Quantifying Mainshock-Aftershock Collapse Probabilities for Woodframe Buildings

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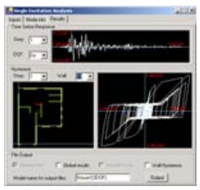

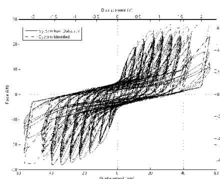

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Aftershocks

- Great Tohoku earthquake 2011
  - M7.9 less than an hour later
- Chile earthquake 2010
  - M7.2 12 days later
- New Zealand
  - M6.3 more than 4 months later
- Indonesia – yesterday
  - M8.2 an hour or two later
- Energy content can differ
- Location differs, triggering.

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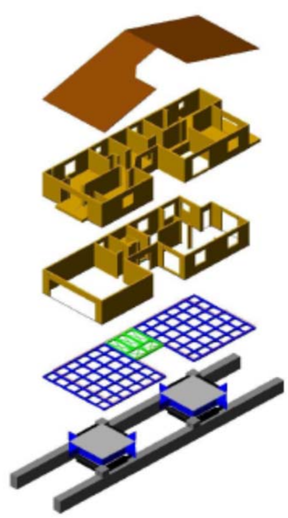
Some of the challenges

- Performance-based earthquake engineering framework - conceptual
  - Yeo and Cornell (2005)
- Occurrence time very difficult to predict
  - Markov process models
- Location very difficult to predict
- Aftershocks do collapse buildings
  - Gas station following 1999 Chi-Chi Taiwan EQ (Lew et al 2000)
  - 9-Story RC building following 1995 Kobe EQ (Whittaker et al, 1997).
  - 2011 Christchurch EQ

NEESWOOD

Benchmark Structure

1. Run at NEES@buffalo testing facility with steel frame attaching two shake tables, allowing full-size building to be tested
2. Five ground motion levels involving scaling of two recorded earthquake ground motions
3. Five test phases (configurations)
4. Testing lead by A. Filiatrault and students



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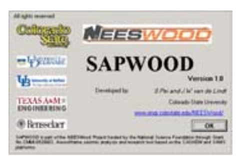
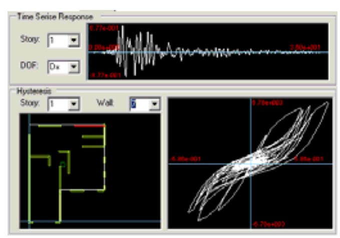
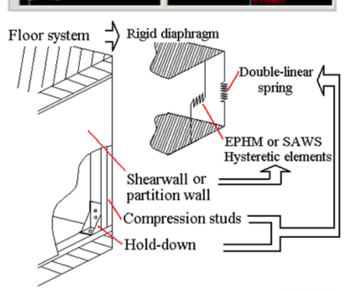
Numerical Modeling

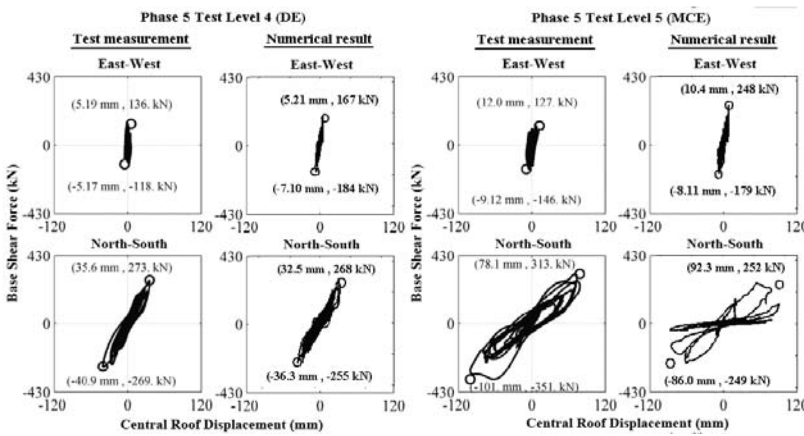


- Story diaphragm behaves like a rigid body in 3-D space
- Inter-story drift is a combination of contributions from shear deformation and global rotation
- Vertical stiffness element: Support and hold down





Comparison of global story hysteresis



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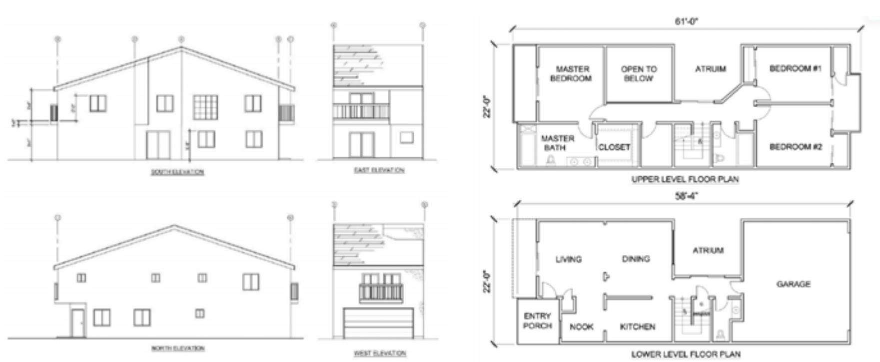
NEESWOOD Wood Building : NEESWood Benchmark Test



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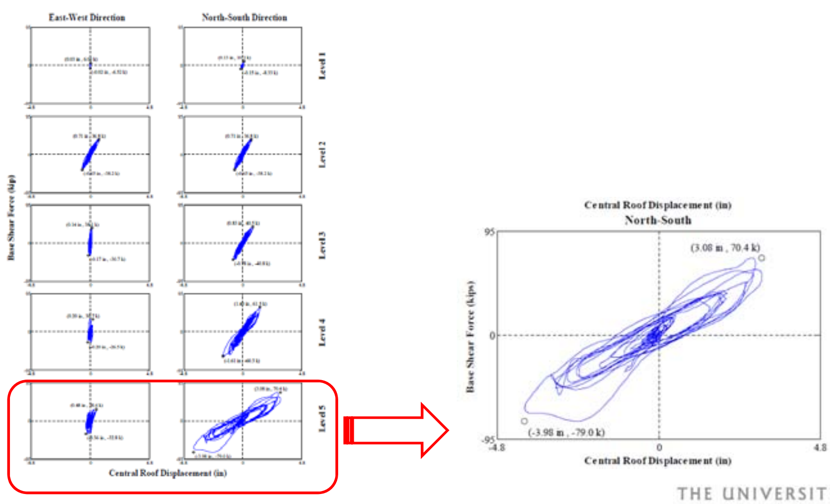
Using Data Available in NEEShub for Model Calibration



Global force-displacement hysteresis loops for the tri-axial tests of Phase 5

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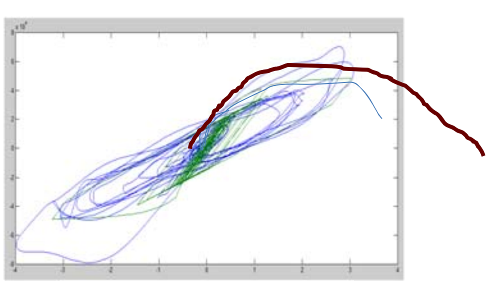
Collapse Model Calibration

- **SAWS-type hysteretic spring (CUREE model)**
  - The 10-parameter model – widely accepted as a reasonable model
  - load-resistance behavior of wood shearwall components.
  - Calibrated to match the larger hysteretic loops, then adjusted for collapse point



Fitted Hysteresis Loop for CUREE model

Weight(lb)	64900
Model	No. 3
K0	90000
F0	45000
F1	14000
r1	0.011
r2	-0.06
r3	0.5
r4	0.19
Xu	430
alpha	0.75
beta	1.1

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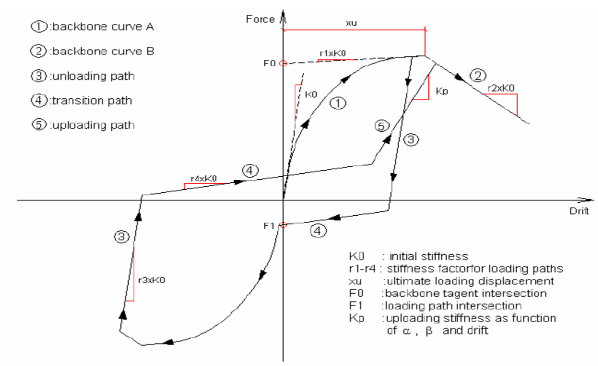
Model Calibration(cont'd)

- Equivalent SDOF model
  - 28 shear wall spring model being used currently, but not in this study/presentation



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Procedure to Quantify the Effect of Aftershocks

STEP1: IDA using calibrated model for earthquake records (mainshock)

STEP2: Determining collapse spectral acceleration and corresponding record-specific collapse drift based on 20% rule, i.e. bounds.

STEP3: Develop mainshock-aftershock record combinations using psi*mainshock + C*aftershock.

STEP4: Run mainshock-aftershock combinations to determine smallest scaling of mainshock + C*aftershock that will collapse structure. Aftershock collapse is based on collapse drift for that earthquake from step 2.

STEP5: identify distribution of psi values from step4

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STEP1: IDA using calibrated model for mainshock only

Identify the collapse drift specific to each earthquake.

Assumption
This EQ-specific collapse drift remains applicable for the same earthquake at lower intensity

EQ No.	Earthquake			PEER-NGA Record File Names	
	M	Year	Name	Component 1	Component 2
1	6.7	1994	Northridge	NORTHR/MUL009	NORTHR/MUL279
2	6.7	1994	Northridge	NORTHR/LOS000	NORTHR/LOS270
3	7.1	1999	Duzce, Turkey	DUZCE/BOL000	DUZCE/BOL090
4	7.1	1999	Hector Mine	HECTOR/HEC000	HECTOR/HEC090
5	6.5	1979	Imperial Valley	IMPVALL/H-DLT262	IMPVALL/H-DLT352
6	6.5	1979	Imperial Valley	IMPVALL/H-E11140	IMPVALL/H-E11230
7	6.9	1995	Kobe, Japan	KOBE/NIS000	KOBE/NIS090
8	6.9	1995	Kobe, Japan	KOBE/SHI000	KOBE/SHI090
9	7.5	1999	Kocaeli, Turkey	KOCAELI/DZC180	KOCAELI/DZC270
10	7.5	1999	Kocaeli, Turkey	KOCAELI/ARC000	KOCAELI/ARC090
11	7.3	1992	Landers	LANDERS/YER270	LANDERS/YER360
12	7.3	1992	Landers	LANDERS/CLW-LN	LANDERS/CLW-TR
13	6.9	1989	Loma Prieta	LOMAP/CAP000	LOMAP/CAP090
14	6.9	1989	Loma Prieta	LOMAP/G03000	LOMAP/G03090
15	7.4	1990	Manjil, Iran	MANJIL/ABBAR--L	MANJIL/ABBAR--T
16	6.5	1987	Superstition Hills	SUPERST/B-ICC000	SUPERST/B-ICC090
17	6.5	1987	Superstition Hills	SUPERST/B-POE270	SUPERST/B-POE360
18	7	1992	Cape Mendocino	CAPEMEND/RIO270	CAPEMEND/RIO360
19	7.6	1999	Chi-Chi, Taiwan	CHICHI/CHY101-E	CHICHI/CHY101-N
20	7.6	1999	Chi-Chi, Taiwan	CHICHI/TCU045-E	CHICHI/TCU045-N
21	6.6	1971	San Fernando	SFERN/PEL090	SFERN/PEL180
22	6.5	1976	Friuli, Italy	FRIULI/A-TMZ000	FRIULI/A-TMZ270

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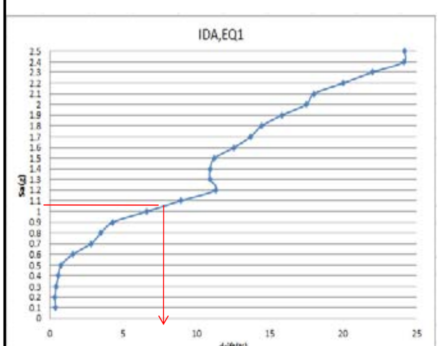
STEP2: Determining collapse bounds and corresponding drift based on 20% slope in IDA curve for each mainshock



	Sa(g)			drift(%)		
EQ	Lower value	Average	Upper value	Lower value	Average	Upper value
1	0.9	1.05	1.2	4.312405093	7.8081863	11.30396759
2	1.1	1.15	1.2	4.278914352	6.1104479	7.941981481
16	1.3	1.35	1.4	3.481387963	4.4651338	5.44887963
8	1.4	1.45	1.5	11.43312037	13.983766	16.53441204
6	1.6	1.65	1.7	1.850526389	2.6008704	3.351214352
11	1.6	1.65	1.7	11.855375	14.680359	17.50534259
13	1.6	1.65	1.7	4.478803704	6.5693	8.659796296
5	1.7	1.8	1.9	11.01750926	12.967	14.91649074
19	1.7	1.8	1.9	12.88885648	14.102155	15.3154537
14	1.9	1.95	2	3.733105556	4.6694509	5.605796296
18	1.9	1.95	2	8.380111111	10.861847	13.34358333
7	2	2.05	2.1	8.657569444	10.187428	11.71728704
9	2	2.05	2.1	7.88850463	9.7581968	11.62788889
12	2	2.05	2.1	9.377328704	10.457275	11.53722222
17	2.1	2.15	2.2	5.787310185	6.586794	7.386277778
15	2.2	2.25	2.3	4.89875463	6.2557755	7.612796296
21	2.2	2.25	2.3	7.380824074	10.129674	12.87852315
3	2.3	2.35	2.4	6.020287037	8.467419	10.91455093
4	2.4	2.45	2.5	11.15874537	13.059424	14.96010185
20	2.5	2.5	2.5	8.190814815	8.1908148	8.190814815
10	2.5	2.5	2.5	4.046585	4.046585	4.046585
22	2.5	2.5	2.5	3.893768056	3.8937681	3.893768056

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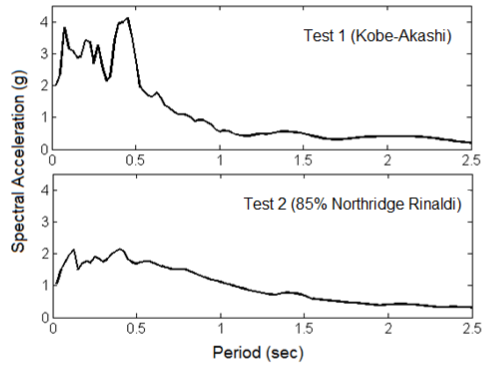
Collapse Drifts from IDA's – Reasonable ?



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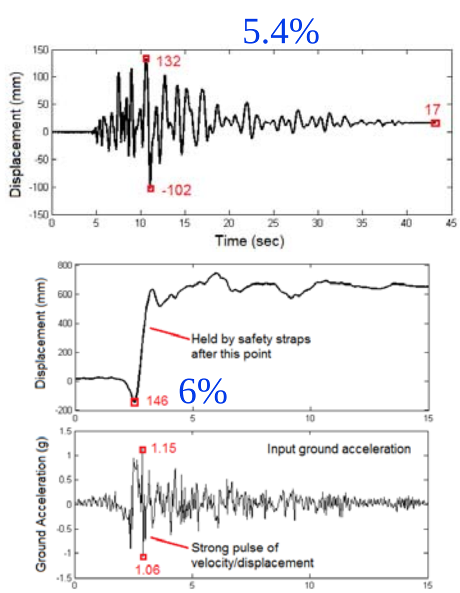

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Approximate Validation

Mean = 8.6% from the numerical "system" model

Isolated garage wall achieved 6%.

Approximate validation

Dependence on ground motion neglected.

	Sa(g)			drift(%)		
EQ	Lower value	Average	Upper value	Lower value	Average	Upper value
1	0.9	1.05	1.2	4.312405093	7.8081863	11.30396759
2	1.1	1.15	1.2	4.278914352	6.1104479	7.941981481
16	1.3	1.35	1.4	3.481387963	4.4651338	5.44887963
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19	1.7	1.8	1.9	12.88885648	14.102155	15.3154537
14	1.9	1.95	2	3.733105556	4.6694509	5.605796296
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4	2.4	2.45	2.5	11.15874537	13.059424	14.96010185
20	2.5	2.5	2.5	8.190814815	8.1908148	8.190814815
10	2.5	2.5	2.5	4.046585	4.046585	4.046585
22	2.5	2.5	2.5	3.893768056	3.8937681	3.893768056

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Northridge 1994

Mainshock Collapse	1.05g	Psi = 1.0
With Aftershock Record @ $0.8S_a^{mainshock}$		
Loma Prieta 1989	0.97g	0.92
Kocaeli, Turkey 1999	1.03g	0.98
Northridge 1994	0.88g	0.85
Chi-Chi, Taiwan 1999	0.98g	0.93

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Imperial Valley 1979

Mainshock Collapse	1.8g	Psi = 1.0
With Aftershock Record @ $0.8S_a^{mainshock}$		
Kocaeli, Turkey 1999	1.37g	0.76
Superstition Hills 1987	1.43g	0.79
Kocaeli, Turkey 1999	1.51g	0.84
Imperial Valley 1979	1.00g	0.56

Some next steps

- Correlation of psi and C
- Application of recurrence relationship for occurrence probability of aftershocks
- Inclusion of spatial statistics
- Collapse obviously important; Correlation of damage states for 2nd gen PBEE
- Generalize with a portfolio of representative buildings
- Steel frame buildings – collaborative work at MTU (Y. Li, PI)

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Thank you!

This material is based upon work supported by the National Science Foundation. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the investigators and do not necessarily reflect the views of the National Science Foundation.

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Foot bridge in downtown Christchurch

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