Nonlinear Analyses Implementation

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Agenda

- Background
  - Displacement vs. Force based design
- Current Methodology in MOTEMS
  - Substitute Structure
  - Substitute Structure Grey areas
  - MOTEMS Improvements
  - Critical Items
- Future MOTEMS
  - Chopra-Goel method: Demand-Capacity Procedure
  - Sensitivity Study
- Recommendations

Background
Displacement vs. Force Based Design

Displacement Based	Force Based
Acceptable damage: ◆Strain ◆ductility ◆Displacement, rotation	Force limits: ◆Strength ◆stress
Directly capture “Seismic Performance”: OLE, CLE	Life Safety “No Structural Collapse”
Pushover or time history analysis	Simplified methods (ELF) or response spectrum analysis
Increase material strength to protect against brittle response (shear)	Overstrength (Ω) to protect against brittle response (shear)
Demand displacement < Displacement capacity	Demand Force < Factored strength

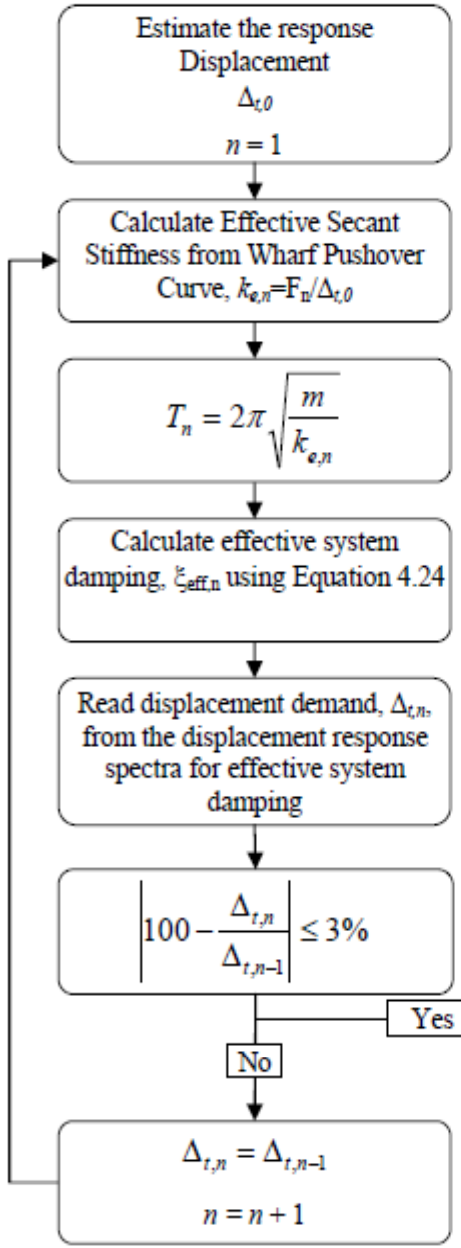
Background
Displacement vs. Force Based Design

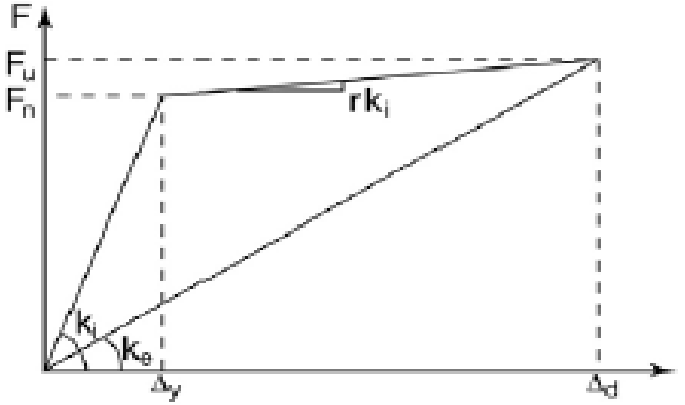
Displacement Based	Force Based
Analytically challenging, Highly variable for small parameter changes	Analytically simple, Prone to oversimplifying complex response
Good for existing	**Better for new**
Cost savings in retrofit costs	Cost savings in Engineering Effort
Supercool! **…(but finicky)** 	**Boring** **…(but reliable)** 

Current Methodology in MOTEMS Substitute Structure Analysis

- Pushover Curve
  - Soil springs, nonlinear materials, etc.
  - Simplify to Bilinear
- Substitute Structure
  - Iterate displacement to determine ductility
  - Alter damping & acceleration based on ductility
- Used for almost all Audits

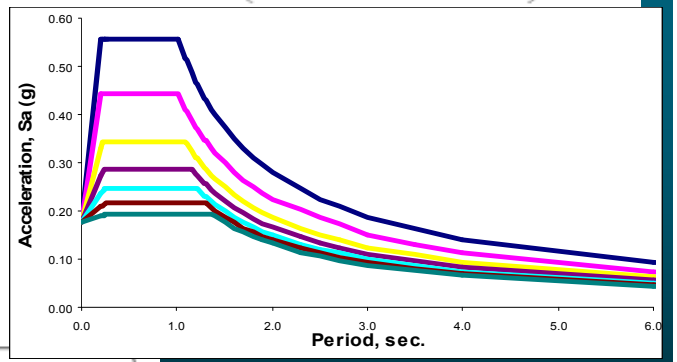
Substitute Structure – Demand Displacement





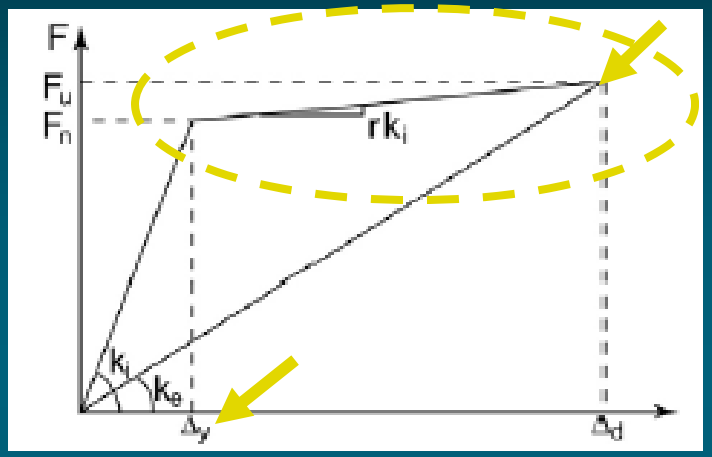
$\mu_\Delta = \Delta d / \Delta y \quad r = k_f / k_i$

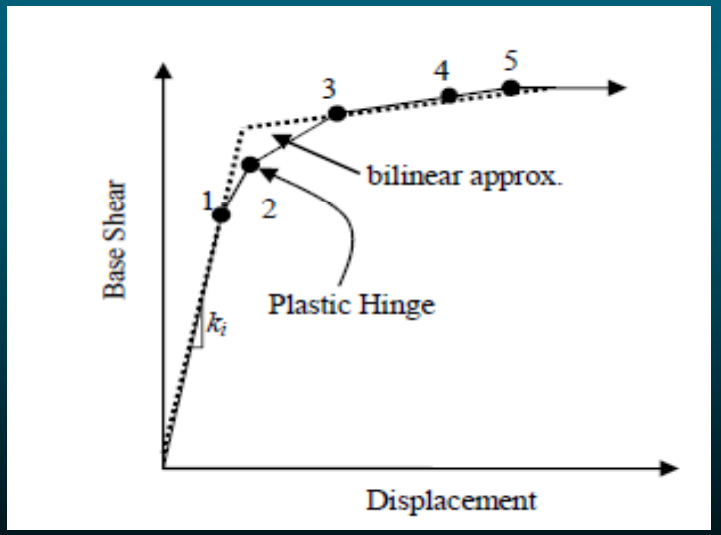
$$\xi_{eff} = 0.05 + \frac{1}{\pi}\left(1 - \frac{1-r}{\sqrt{\mu_\Delta}} - r\sqrt{\mu_\Delta}\right) \quad (4\text{-}3)$$



Substitute Structure Analysis Grey Areas

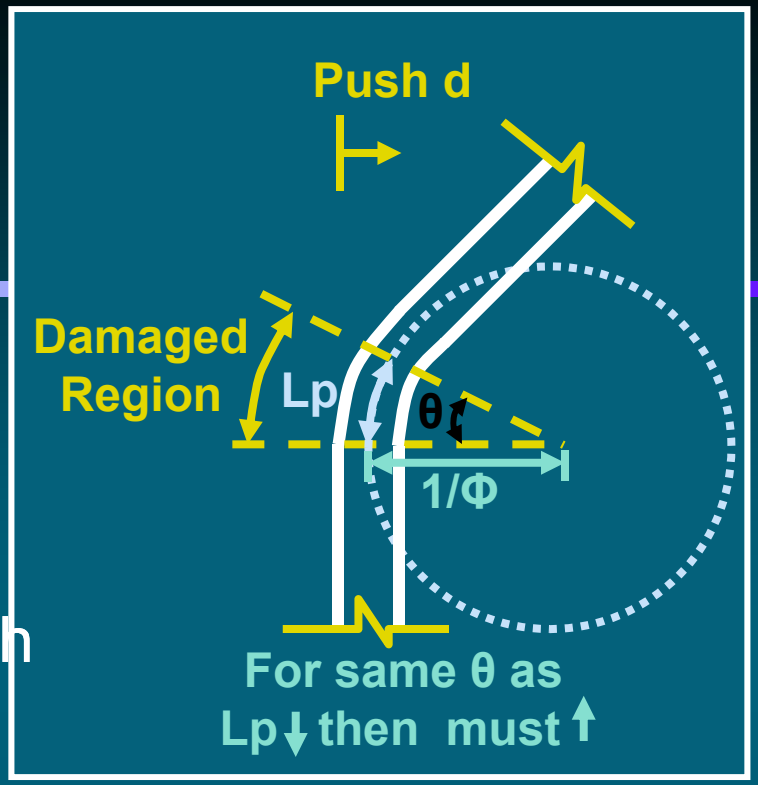
- Bilinear Yield Point
- Secondary Stiffness
  - Where from, to
  - Practical method
- Damping Equations
  - ATC 40 has different equations
- Orthogonal Effects

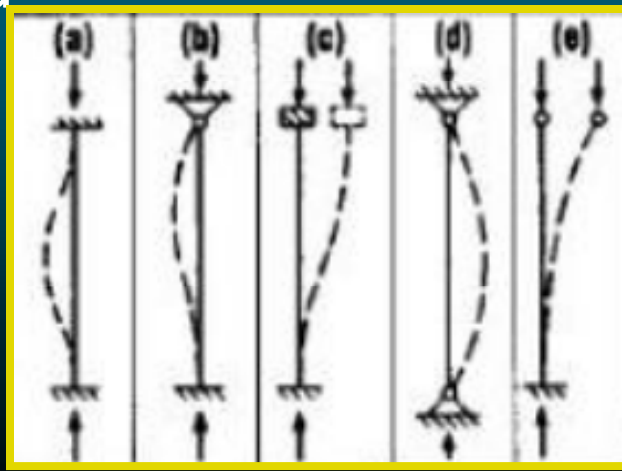




MOTEMS Future Improvements

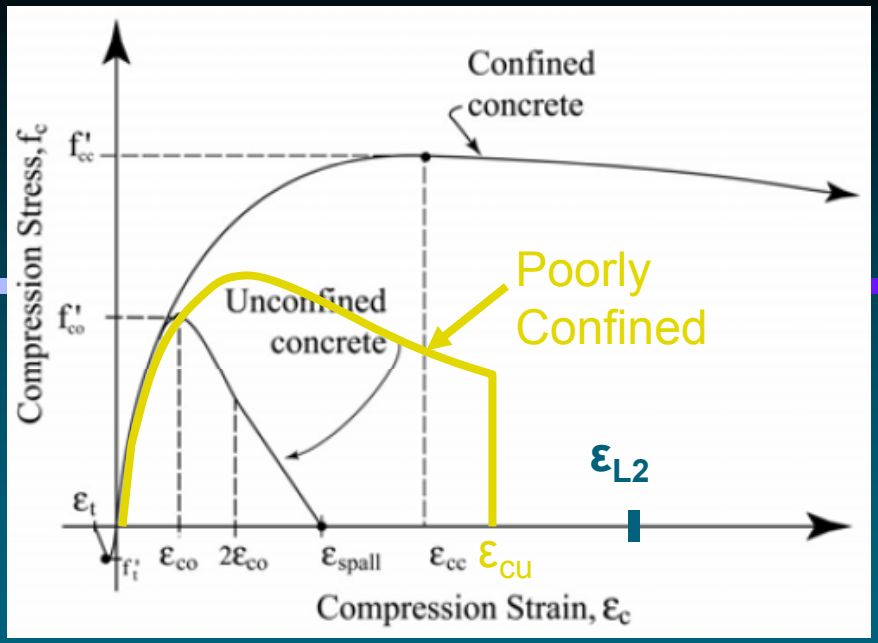
- Plastic Hinge Length
  - Steel piles
  - Prestressed piles
- Effective buckling length "k" factors
- Knowledge factor
- Soil Kinematic & Inertial Load
  - Combine? How?
- Simplified Structural Analysis



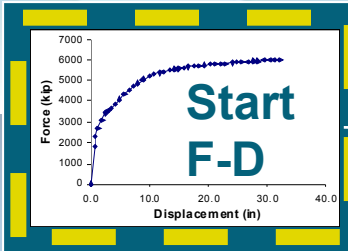


Critical Items

- Existing Poorly Confined Concrete
  - ε_{cu} < L2 strain
- Balance Stiffness and Ductility
- Pipe Stress for Seismic displacement



Chopra-Goel PEER 1999 Method (spectra iteration equivalent linearization)

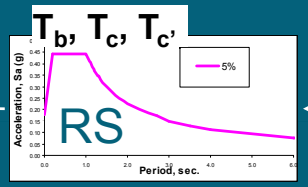


Find Yield Δ_y, V_y

System Mass (m)

$K_0 = V_y / \Delta_y$

$$T_0 = 2\pi\sqrt{\frac{m}{k_0}}$$



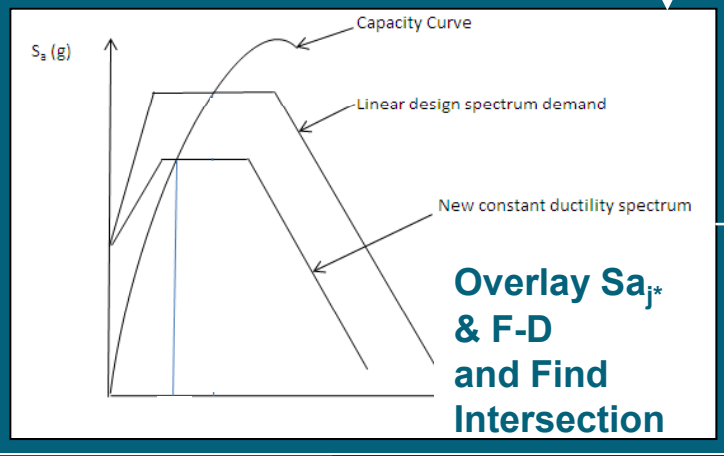
Assume Ductility (μ^*)

Find R_y (from μ, T_b, T_c, $T_{c'}$)

Acceleration $Sa_{j^*} = Sa_j / R_y$

Displacement $Sd_{j^*} = \mu * Sa_{j^*} * (T_j / 2\pi)^2$

For all Periods (T_i)



Ductility $\mu^* = \Delta_1 / \Delta_y$

If $\mu^* - \mu^*_{-1}$ < Tolerance

no

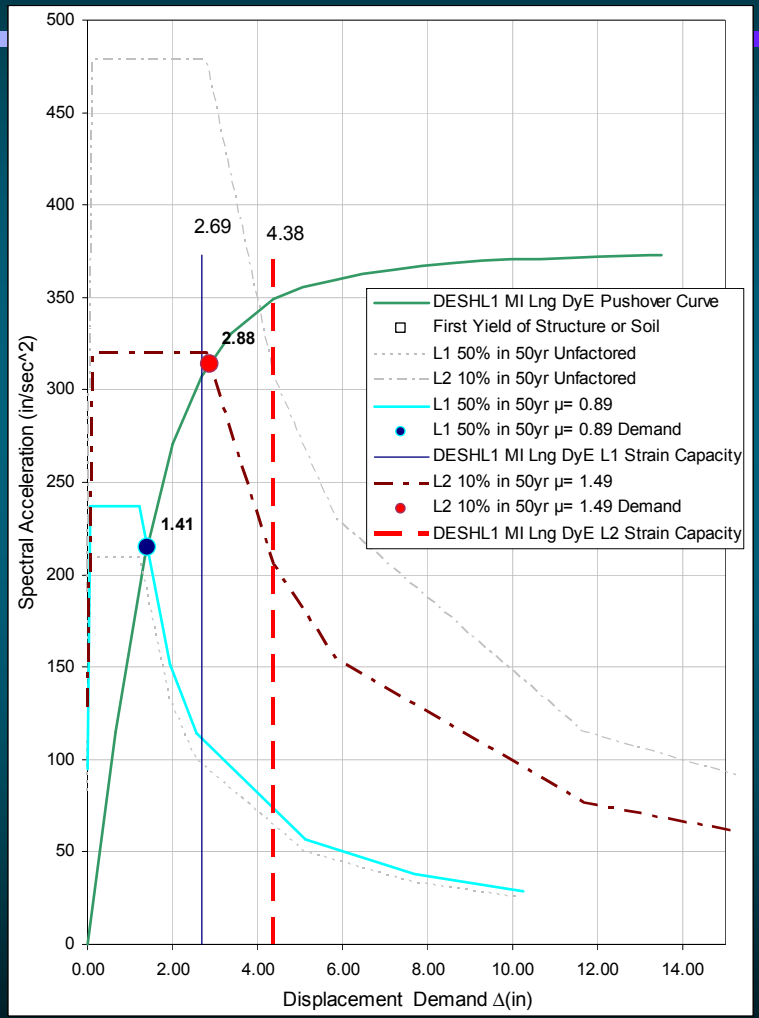
yes

Finished $\Delta_d = \Delta_1$

Note: Similar to ATC 40

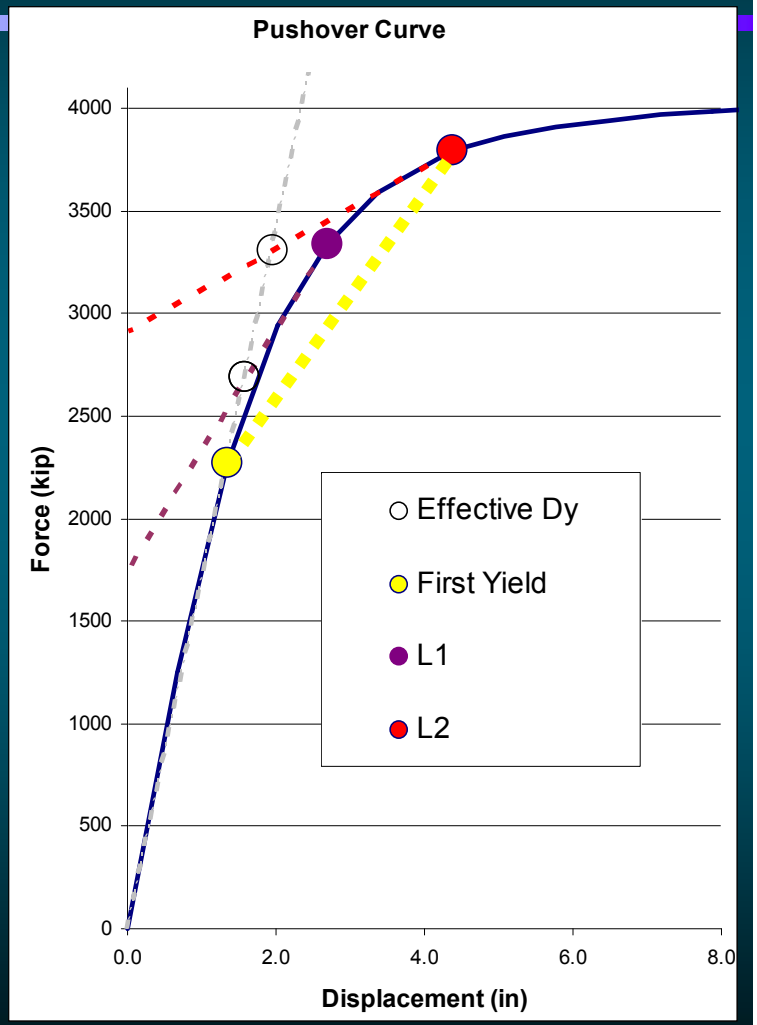
Chopra-Goel Methodology Grey Areas

- Bilinear Yield Point
- Hinge Length
- "R" Equations
- Orthogonal Effects
- Iteration Sensitivity



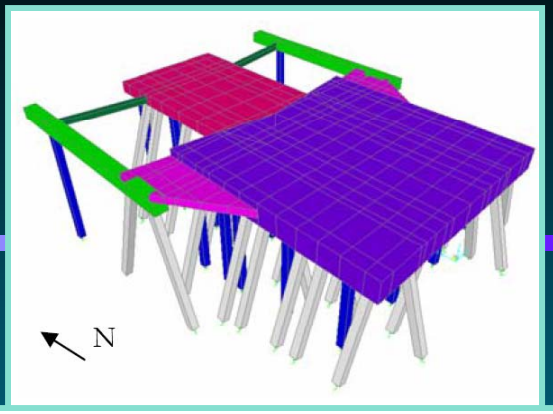
Sensitivity Study

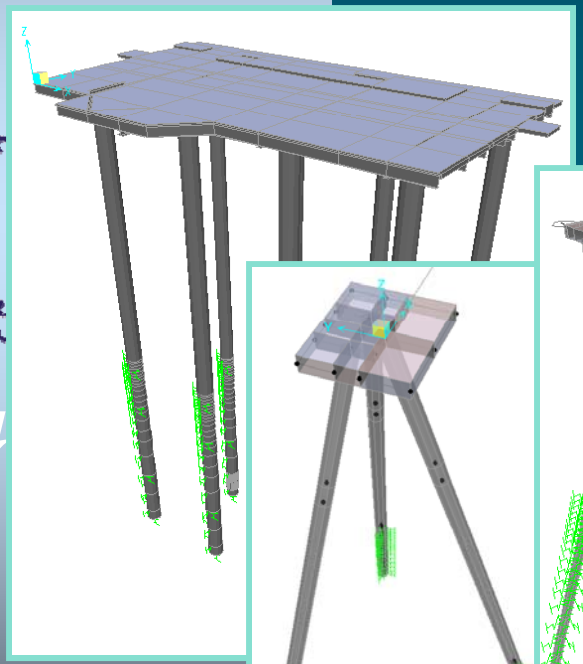
- Effective Bilinear Curve
  - First Yield or Effective
  - Locate Du at L2 strain for practicality
- Damping Equations
  - MOTEMS
  - FEMA 440 (eq. only)
- Method Comparison
  - Spectra iteration vs displacement iteration

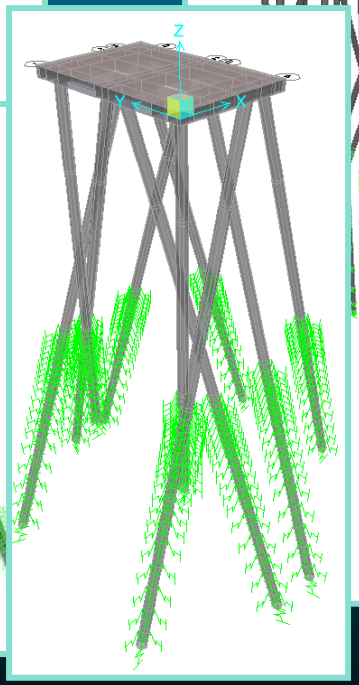


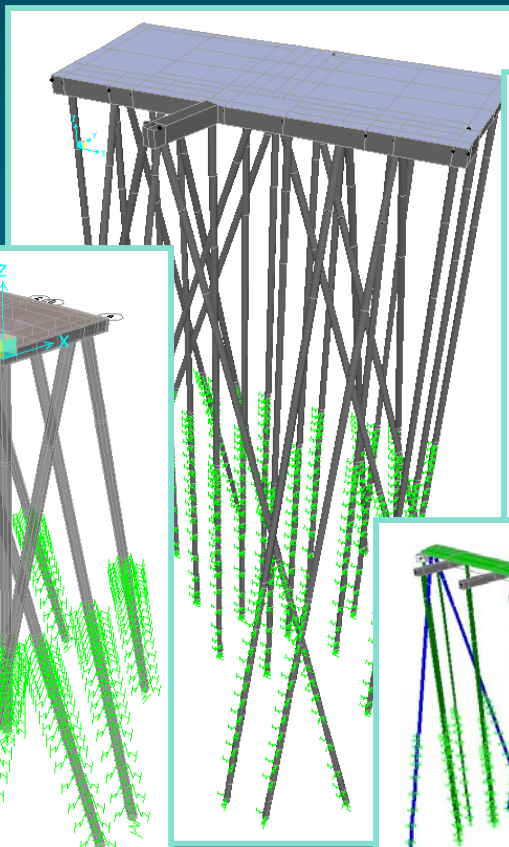
Sensitivity Study

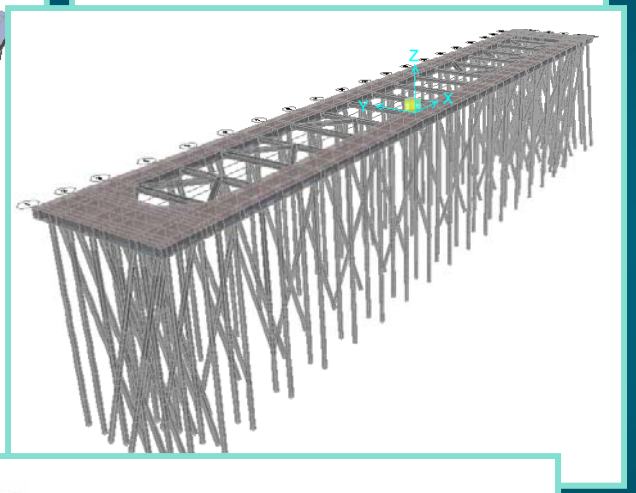
- Examined 12 REAL structures

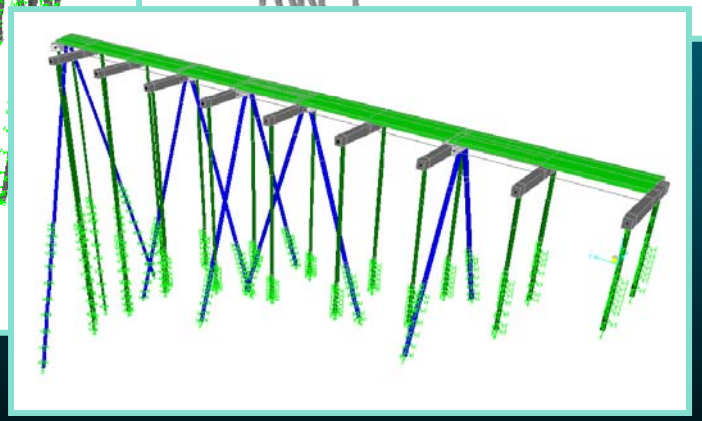




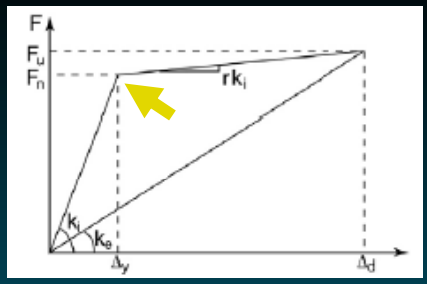




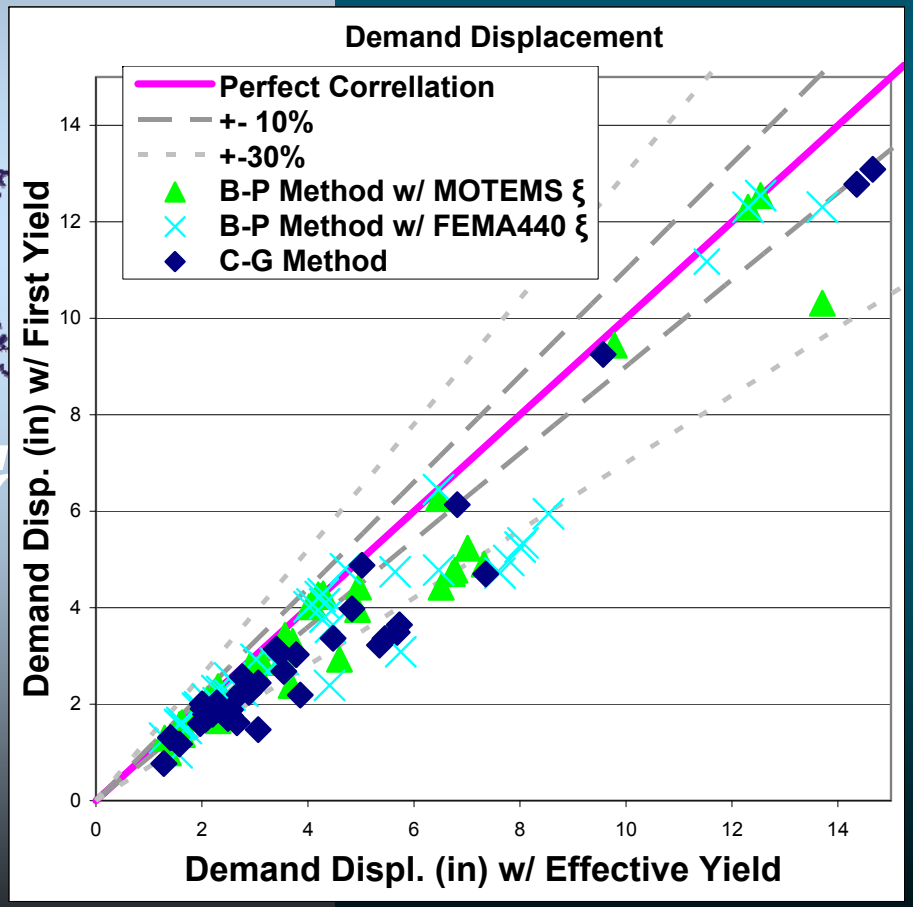


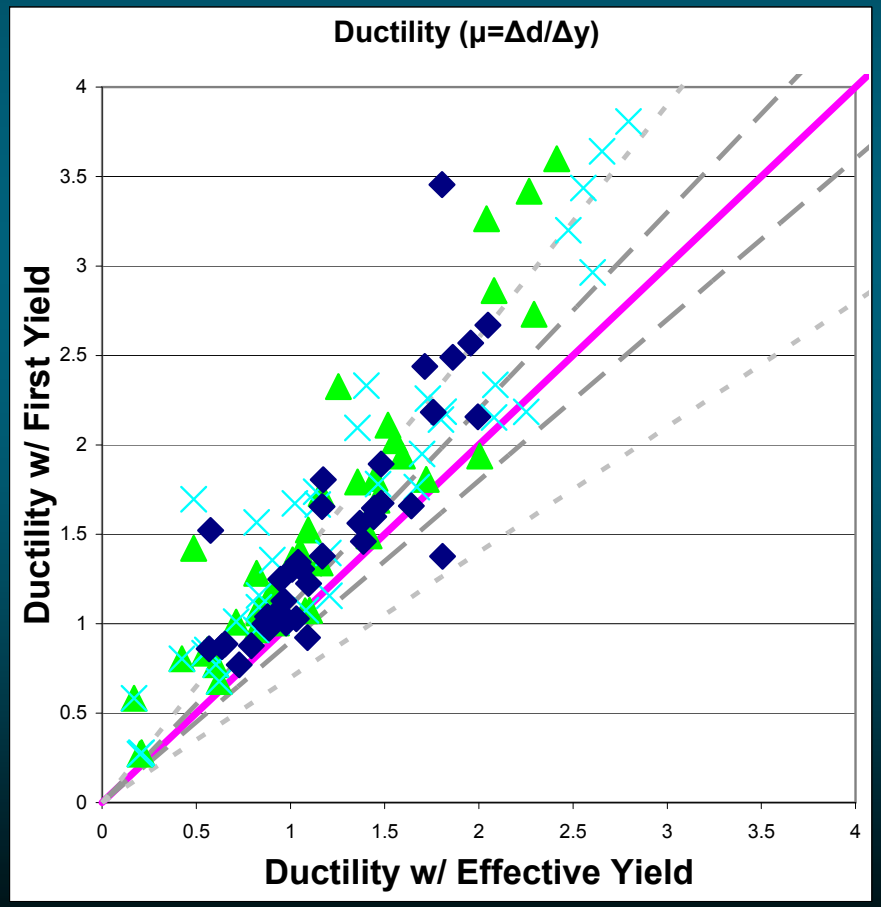


Yield Point



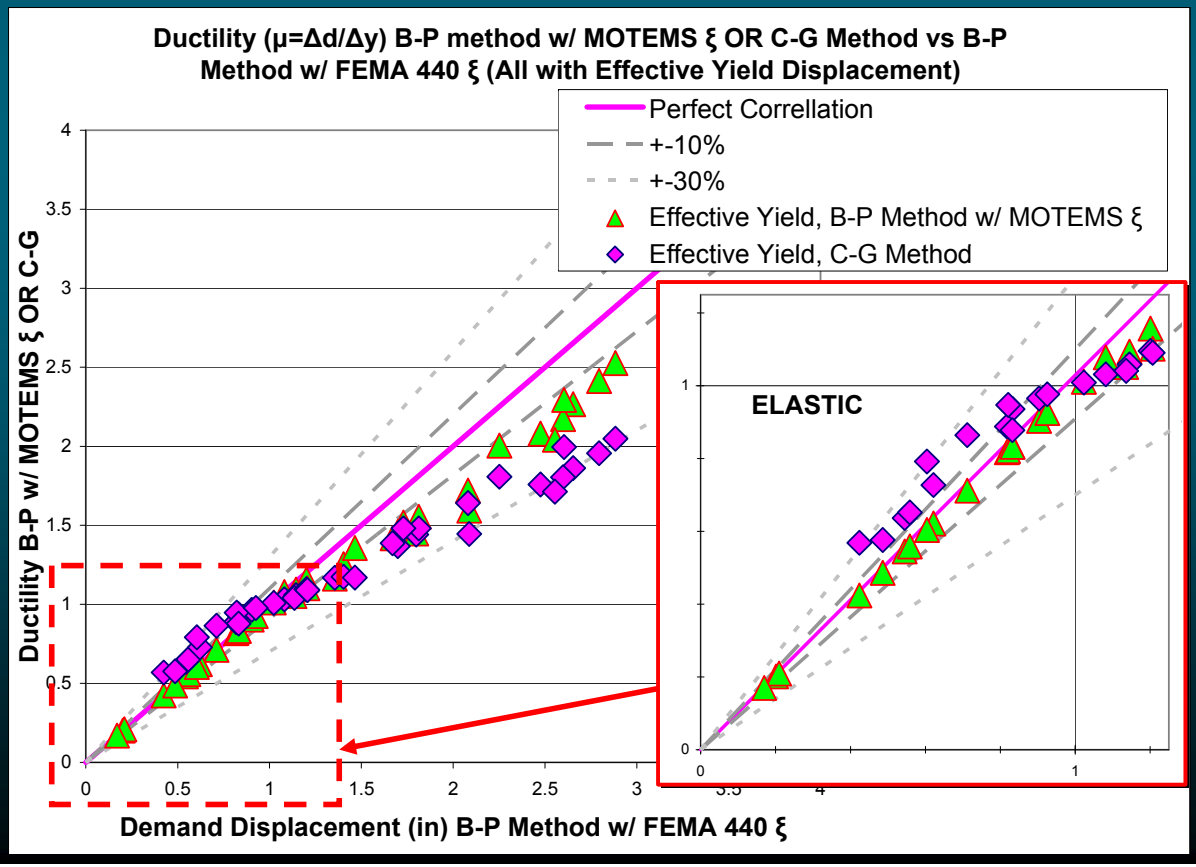
- Effective Yield → Larger Demand Displacement → Smaller Ductility





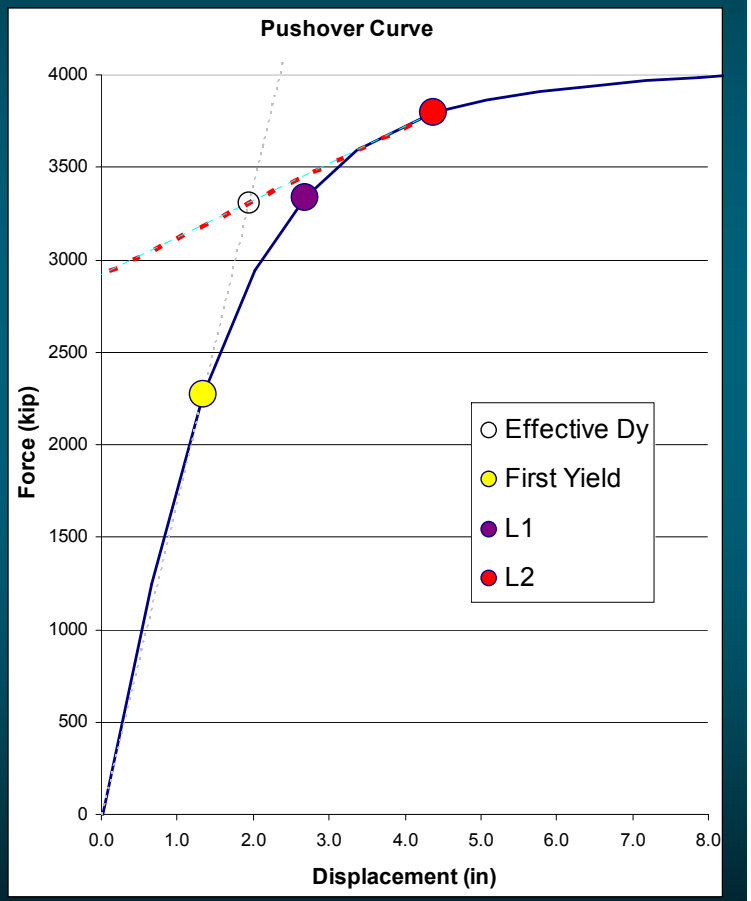
Methodology

- Damping vary ±10%, Methods vary ±30%
- All converge at ductility = 1.0
- More ductility more variation



Recommendations Significant Parameters

- Effective Yield at secondary stiffness to L2 capacity
  - FEMA 440 method OK
- Hinge Lengths Steel
  - 1 diameter in ground
  - ½ diameter at deck
  - NEEDS more research
- Keep “r” in MOTEMS damping reasonable (< 0.3)



Lessons Learned

- Methods vary significantly
  - Consider answer **PASS/FAIL**
  - **Brittle will NOT pass**
- NEED additional research, comparison with real world
  - Orthogonal loading
  - Kinematic loading
  - **Instrumented structures**
- Ramps / piping / other must satisfy displacements
- Some Existing structures **CAN** satisfy MOTEMS

Questions?