PEER

Open System for Earthquake Engineering Simulation
Pacific Earthquake Engineering Research Center

OpenSees Framework for Seismic Simulation

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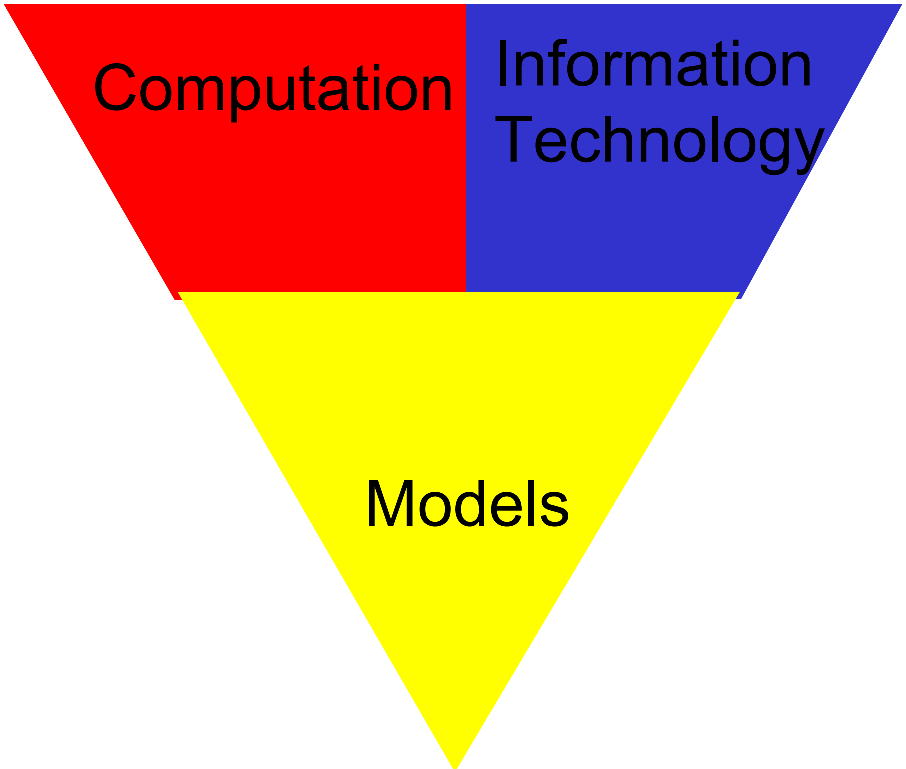
and a community of contributors in the PEER research program

2001 PEER Annual Meeting

Simulation in PBEE

- Assumption:
  - rational, validated models of behavior of complex materials and systems can be be developed.
- Need for simulation:
  - Evaluation
  - PEER Framing Equation
  - Design using parameterized models

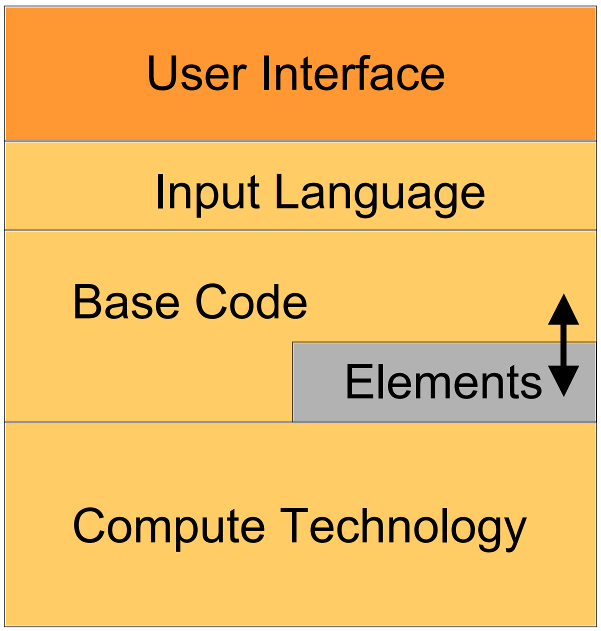
Conceptual Approach



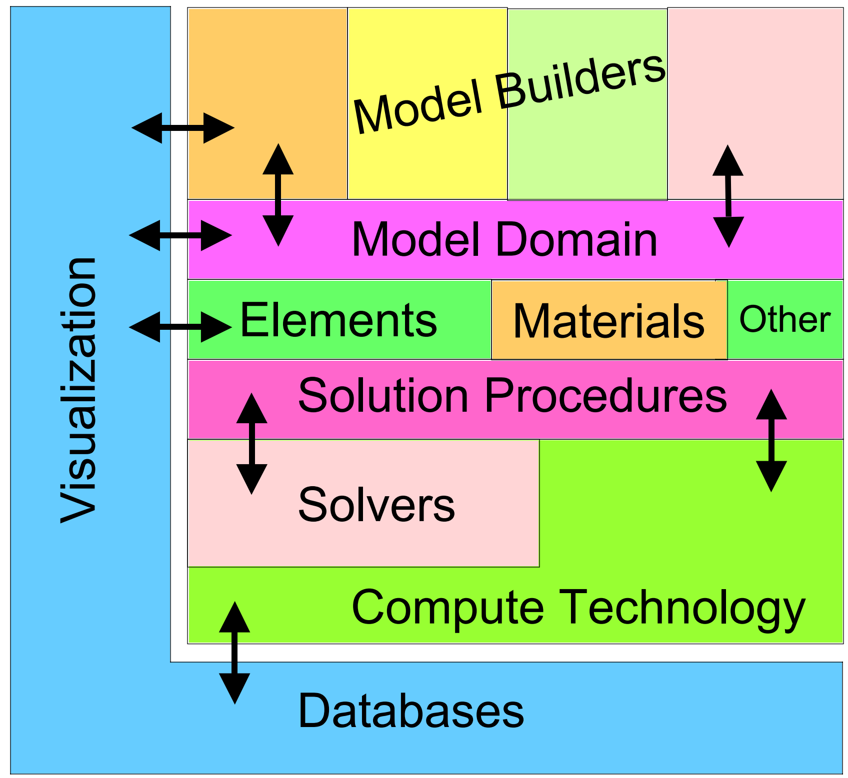
Address User Needs in PBEE

Software Design Approach

Traditional Code

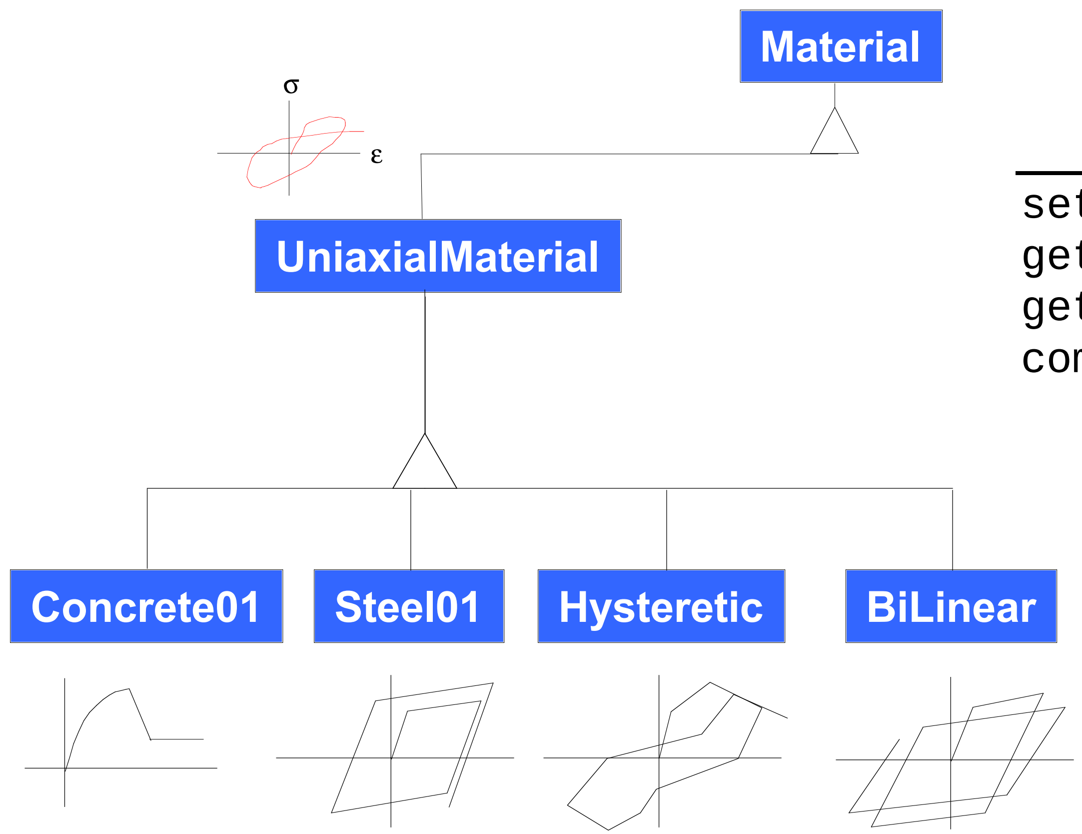


Framework of Components



↔ Application Program Interface (API)

UniaxialMaterial Behavior

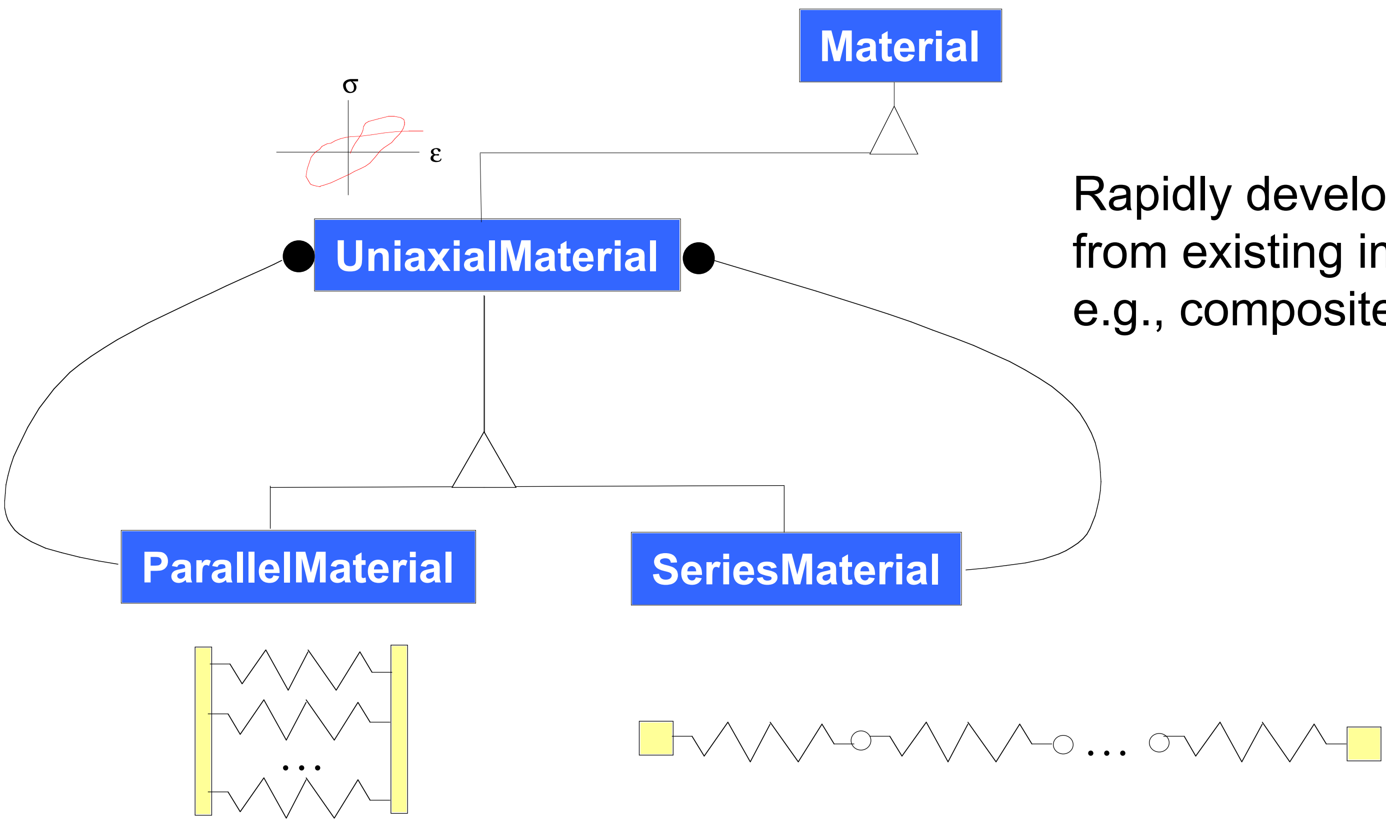


API

```
setTrialStrain()
getStress()
getTangent()
commitState()
```

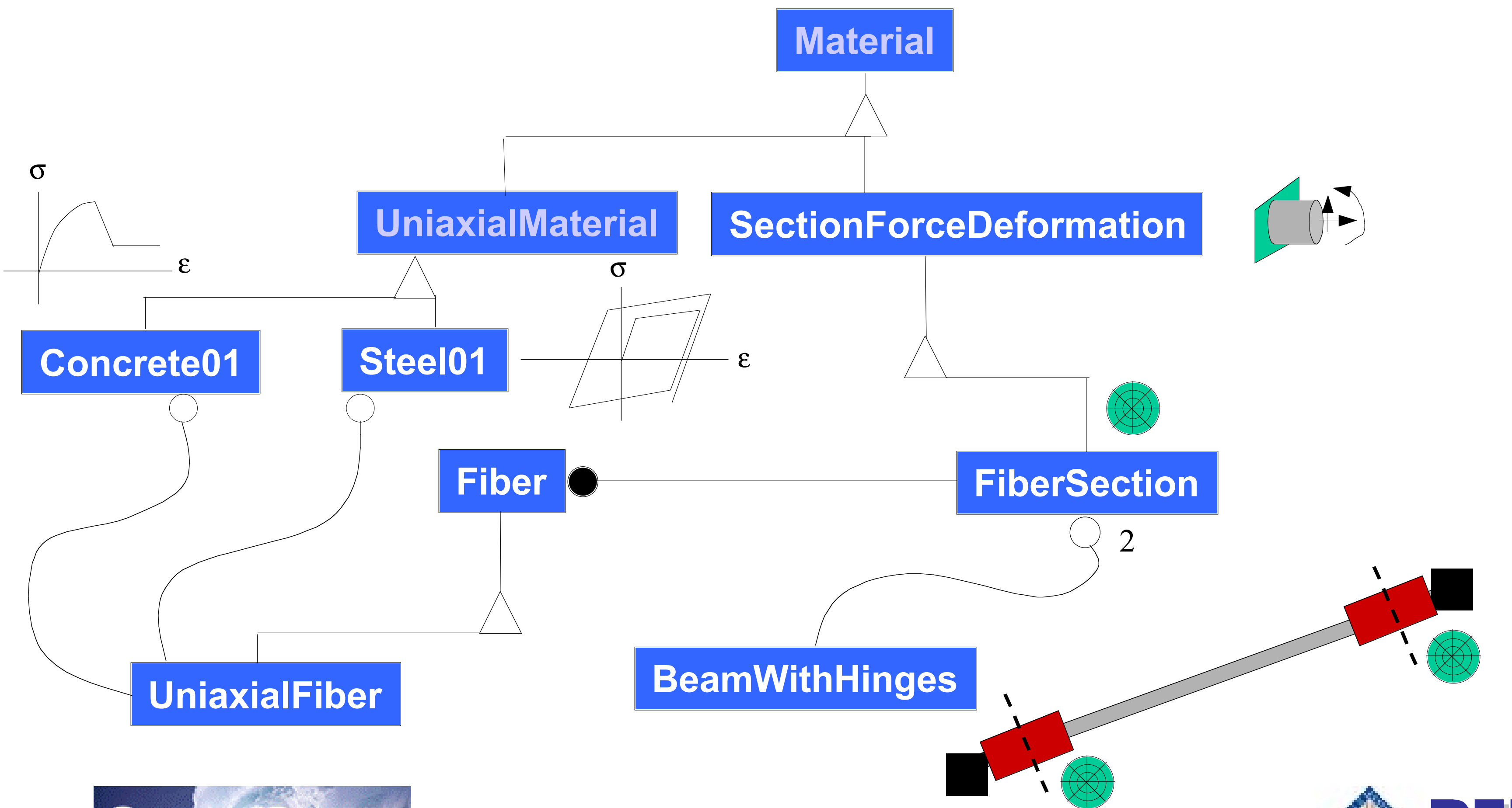
Also:
Viscoelastic
EPP
EPP-Gap
Clough
Pinch
Hardening

Aggregate UniaxialMaterials

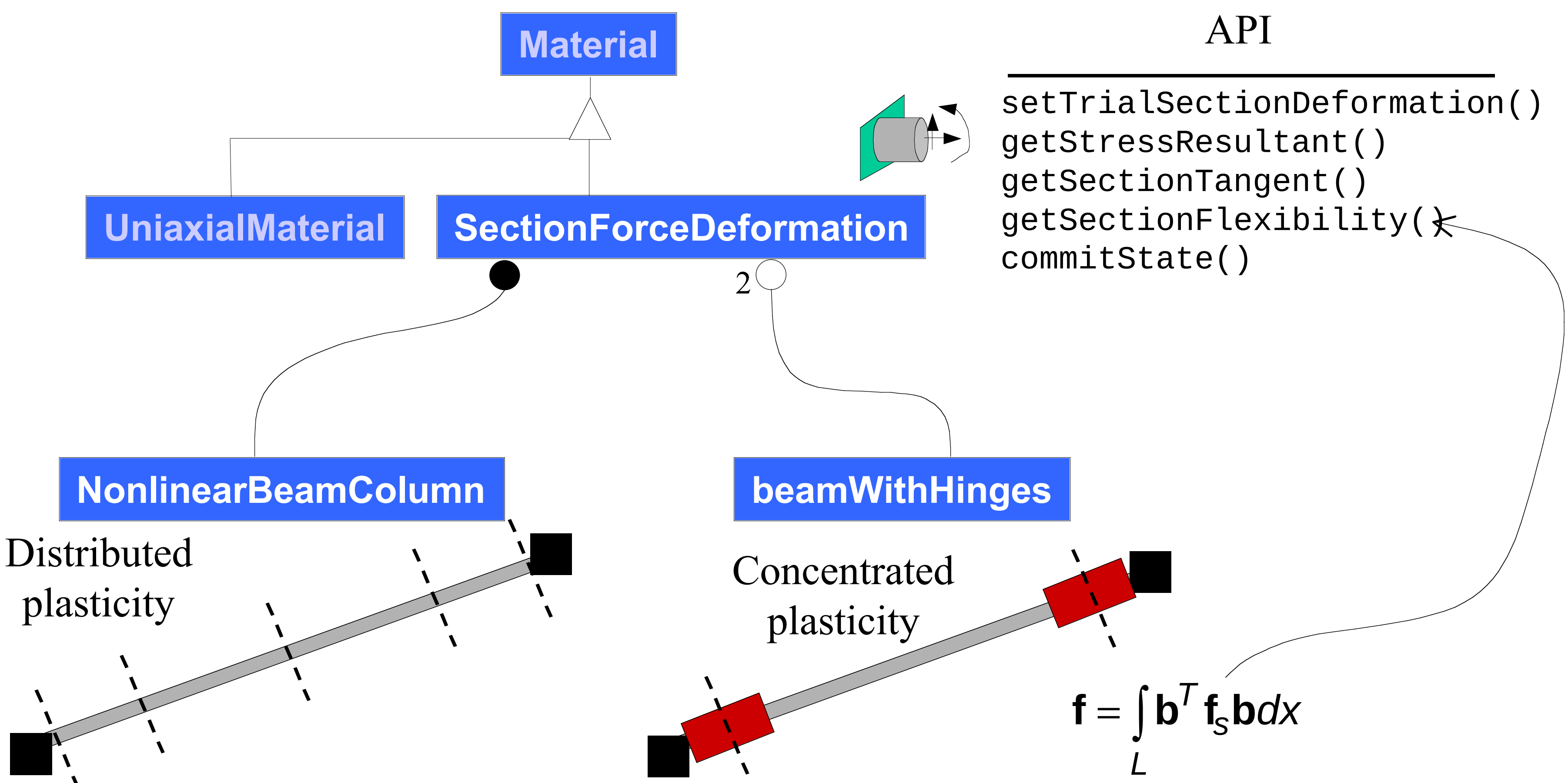


Rapidly develop models from existing implementations, e.g., composite gapping material

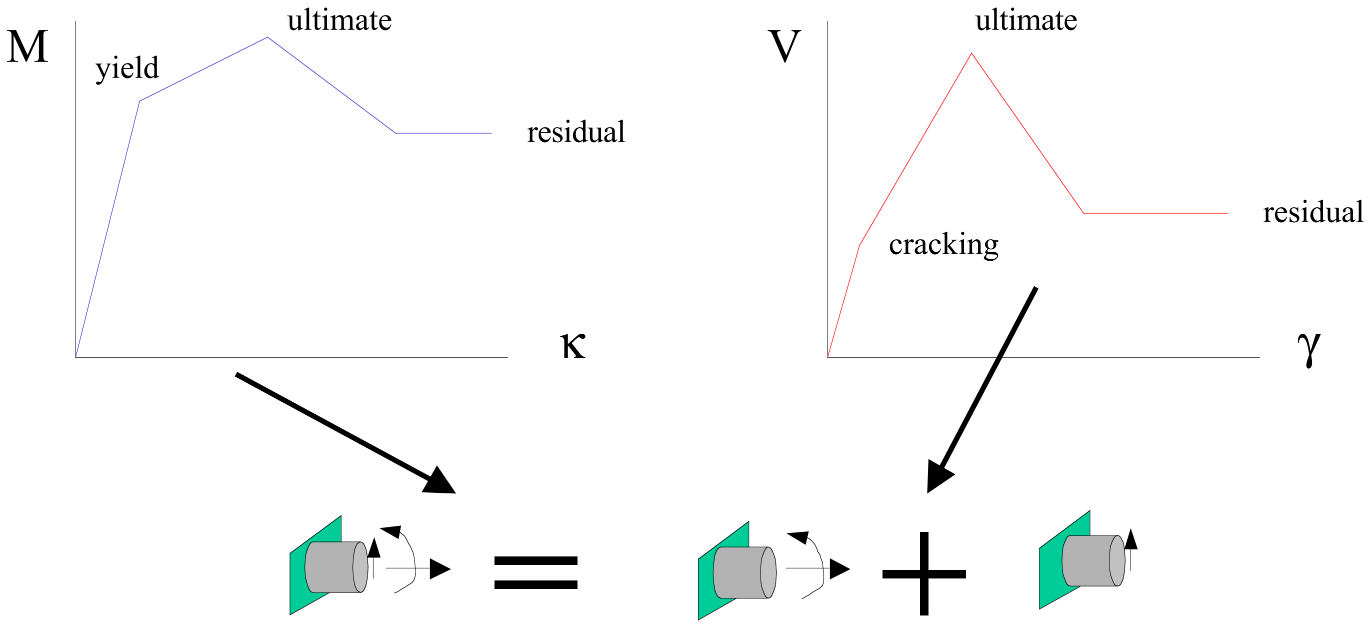
Form Follow Function: Architecture Follows Mechanics



Beam-Column Modeling



Aggregation of Section Model

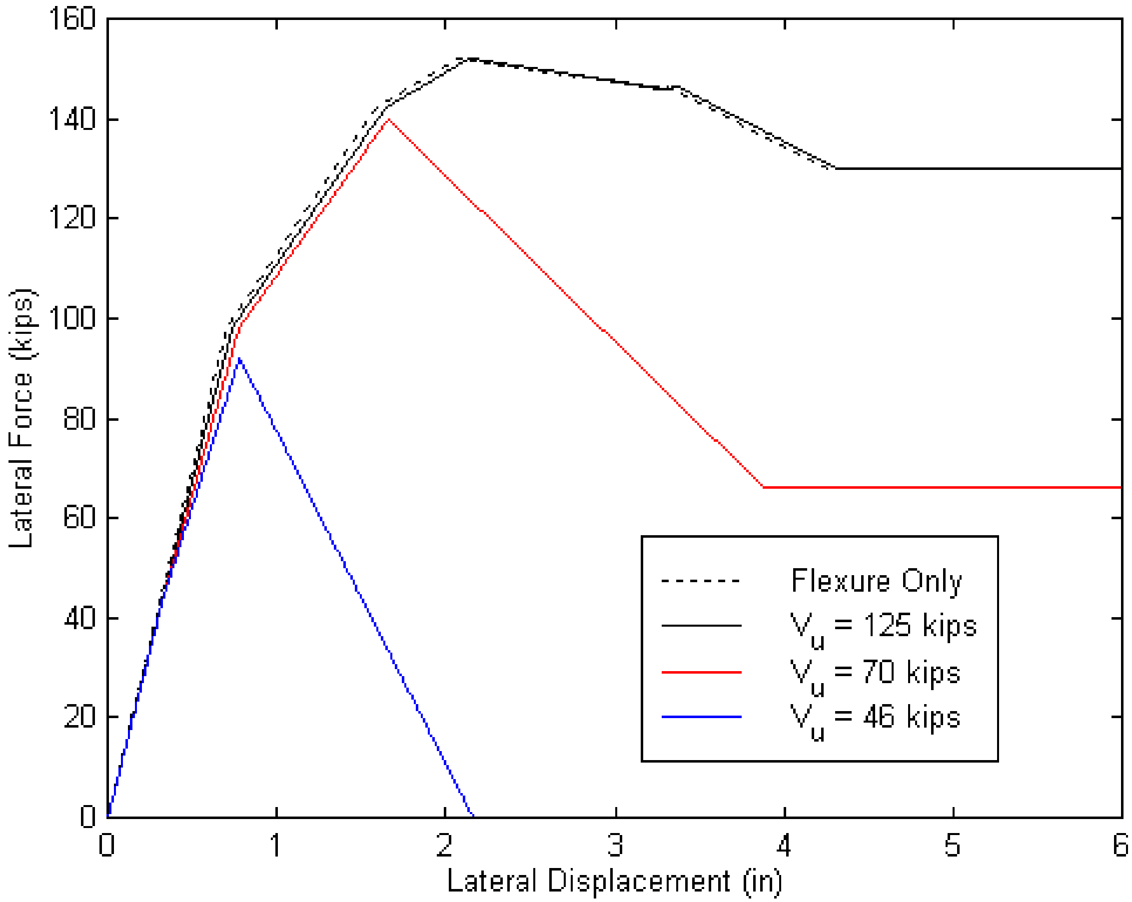


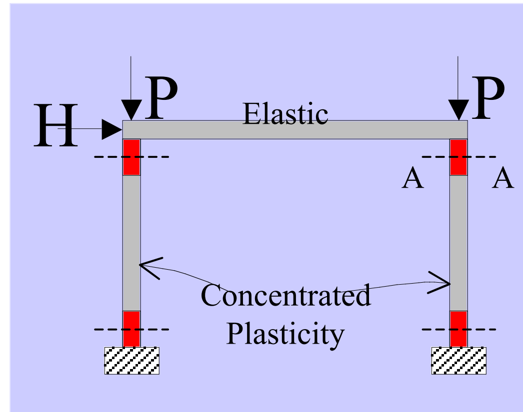
$$\mathbf{e} = \begin{bmatrix} \varepsilon_0 \\ \kappa \\ \gamma \end{bmatrix} \quad \mathbf{s} = \begin{bmatrix} P \\ M \\ V \end{bmatrix} \quad \mathbf{k_s} = \begin{bmatrix} \mathbf{k}_{s-\mathrm{sec}} & \mathbf{0} \\ \mathbf{0} & \dfrac{\partial V}{\partial \gamma} \end{bmatrix}$$

Uncoupled section stiffness matrix

M. Scott

Frame Load-Displacement



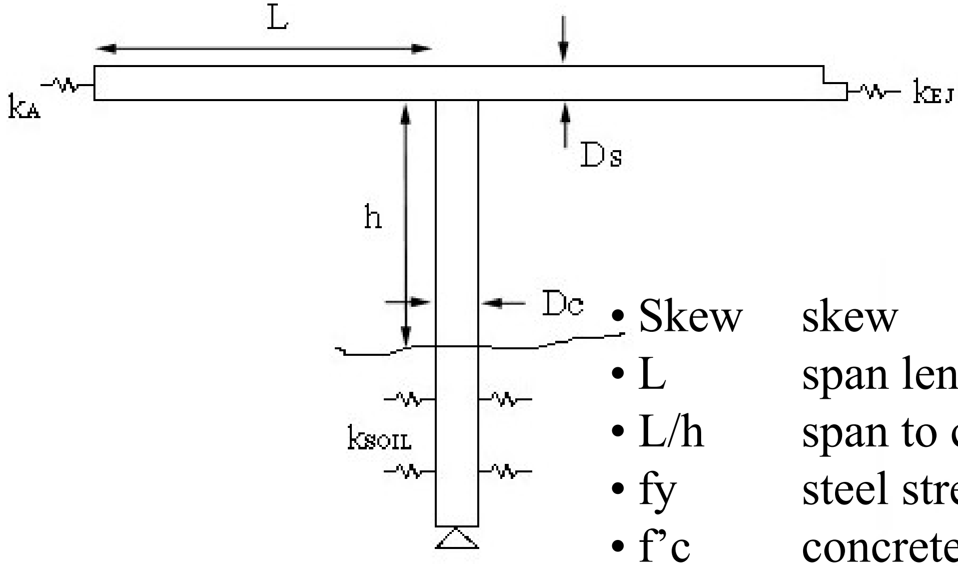


- Ductile and brittle modes represented
- Solution method converges rapidly even with strong softening

Simulation Applications

- Parametric studies to examine DM and IM and design procedures
- Soil-structure-foundation interaction
- Computational reliability for PBEE

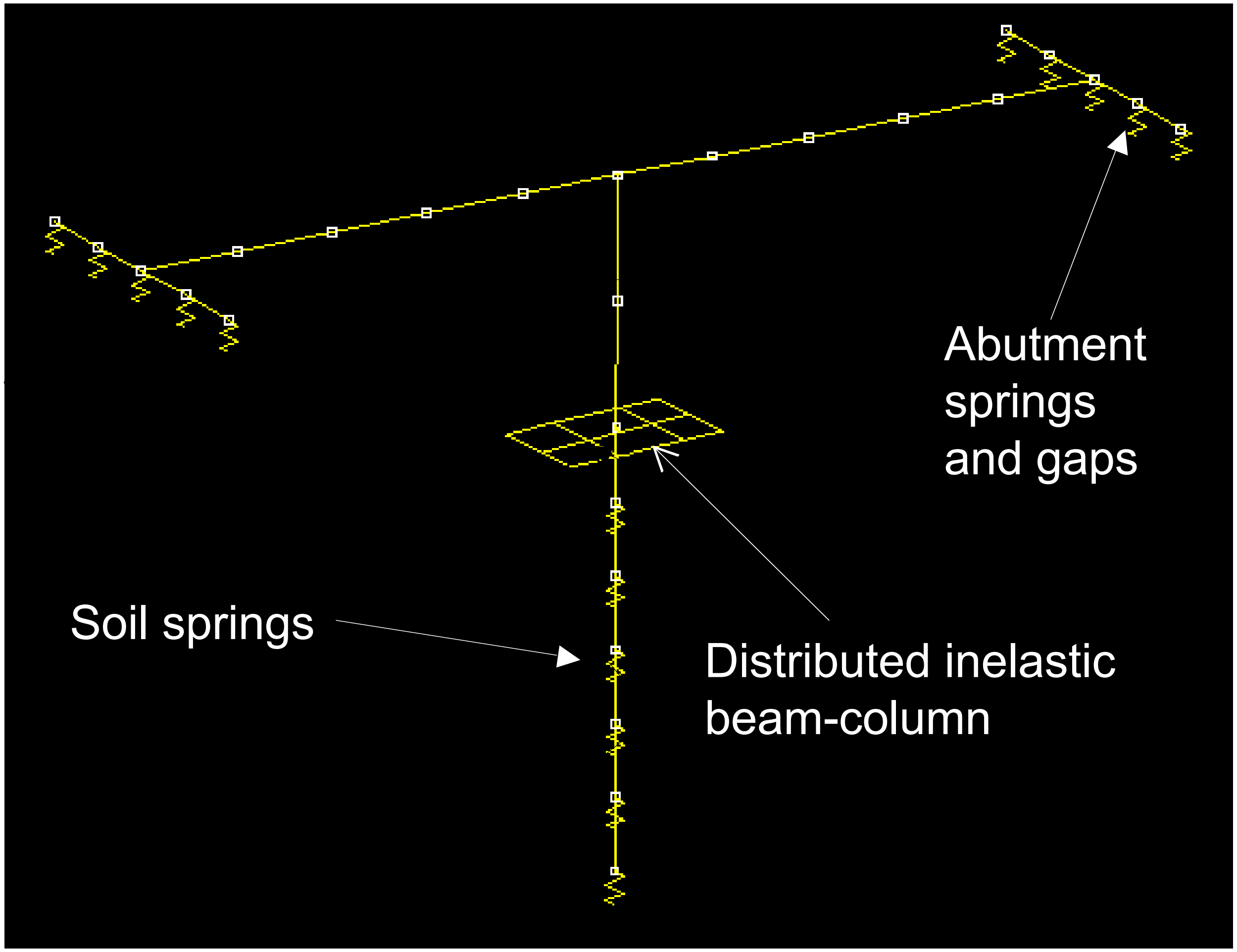
Damage Measures for Bridges



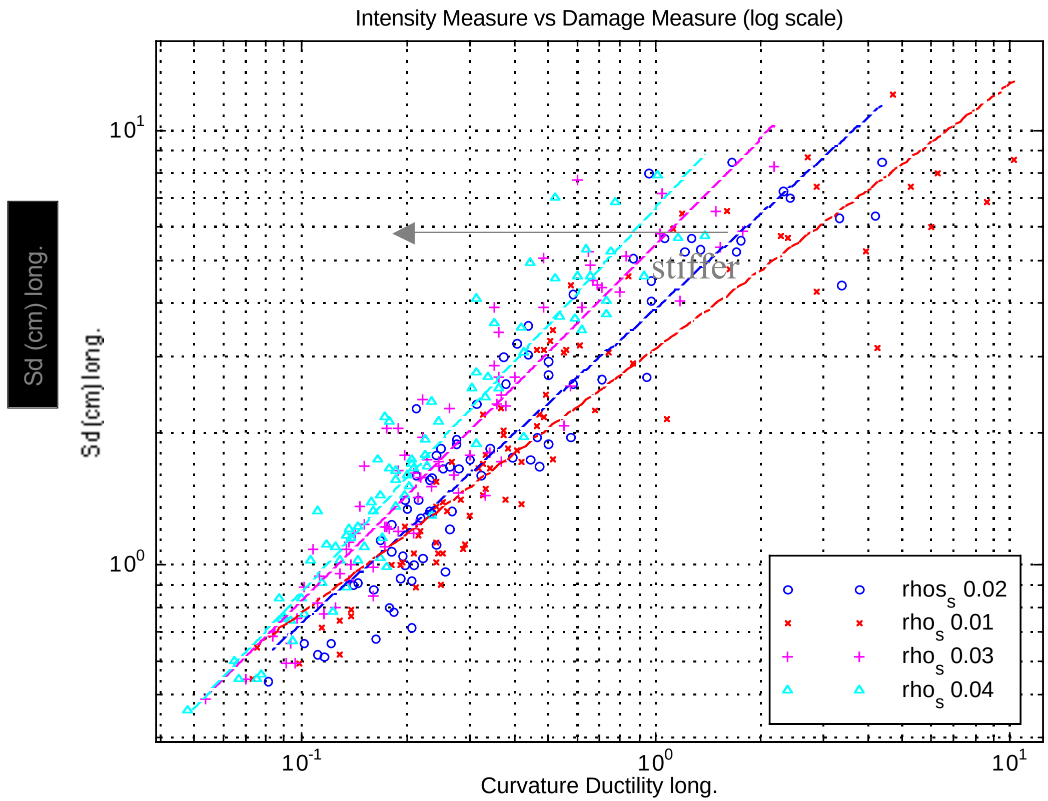
• Skew	skew	0-50º
• L	span length	60-180 ft
• L/h	span to column height ratio	1.2-2.0
• fy	steel strength	68-95 ksi
• f'c	concrete strength	3-8 ksi
• $\rho_{s,long}$	column longitudinal reinforcement	1-4%
• Dc/Ds	column to superstructure dimensions	0.67-1.33
• Ksoil	NEHRP soil group	B,C,D
• Wt	additional superstructure weight	0.1-50%
• $\rho_{s,trans}$	column transverse reinforcement	0.4-1.0%

B. Stojandinovic

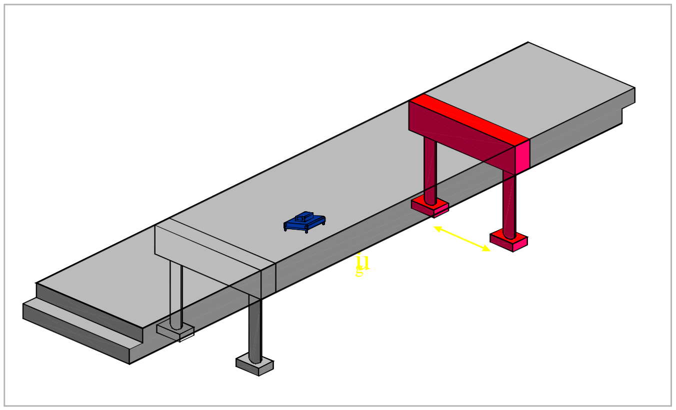
OpenSees Model

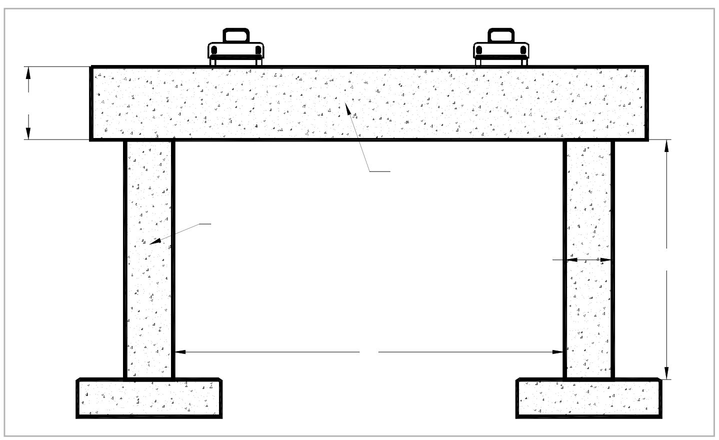


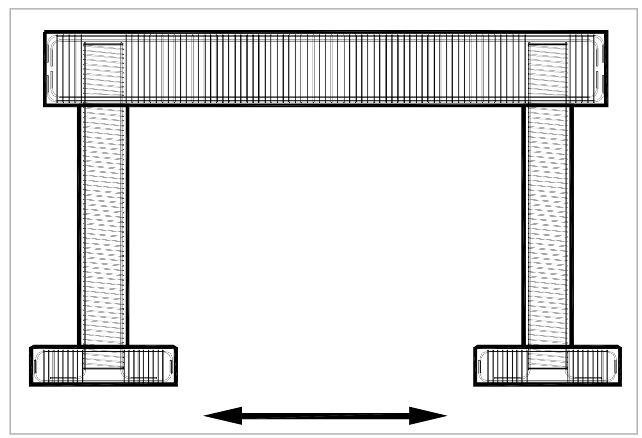
Demand vs. Curvature



Parametric Studies for Design





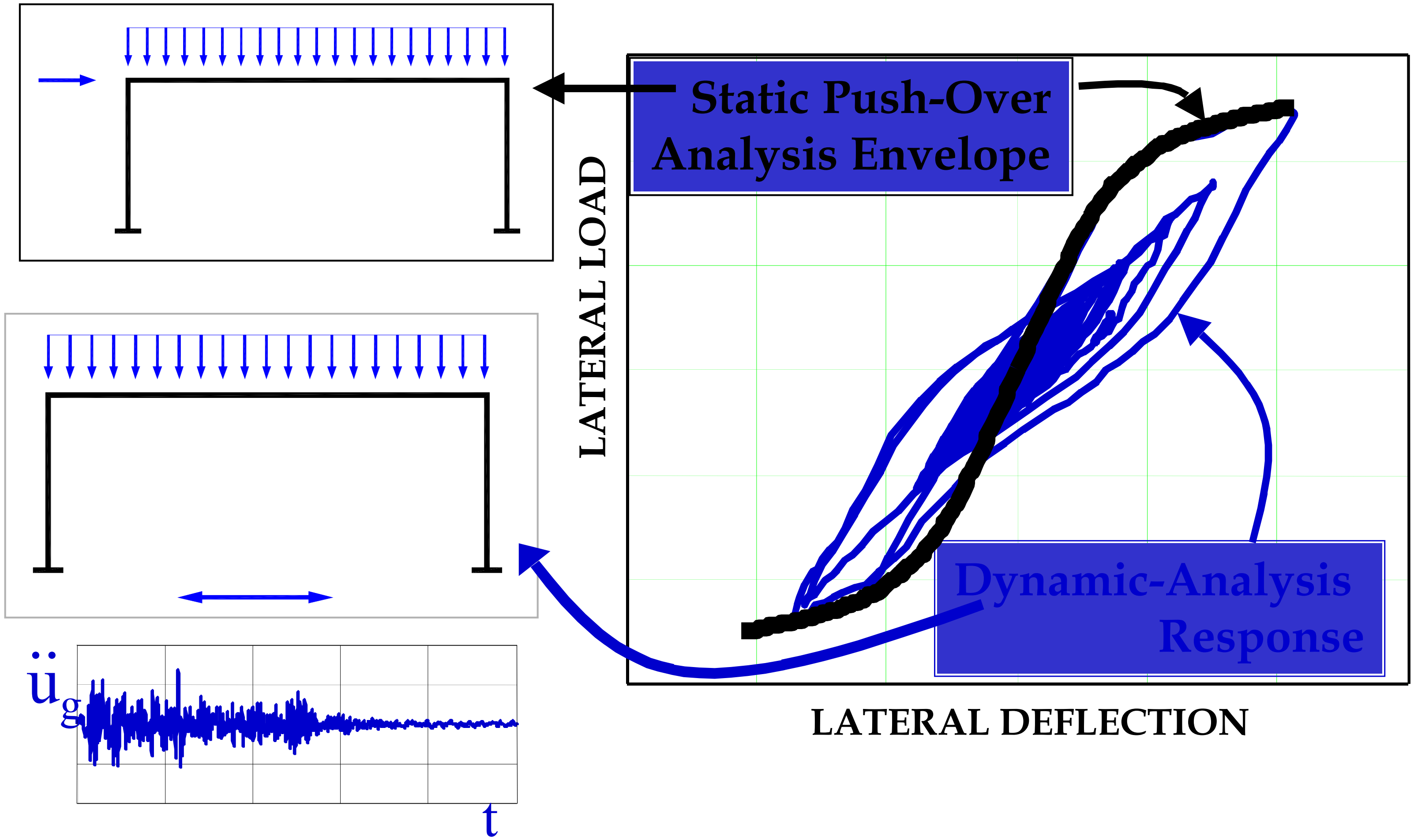


S. Mazzoni

OpenSees

PEER

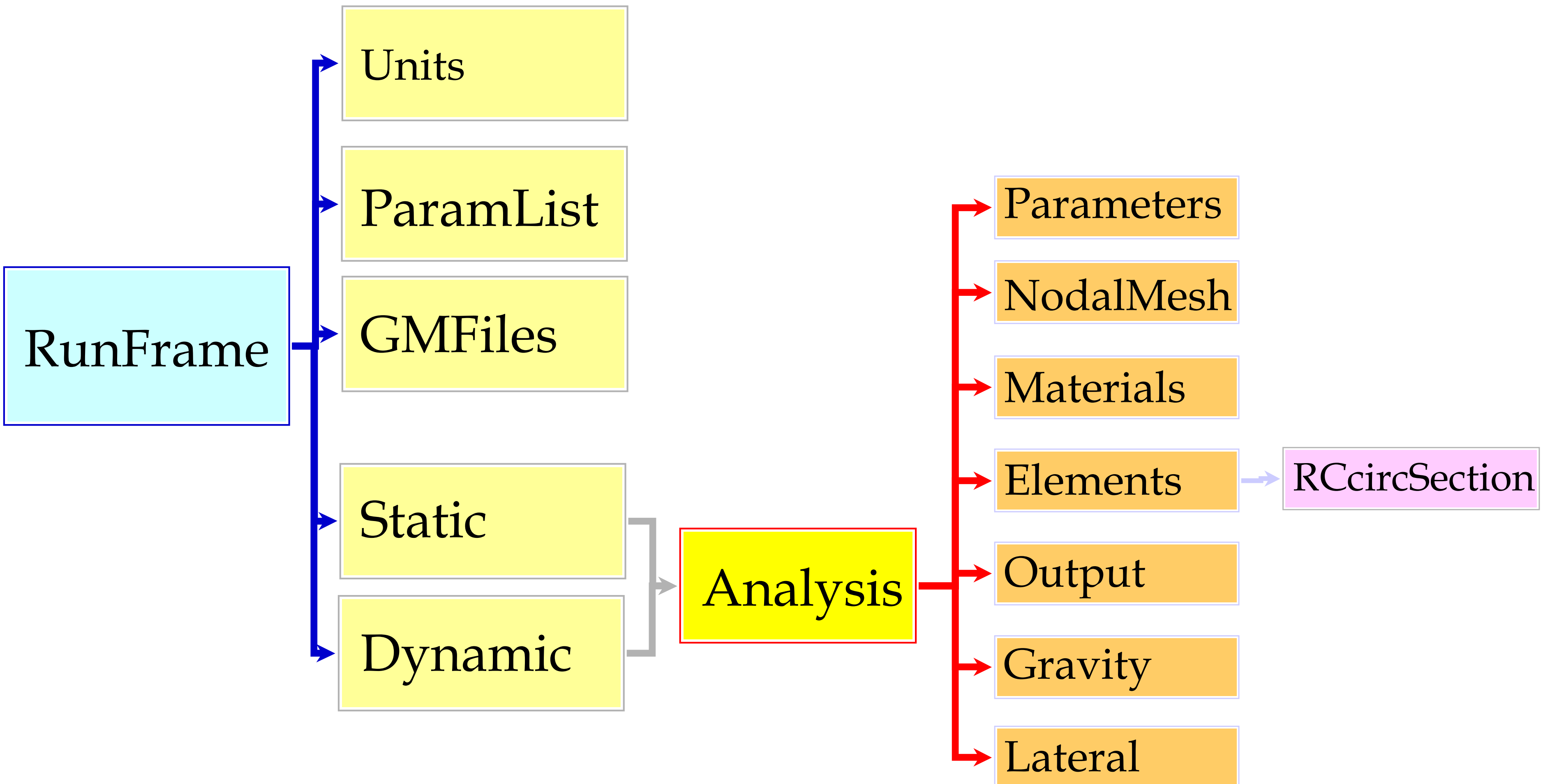
OpenSees Analyses of Pier



Pier Parameterizaton

Xframe	frame ID
Hcol	column diameter
Lcol	column length
Lbeam	beam length
GIbIc	Ig_{beam}/Ig_{col} – beam-column stiffness ratio
GrhoCol	ρl_{col} – column longitudinal-steel ratio
Gpcol	P_{col}/Po – column axial-load ratio
Gmfact	ground-motion scaling factor

Organizing the Parameterization



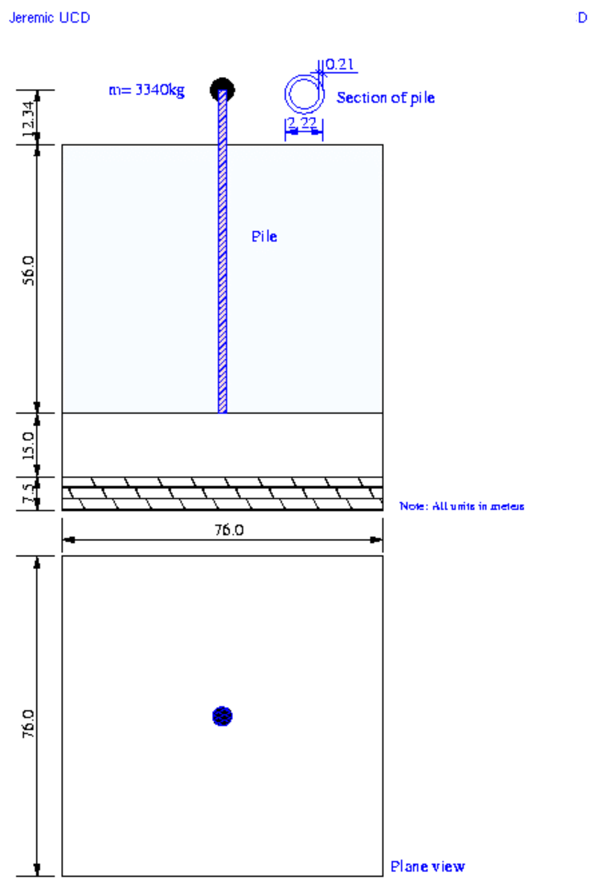
Scripting the Models

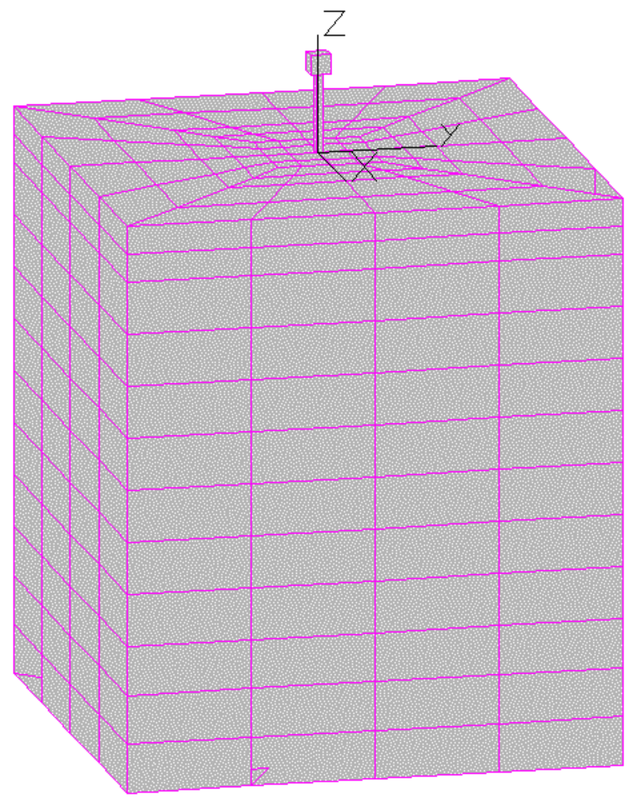
```
wipe
source Units.tcl;                          # define units
source ParamList.tcl;                      # load up parameter values
source GMFiles.tcl;                        # load up ground-motion filenames

foreach Xframe $iXframe Hcol $iHcol Lcol $iLcol Lbeam $iLbeam
        GIbIc $iGIbIc GrhoCol $iGrhoCol GPcol $iGPcol GMfact $iGMfact {
  {  source Static.tcl; # load procedure for static analysis
     source Dynamic.tcl;          # load procedure for dynamic analysis  }
   puts FRAME$Xframe........FRAME$Xframe........
   puts STATIC_ANALYSIS
   Static $Xframe $Hcol $Lcol $Lbeam $GIbIc $GrhoCol $GPcol $GMfact ;
   puts DYNAMIC_ANALYSIS
   foreach GroundFile $iGroundFile {
        puts GroundMotion$GroundFile
        Dynamic $Xframe $Hcol $Lcol $Lbeam $GIbIc $GrhoCol $GPcol $GMfact $GroundFile;
   }
}
```

FRAME

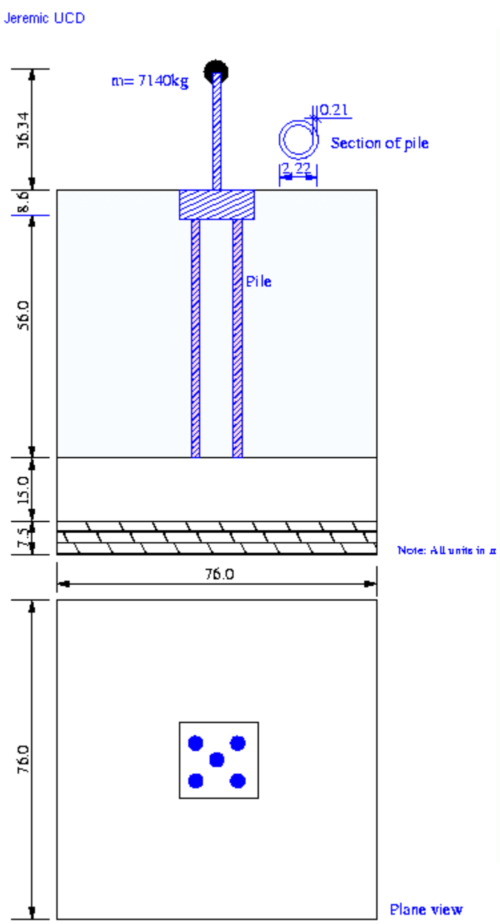
GROUND MOTION

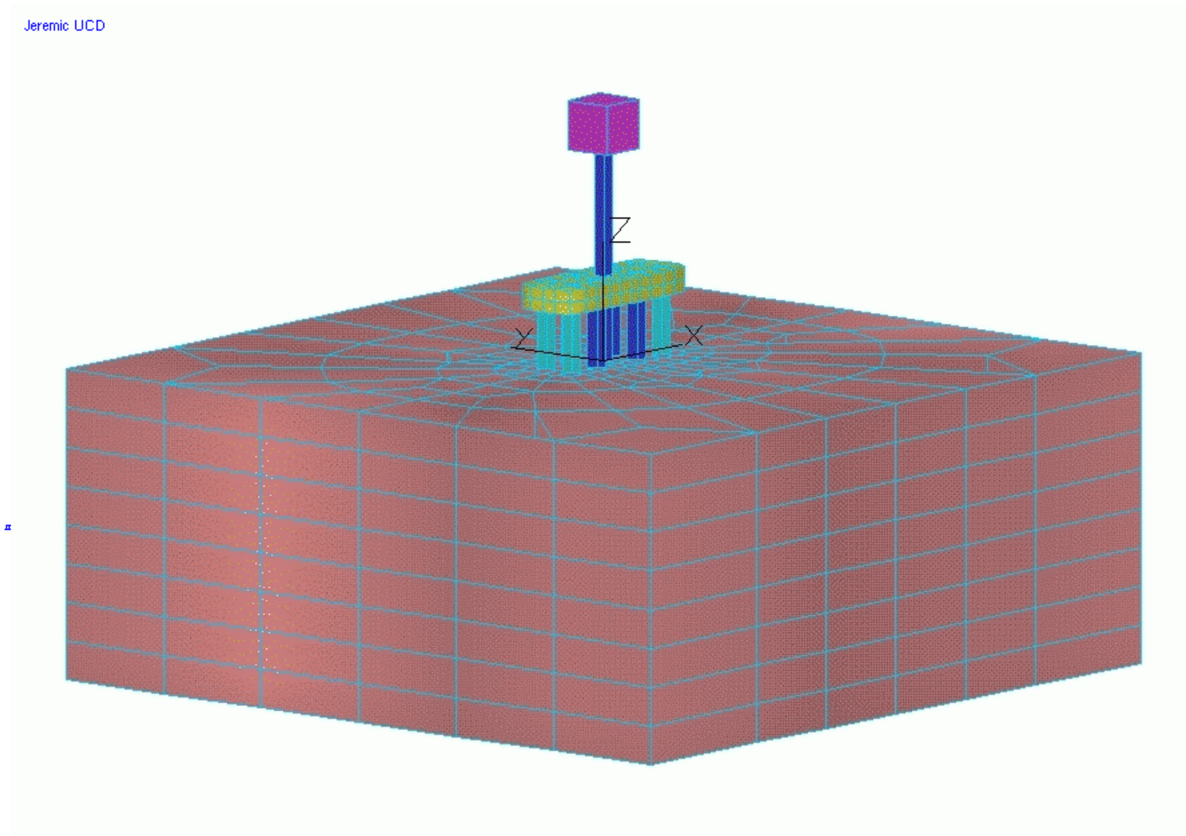
Geotechnical Model Calibration





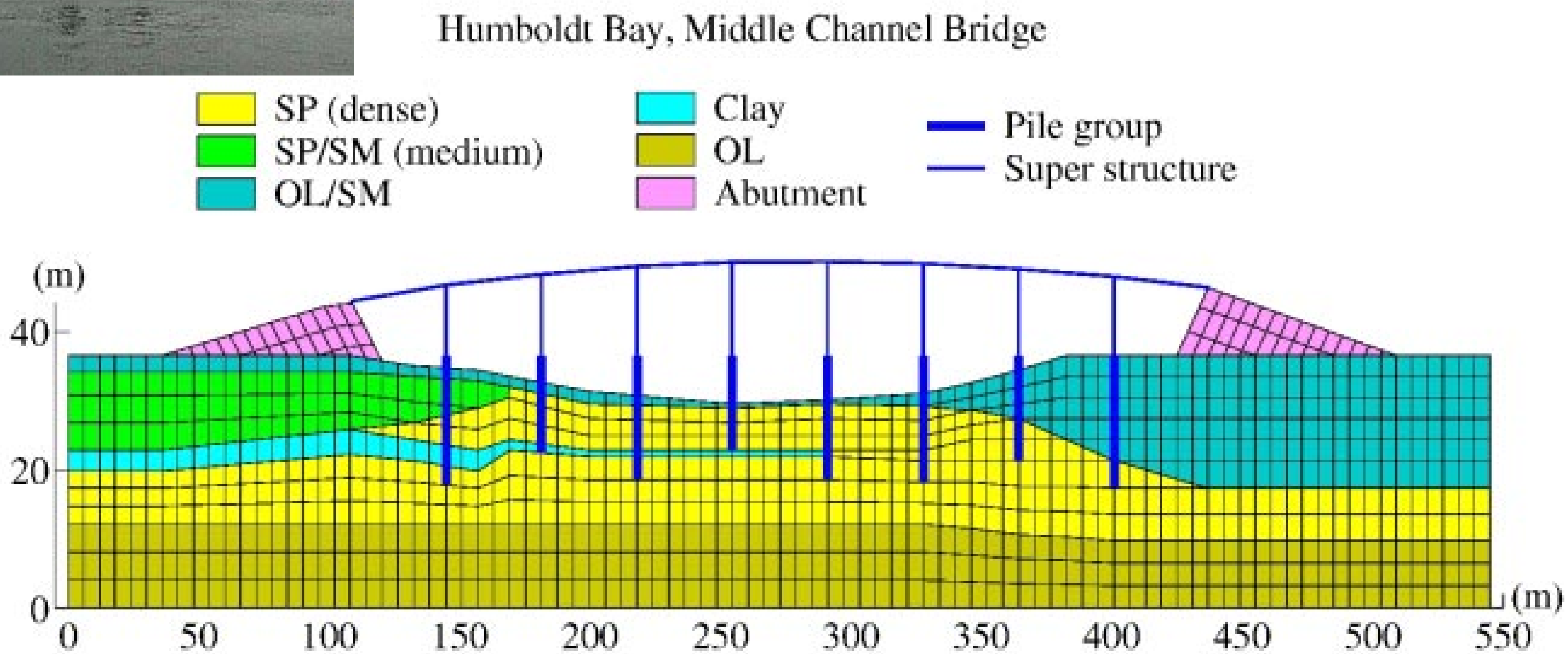
B. Jeremic


Jeremic UCD
m= 7140kg
0.21
Section of pile
2.22
36.34
8.6
56.0
15.0
7.5
Pile
Note: All units in m
76.0
76.0
Plane view


Jeremic UCD
Z
Y
X

Soil-Foundation-Structure Interaction

A. Elgamal
Z. Yang



Current Developments

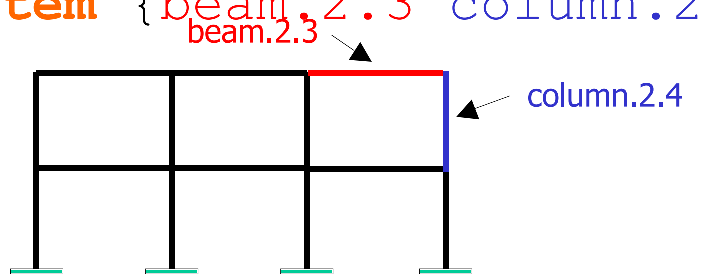
- User interfaces
- Computational Reliability
- Internet-based simulation

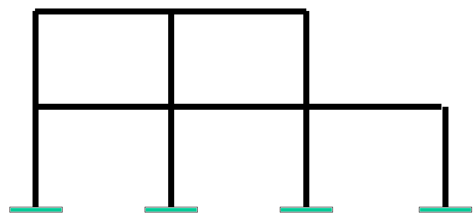
High-Level Scripting Language for Model Generation

- Complete frame models may be generated with simple commands

```
Frame f -bays 0:240:720 -stories 0:240:480
f setitem beam.1:2.1:3 -template beamtype
f setitem column.1:2.1:4 -template columntype
```

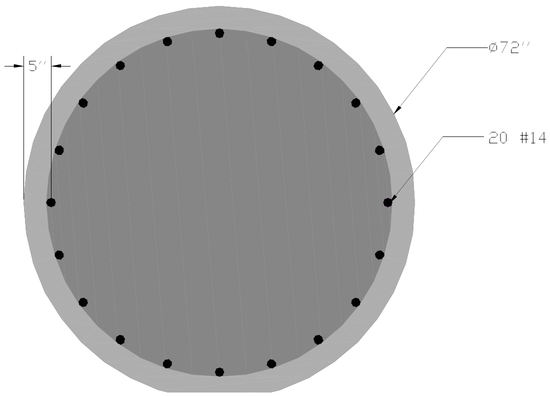
- Irregular frames maybe created by deleting selected beams and columns
  - `f deleteitem {beam.2.3 column.2.4}`

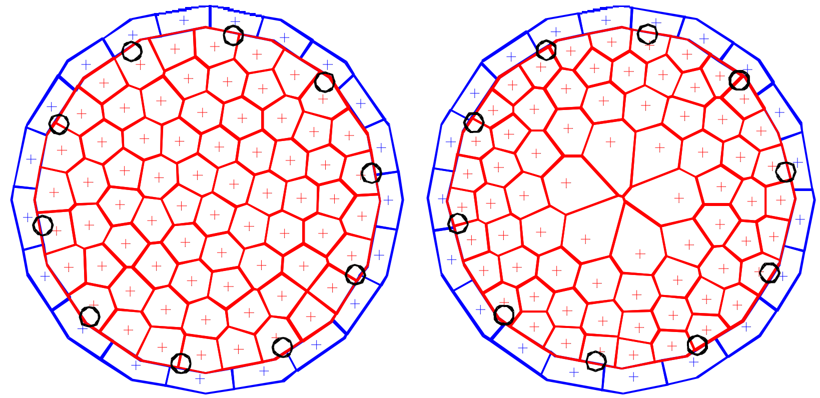


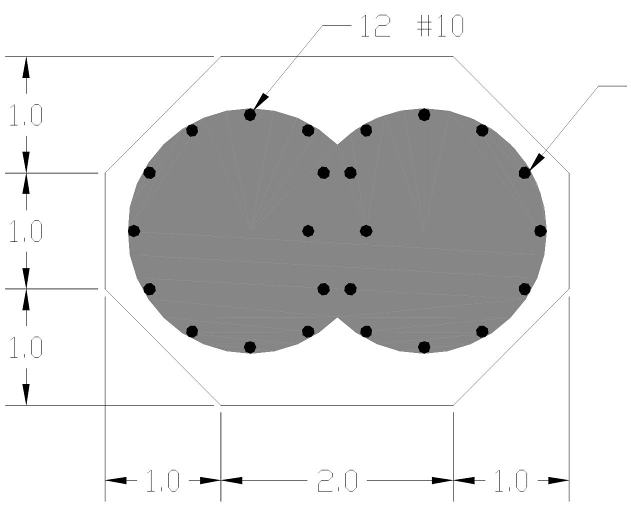


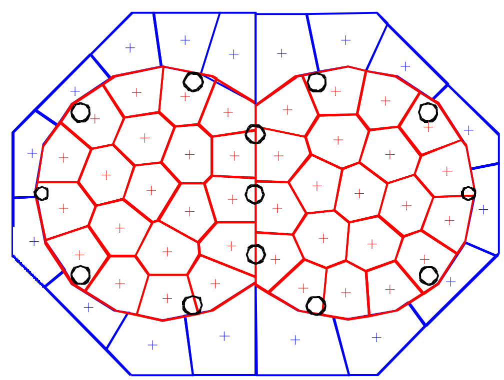
G. Turkiyyah

Automatic Section Generation



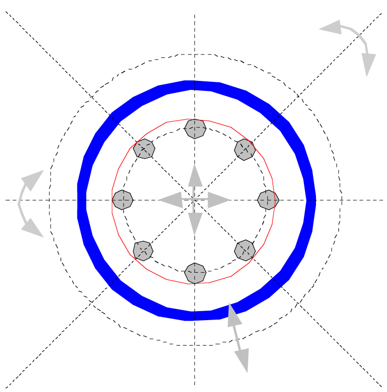


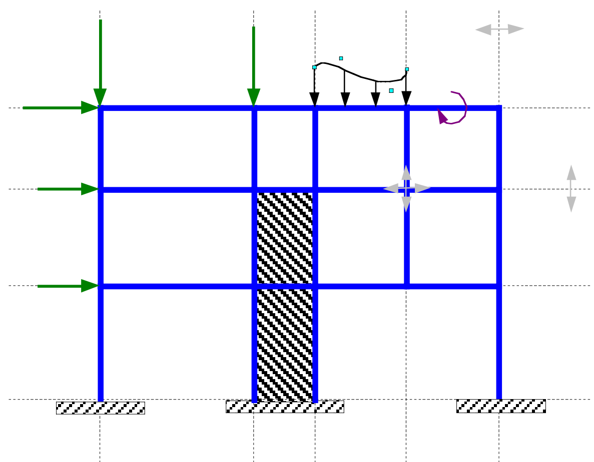


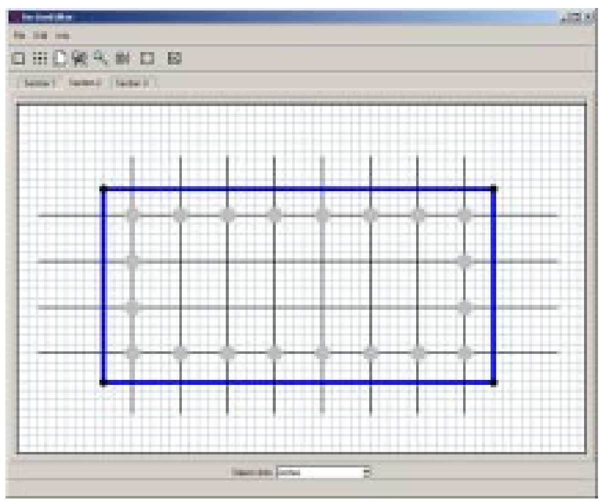


Graphical Model Building

- Graphical definition of cross-sections and wall/frame models
- Support for catesian and polar grids
- Built-in wizards for common section and frame configurations
- Graphical access to response quantities







OpenSees/Reliability for PBEE

OpenSees/Reliability addresses the “component problem” of structural reliability:

$$p_f = \int_{g(\mathbf{x})\le 0} f(\mathbf{x})d\mathbf{x}$$

User-defined limit-state functions (performance criteria), e.g.:

$$g_1 = u_d - u_{node\ 32}$$

$$g_2 = 1 - \left(\frac{M}{M_d}\right)^2 - \left(\frac{P}{P_d}\right)$$

$$g_3 = 1 - \frac{\sigma_{max}}{\sigma_d}$$

Wanted: probability of failure for the defined limit-state function.

Vector of uncertain (random) variables.

Joint probability density function associated with the random variables.

T. Haukhass
A. Der Kiureghian

Extensions to Scripting Language

Command to create the structural reliability model builder:

```
reliability
```

Commands to populate the structural reliability domain:

```
randomVariable type rvTag? mean? stdv? <startPt?>
randomVariable type rvTag? par1 par2 par3 par4 <startPt?>
correlate corrTag? rv1? rv2? correlationValue?
limitState lsfTag? limitStateExpression
```

Commands to pick components for the structural reliability analysis:

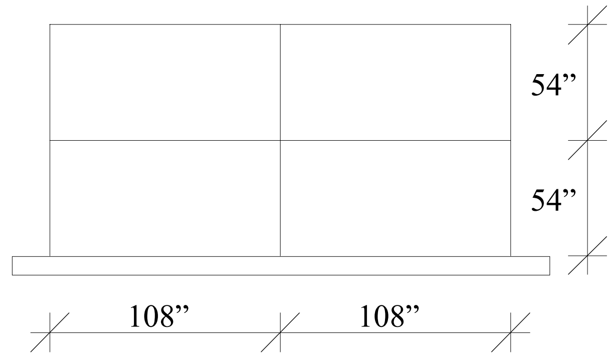
```
sensitivityEvaluator typeOfSensitivityEvaluator
stepSizeRule typeOfStepSizeRule
searchDirection typeOfSearchDirection
findDesignPointAlgorithm typeOfFDPAlgorithm
findCurvaturesAlgorithm typeOfFCAlgorithm
addFORMAnalysis
addSORMAnalysis
addSimulationAnalysis samplePoint numSim? targetCOV?
```

Command to perform structural reliability analysis:

```
analyzeReliability
```

Example of Reliability Analysis

- Characterize the Young’s moduli and moments of inertia of the columns as having 10% coefficient of variation; independent lognormal random variables.
- Limit-state function: probabilityof the max drift exceeding 15 inches.



Results from structural reliability analsysis.

Method	Reliability index	Prob. of failure
FORM	3.2635	0.00055027
SORM	3.3253	0.00044169
Simulation	3.3223	0.00041969

The simulation analysis was performed by sampling around the design point. 1000 simulations were pe r-formed, yielding a coefficient of variation of 6.27% for the estimated probability of failure. In the SORM anal y-sis; only the first principal curvature of the limit-state su r-face was used.

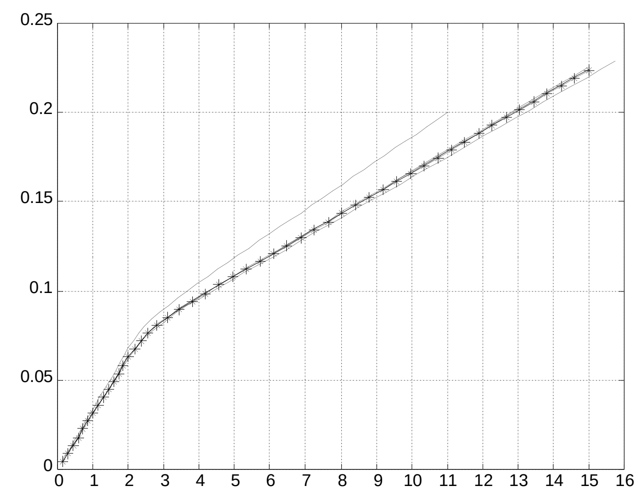
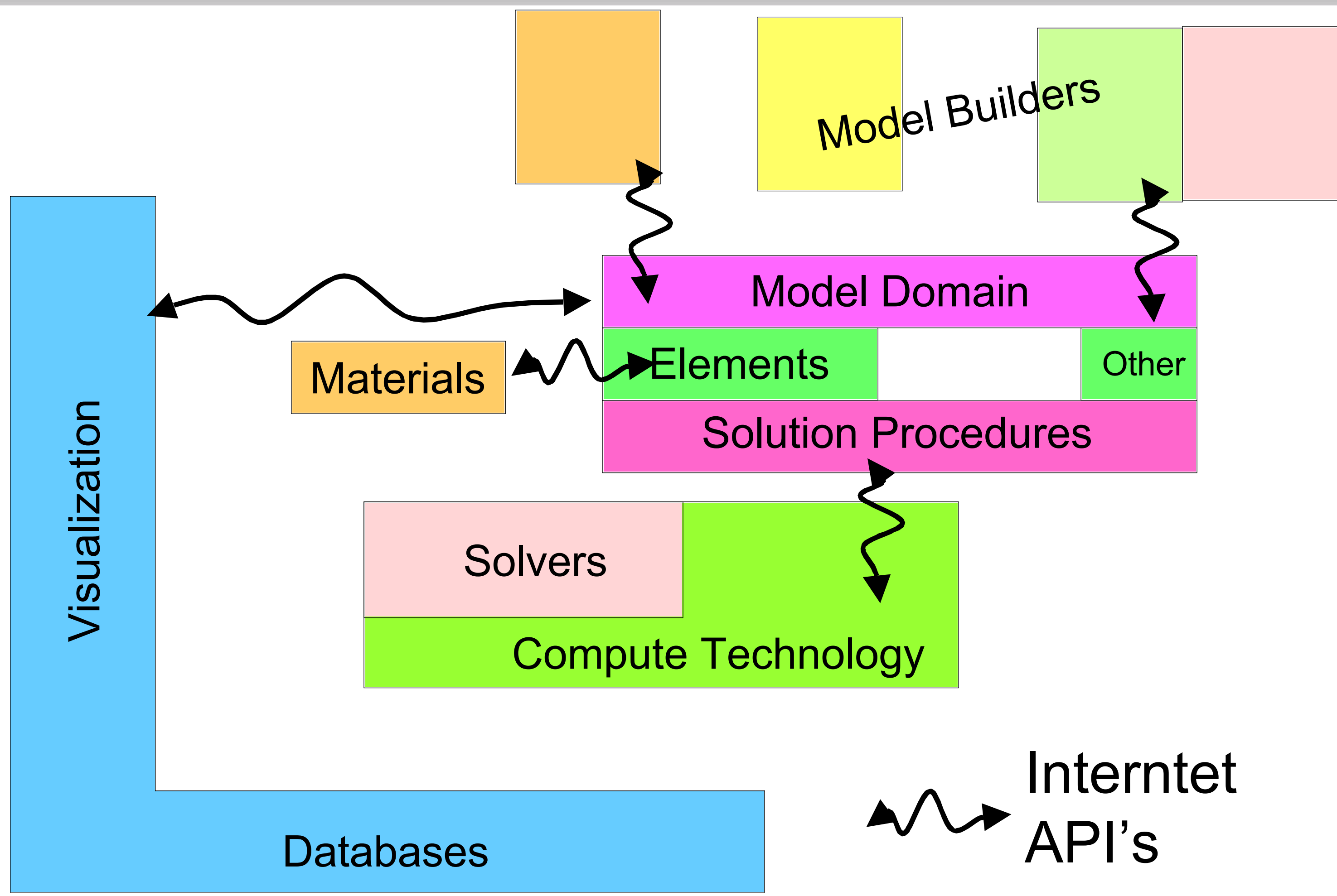
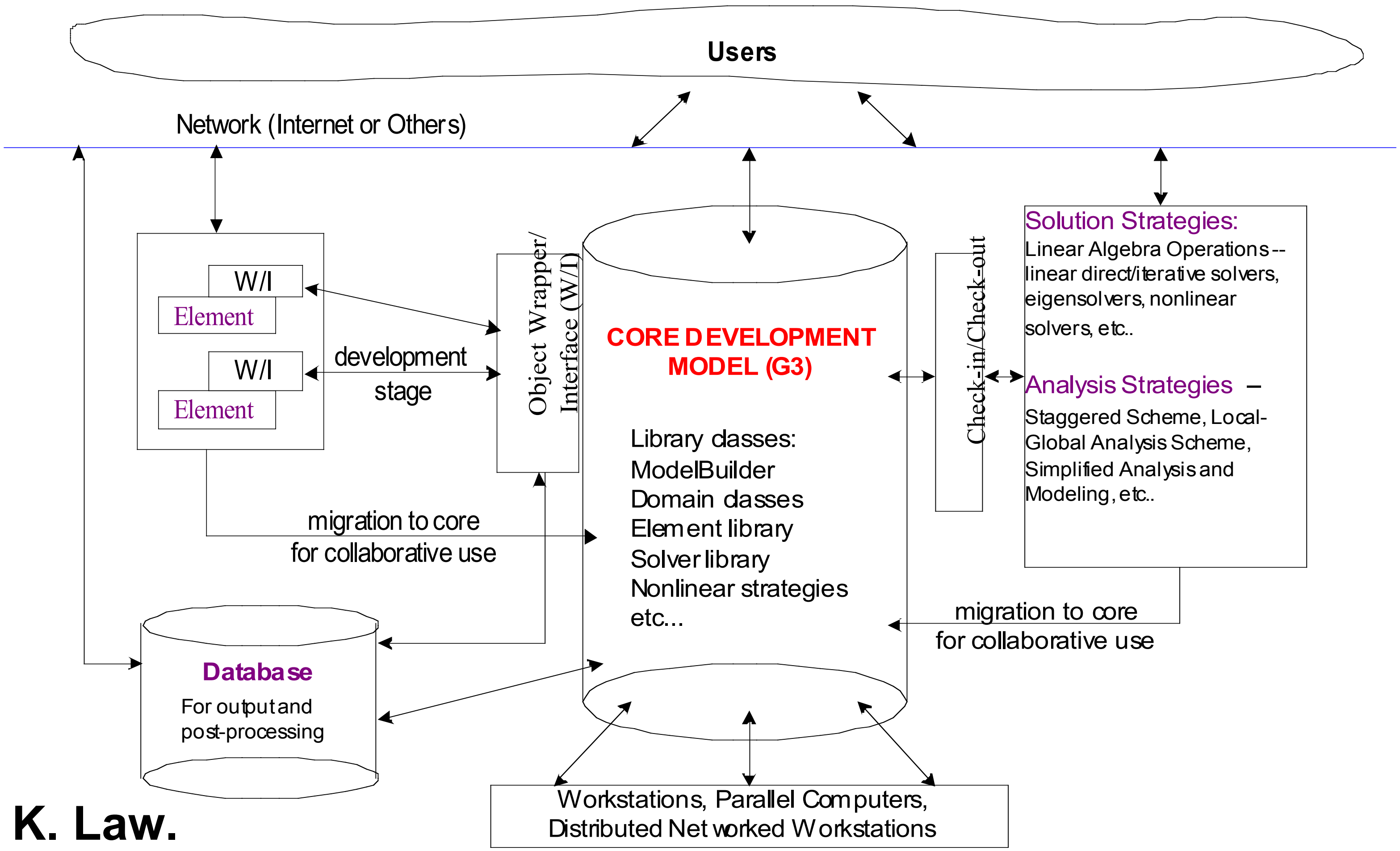


Figure 2. Load-displacement curves for the 7 structural analyses needed to find the “design point” in the FORM reliability analysis.

Using the Internet for Simulation



Internet Enabled Collaborative Environment

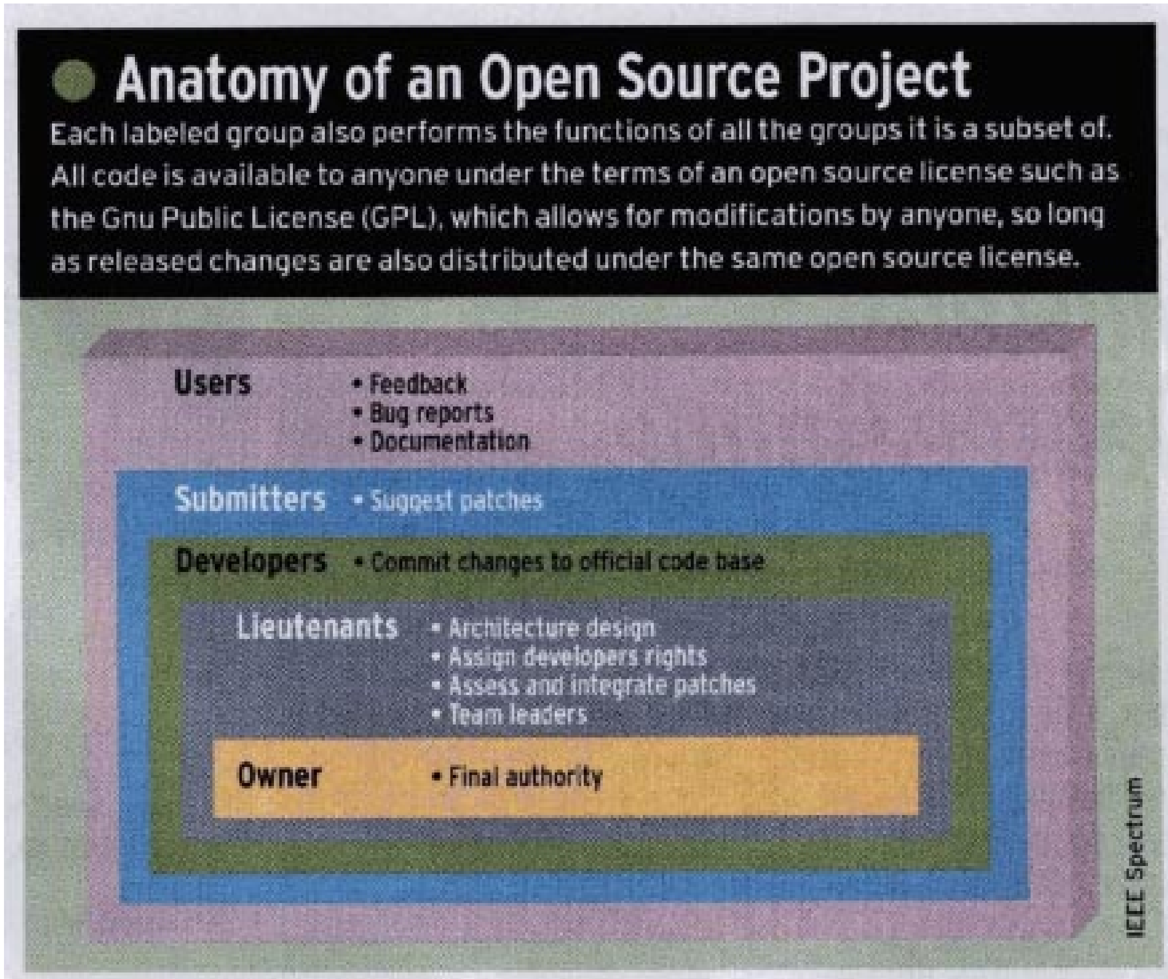


K. Law.

OpenSees

PEER

Building Community Through Open Source



...a center makes this possible...

OpenSees Users

J. Conte, L. Lowes,
A. Der Kiureghian,
J. Pestana, S. Mazzoni

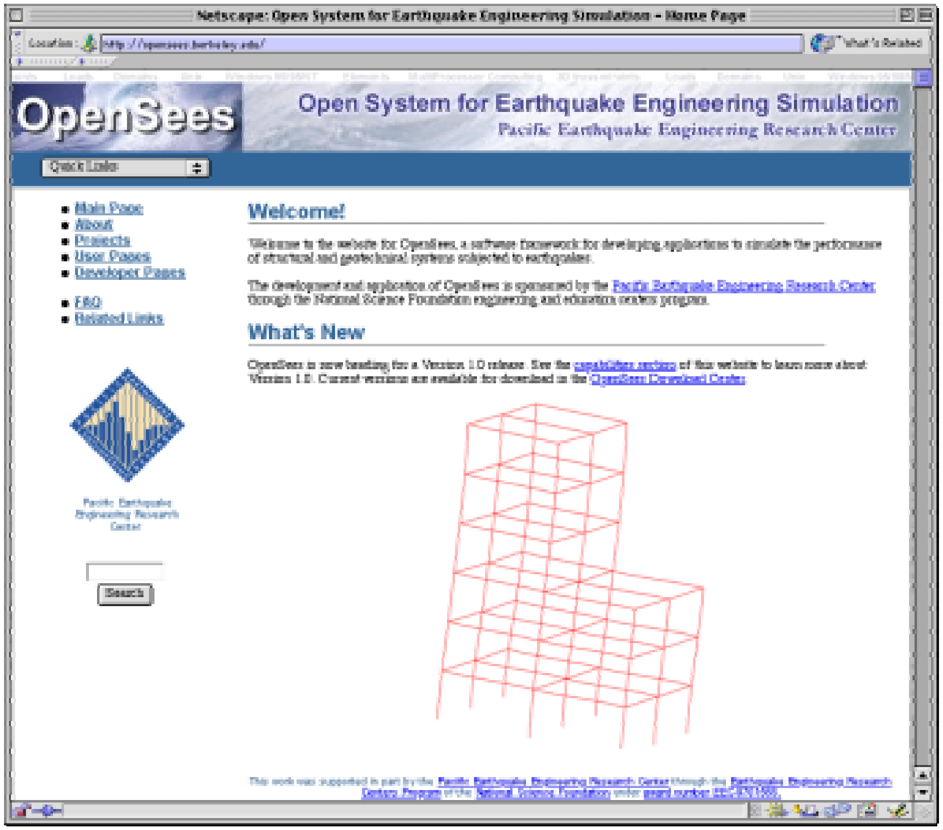
F. Filippou G. Deierlein
G. Turkiyyah K .Law
Z. Yang P. Arduino

B. Jeremic

F. McKenna

Open Source Depends on Open Communication

http://opensees.berkeley.edu



User “guest”
Password “OSg3OS”

Issues for the Future

- Models
  - Degradation, shear-flexure, bond slip, joints
  - Soil-pore fluid models
  - Pile-foundation models
  - Validation protocols
  - Input motions and coupled simulations
- PB Design and Simulation
  - Parameterization including random variables and fields
  - Reliability
- Computing and Information Technology
  - Parallel and distributed computing
  - Visualization and databases
  - Internet applications

Serving User Needs

- Useable interfaces
- Validation Studies
- User support and forums
- Commercial alliances