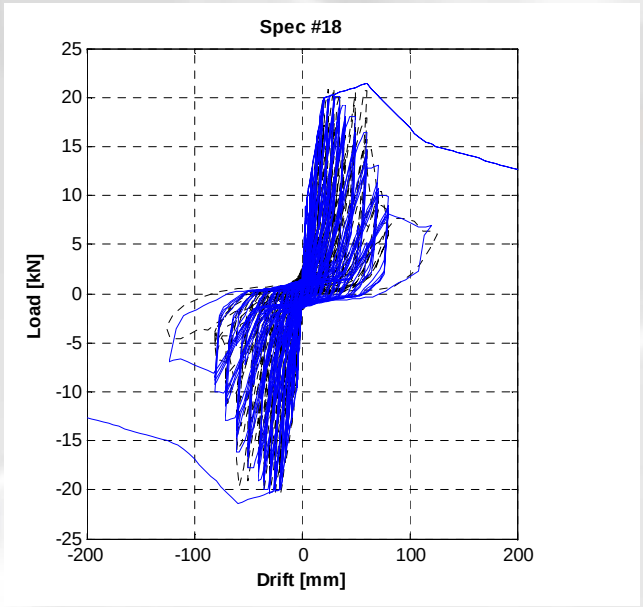
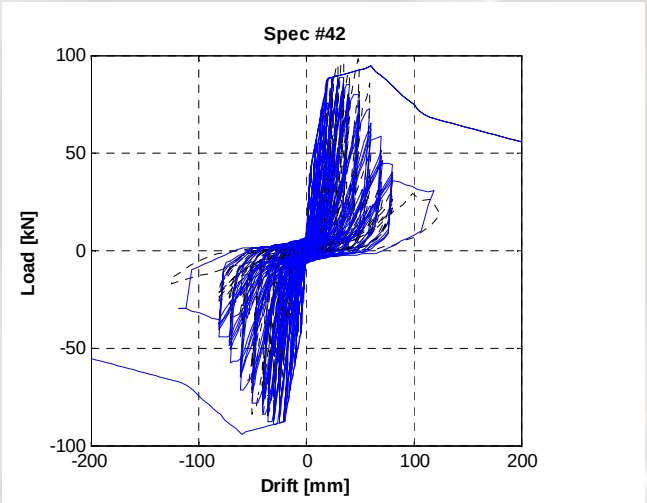


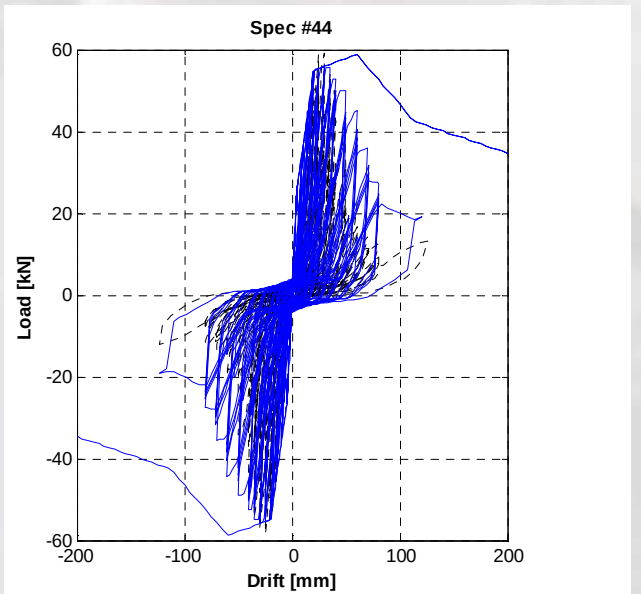
Model calibration

- **final – uniform – model**









Assembly	stud gauge	20	18	16	16
	screw size	12	12	12	14
sheathing	screw spacing	Group #			
22	6"	1	25	7	
22	3"	3	6	8	
16	3"		13	14	16

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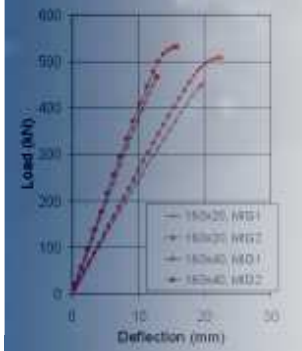
Model calibration

- **final – uniform – model**



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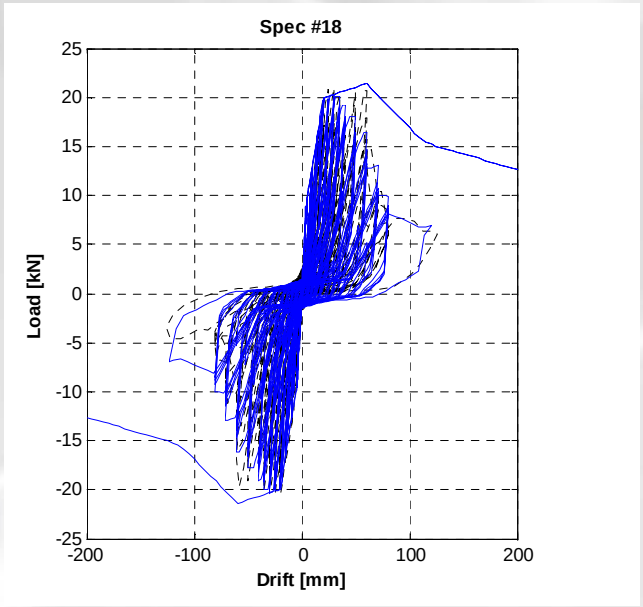

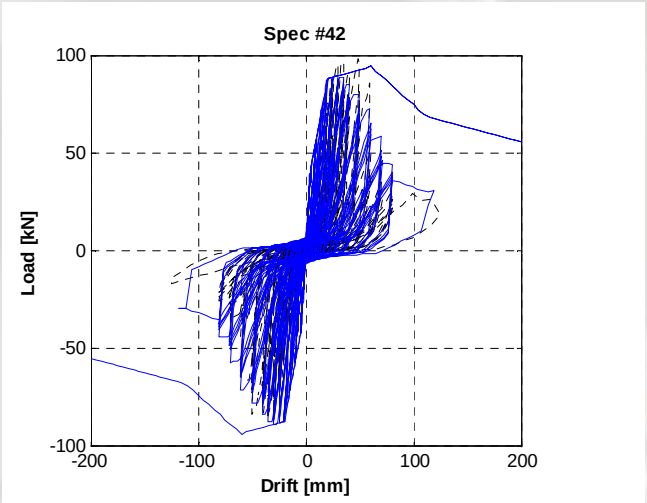

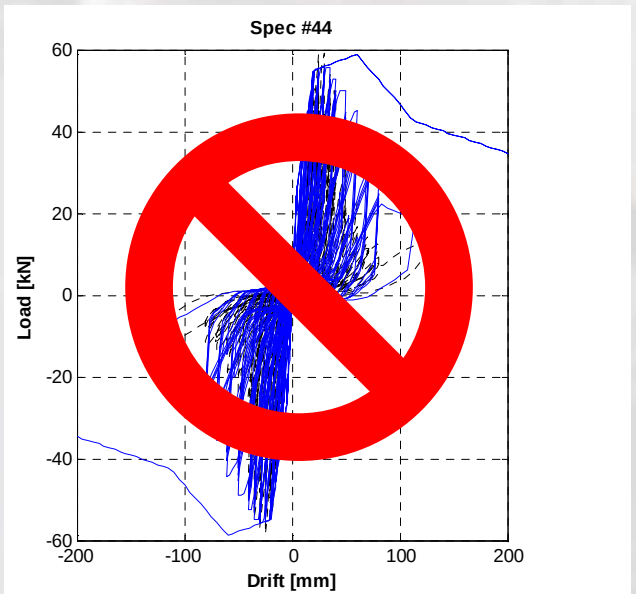

Assembly	stud gauge	20	18	16	16
	screw size	12	12	12	14
sheathing	screw spacing	Group #			
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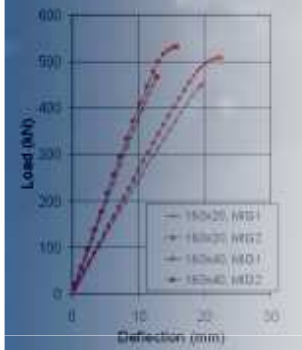
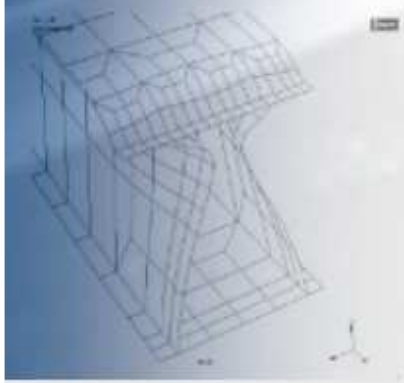
22	3"	3	6	8	
16	3"		13	14	16

Building archetypes

- **Archetype definitions**
  - **building function, configurations**
  - **number of stories**
  - **seismic zone**





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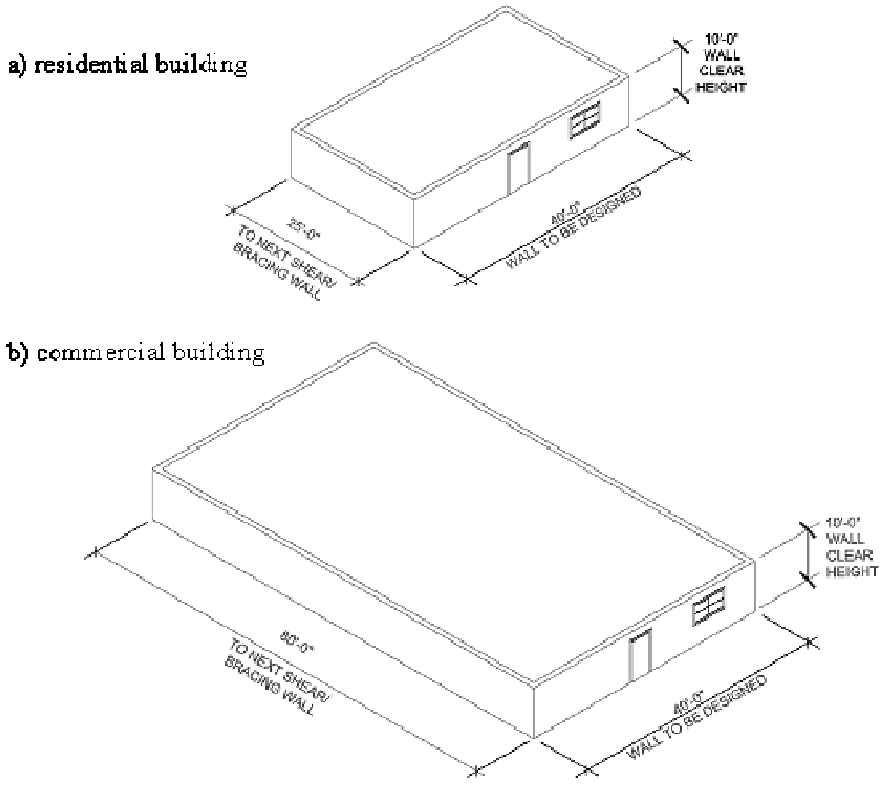
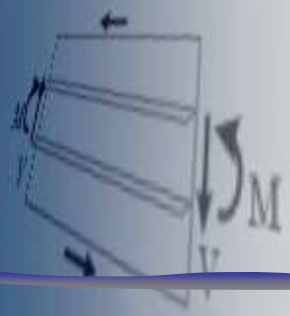
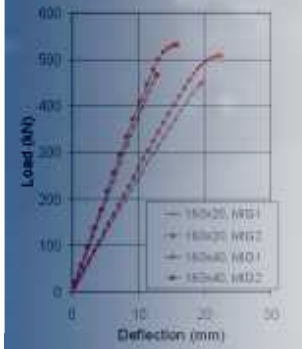




Building archetypes

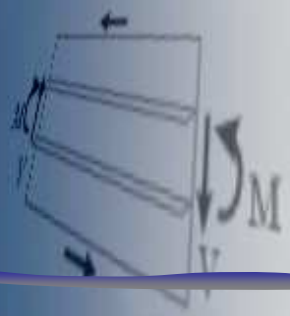
- **Archetype definitions**



R = 4 High seismic (SDC Dmax)

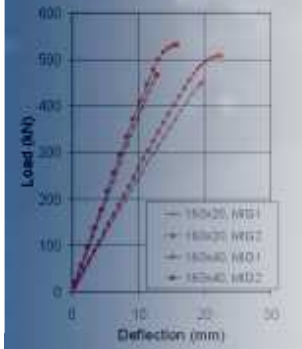
S_S = 1.5, S_1 = 0.9 (S_{DS} = 1.0, S_{D1} = 0.6)

Archetype	Story #	Function	A_{floor} [sqft]	seismic weight [psf]	Appr. period [s]	Upper limit of period [s]	S_{MT} (at T_a) [g]	C_s [-]	Design base shear [kip]	wall length [ft]
1	1	Commercial	1600	30	0.112	0.16	1.50	0.25	12	12
5	2	Commercial	1600	30	0.19	0.27	1.50	0.25	24	24
9	3	Commercial	1600	30	0.26	0.36	1.50	0.25	36	20
2	1	1&2 Family	500	10	0.112	0.16	1.50	0.25	1.25	8
6	2	1&2 Family	500	10	0.19	0.27	1.50	0.25	2.5	8
10	3	Multi-Family	500	30	0.26	0.36	1.50	0.25	11.25	12
13	4	Multi-Family	500	30	0.32	0.45	1.50	0.25	15	16
15	5	Multi-Family	500	30	0.38	0.53	1.50	0.25	18.75	20



Building archetypes

- **seismic design**
  - **based on assumed R**
  - **simplified proc: equivalent static loading**



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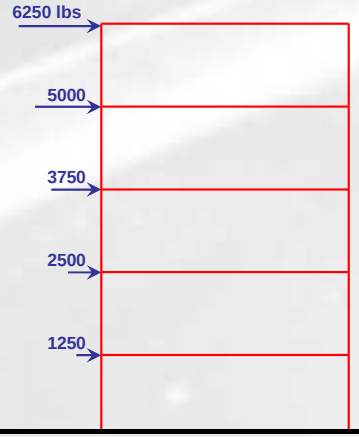
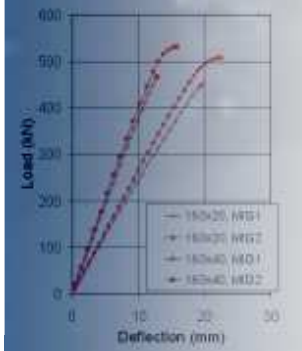
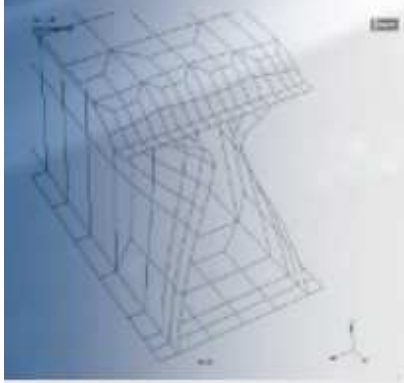
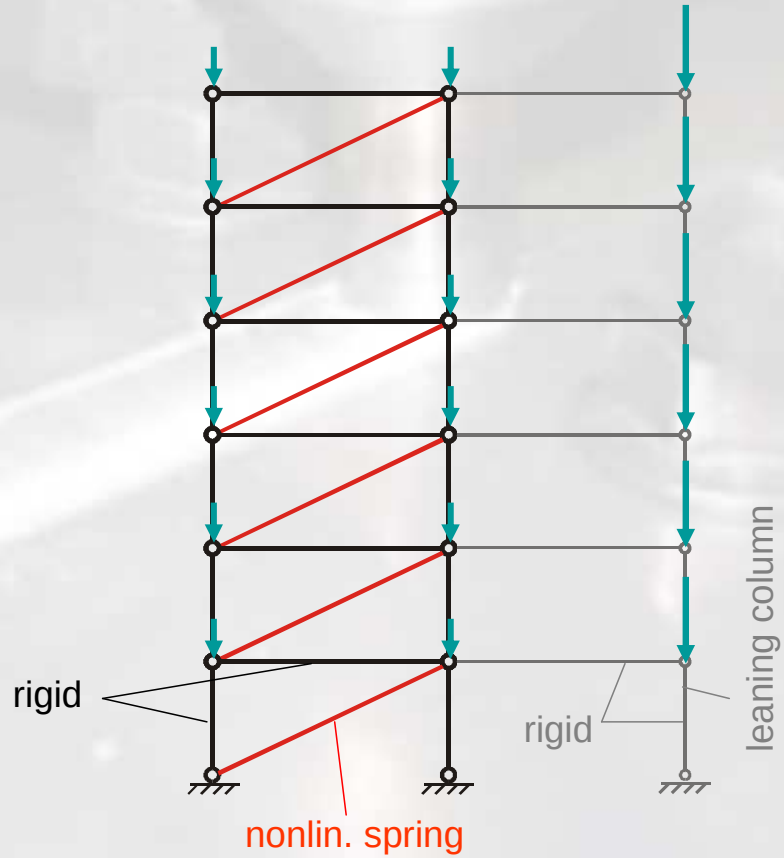
Story	EQ loading [kip]	demand, V_u [lbs]	demand, V_u [plf]	wall type (group#)	V_{nom} [plf]	V_{ASD} [plf]	V_{LRFD} [plf]
R		6250	**312**	1	1173	469	**657**
4		11250	**563**	1	1173	469	**657**
3		15000	**750**	25	1505	602	**843**
2		17500	**875**	7	1836	734	**1028**
1		18750	**937**	7	1836	734	**1028**

Analytical model

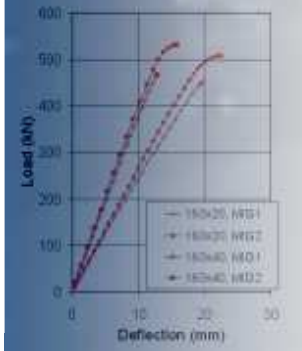
- **2D truss structure**







Pushover analysis



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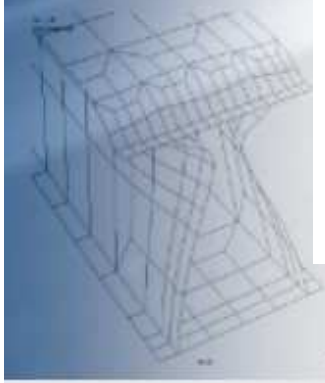
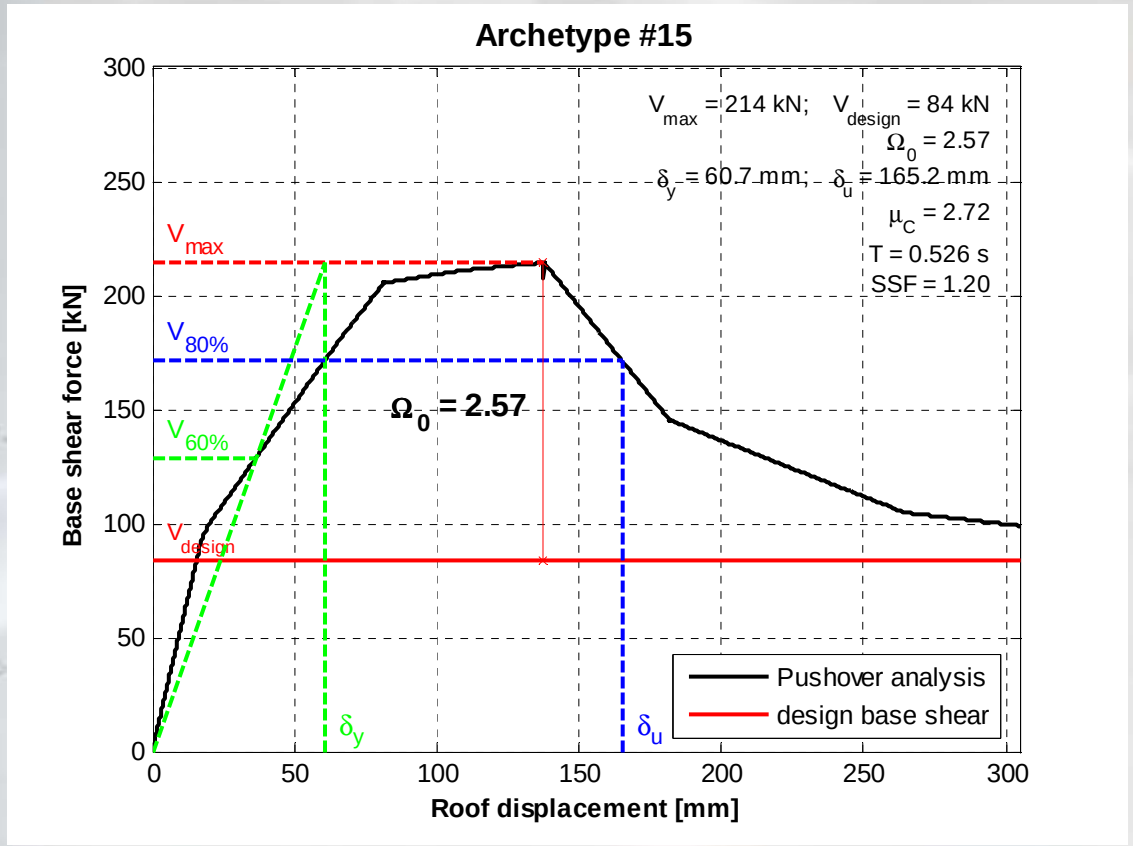
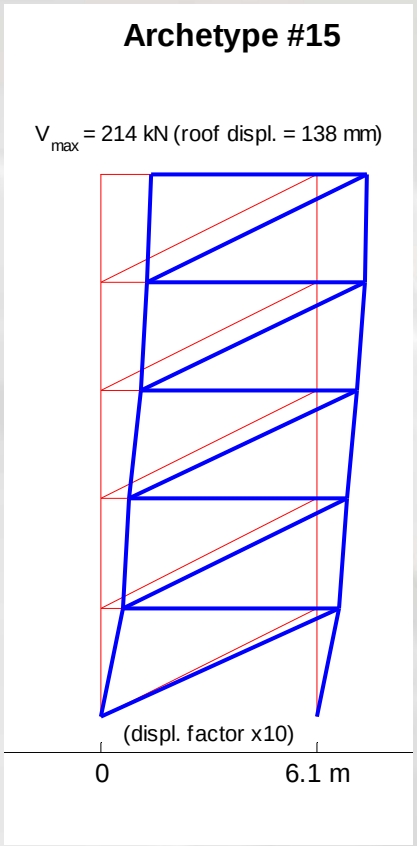
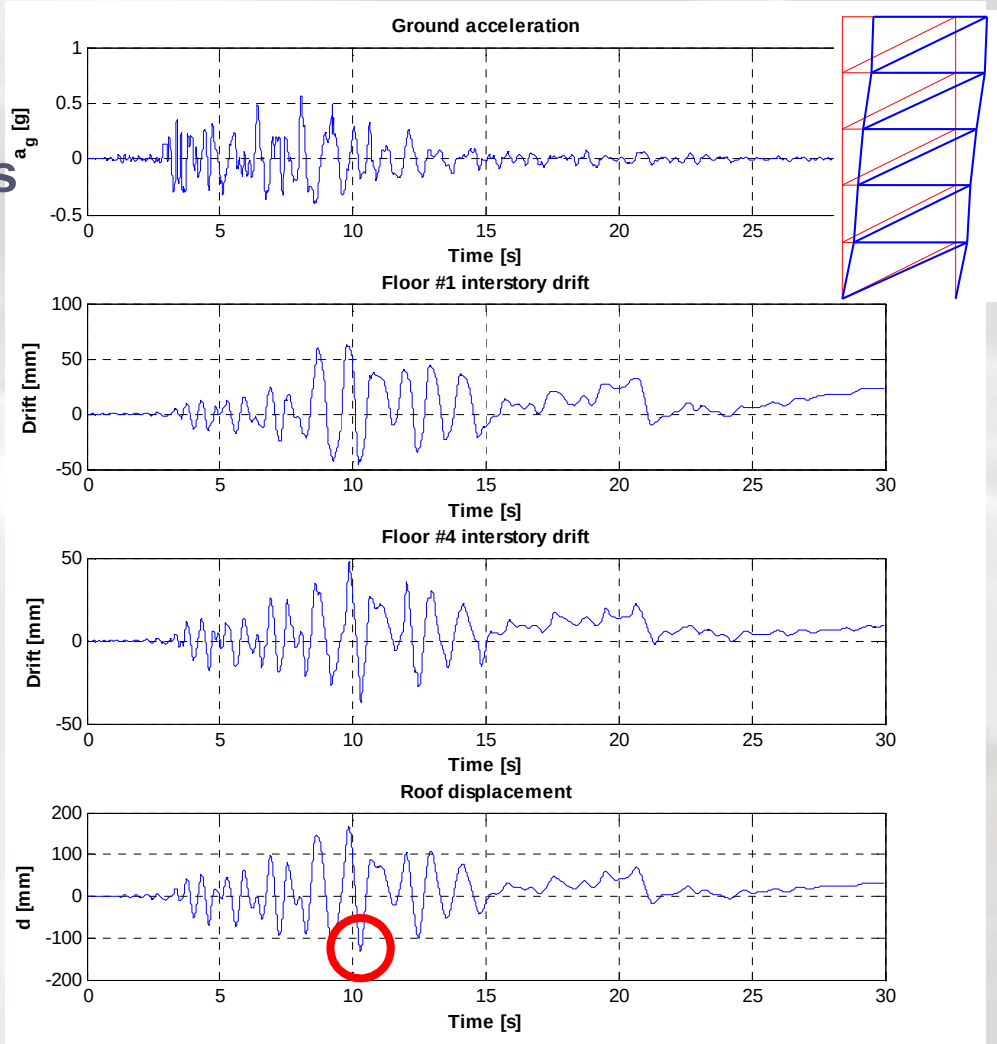


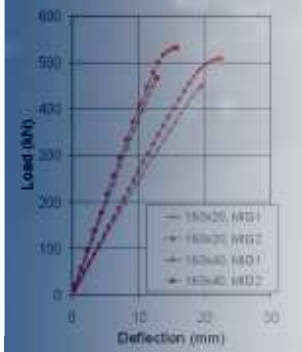




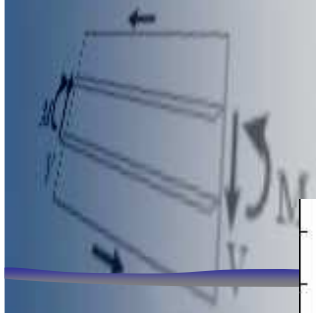
IDA analysis

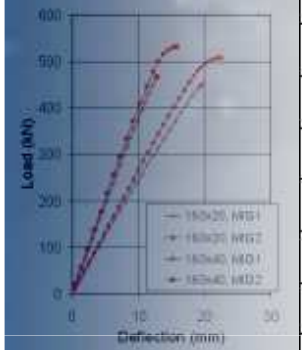
- each archetype
- 44 EQ records
- nonlin. dyn. analysis
- max. interstory drift

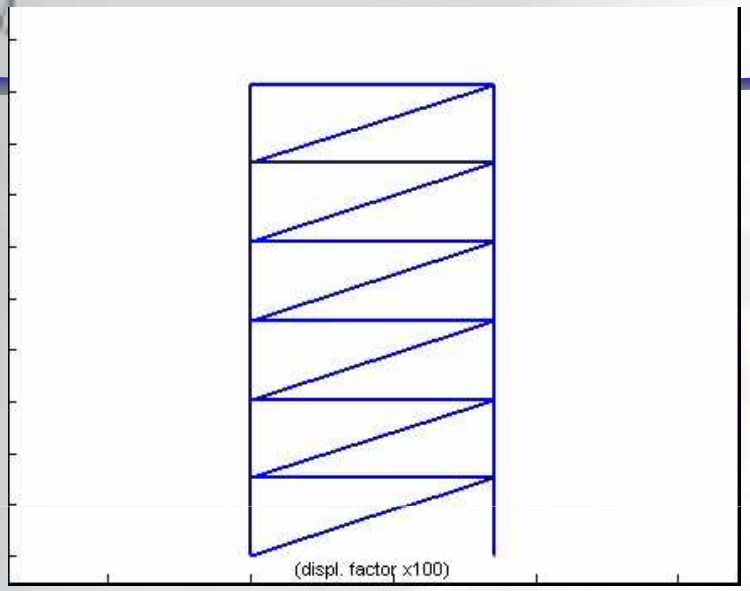


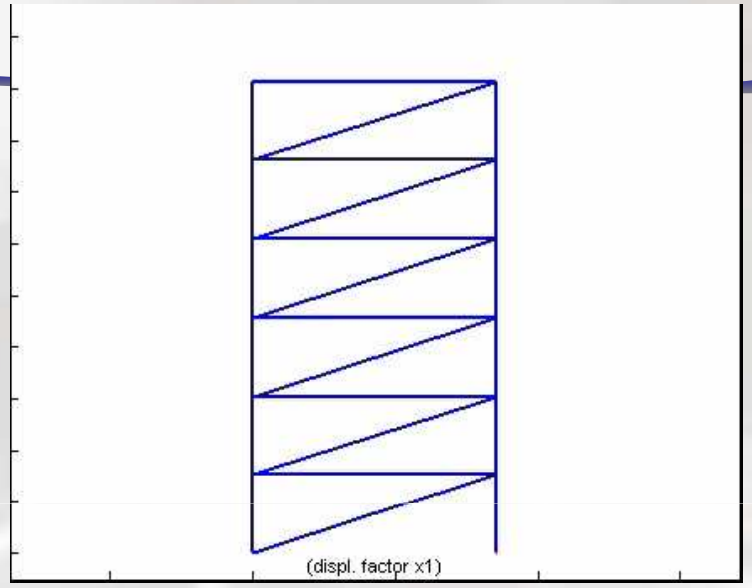


IDA analysis









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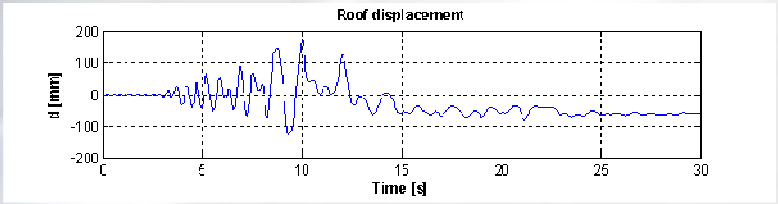
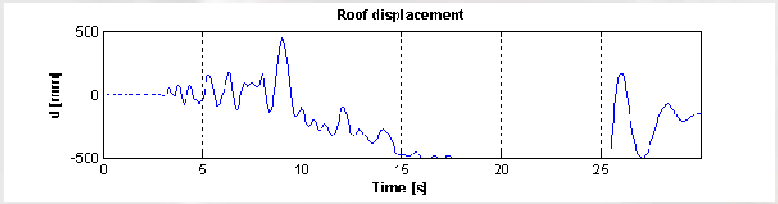
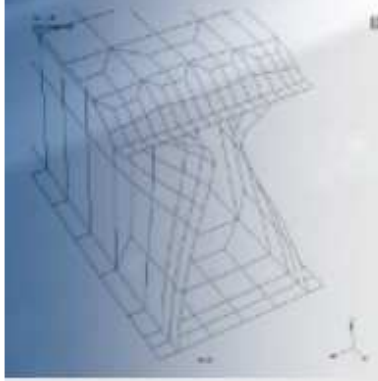
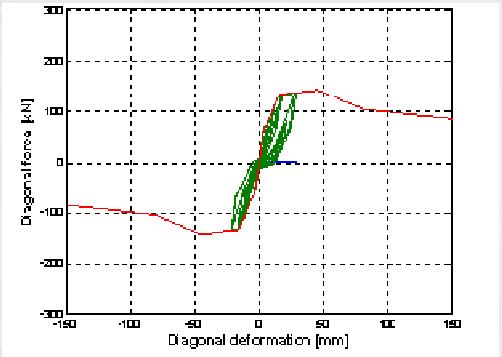
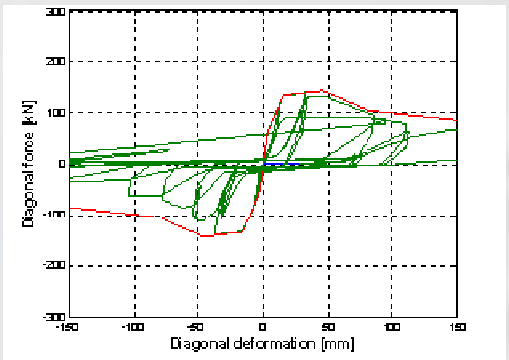




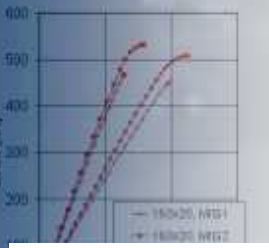


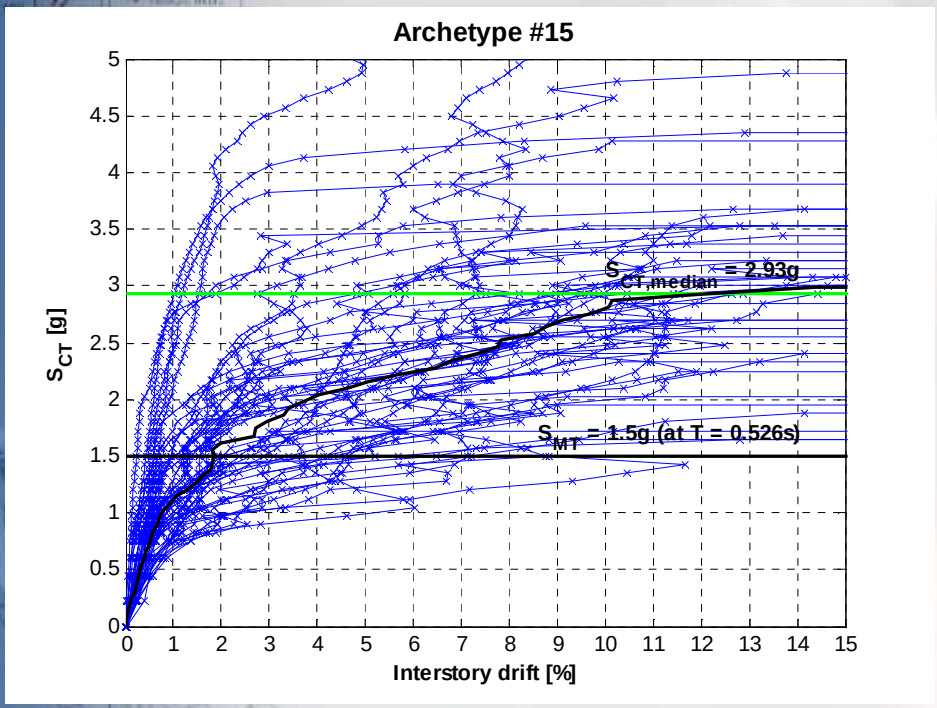


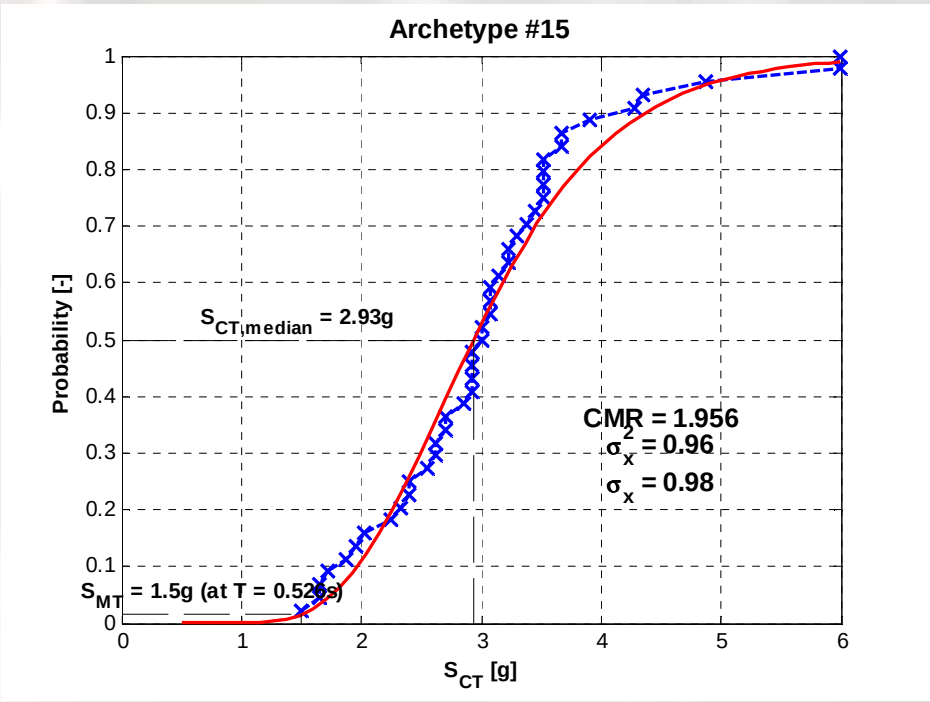


IDA analysis

- each archetype
- each record
- scaled up to collapse



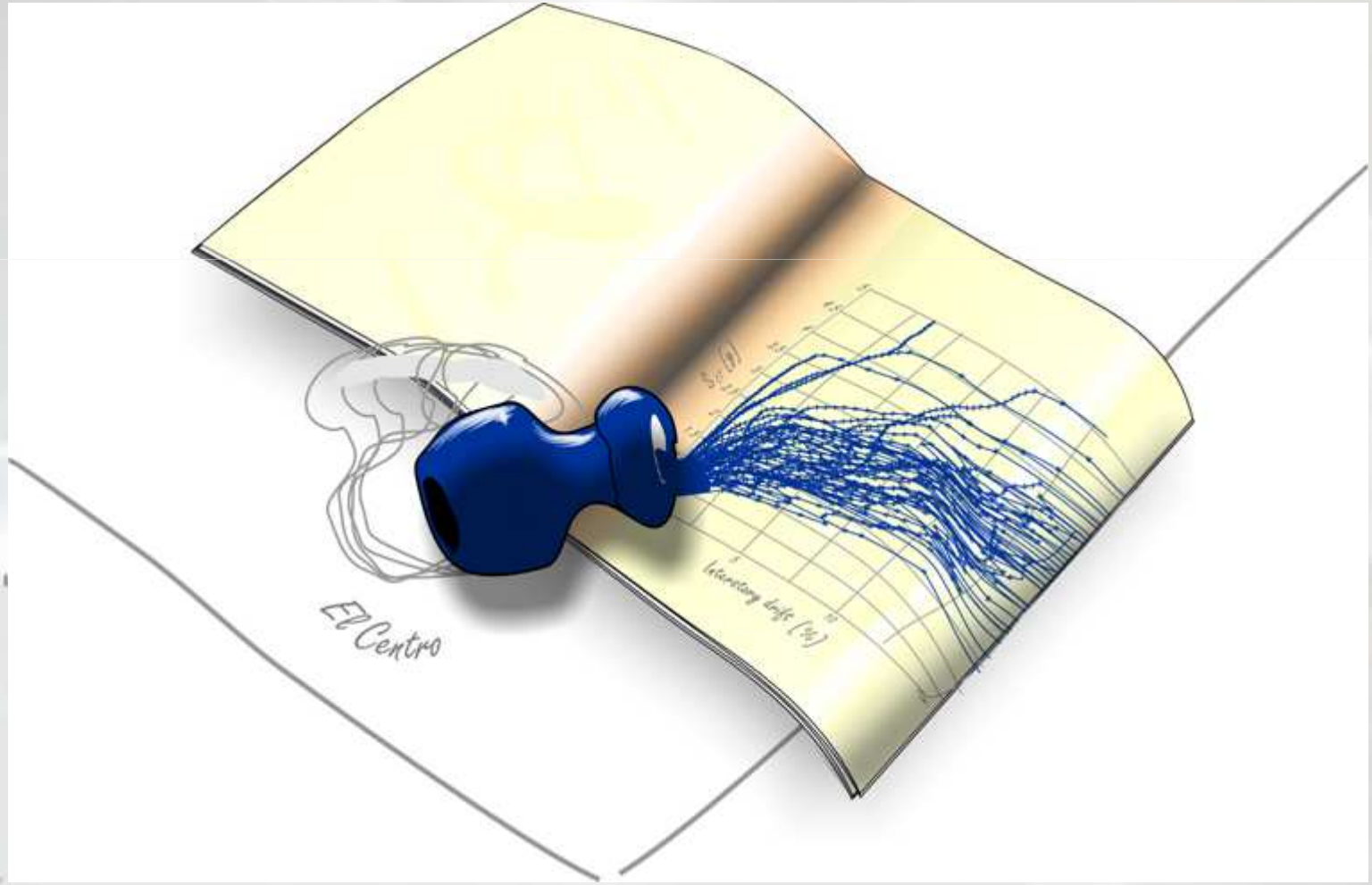




(adjusted) collapse margin ratio

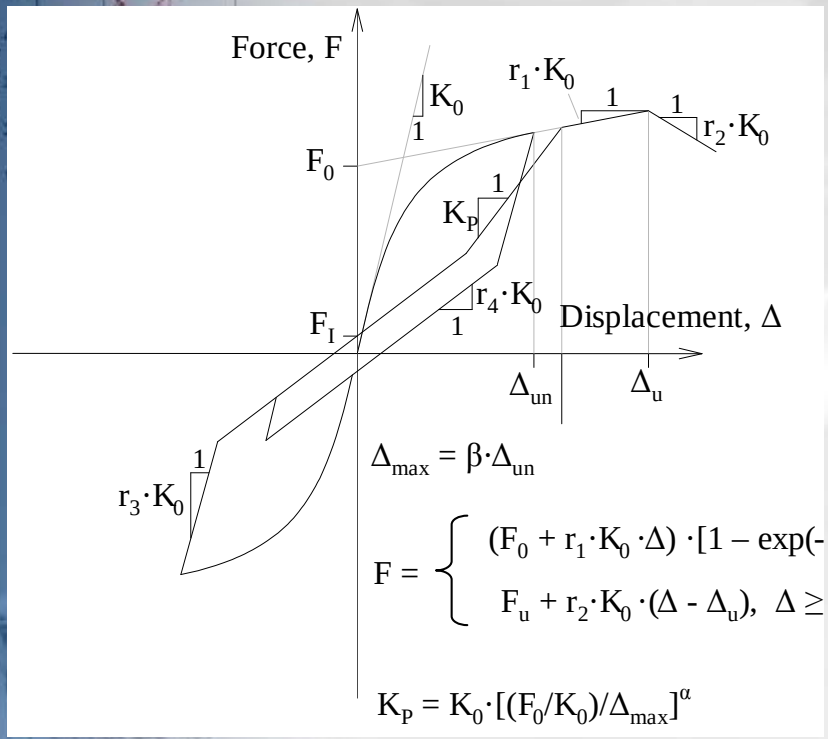
IDA analysis

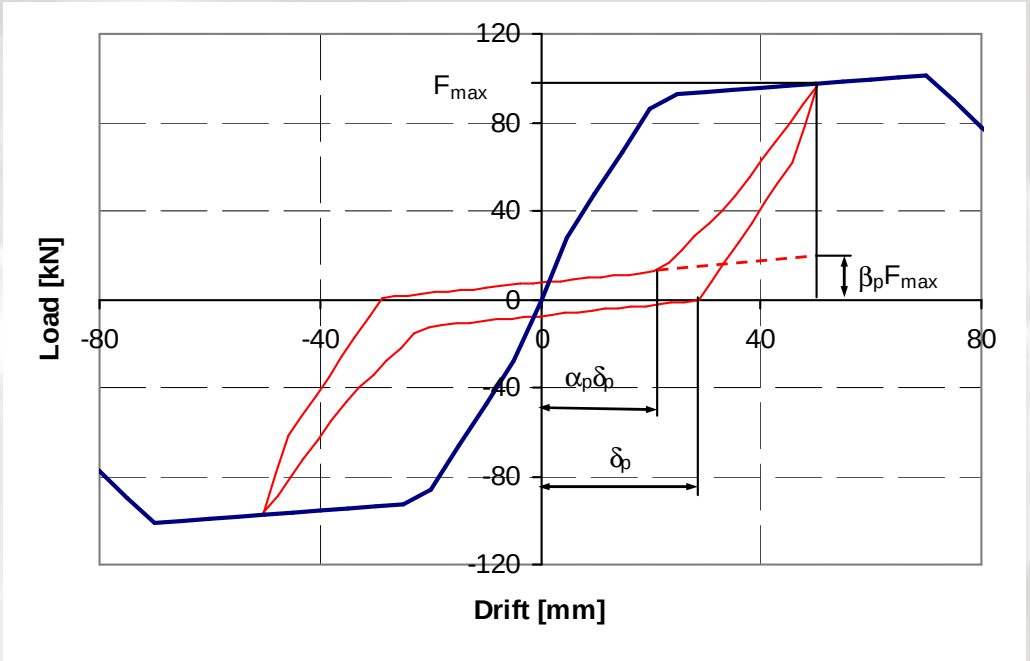
- or…



Discussion

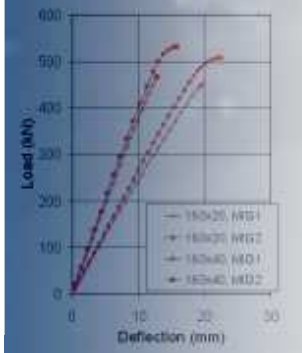
- **comparison to wooden shear wall**





Discussion

- comparison to wooden shear wall



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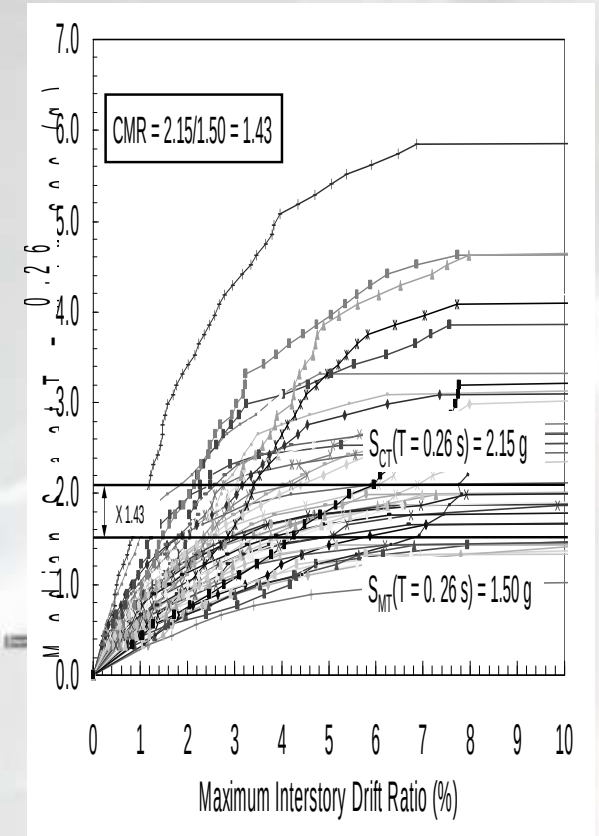
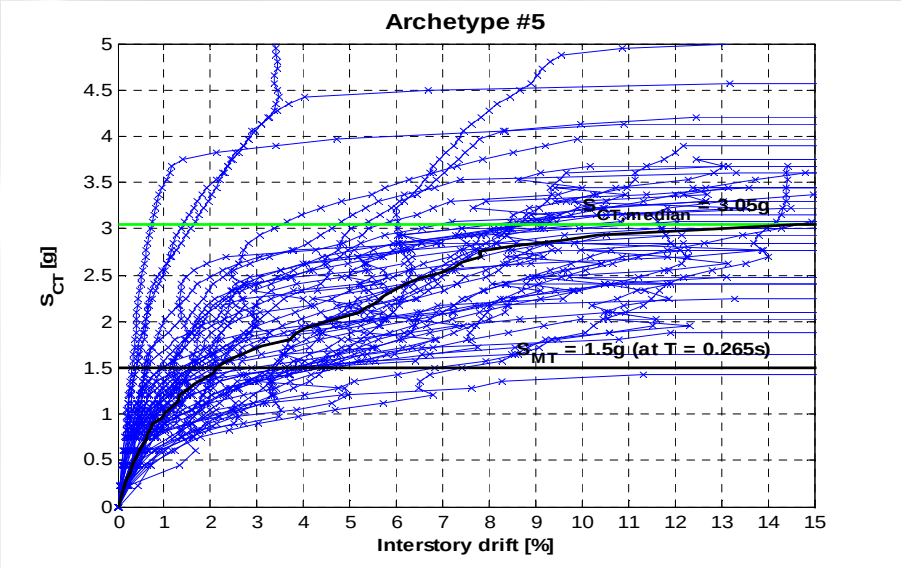
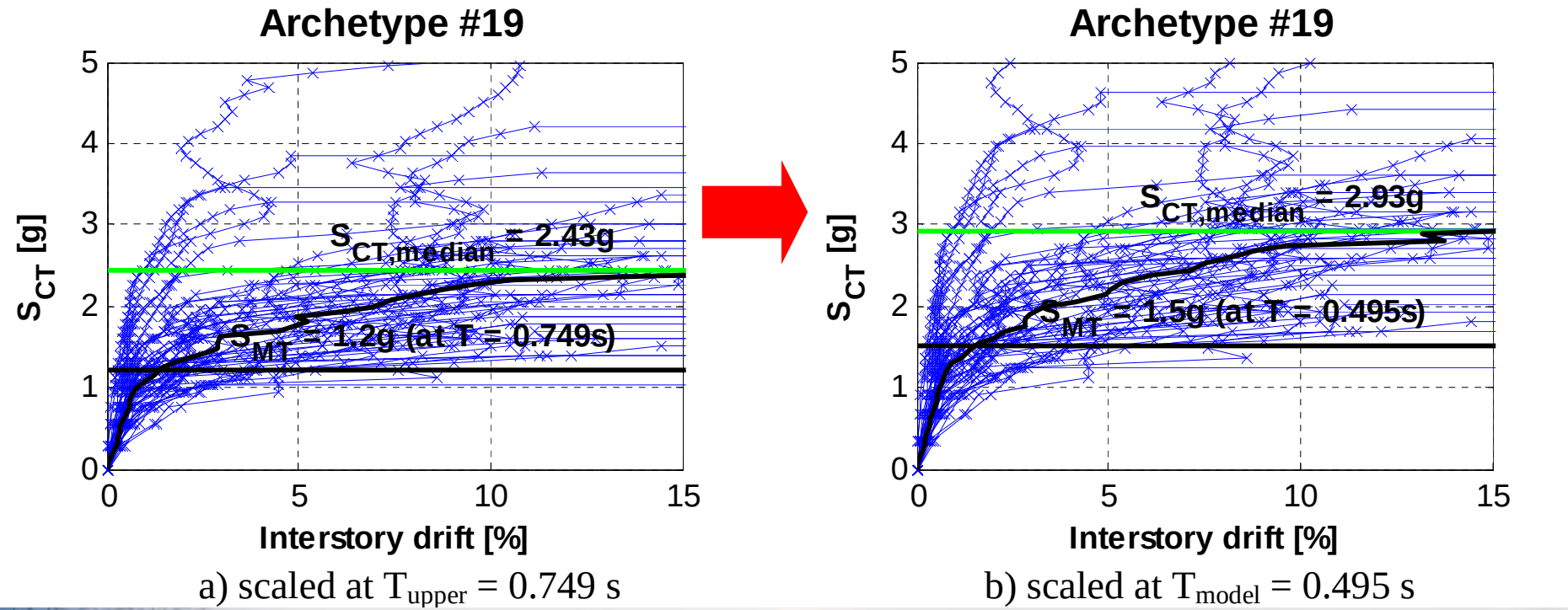




- in general, very similar results

Further observations

- **Effect of 'scaling' fundamental period**

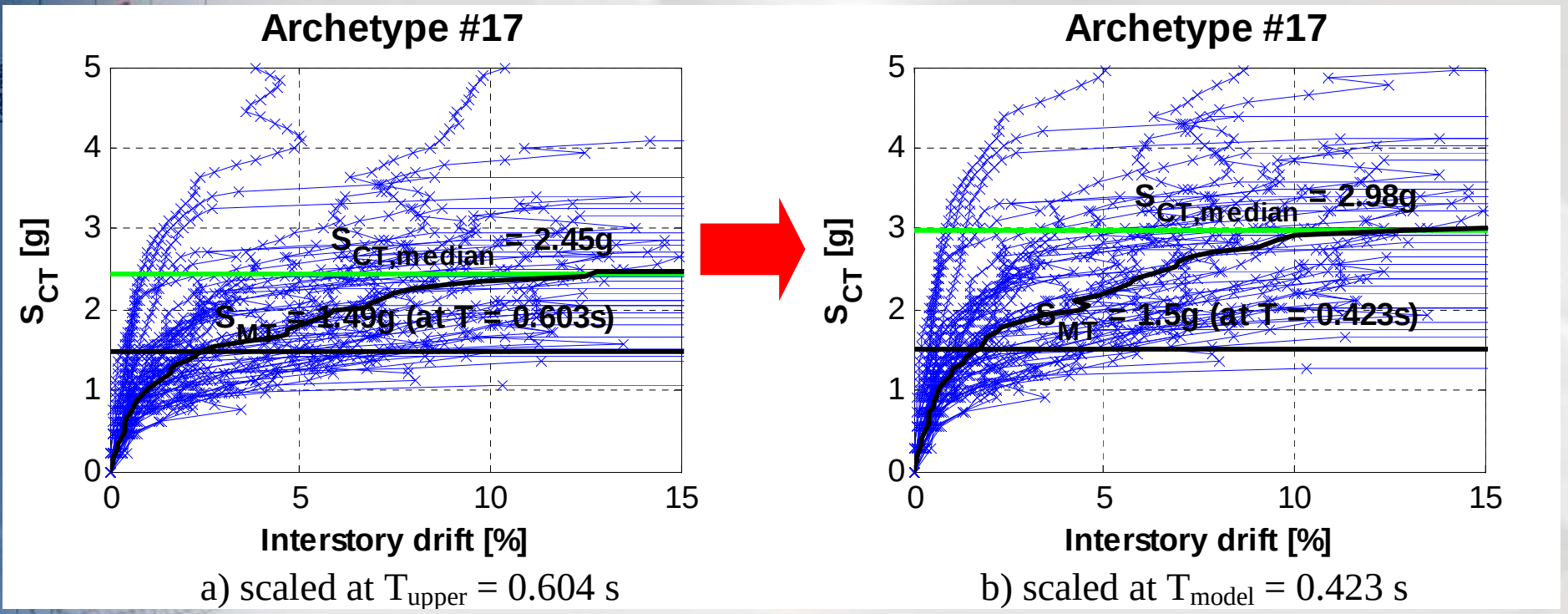


a) scaled at T_{upper} = 0.749 s

b) scaled at T_{model} = 0.495 s

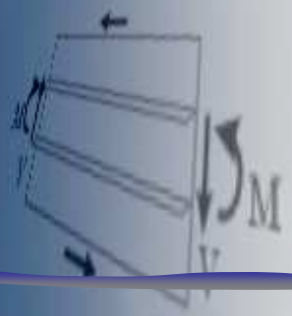
Further observations

- **Effect of 'scaling' fundamental period**



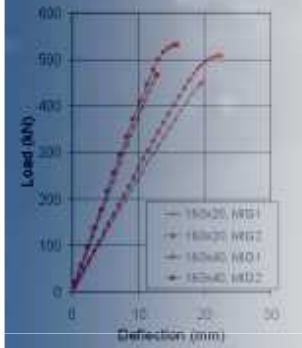
a) scaled at T_{upper} = 0.604 s

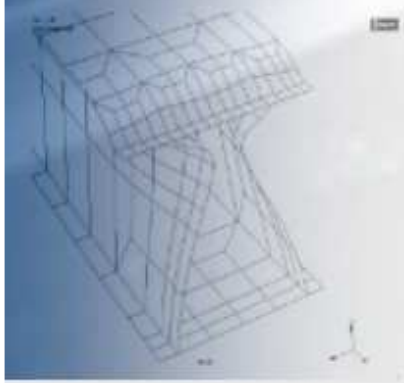
b) scaled at T_{model} = 0.423 s

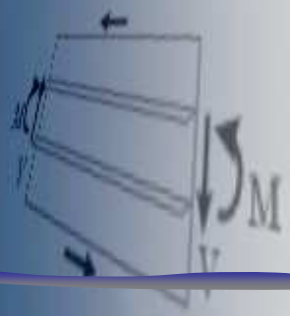


Further observations

- **Model parameter sensitivity**
  - **capping displ. 50 → 75 mm**
    capping slope -0.15 → -0.05 **+6%**
  - **.α_P 0.75 → 0.40**
    β_P 0.25 → 0.21 **+8%**
  - **adjusted initial stiffness** **+6%**
  - **1.4 x strength** **+30%**

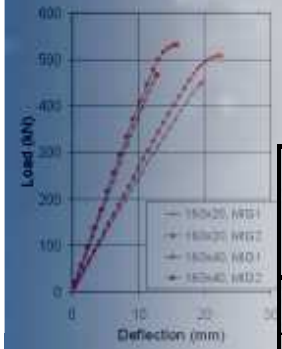






Performance quantification

- **check**



R = 4 **High seismic (SDC Dmax)**

S_S = 1.5, S_1 = 0.9 (S_{DS} = 1.0, S_{D1} = 0.6)

Archetype	Story #	Function	Ω_0 [-]	μ_C [-]	SSF [-]	S_{MT} (T_{upper}) [g]	SF_{anchor} [-]	β_{tot} [-]	$\hat{S}_{CT}$ [g]	CMR [-]	ACMR [-]	
1	1	Commercial	2.38	6.25	1.31	1.50	2.1	0.70	**2.79**	1.86	**2.44**	>
5	2	Commercial	2.40	4.37	1.26	1.50	1.89	0.70	**3.06**	2.04	**2.57**	>
9	3	Commercial	2.39	3.36	1.22	1.50	1.98	0.70	**2.88**	1.92	**2.34**	>
										Mean	**2.45**	>
2	1	1&2 Family	9.91	6.31	1.31	1.50	2.1	0.70	**6.00**	4.00	**5.24**	>
6	2	1&2 Family	4.91	4.95	1.27	1.50	1.89	0.70	**4.63**	3.09	**3.92**	>
10	3	Multi-Family	2.52	4.06	1.25	1.50	1.98	0.70	**3.16**	2.11	**2.64**	>
13	4	Multi-Family	2.56	3.00	1.20	1.50	2	0.70	**2.94**	1.96	**2.35**	>
15	5	Multi-Family	2.57	2.72	1.20	1.50	2.1	0.70	**2.93**	1.96	**2.35**	>
										Mean	**3.30**	>

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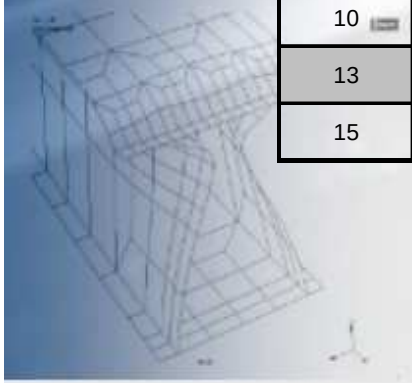
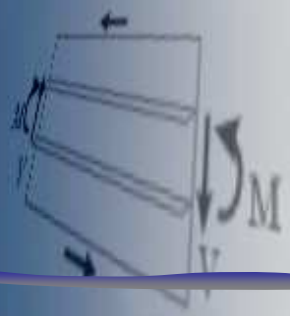
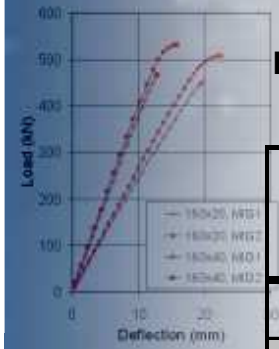




Performance quantification

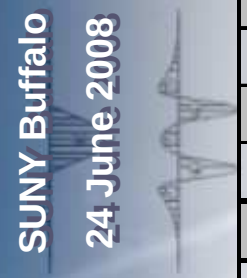
- **even for taller buildings**

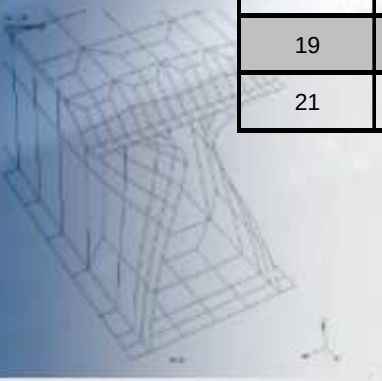


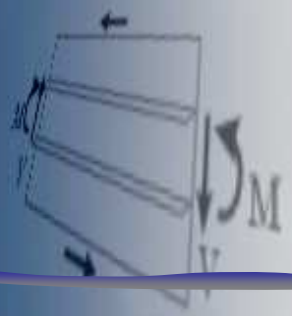
R = 4 **High seismic (SDC Dmax)**

S_S = 1.5, S_1 = 0.9 (S_{DS} = 1.0, S_{D1} = 0.6)

Archetype	Story #	Function	Ω_0 [-]	μ_C [-]	SSF [-]	S_{MT} (T_{upper}) [g]	SF_{anchor} [-]	β_{tot} [-]	$\hat{S}_{CT}$ [g]
2	1	1&2 Family	9.91	6.31	1.31	1.50	2.1	0.70	**6.00**
6	2	1&2 Family	4.91	4.95	1.27	1.50	1.89	0.70	**4.63**
10	3	Multi-Family	2.52	4.06	1.25	1.50	1.98	0.70	**3.16**
13	4	Multi-Family	2.56	3.00	1.20	1.50	2	0.70	**2.94**
15	5	Multi-Family	2.57	2.72	1.20	1.50	2.1	0.70	**2.93**
17	6	Multi-Family	2.57	2.48	1.22	1.49	2.49	0.70	**2.45**
18	7	Multi-Family	2.08	2.40	1.22	1.33	2.37	0.70	**2.54**
19	8	Multi-Family	2.34	2.34	1.22	1.20	2.46	0.70	**2.43**
21	10	Multi-Family	2.42	2.31	1.23	1.02	2.49	0.70	**2.25**

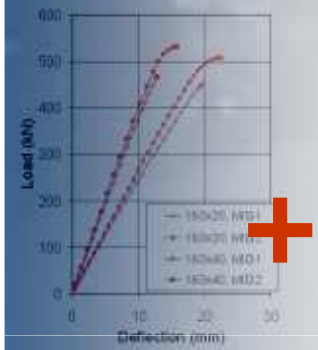






Performance quantification

- R = 4 !



+

- results and component behavior are very similar to wooden shear wall – as good as wood
- R = 6 is in code for wooden shear wall
- additional finishing, partition walls?

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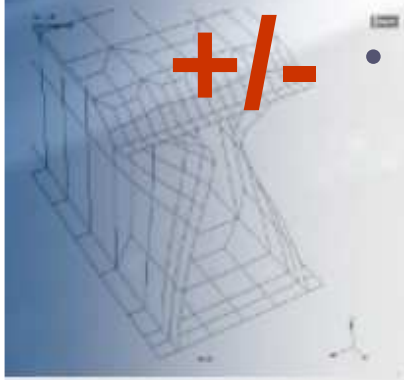
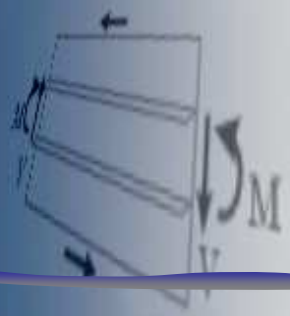
-

- short period bldgs!
- ASD design strength derivation from test

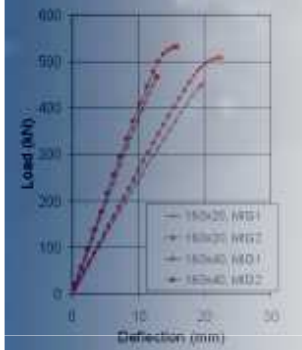


+/-

- uncertainties in the monotonic backbone estimation



Performance quantification



conventional R factor vs. ATC-63

?

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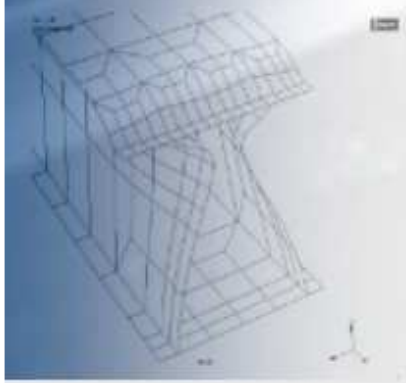

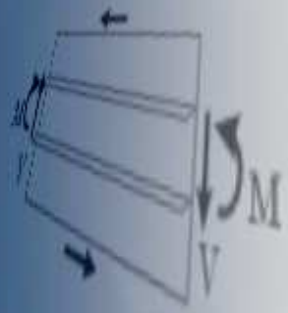

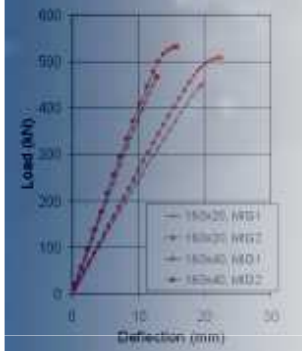

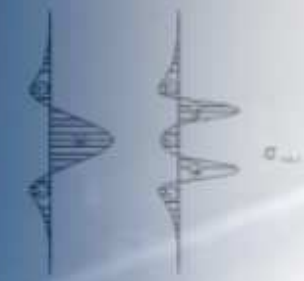

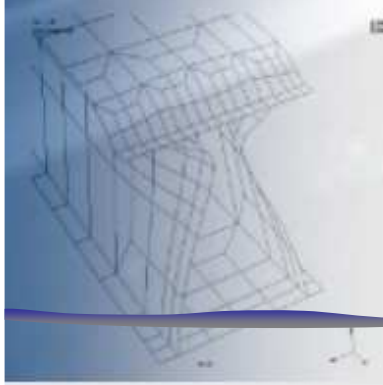

Thank you for your attention!

But don’t go anywhere…