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Seismic Assessment and Rehabilitation of Existing Buildings

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Nonlinear Drift Demands on Moment-Resisting Stiff Frames

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Introductory remarks

A realistic seismic performance evaluation requires the estimation of deformation demands associated with the lateral strength capacity of the system for a given seismic hazard.

Choice of deformation demand measure depends on the selected performance level at a given seismic hazard.

Drift related demand measures

Maximum roof and interstory drift, variation of maximum story drift along the building height are useful if the performance targets of interest are related to downtime and monetary losses.

Estimation of these parameters are still challenged by many factors; *record to record variability, complex nonlinear structural behavior, intricate relation between the structure and ground-motion.*

Present state of practice

- Reduce MDOF into an equivalent SDOF system using NSPs (pushover)
- Determine the equivalent SDOF maximum response from an approximate procedure (DCM, CSM, MADRS etc) or directly from nonlinear response history analysis.
- From this information extrapolate the MDOF deformation demands using empirical MDOF – SDOF relationships

Objective

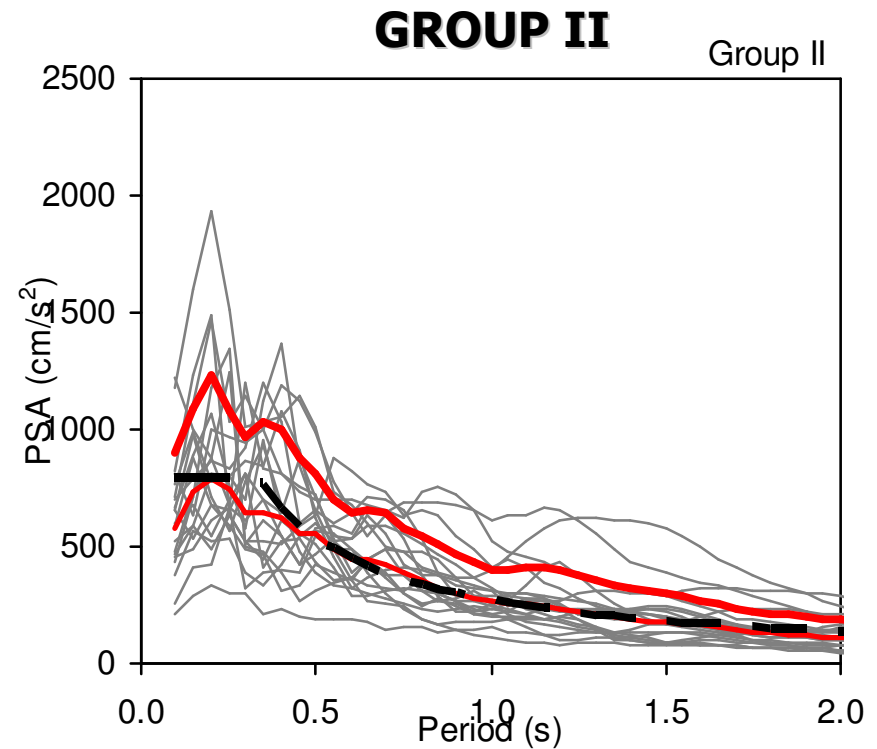
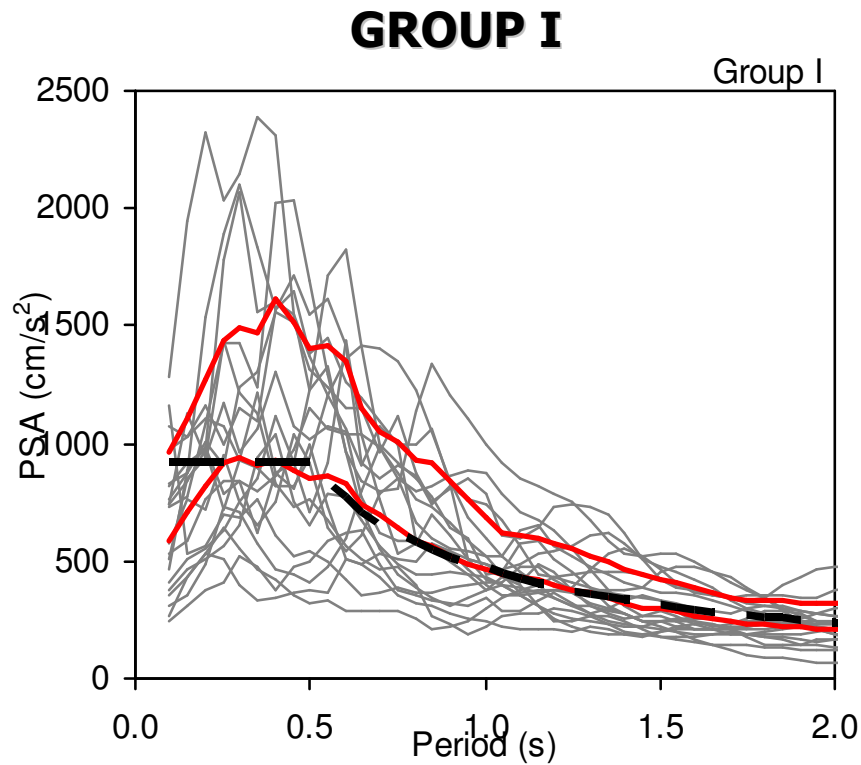
Using a total of 40 ground motions and 8 moment-resisting frames (MRFs) of different story levels

- Variation of maximum roof and maximum interstory drift; height-wise variation of story drift for MRFs
- Adequacy of first mode approach in describing the expected drift demands on stiff MRFs.
- Verification of a new procedure to estimate the maximum interstory drift ratio (MIDR) for MRFs.

Ground-motions

- 40 soil site (NEHRP C and D) records
- $5.7 < \mathbf{M} < 7.6$
- $2.5 \text{ km} < d < 23.5 \text{ km}$
- Records without pulse signals
- Ground-motions are divided into two equal bins to represent different seismic hazard

Median spectra

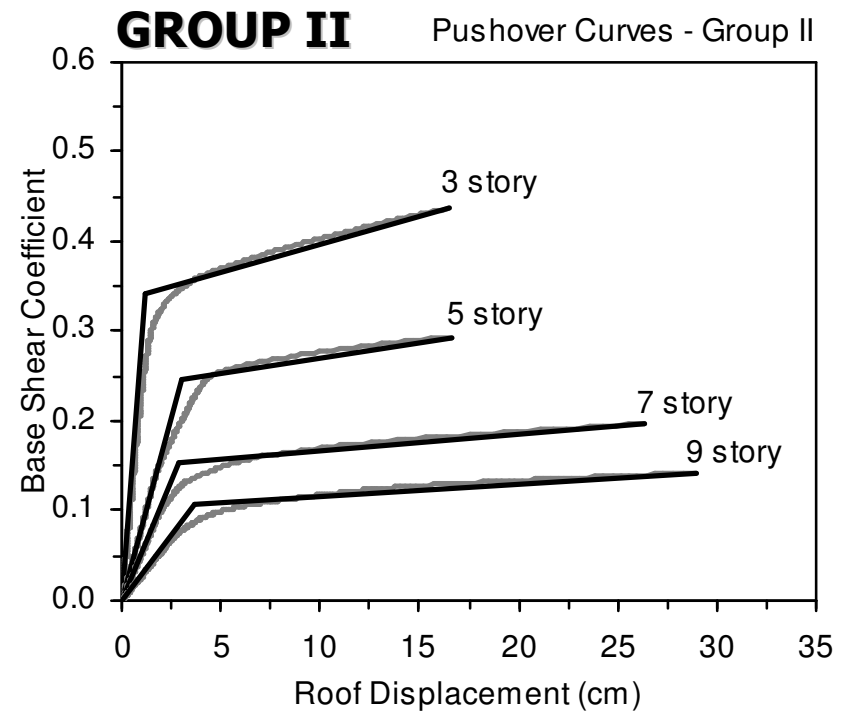
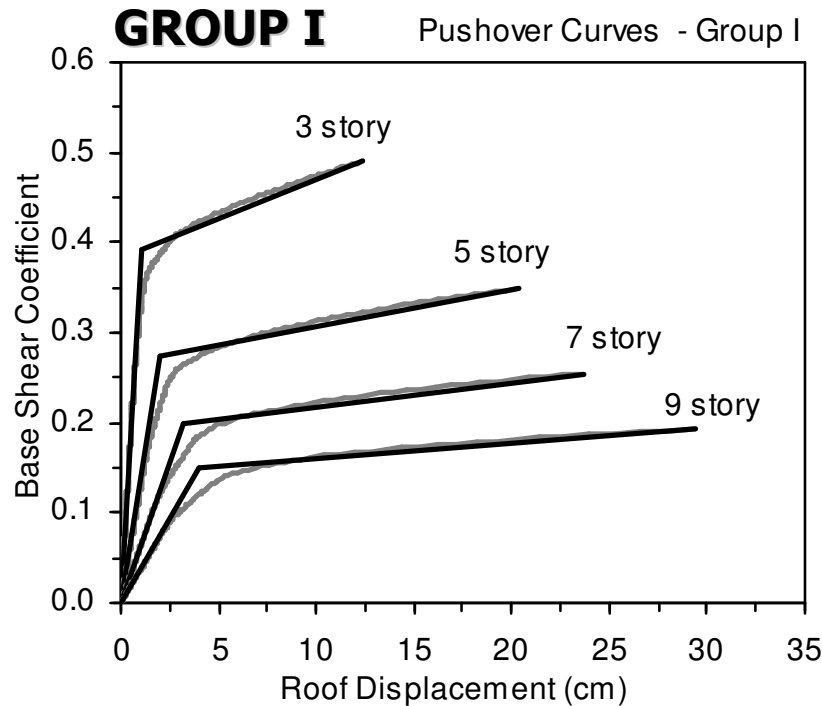


On average, Group I ground motions represent a higher hazard level

Frame models

- Smoothed spectra for the ground-motion bins are used to design MRFs of 3-, 5-, 7- and 9-story levels that comply the recent codes
- Model frames are special MRFs
- No lateral stiffness reduction along the height for Group I frames
- Uniform lateral stiffness reduction along the height for Group II frames

Global capacity envelopes



Pushover analysis using height invariant inverse triangular loading

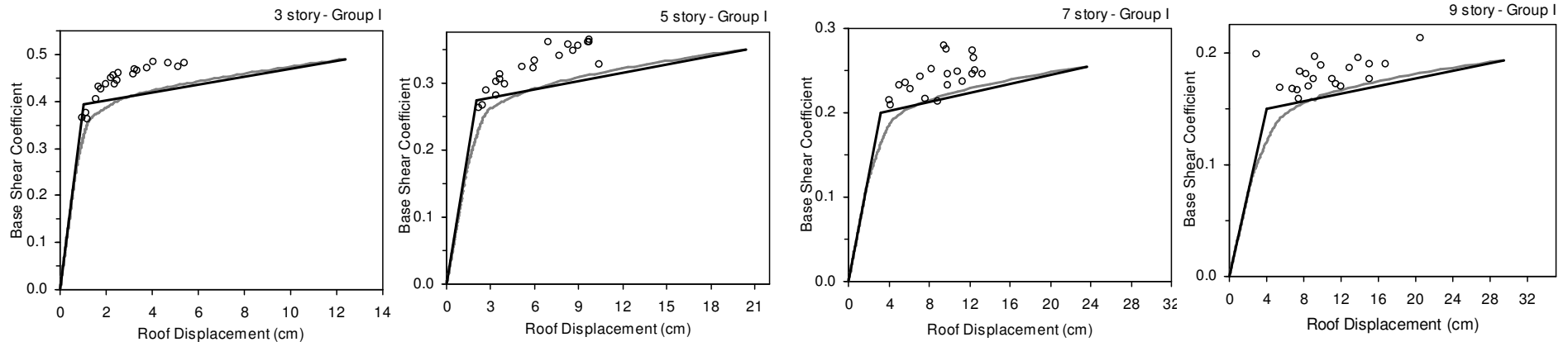
**Fundamental period
range is approximately
 $0.1n$**



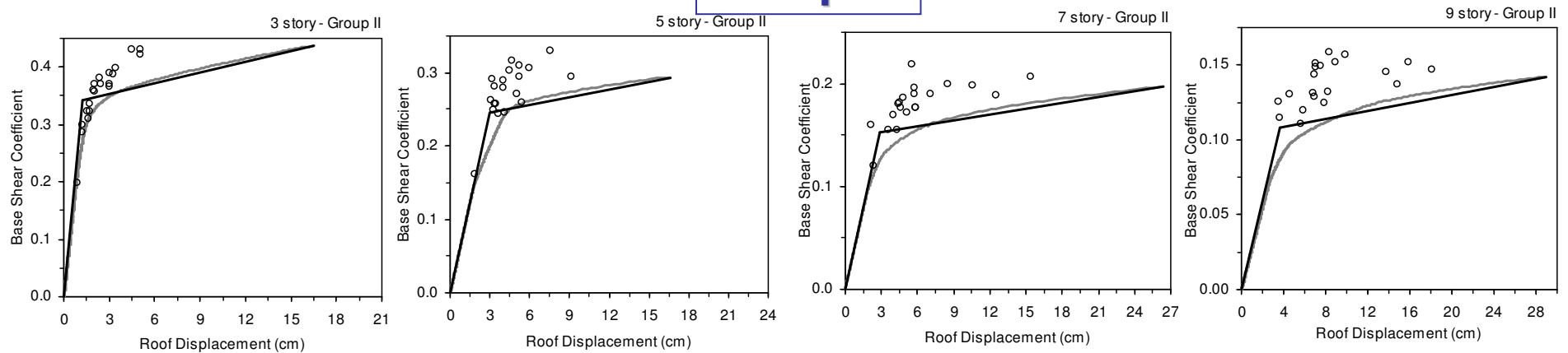
**SPECIAL STIFF MOMENT-
RESISTING FRAME**

Nonlinear RHA vs. Capacity envelopes

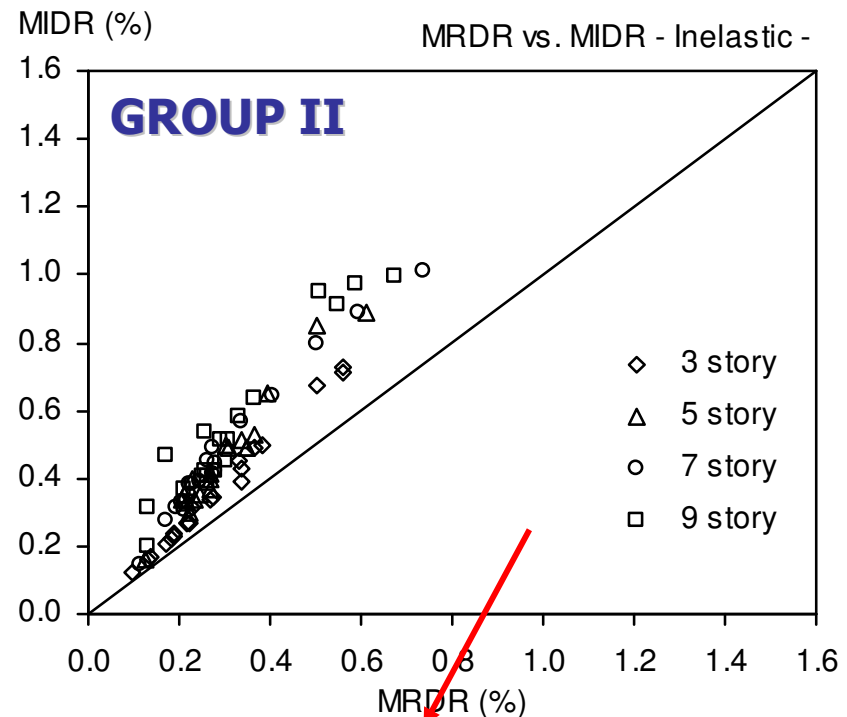
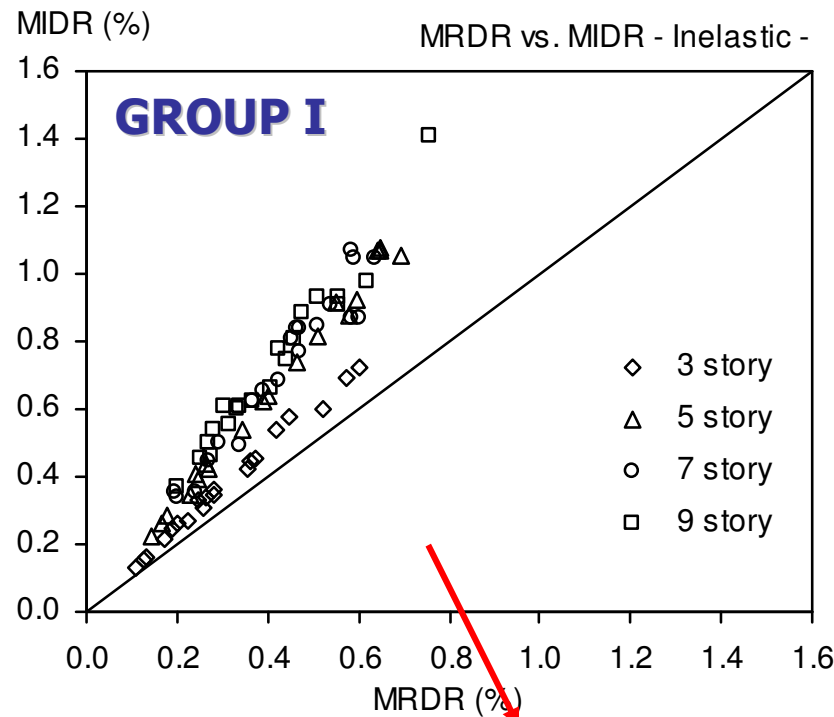
Group I



Group II



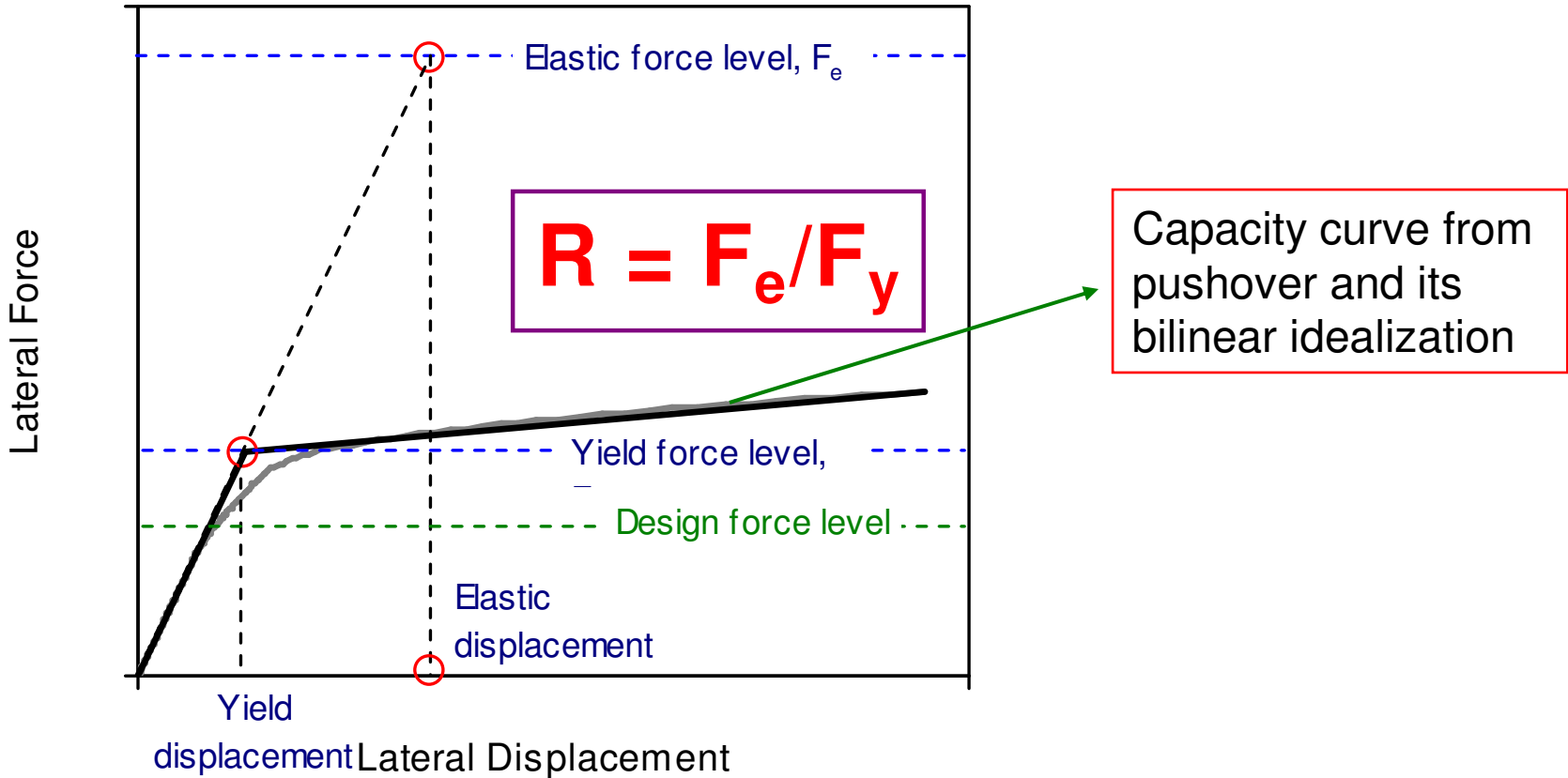
Nonlinear RHA: *Maximum roof versus maximum interstory drift*



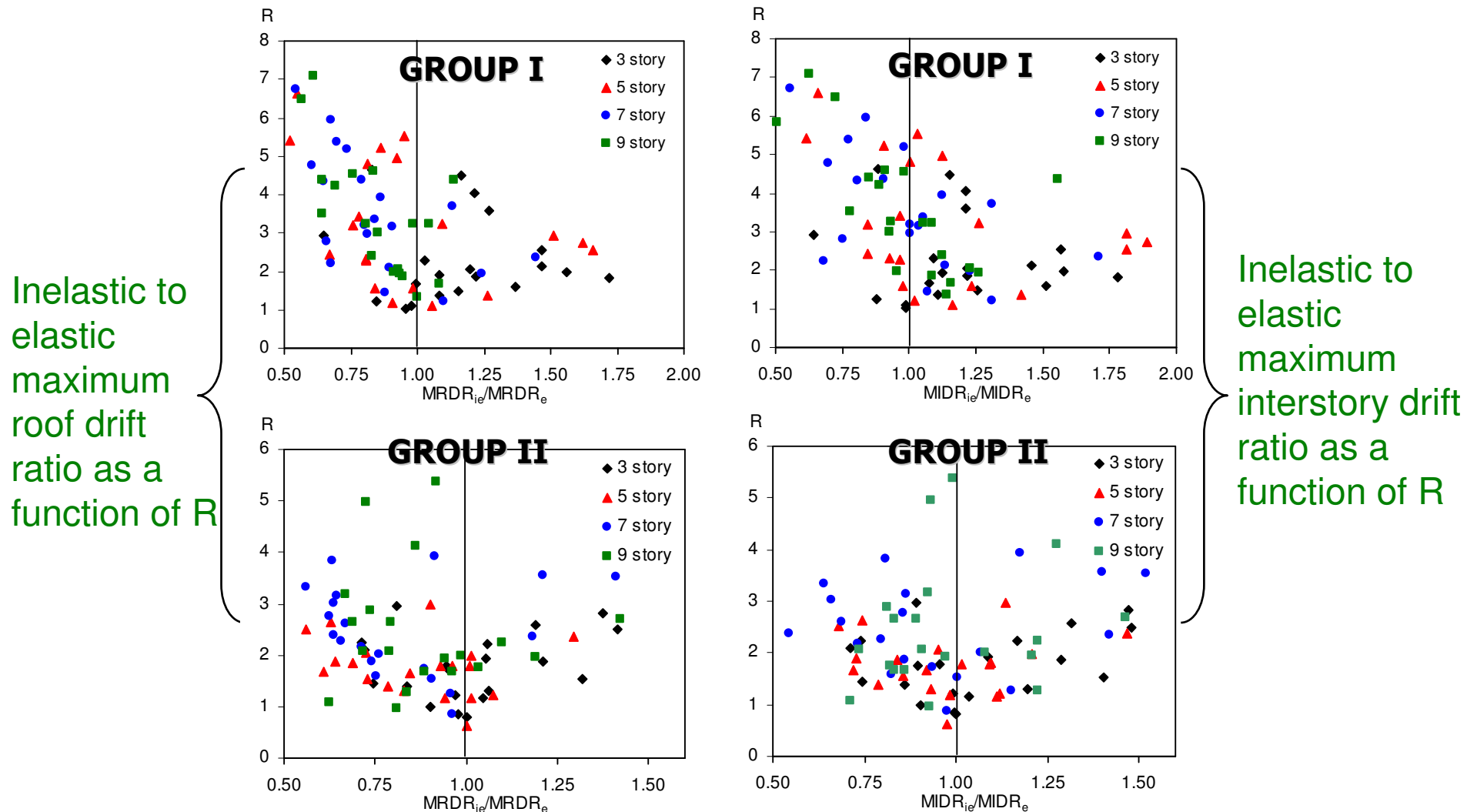
$$MIDR = 4.61(1 - e^{0.35MRDR})$$

(Stiff MRFs conforming the codes with $T_1 < 1.0$ s and $R < 7$)

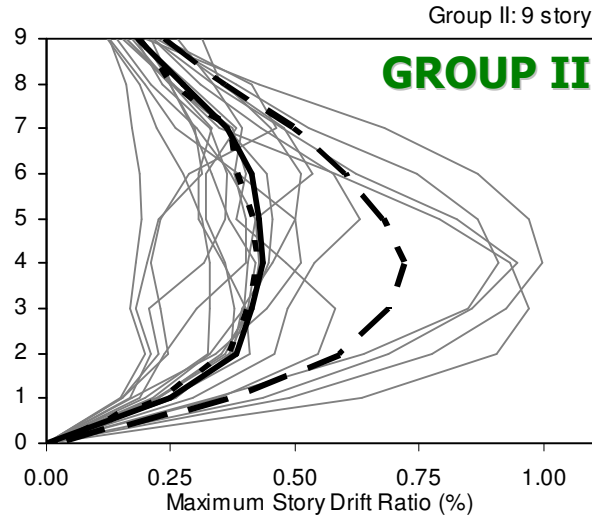
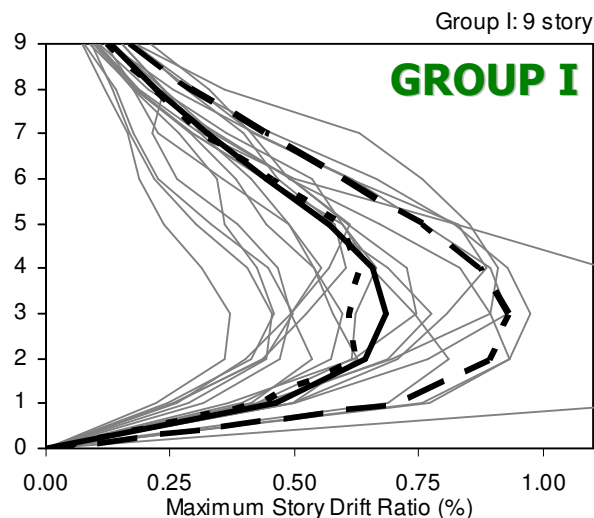
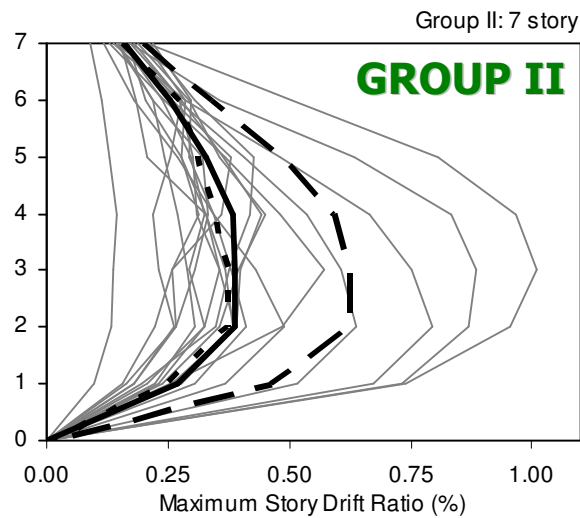
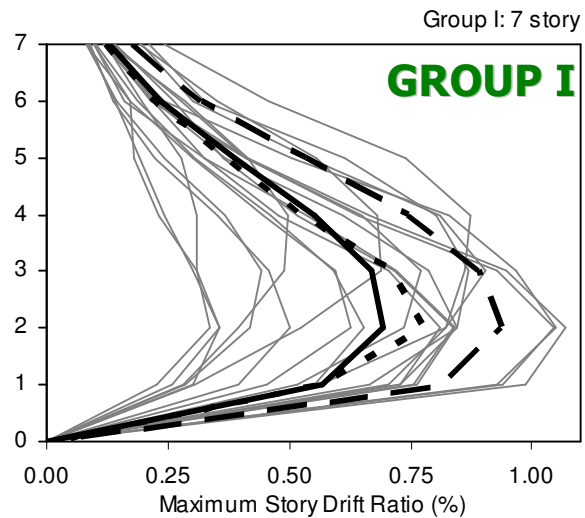
Definition of R



Nonlinear RHA: *Maximum roof & interstory drifts as a function of R*

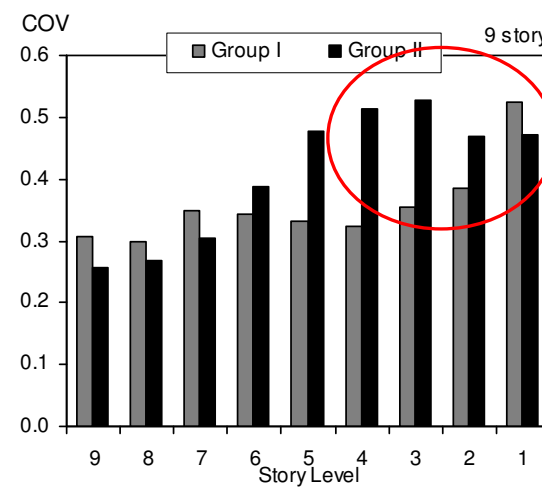
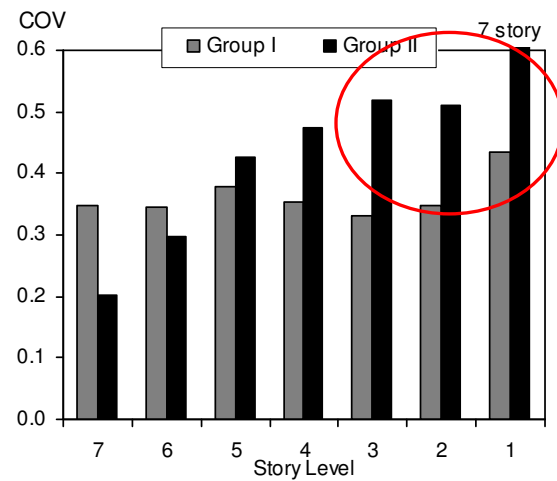
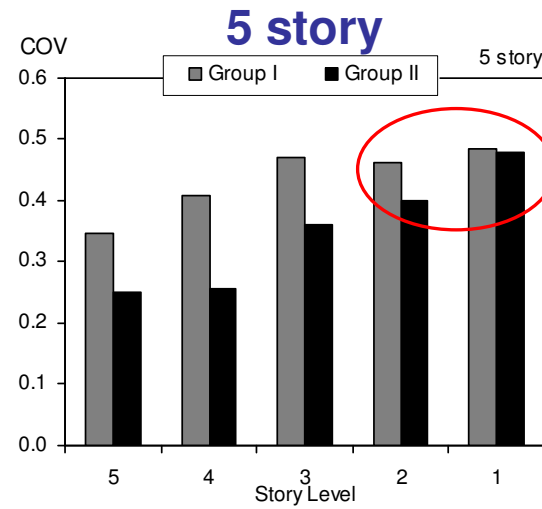
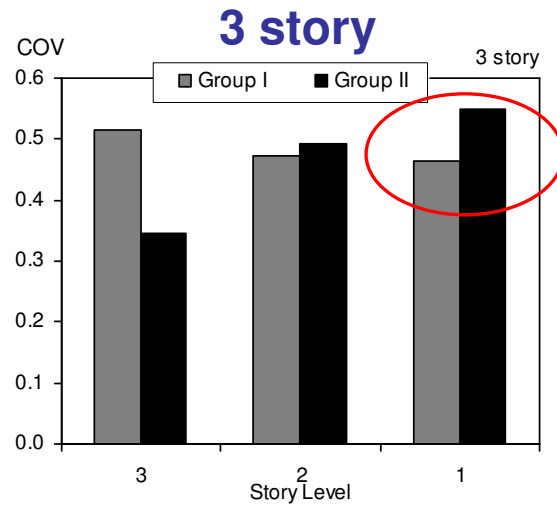


Nonlinear RHA: Typical variation of *maximum story drifts*



1. The overall behavior resembles first mode dominant behavior
2. The maximum interstory drift variation shows more scatter particularly for Group II frames

Dispersion (COV)



Statistics to relate SDOF to MDOF deformations using first mode

Relates elastic MDOF - SDOF

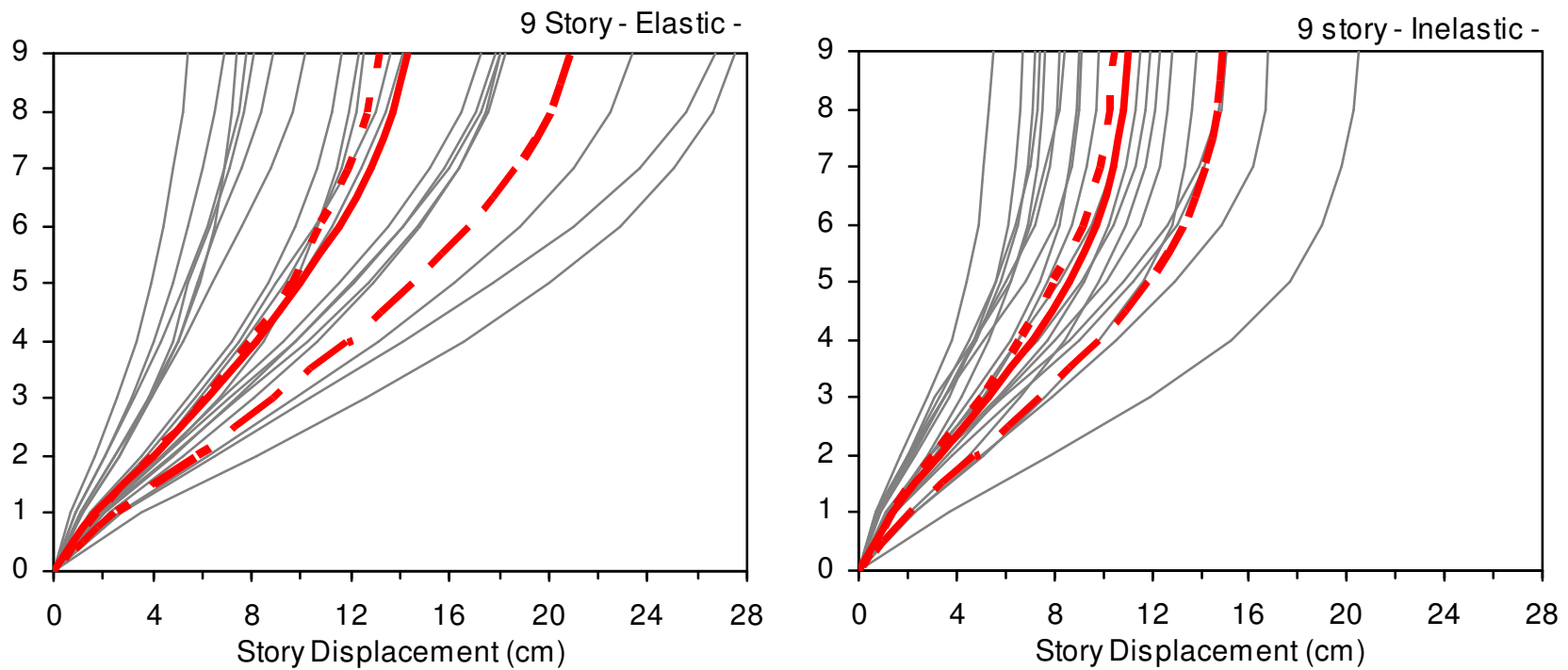
		Group I			Group II		
Fractiles		$\Gamma_{1,e} \times \Phi_{1,e}$	$\Delta_{top,e}/S_{d,e}$	$\Delta_{top,i}/S_{d,i}$	$\Gamma_{1,e} \times \Phi_{1,e}$	$\Delta_{top,e}/S_{d,e}$	$\Delta_{top,i}/S_{d,i}$
3-story	50%	1.29	1.29	1.21	1.30	1.40	1.26
	84%		1.30	1.68		1.60	1.64
5-story	50%	1.30	1.32	1.19	1.32	1.34	1.20
	84%		1.35	1.32		1.43	1.43
7-story	50%	1.30	1.31	1.29	1.35	1.41	1.11
	84%		1.34	1.50		1.59	1.34
9-story	50%	1.31	1.32	1.31	1.36	1.51	1.22
	84%		1.39	1.42		1.78	1.39

good agreement for median

inelastic median ratios are smaller

agreement is not as good as in Group I

Lateral deformation profiles



Concentration of plastic hinging at lower levels results lesser roof drifts in nonlinear behavior

Statistical evaluation

First mode approach:

$$MRDR = \frac{1}{H} [\Gamma_{1,e} \times \phi_{1,e} \times S_{d,i}(T_{1,ideal}, \xi = 5\%, R)]$$

$$MIDR = \frac{1}{h} [\Gamma_{1,e} \times |\phi_{1,e}^n - \phi_{1,e}^{n-1}|_{\max} \times S_{d,i}(T_{1,ideal}, \xi = 5\%, R)]$$

RHA using idealized bilinear curves from PO

particular for each model

New procedure:

$$MIDR(T, \xi, \rho) = \gamma_1(T, \rho) \gamma_2(T, \rho) GSDR_{sh}; \quad \gamma_1 = c_1 + \frac{c_2}{T}; \quad \gamma_2 = e^{(c_3 + c_4/T)}$$

Regression expressions using first mode behavior

$$GSDR_{sh} = 1.27 \sin\left(\frac{\pi h}{2H}\right) \frac{S_{d,i}(T_{1,ideal}, \xi = 5\%, R)}{H}$$

Error statistics

(Error = Approximate/Exact)

1st mode approach MRDR

	Error	
	Group I	Group II
	50%	50%
3-story	1.10	1.02
5-story	1.09	1.10
7-story	1.10	1.22
9-story	1.09	1.11

1st mode approach MIDR

	Error	
	Group I	Group II
	50%	50%
3-story	1.07	0.99
5-story	0.92	1.02
7-story	0.93	0.92
9-story	1.00	0.85

New method MIDR

	Error	
	Group I	Group II
	50%	50%
3-story	1.24	1.17
5-story	1.02	1.17
7-story	1.04	1.15
9-story	1.00	1.03

Conclusions

- Variation of story drifts are sensitive to the structural configuration.
- First mode approach, on average, tends to overestimate the roof drift for stiff MRFs.
- Maximum interstory drift cannot be estimated successfully by this approach.
- A new procedure that has been tested on elastic frames seems to be promising for nonlinear behavior.