Loading Histories for Cyclic Tests in Support of Performance Assessment

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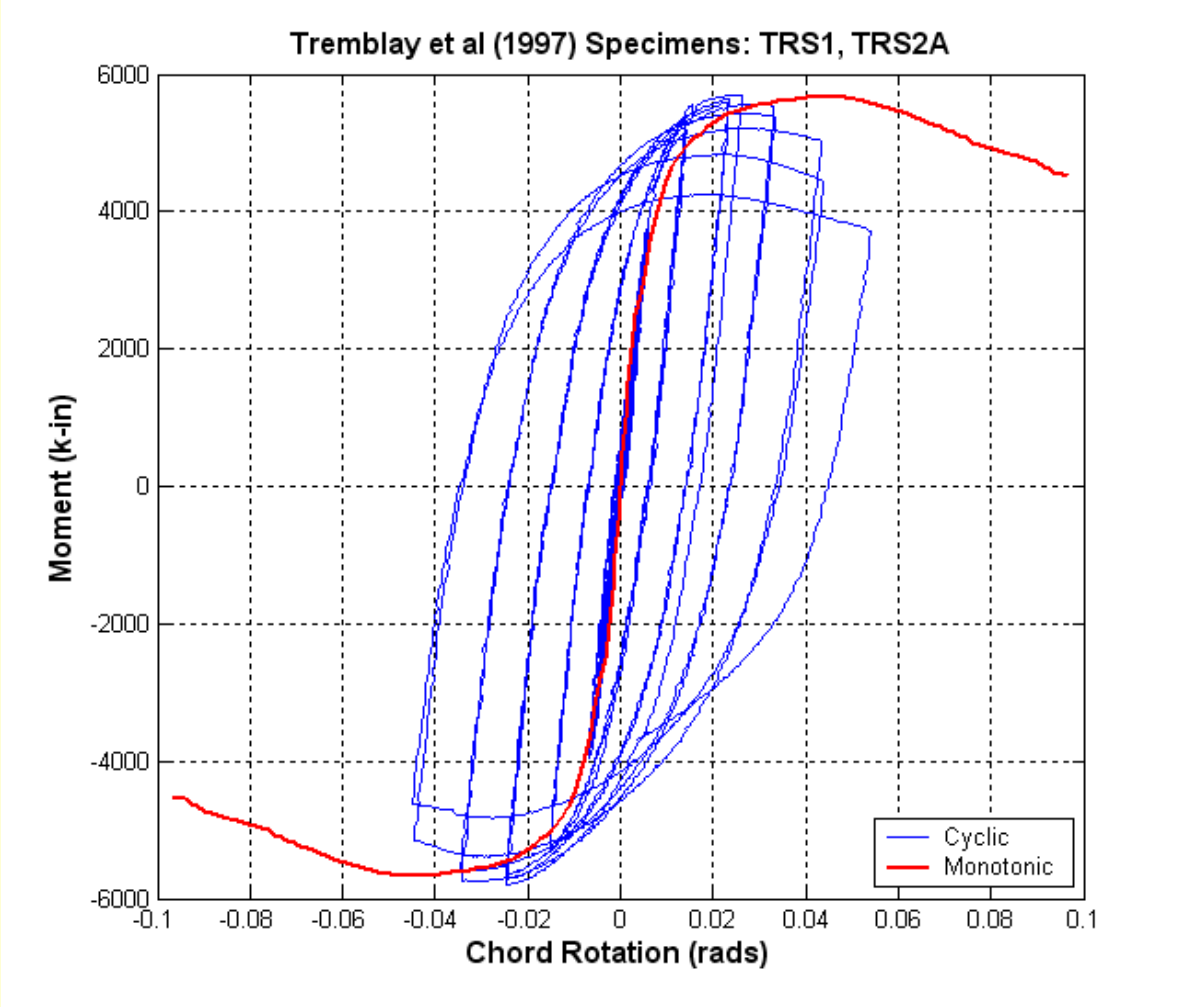
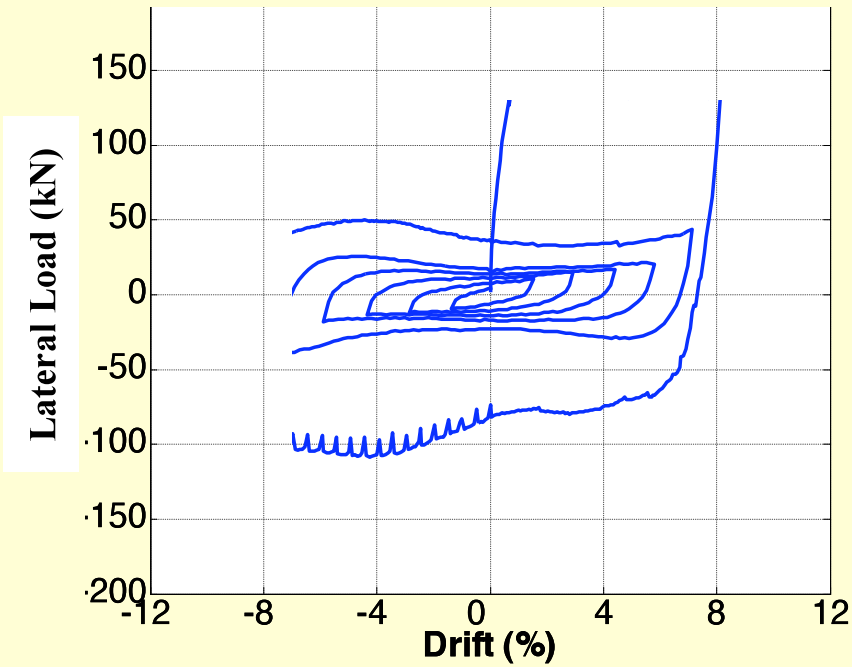
Loading History Effects Identical Steel Beams



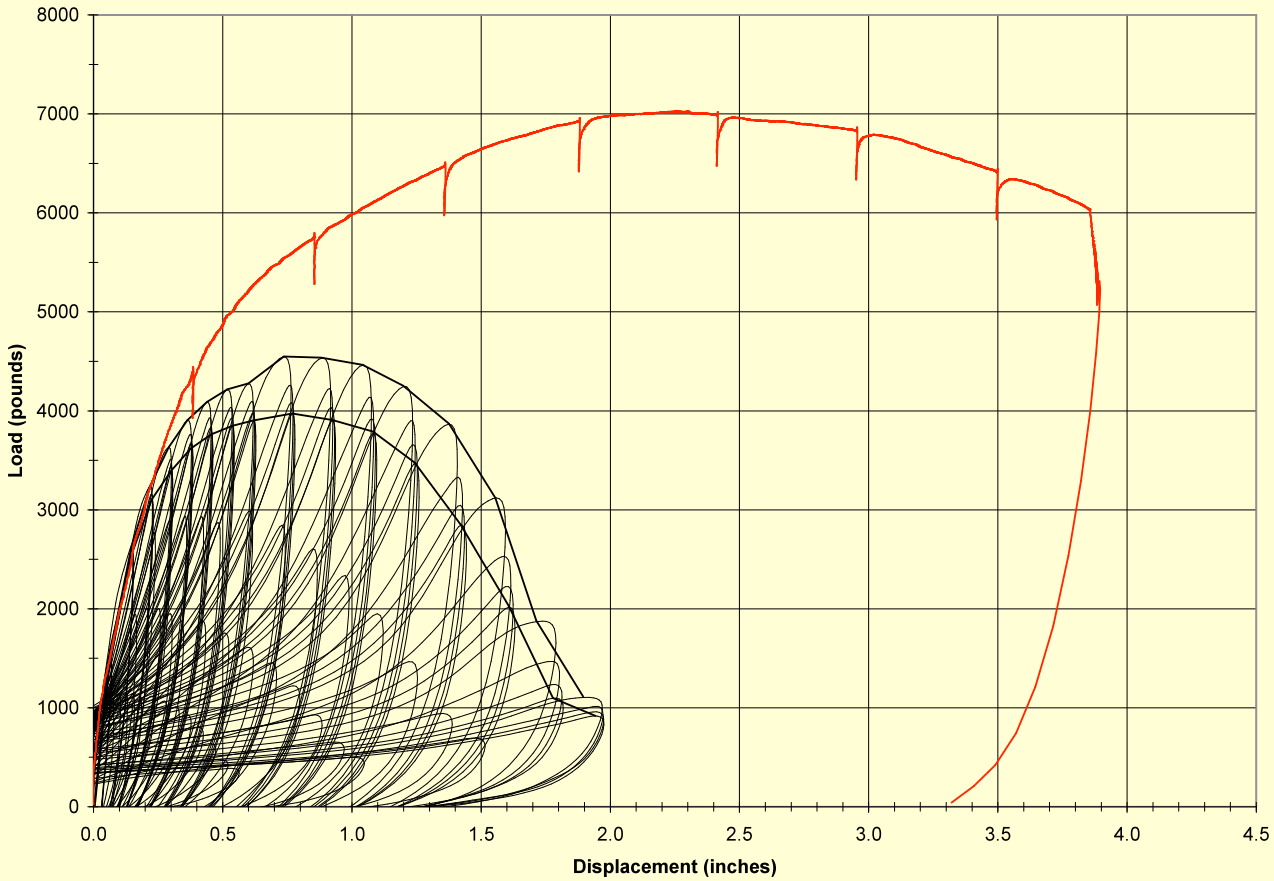
Loading History Effects
Identical RC Columns



Lateral Load (kN)

Data from Prof. Kawashima

Loading History Effects
Identical Plywood Shear Wall Panels



Why Bother with Loading Protocols

Objectives of Testing

- Evaluation of behavior
- Study of damage and failure modes
- Development of design/detailing criteria
- Analytical modeling

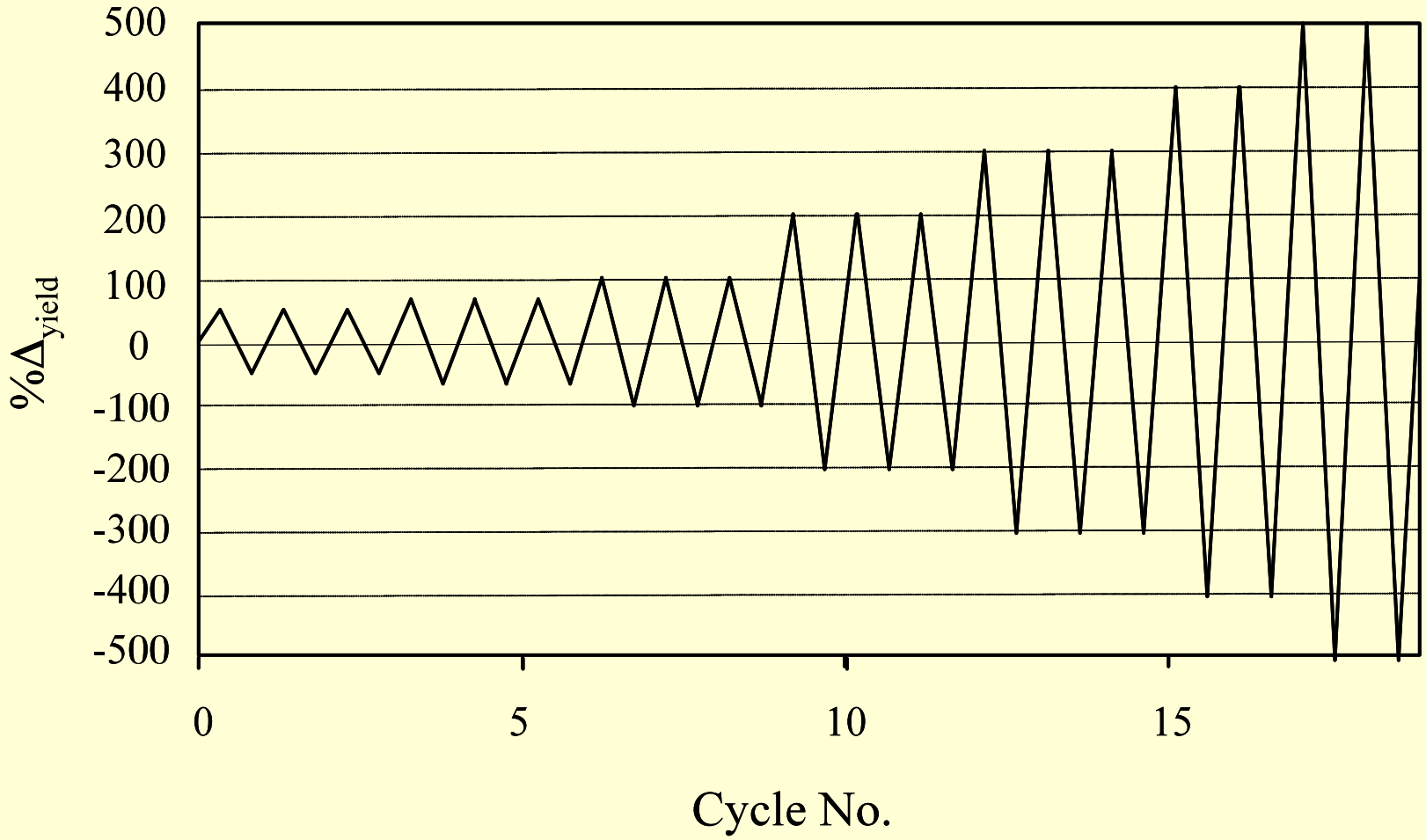
Dilemmas:

- Single test should represent many different conditions existing in a structure
- The demands imposed by ground motions on the structure depend strongly on structural characteristics
- The imposed demands are a function of ground motion characteristics, which depend strongly on soil type, source-to site distance, and many other geophysical parameters
- Various performance levels of interest, from immediate occupancy to collapse
- **Loading history never is "right"**

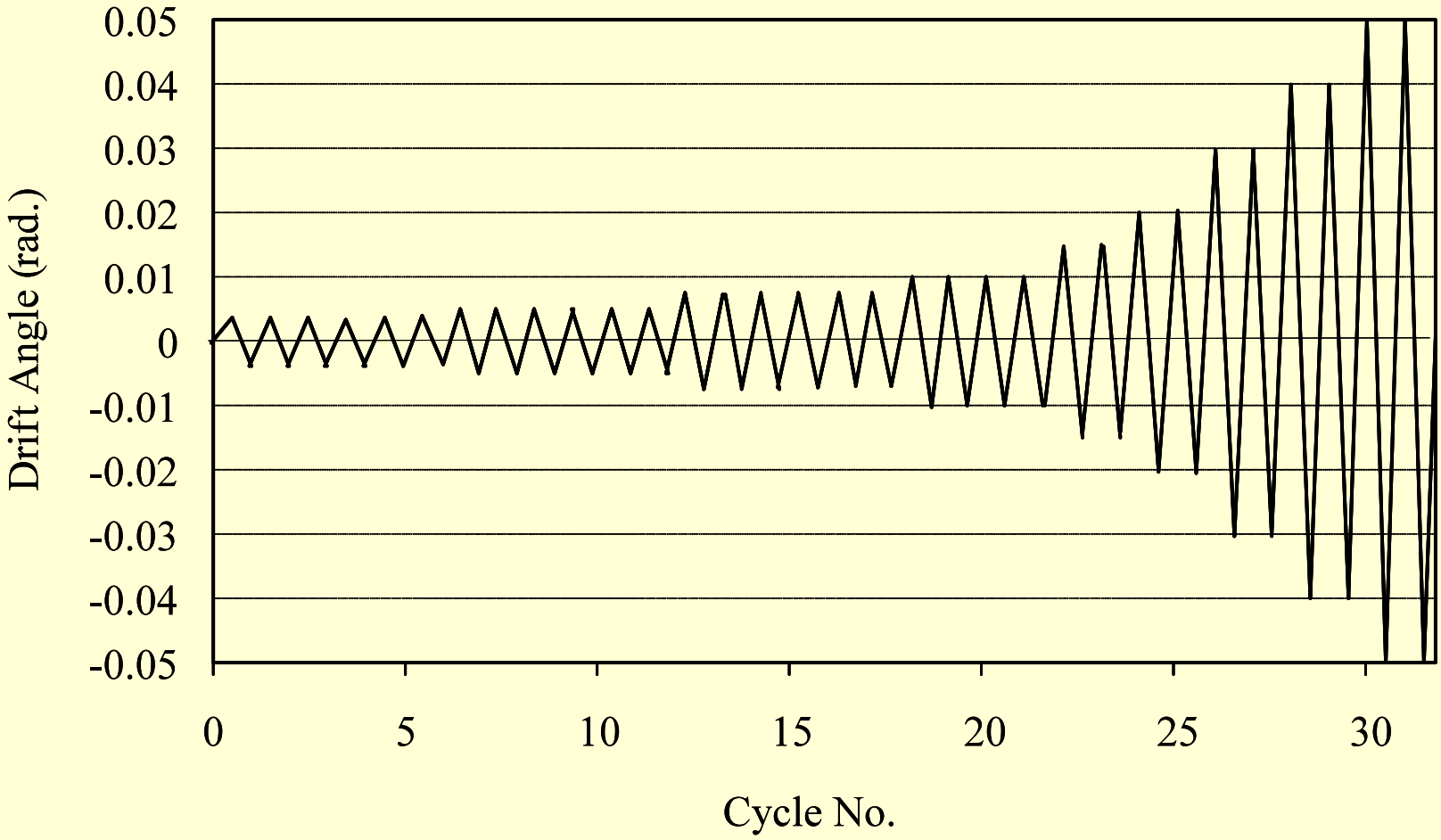
Basic Observations

- Experimental data should be community property, i.e., they should be shared
- Progress in earthquake engineering depends on experimental data that needs to be interpreted by others
- Databases of experimental data are treasures
  - PEER RC column database (Eberhard)
  - Kawashima database
  - NEES steel component database (Lignos)
  - And several others
- Database evaluation depends strongly on consistency of data

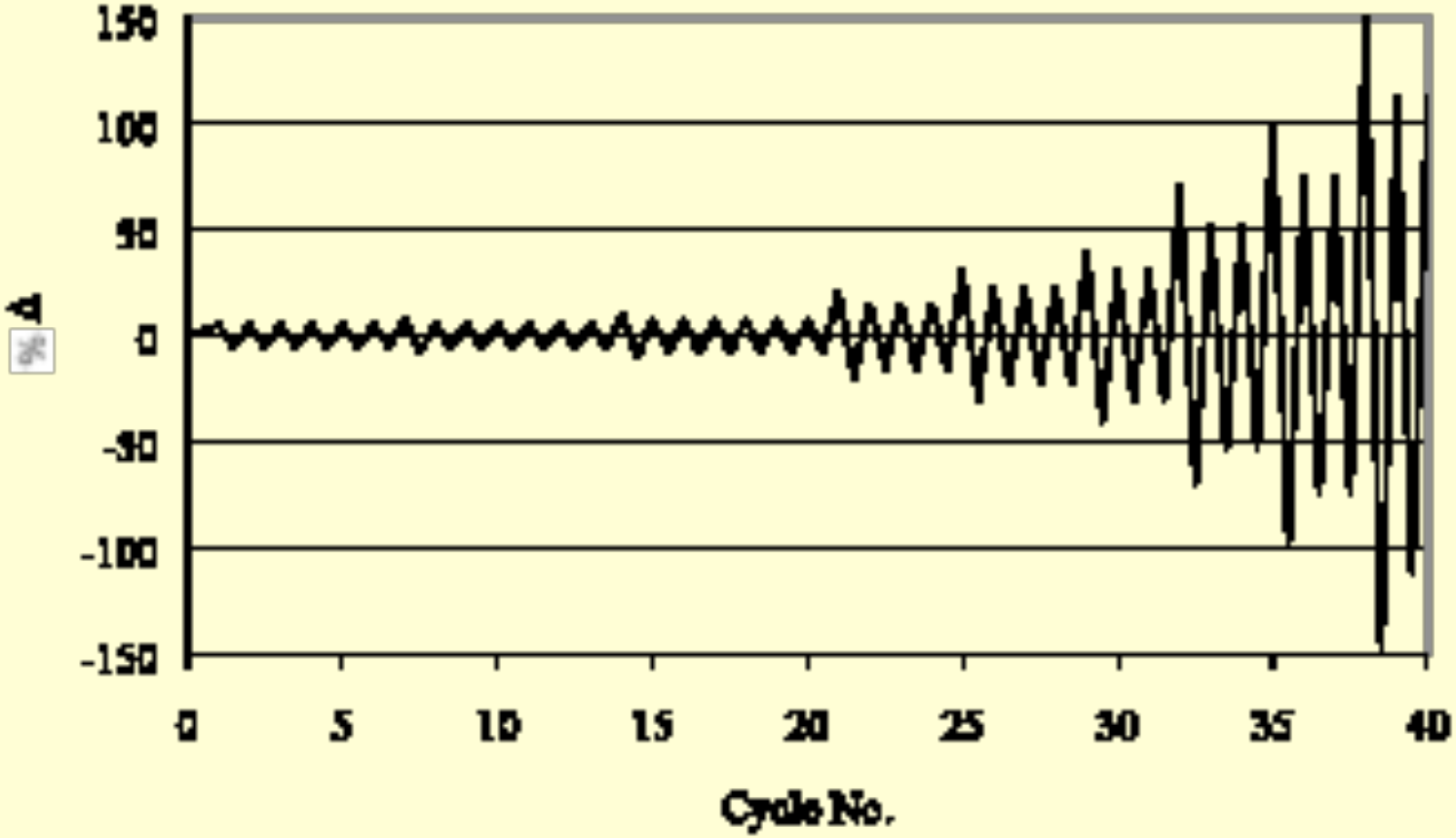
ATC-24, 1992


500
400
300
200
100
0
-100
-200
-300
-400
-500
%Δyield
0
5
10
15
Cycle No.

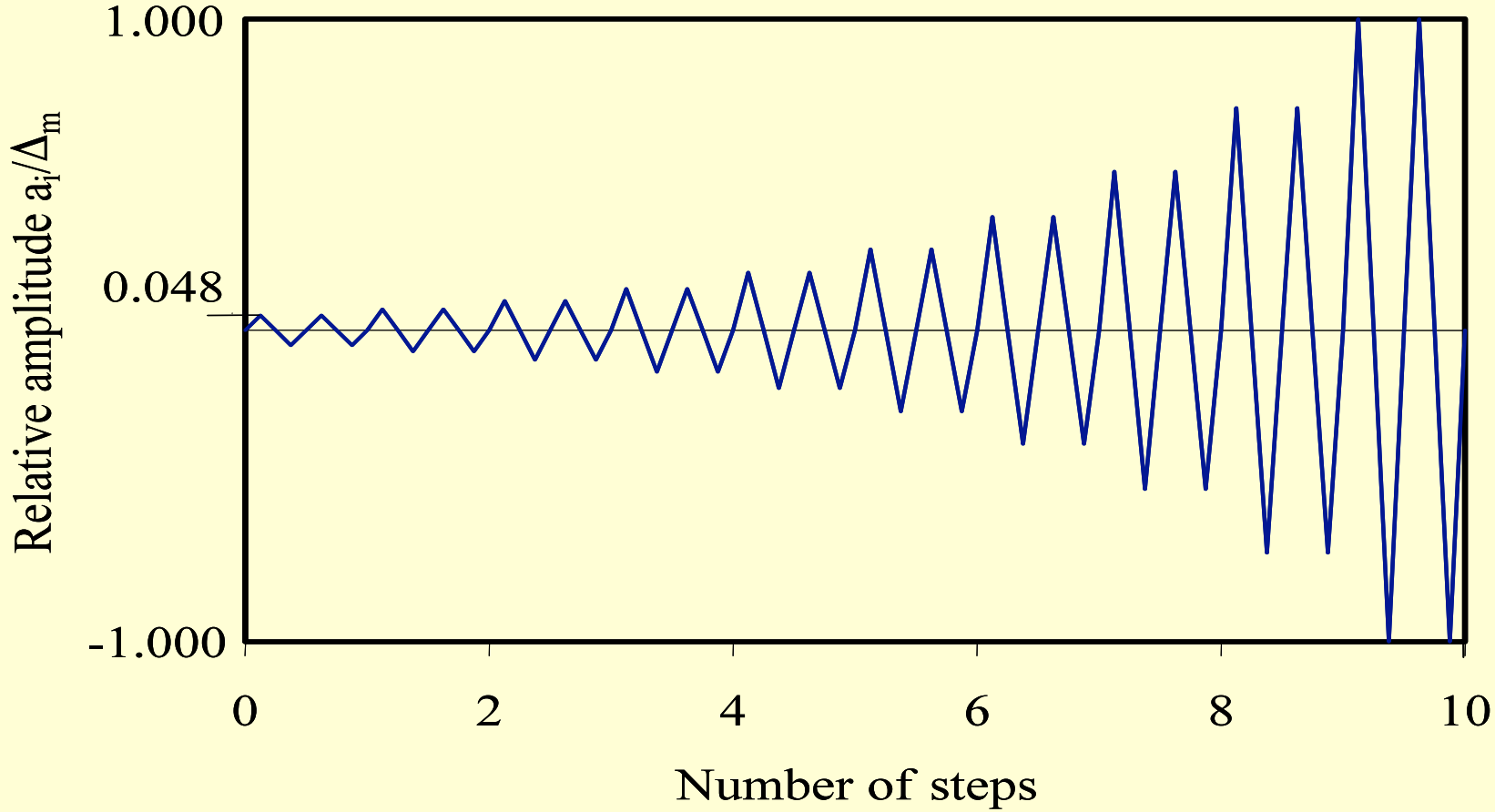
SAC – AISC, Steel, 1997



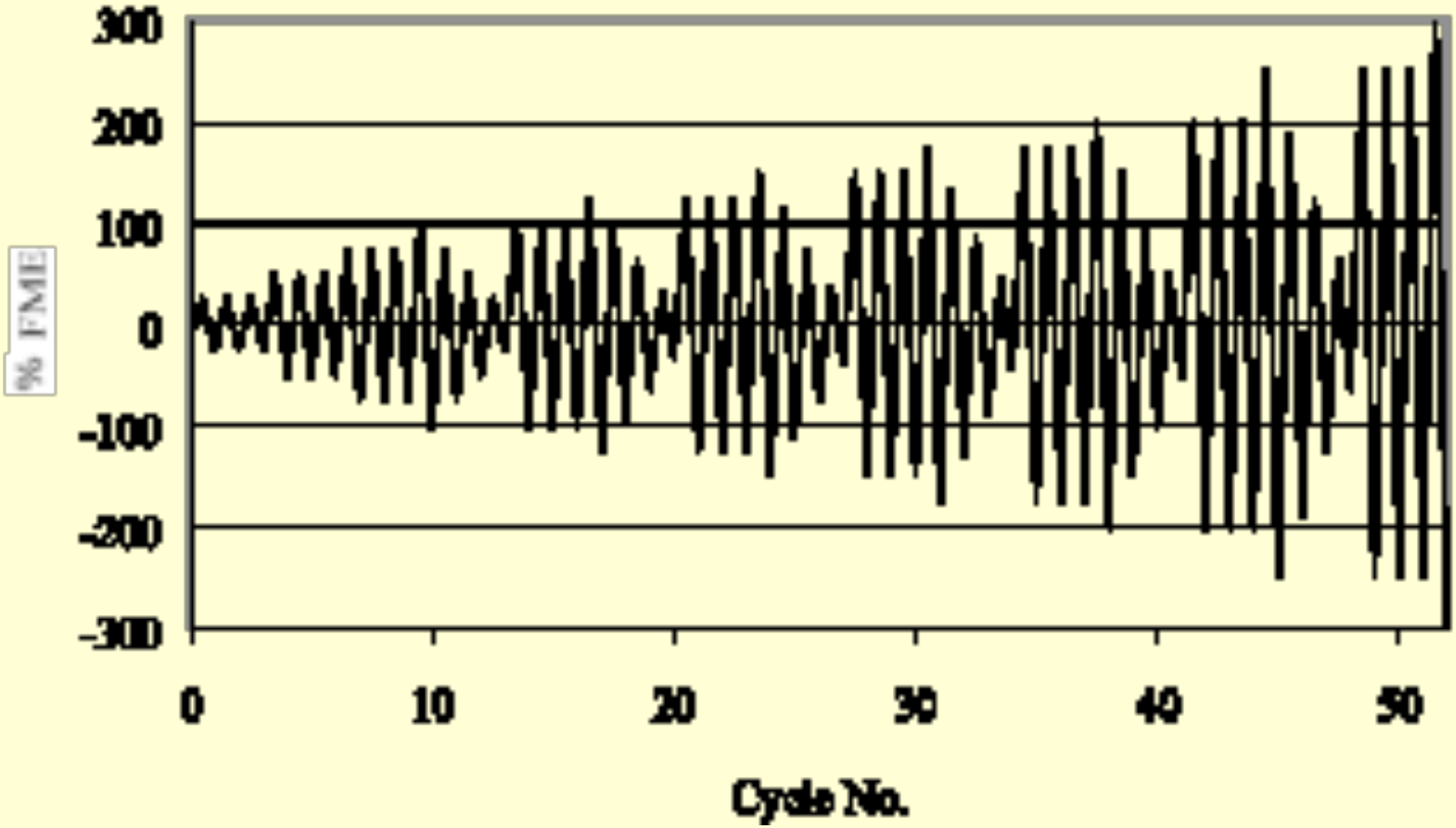
CUREE – Wood, 2000



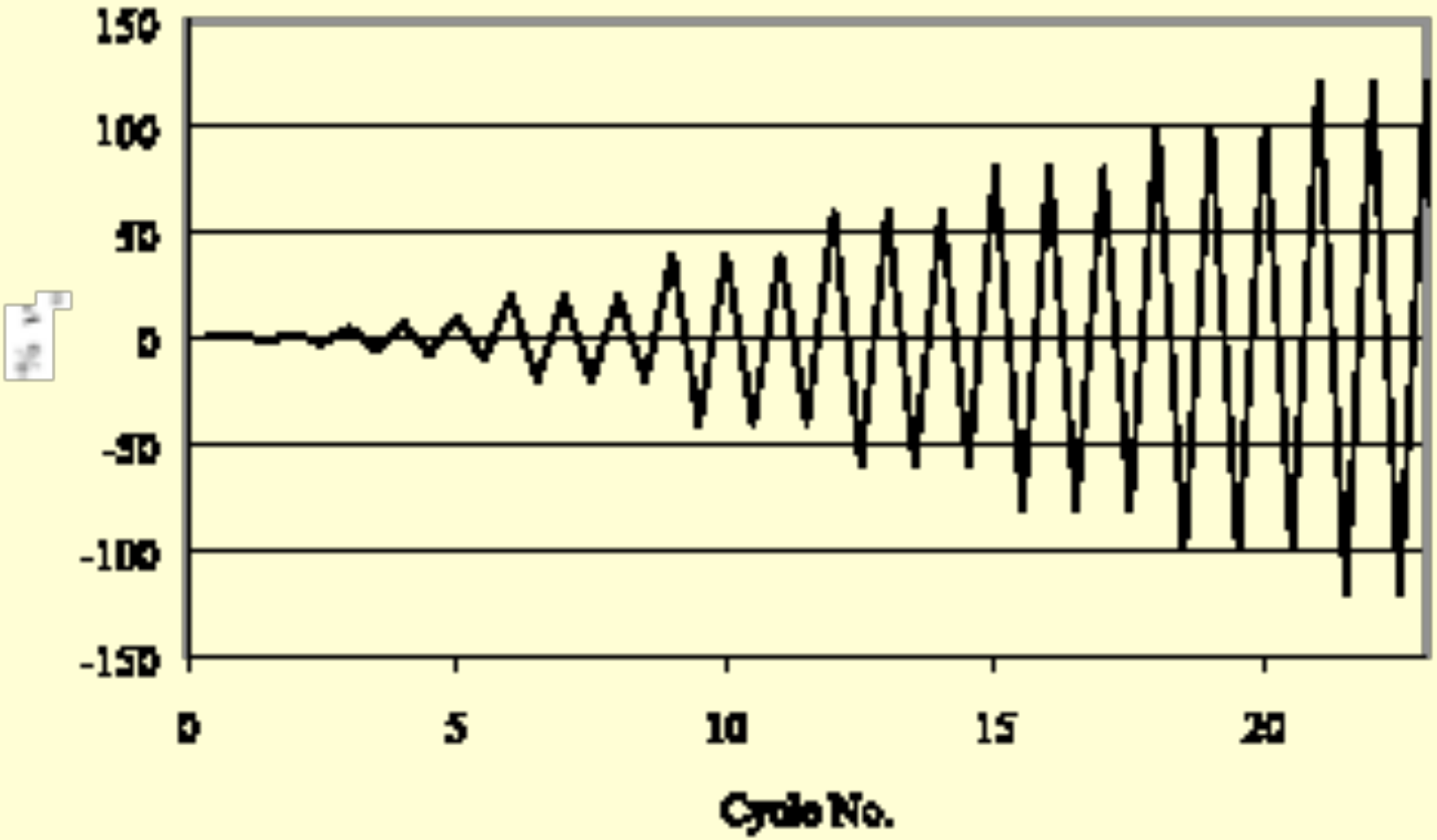
FEMA 461, 2007



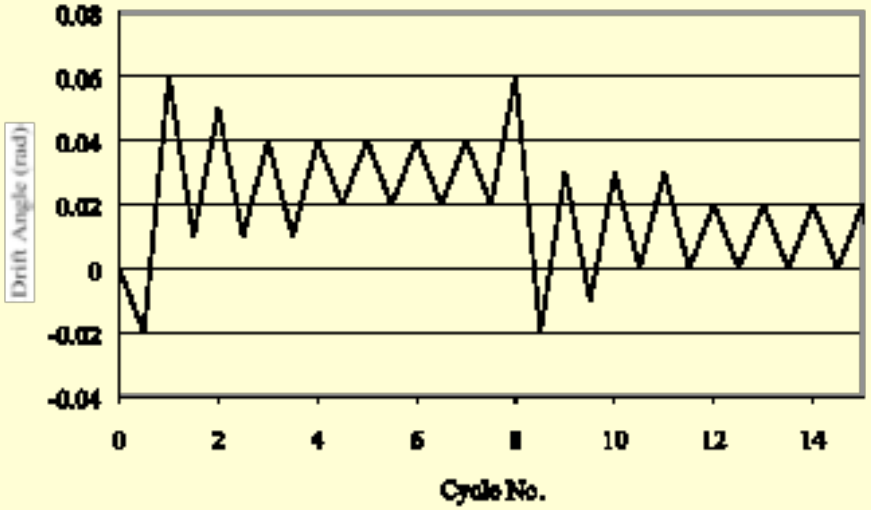
SPD, 1987



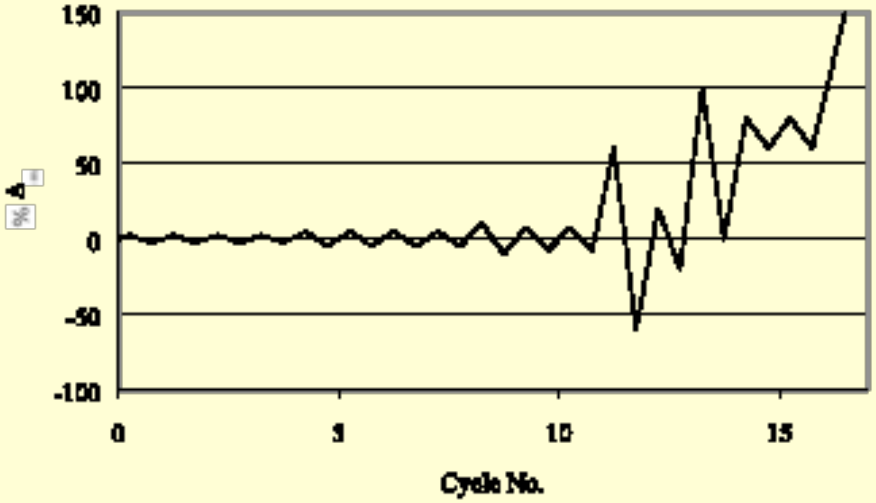
ISO – Wood, 1998



Near-Fault Loading Protocols

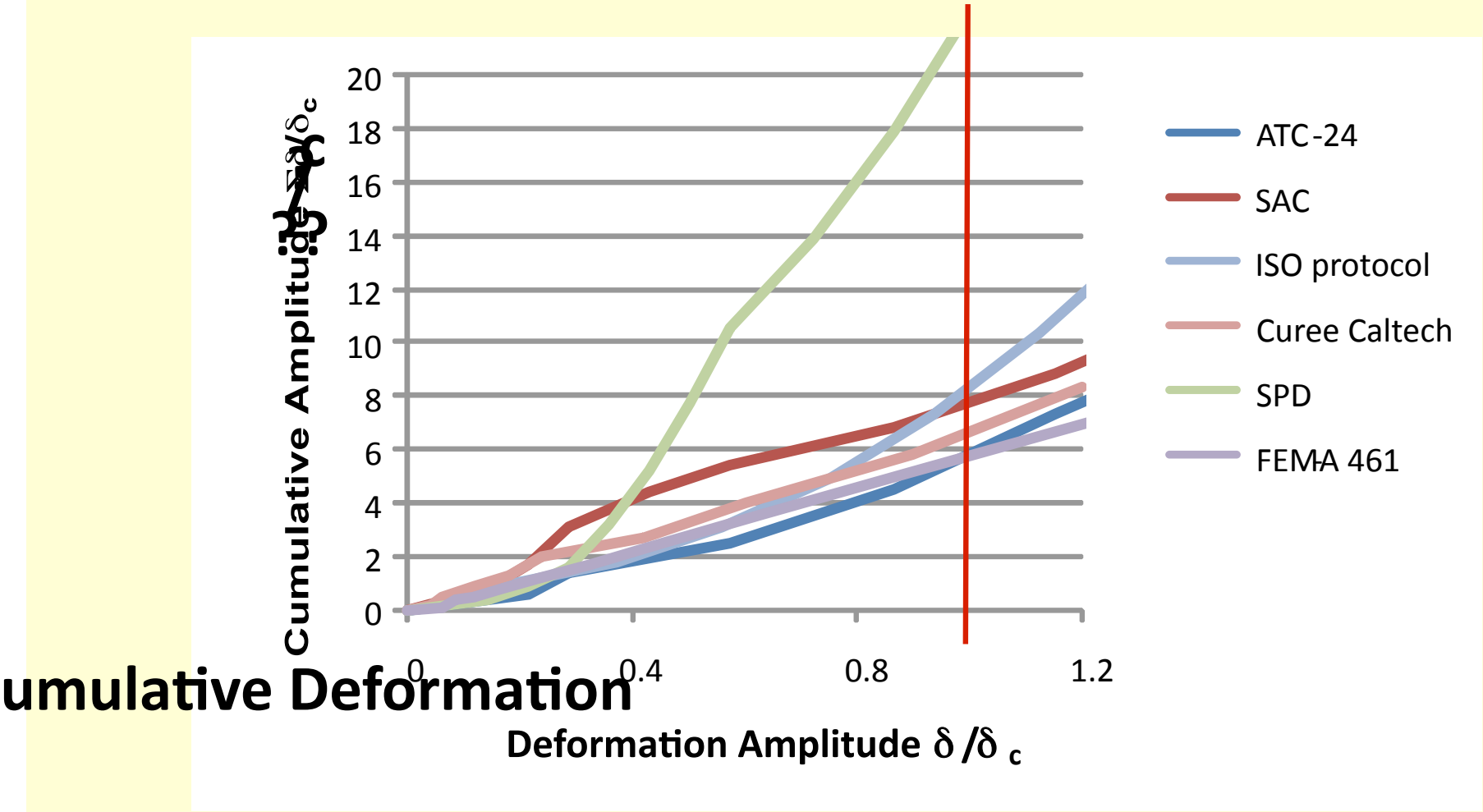


SAC Near-Fault, 2000



CUREE Near-Fault, 2000

Comparison of Cumulative Damage



Source: Haselton & Liel

ATC-24 and SAC approach

- All seismic capacity parameters are expected to deteriorate as the number of cycles and the amplitude of cycling increases
- The onset of deterioration, as well as the rate of deterioration, can be described by a cumulative damage model, e.g.,

$$D = \Sigma(\Delta\theta)^c$$

- Large cycles cause much larger damage than small cycles (exponent in the damage model ≥ 1.0), thus, emphasis needs to be placed on more accurately representing the large cycles
- Sequence and mean effects are negligible, except for one-sided responses such as those occurring under near-fault ground motion.

ATC-24 and SAC approach, cont'd

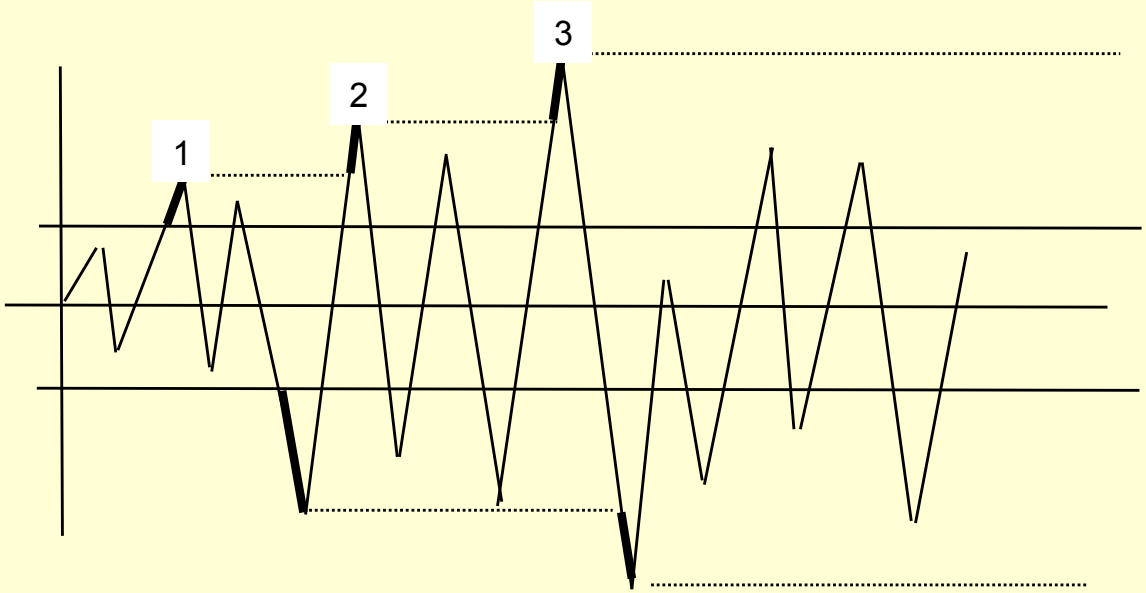
- The number of damaging cycles, N_t, the maximum story drift range, $\Delta\theta_{max}$, (peak to peak of largest cycle), and the sum of the story drift ranges of all damaging cycles, $\Sigma\Delta\theta_i$, are the primary demand parameters that must be simulated in a representative loading history
- These demand parameters can be estimated by subjecting simplified models of representative structures to sets of ground motions associated with the hazard levels at which performance evaluation is desired – SDOF & MDOF
- In order to represent the response by a series of full cycles, a cycle counting method is applied to the drift histories obtained from analysis (usually the rainflow cycle counting method is employed)
- The so estimated values can be used to construct a step-wise increasing "loading" history, in which story drifts are incremented in a manner that represents, reasonably and in general conservatively, N_t, $\Delta\theta_{max}$, and $\Sigma\Delta\theta_i$, at all hazard levels of interest.

CUREE-Wood

- Deterioration in strength and stiffness was first considered in demand predictions
- But it was found to add another huge variation, i.e., it was ignored with good arguments (focus on DLE and MCE, i.e., no focus on collapse)
- Continue testing to 50% strength loss
- Pre-peak and post-peak excursions
- Primary and trailing excursions

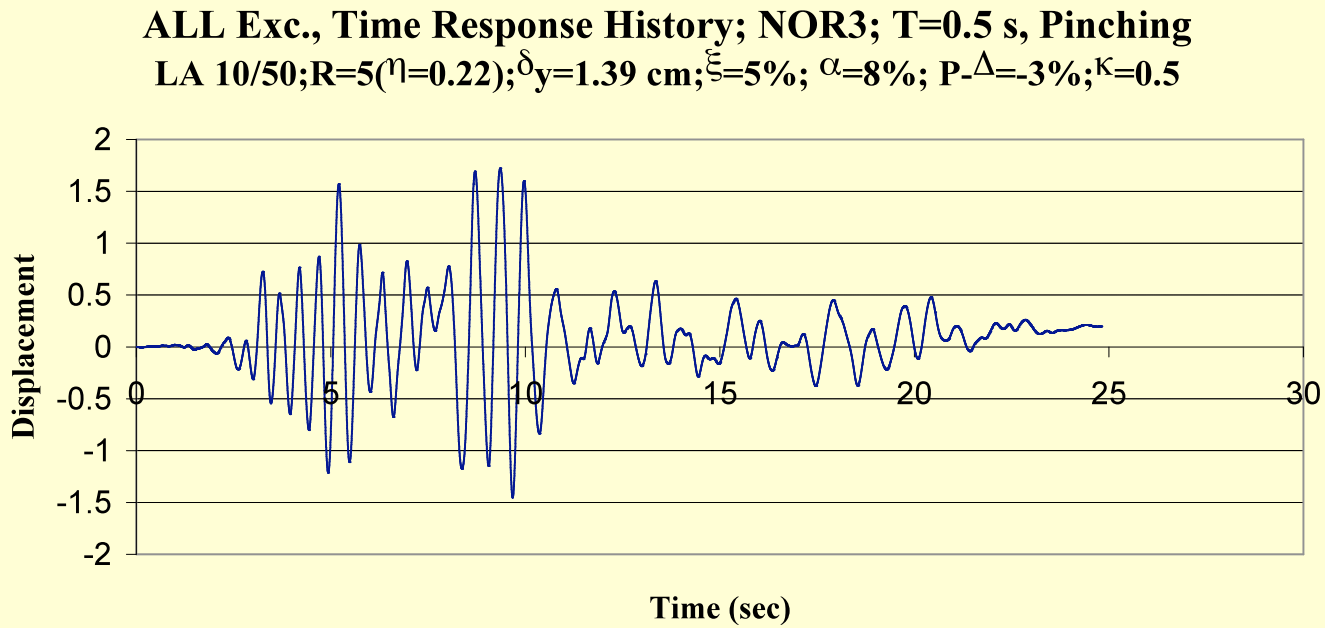
CUREE-Wood

Primary Excursions:
Excursions that push (widen) the envelope
Trailing Excursions:
Excursions that are between primary excursions
Post-Peak Excursions:
Excursions occurring after the largest primary excursion
Pre-Peak Excursions:
Excursions occurring prior to the largest primary excursion

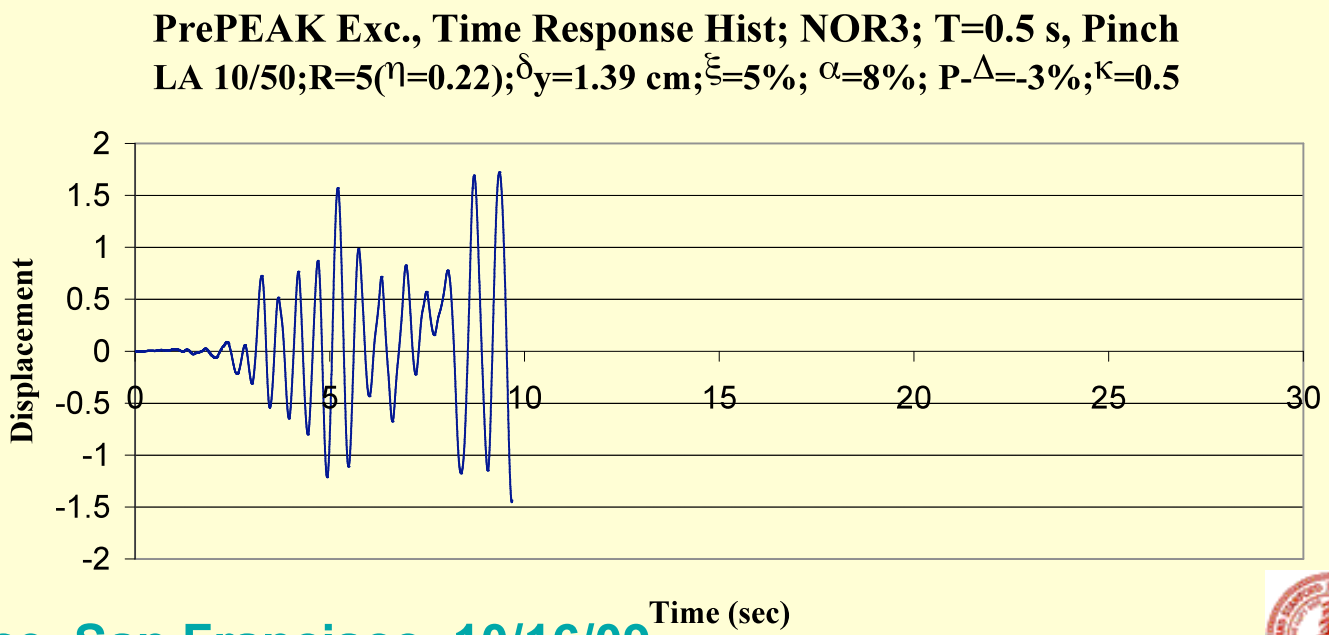


Displacement Response History

All Excursions

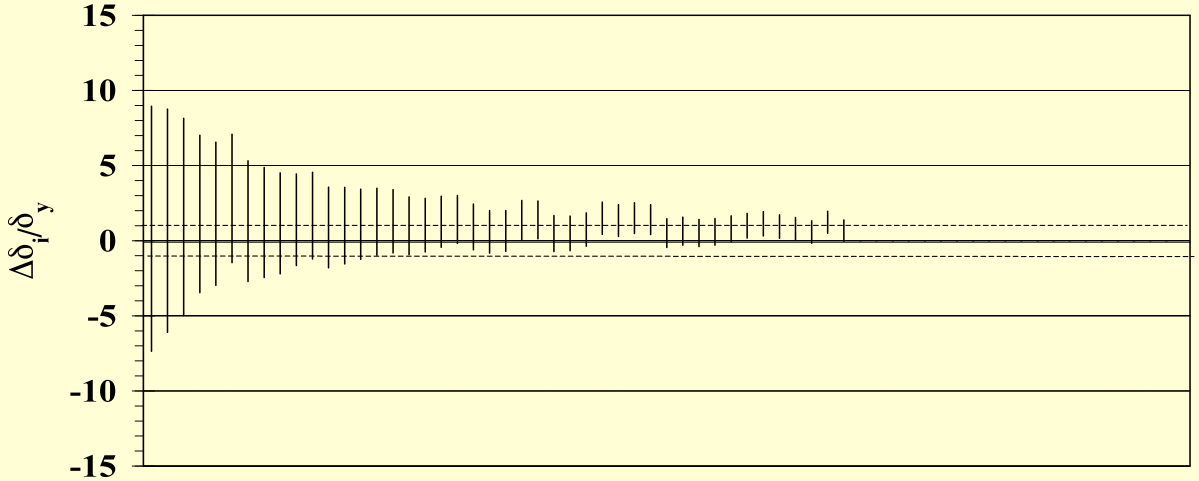


Pre-Peak Excursions

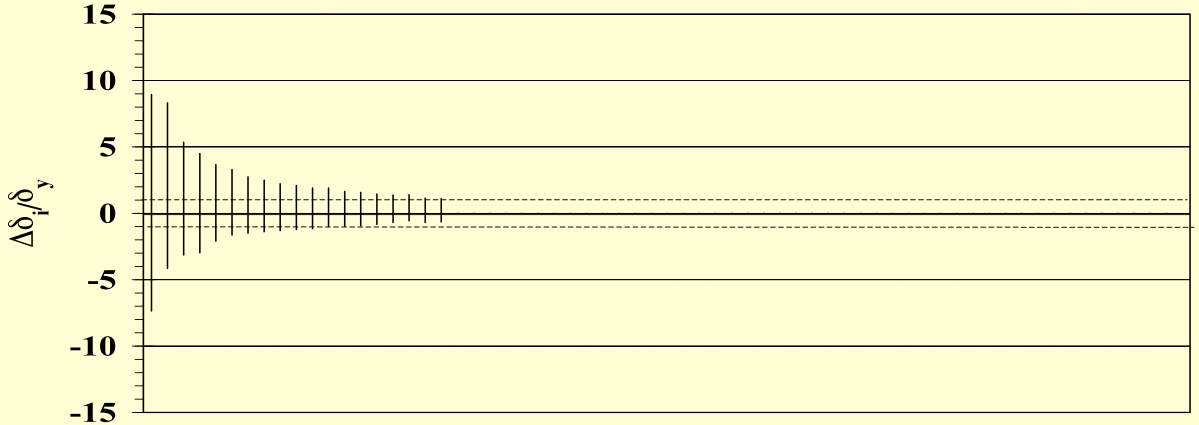


Rainflow Excursions

All Excursions

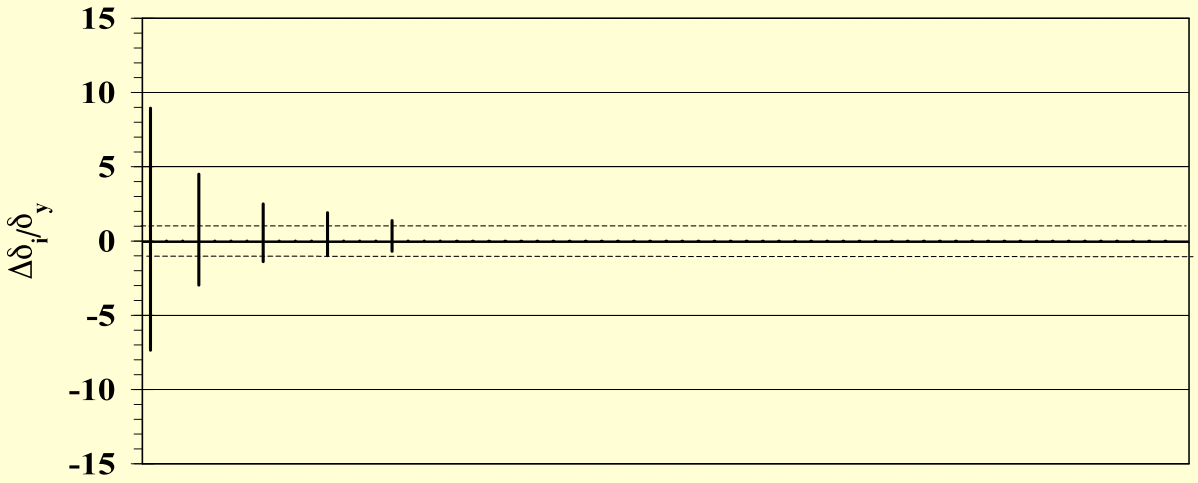


Pre-Peak Excursions

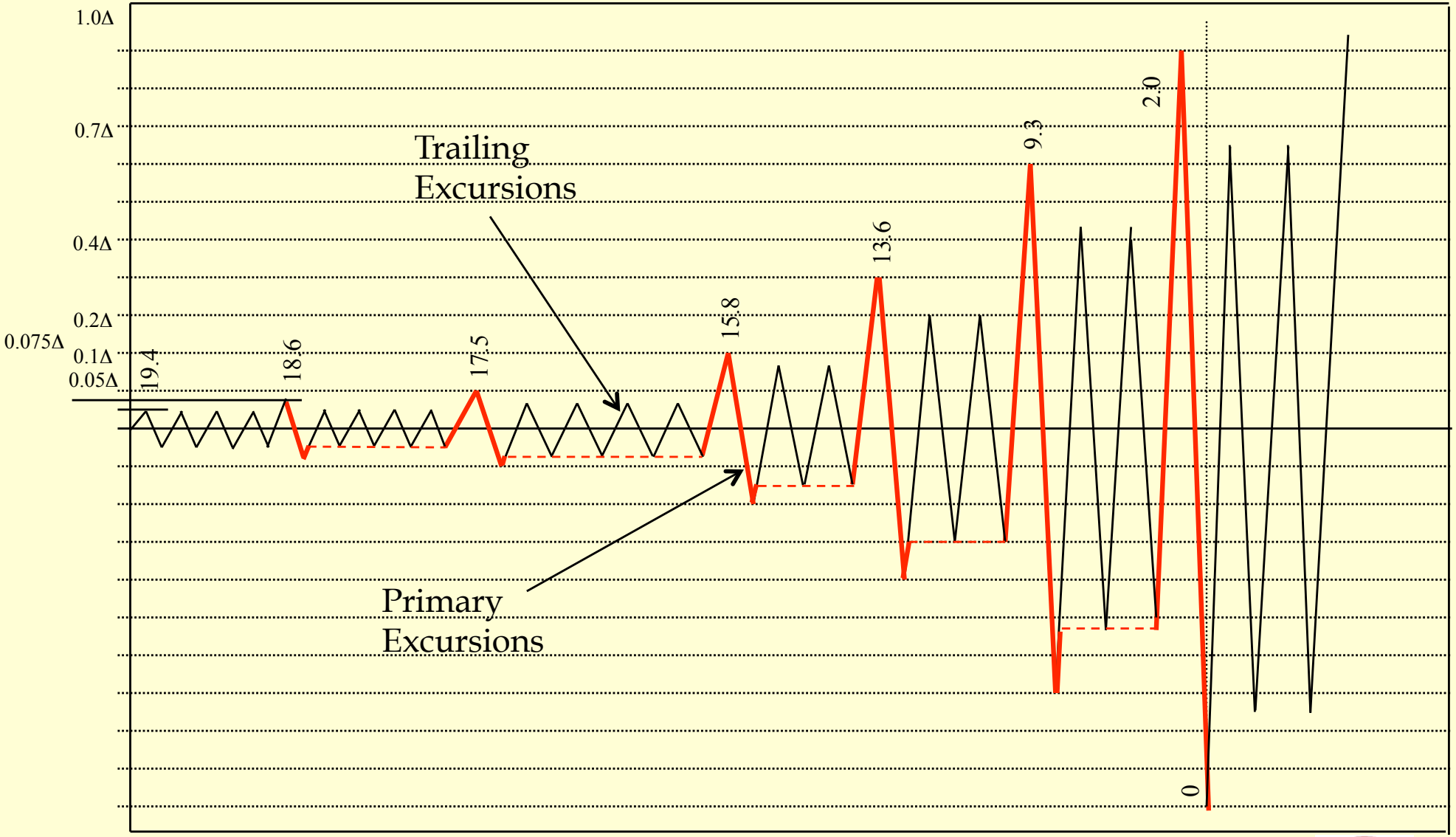


Primary Excursions

Primary
Excursions



CUREE Loading Protocol



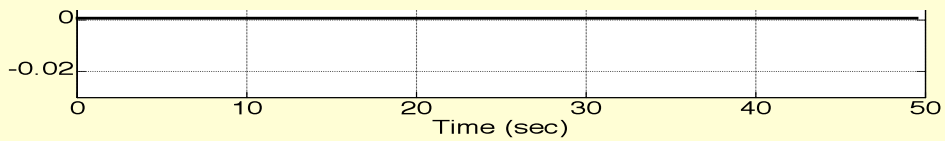
Why Revisit an Old Story?

- Previous loading histories were based on response to **design level** ground motions
- Design level ground motions cause reasonably symmetric response histories, which is the main justification for symmetric step-wise increasing deformation cycles
- Recently there is more emphasis on **collapse** prediction
- Response of structures close to collapse is not at all symmetric

SDOF Drift Response (NR94stc)

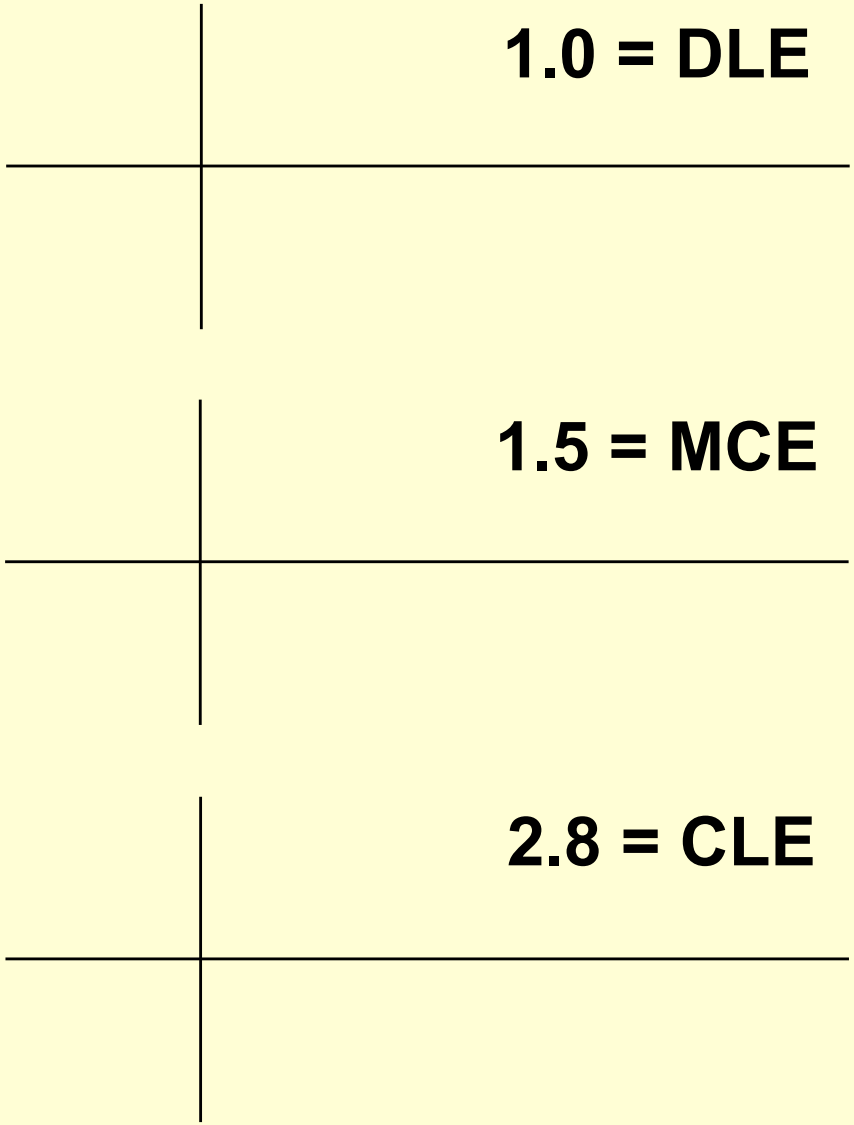
1.0 = DLE

1.5 = MCE

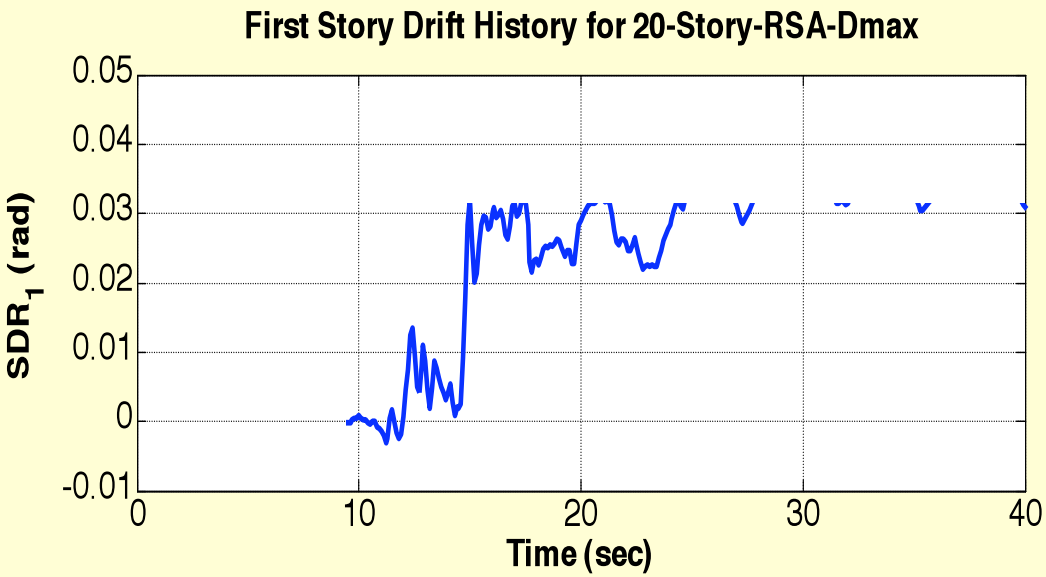


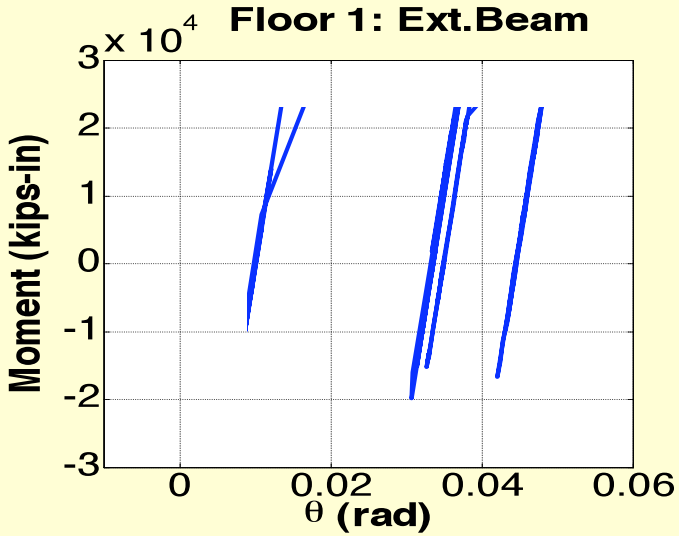
2.8 = CLE

SDOF V-δ Response



First Story Response of a 20-story Steel MRF Structure





Summary Observations

- Existing cyclic loading protocols are appropriate for design level response
- They do not simulate response close to collapse
- If collapse modeling is a primary objective, then tests with existing cyclic loading protocols should be supplemented with monotonic tests