PEER Tall Building Seismic Design Guidelines

Analysis, Modeling and Acceptance Criteria

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SEAW

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Purpose of Analysis

- Demonstrate that the design is capable of acceptable performance
- Two performance objectives considered:
  - Service Level
  - Maximum Considered Level

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Service Level Analysis

Performance Goal:

- Minor structural damage
  - Does not compromise structure's safety
  - Repair not required for occupancy
  - Repair may be desirable for:
    - Appearance
    - Durability, moisture and fire resistance

Acceptable Damage

- For a limited number of elements:
  - Minor cracking of concrete
  - Minor yielding of steel

- Unacceptable behavior
  - Permanent cracks exceeding 1/8”
  - Spalling of cover or core concrete
  - Buckling of steel member or rebar
  - Measurable residual drift
  - Punching of slab-column joints

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Service Level Analysis

- Linear response spectrum analysis (RSA) required
  - Appropriate to response anticipated at this performance level
  - Provides benchmark for later analyses using nonlinear models

- Nonlinear response history analysis can be run as a supplement, to demonstrate acceptability when RSA does not so indicate

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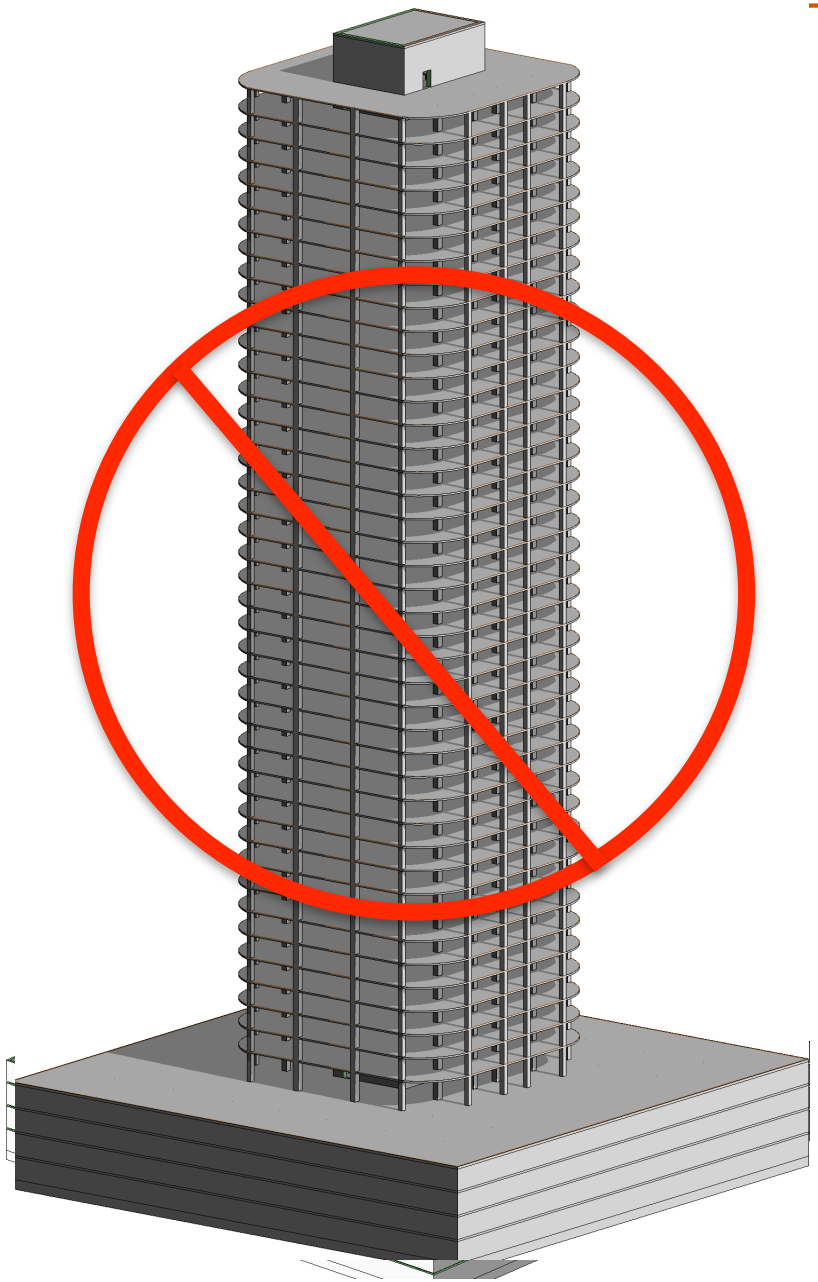
What should be modeled?



- Intended lateral system
  - From base to penthouse
- Any element that effects stiffness or can be damaged by response
  - Gravity columns
  - Slabs
  - Gravity beams
  - Basement walls

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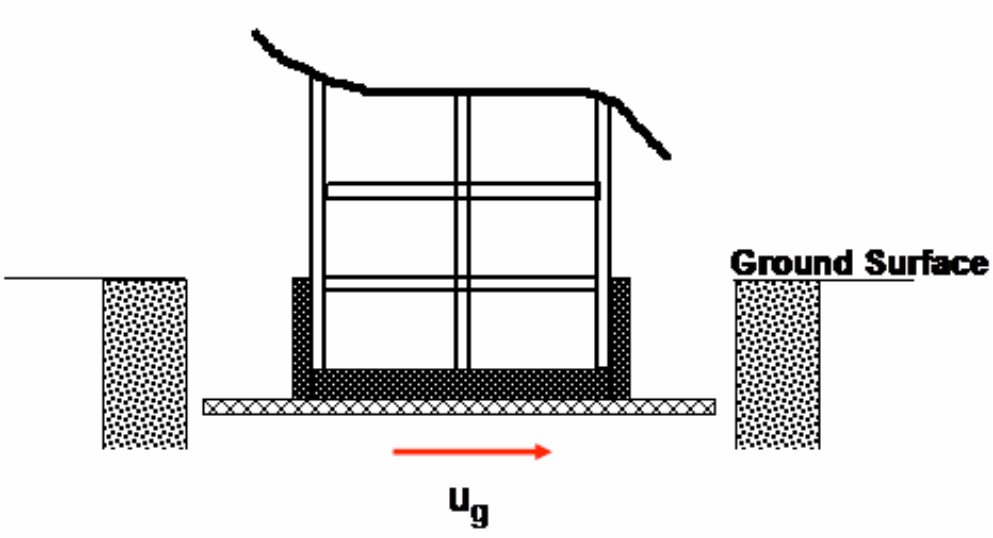
Soil-Structure-Foundation Interaction

- Need not be considered

  But-

  - Model must extend to soil-structure interface
    - Typically top of mat
  - Include basement walls and slabs
  - Include mass of basement levels



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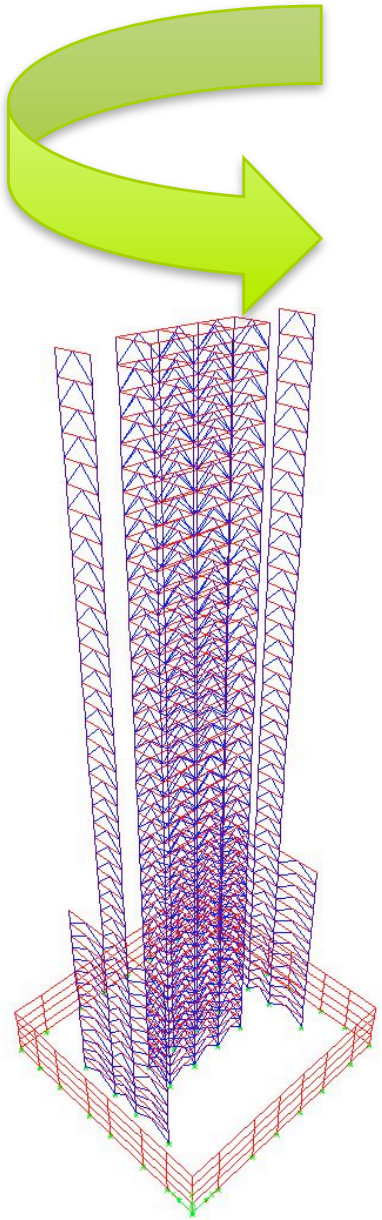
Torsion

- Inherent (natural) torsion must be modeled
- Accidental torsion neglected



Element Stiffness

- Models must include reasonable representation of stiffness

Component	Flexural Rigidity	Shear Rigidity	Axial Rigidity
Structural steel Beams, Columns and Braces	$E_s I$	$G_s A$	$E_s A$
Composite Concrete Metal Deck Floors	$0.5E_c I_g$	$G_c A_g$	$E_c A_g$
R/C Beams – nonsprestressed	$0.5E_c I_g$	$G_c A_g$	$E_c A_g$
R/C Beams – prestressed	$E_c I_g$	$G_c A_g$	$E_c A_g$
R/C Columns	$0.5E_c I_g$	$G_c A_g$	$E_c A_g$
R/C Walls	$0.75E_c I_g$	$G_c A_g$	$E_c A_g$
R/C Slabs and Flat Plates	$0.5E_c I_a$	$G_c A_a$	$E_c A_a$

Notes:

E_c shall be computed per ACI 318, using expected material strength per Table 7-1.

G_c shall be computed as $E_c / \left(2\left(1+\nu\right)\right)$, where ν shall be taken as 0.2.

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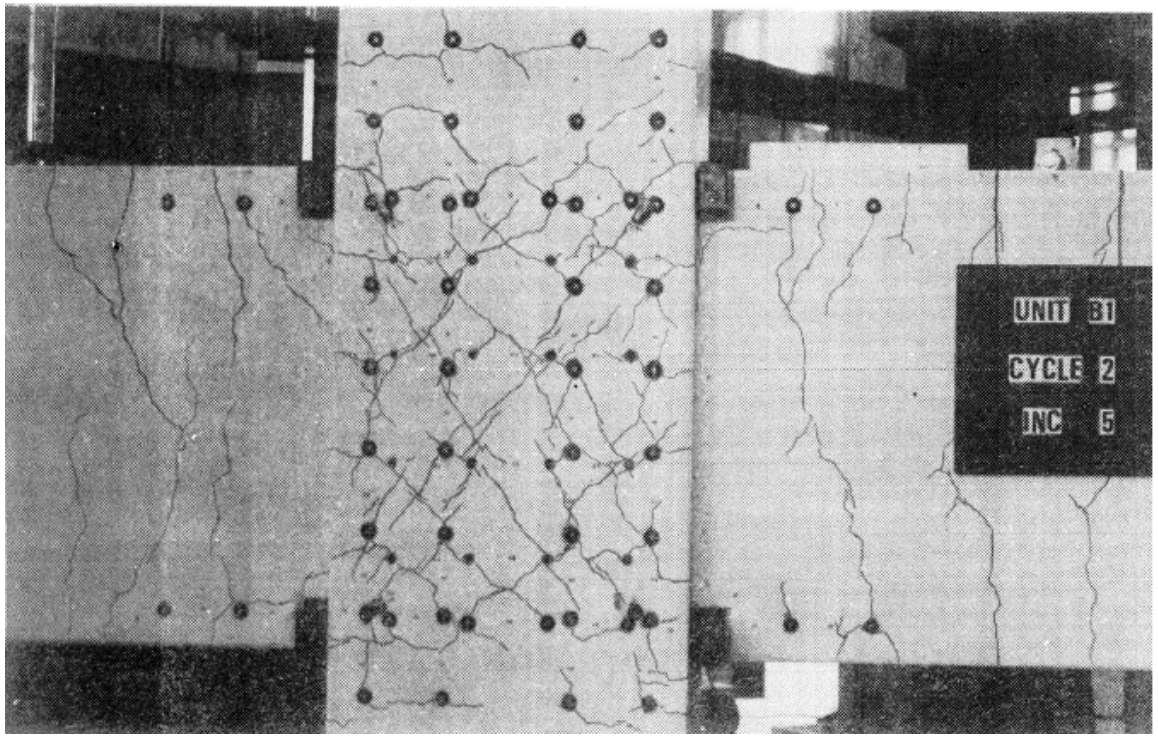
Element Stiffness



- Beam-column joints
  - Explicit modeling of stiffness, or
  - No rigid end offsets for beams

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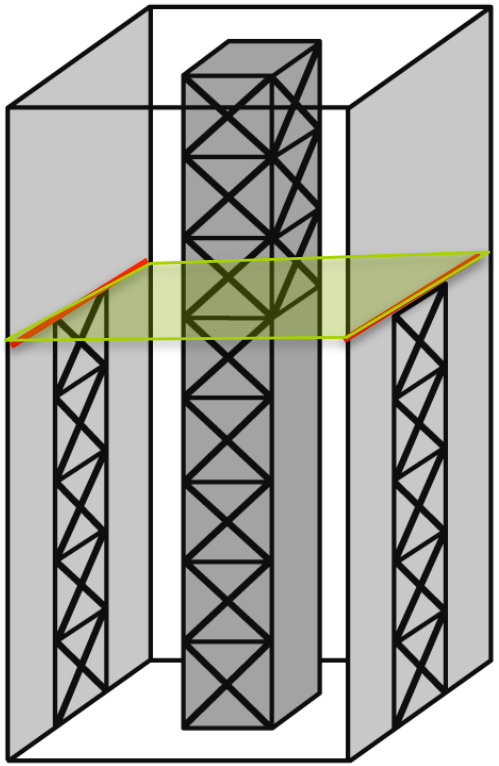
Element Stiffness



- Diaphragms
  - Use realistic assessments of stiffness
  - Transfer diaphragms must be explicitly modeled

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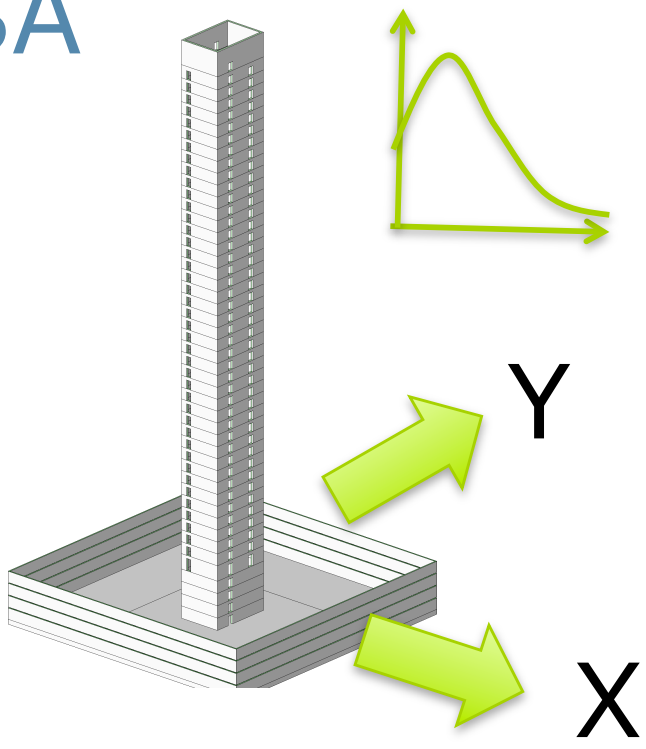
Load Combinations & Acceptance

RSA



$$Q = D + L_{\text{exp}} + 1.0E_X + 0.3E_Y$$

$$Q = D + L_{\text{exp}} + 0.3E_X + 1.0E_Y$$

$$L_{\text{exp}} = 0.25L$$

$$Q < 1.5\phi C_n$$

Story Drift < 0.005h

- C_n = nominal capacity (per code)
- ϕ = resistance factor per ACI or AISC

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Nonlinear Analysis

- Use best estimates of stiffness and strength

Material		Expected Strength
Structural Steel		
	Hot-rolled structural shapes and bars	
	ASTM A36/A36M	$1.5 f_y^*$
	ASTM A572/A572M Grade 42 (290)	$1.3 f_y$
	ASTM A992/A992M	$1.1 f_y$
	All other grades	$1.1 f_y$
	Hollow Structural Sections	
	ASTM A500, A501, A618 and A847	$1.3 f_y$
	Steel Pipe	
	ASTM A53/A53M	$1.4 f_y$
	Plates	$1.1 f_y$
	All other Products	$1.1 f_y$
Reinforcing Steel		$1.17 f_y$
Concrete		$1.3 f_c'$

$^*f_y$ is used to designate specified yield strength of steel materials in this Guideline. It is equivalent to F_y used in AISC standards.

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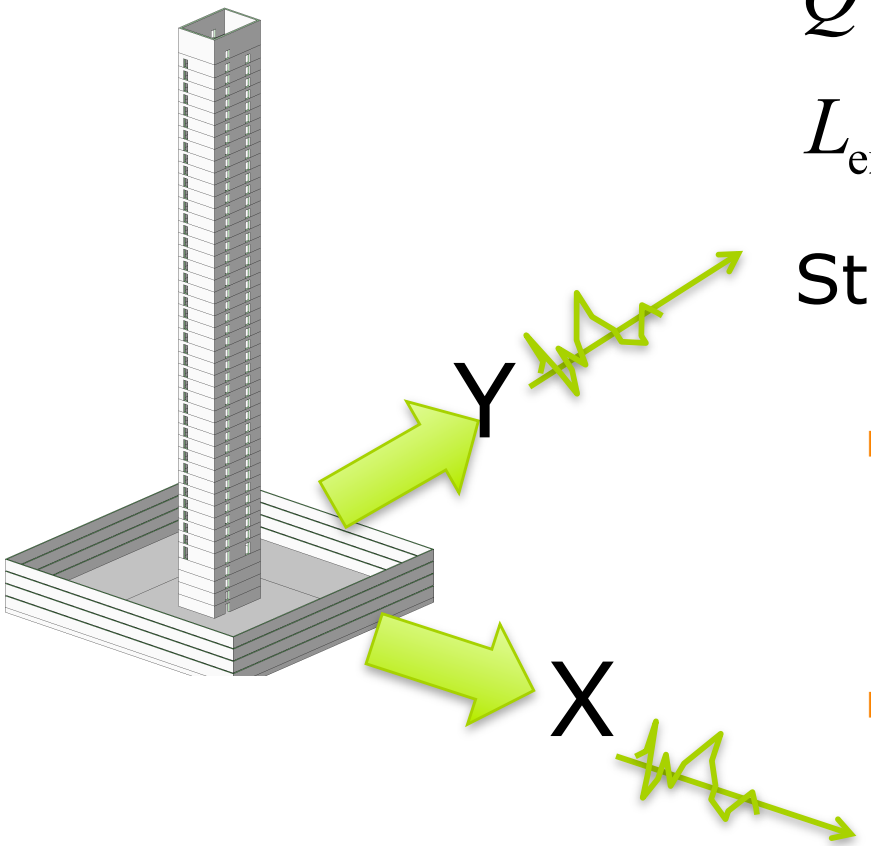
Load Combinations & Acceptance

NLRH



$$Q = D + L_{\text{exp}} + 1.0E_X + 1.0E_Y$$

$$L_{\text{exp}} = 0.25L$$

Story Drift < 0.005h

- Use minimum of 3 pairs of ground motions
- Demand based on max values from suite unless 7 or more pairs of motions used

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Nonlinear Analysis

- Nonlinear behavior limited to deformation-controlled (ductile) actions
  - Deformations shall be within range that does not require repair to restore system strength, as demonstrated by laboratory testing
  - Repair, if required, shall not include:
    - Removal or replacement of concrete other than cover concrete
    - Removal or replacement of reinforcing or structural steel
  - ASCE 41 Immediate Occupancy values may be used
- Force-controlled (brittle) actions shall not exceed the expected strengths

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Maximum Considered Level Analysis

Performance Goal:

- Minor implicit risk of collapse
- Modest residual drift
- Limited potential for failure of cladding

Pragmatically

- Confirm that:
  - Inelastic behavior occurs in favorable modes, envisaged by the design
  - Excessive force and deformation demands do not result in undesirable behavioral modes
  - Transient drifts remain within reliable range of model and analysis validity
  - Residual drifts are not excessive
  - Cladding is capable of sustaining anticipated drifts

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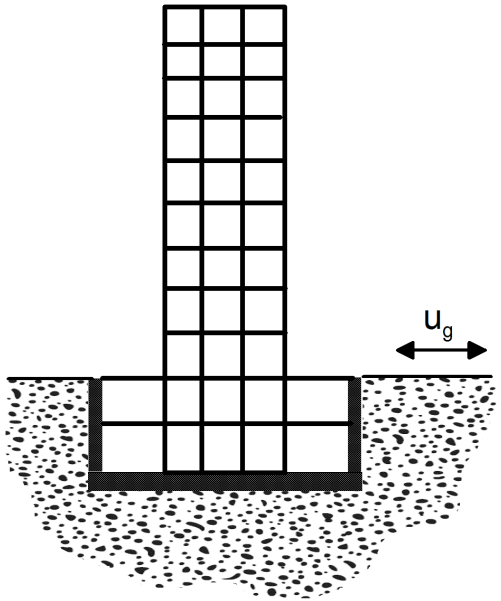
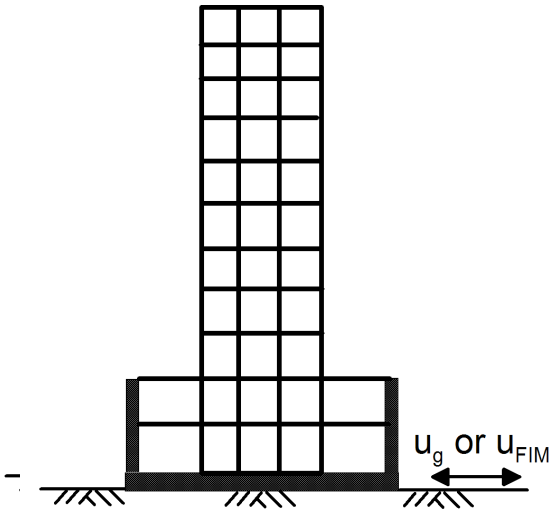
Maximum Considered Level

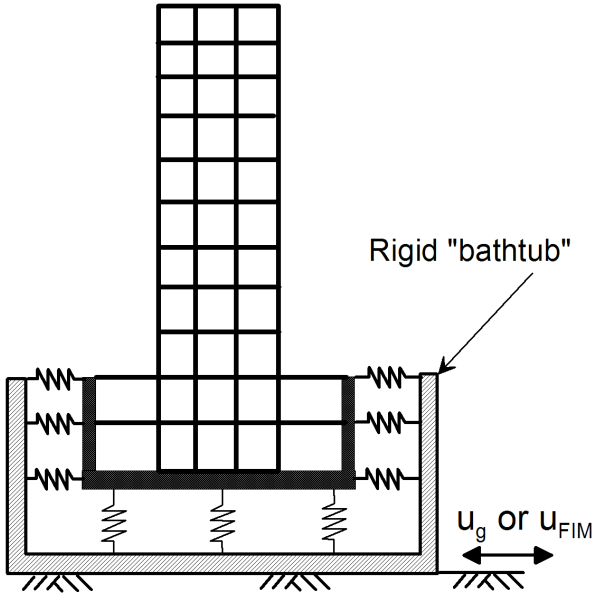
- 3-D nonlinear response history analysis
- Ground motion input at structure base
- SSI Permitted – but not required



Desired



Typical



Optional

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Behavior Modeling

- If structural response approaches collapse levels, model must capture:
  - Monotonic behavior at deformation levels beyond peak (capping) strength
  - Hysteretic properties characterizing component behavior:
    - With cyclic degradation
    - Without cyclic degradation

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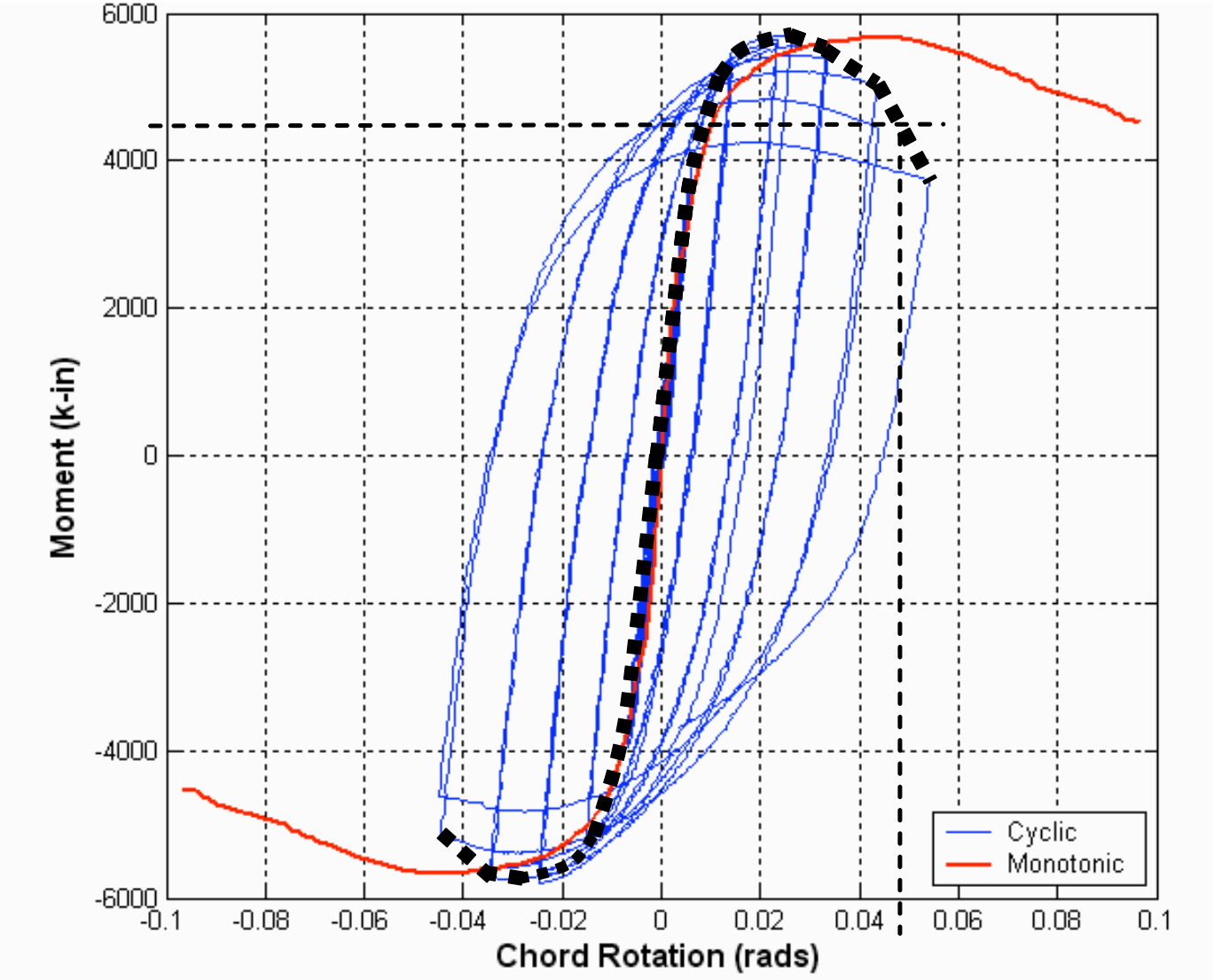
Cyclic Degradation



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Cylic Degradation

1. Explicit incorporation
2. Cyclic envelope
3. Factored monotonic
4. Monotonic

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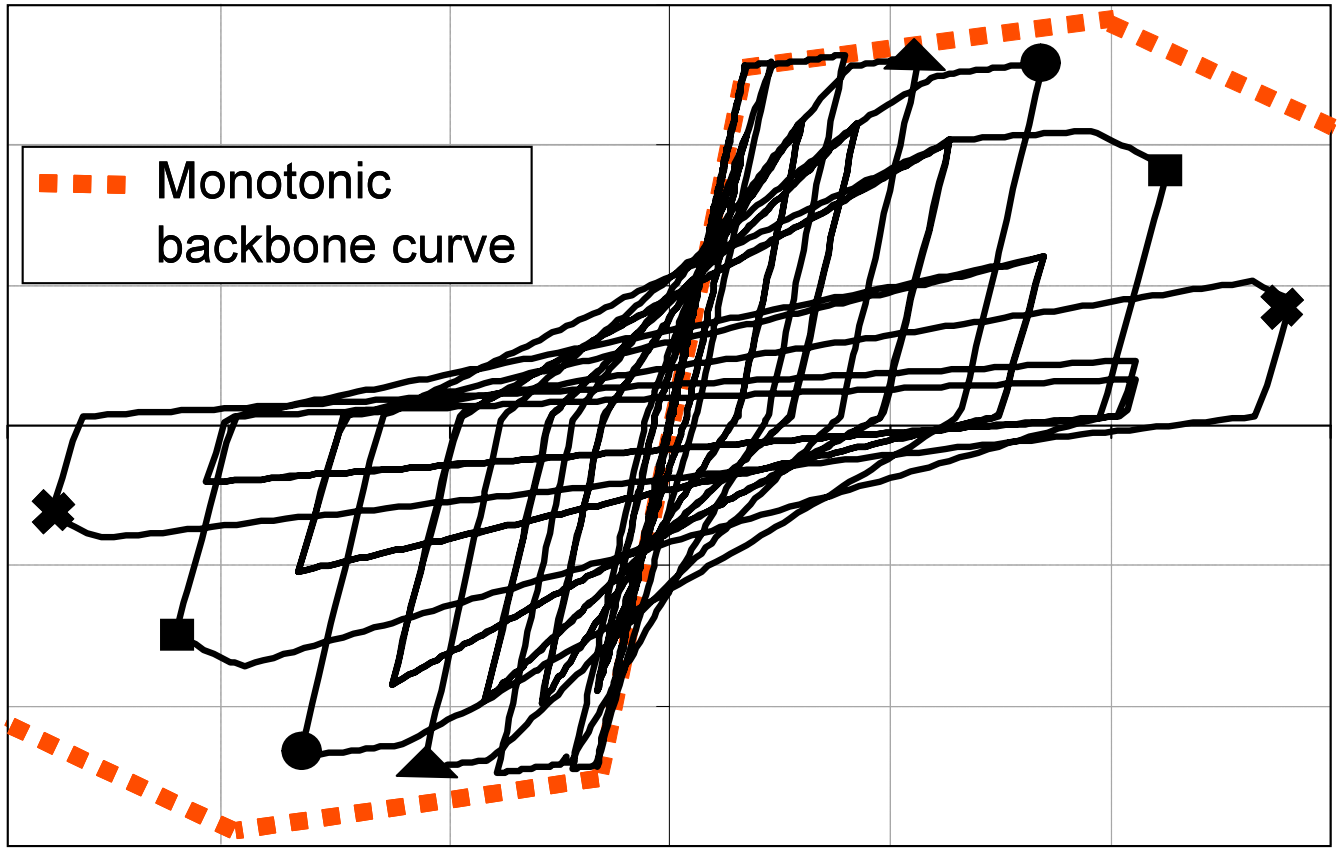
Explicit Modeling of Degradation



- No limitations on use

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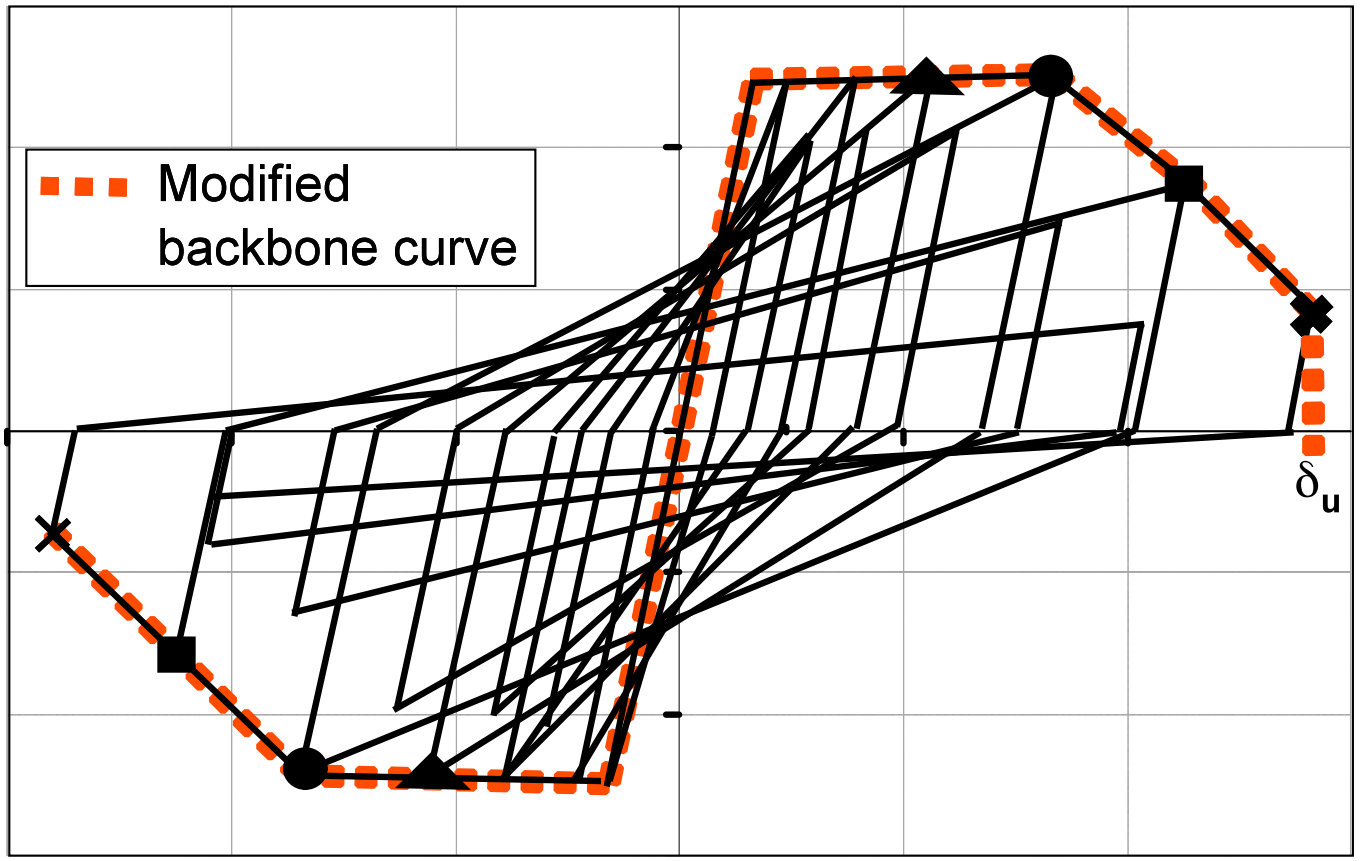
Cyclic Envelope



- Deformations cannot exceed the backbone envelope established by test

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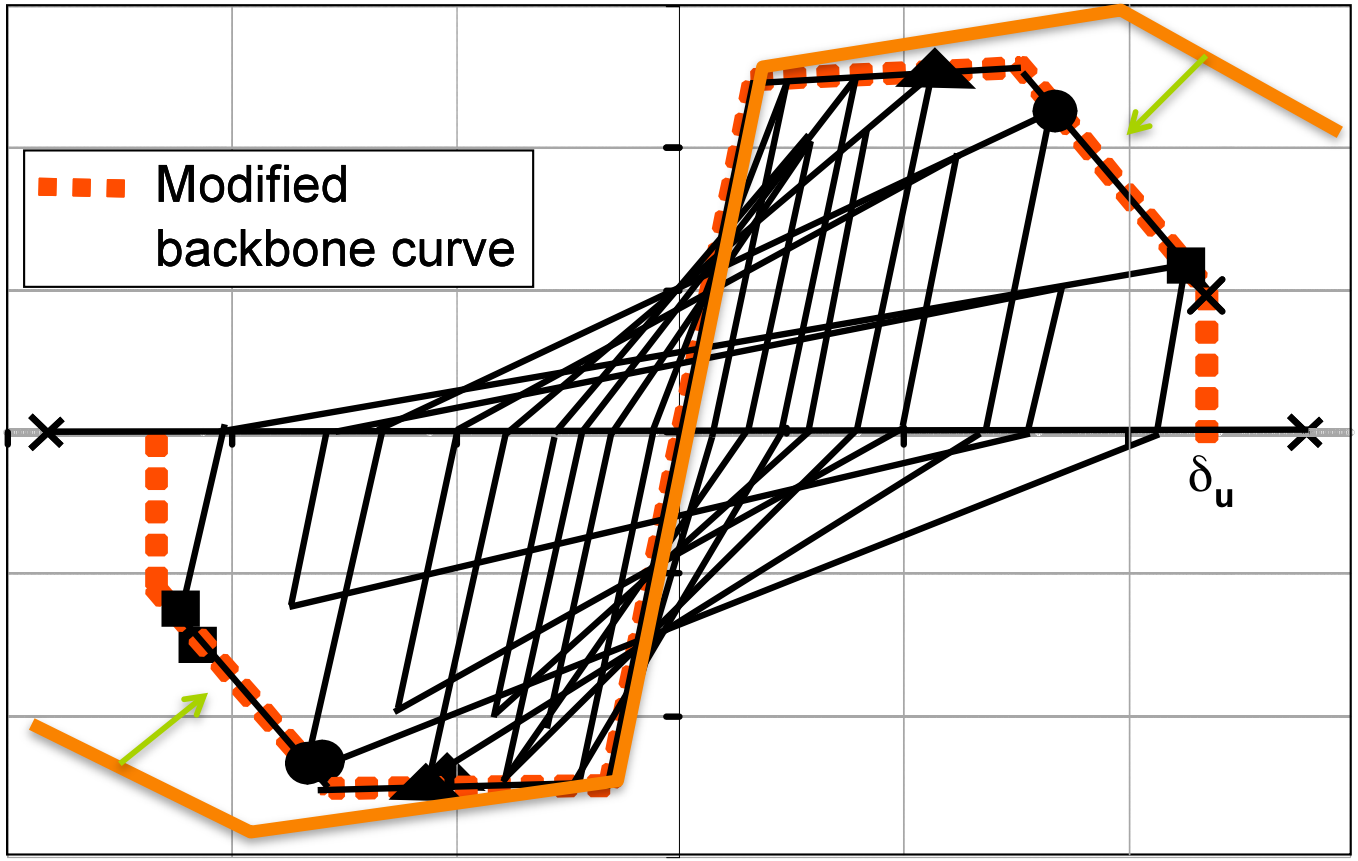
Modified Monotonic



$$F_p = .9F_{p-mono}$$

$$\delta_p = 0.7\delta_{p-mono}$$

$$\delta_u = 0.5\delta_{u-mono}$$

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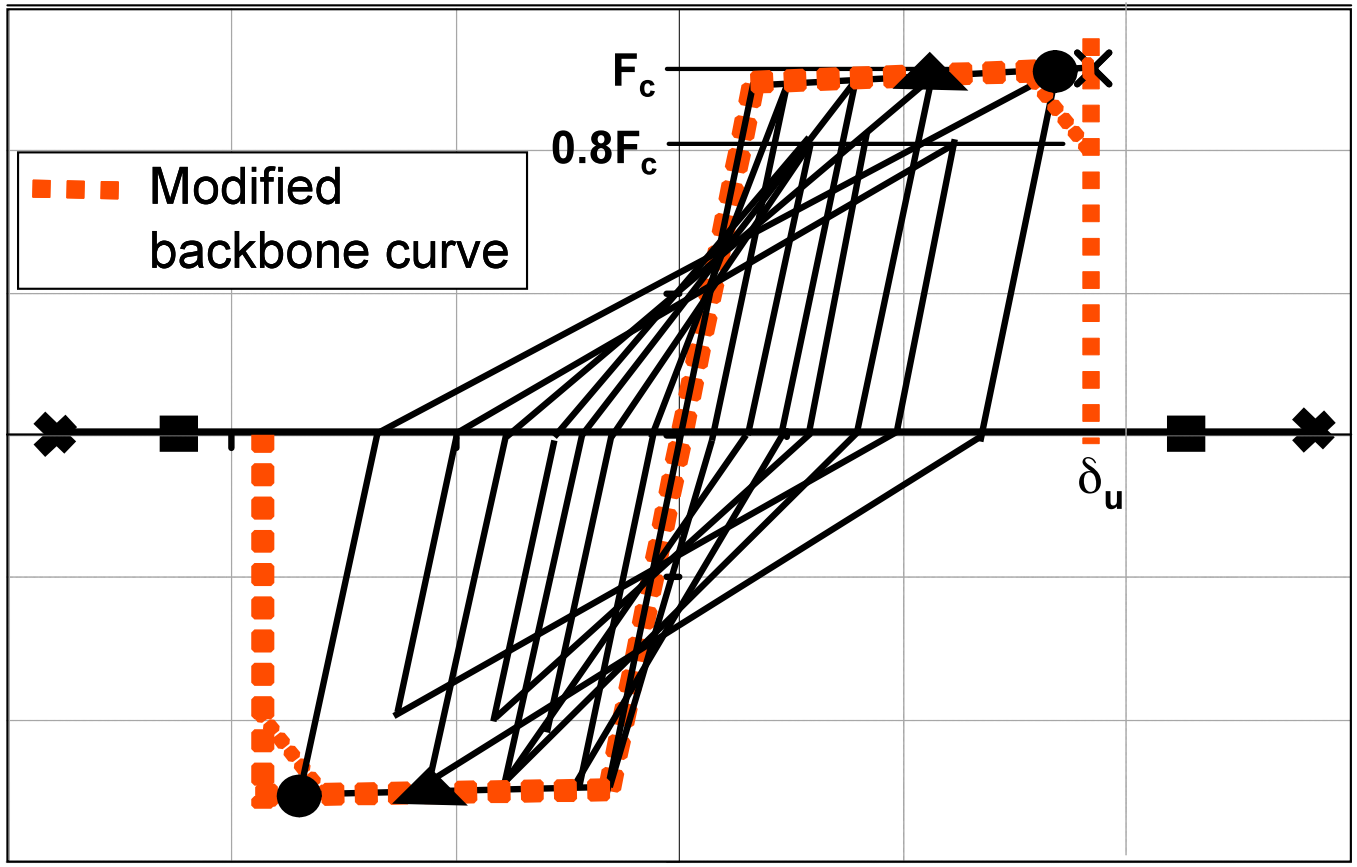
Monotonic



- Max deformation limited to deformation at $0.8F_{u\text{-mono}}$

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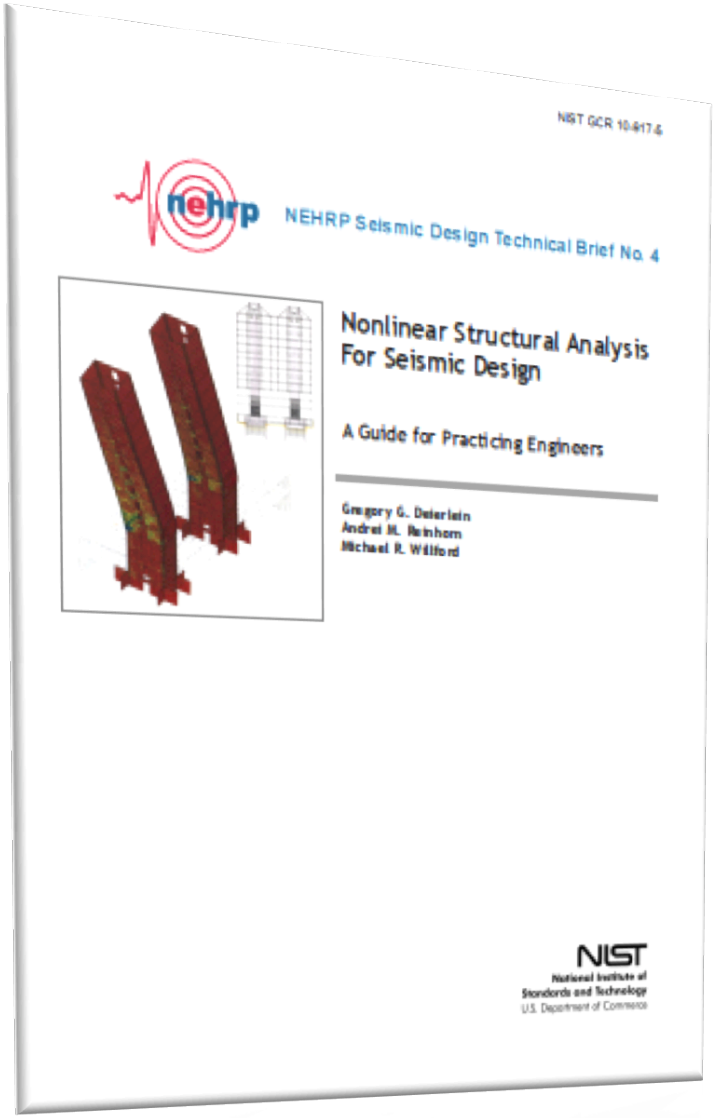
Analysis References



- ATC-72
- NIST Tech Brief

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Maximum Considered Level

- Acceptance Criteria
  - Deformation controlled – behavior modes associated with slow deterioration
  - Force controlled – rapid deterioration
    - Elements the failure of which could result in partial or total collapse
    - Elements the failure of which have minor consequences
  - Story strength loss
  - Peak transient drift
  - Residual drift

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Deformation Controlled Elements

- No criteria other than deformation demand in any analysis can not exceed valid range of modeling or δ_u.

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Force-controlled elements

$$F_u \leq \phi F_{n,e}$$

$$F_u = 1.5\bar{F}$$

$$F_u = \bar{F} + 1.3\sigma \geq 1.2\bar{F}$$

- ϕ = 1 for inconsequential failures
- ϕ = applicable resistance factor from material standards otherwise

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Story strength loss

- Deformation imposed on any story should not result in story shear strength loss of more than 20%

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Transient and residual drift

- Transient story drift
  - Mean of 7 runs $\leq$ 0.03
  - Maximum of any run $\leq$ 0.045
- Residual story drift
  - Mean of 7 runs $\leq$ 0.01
  - Maximum of any run $\leq$ 0.015

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Lets Try to Avoid This