OpenSees

Computational Simulation

Frank McKenna
UC Berkeley

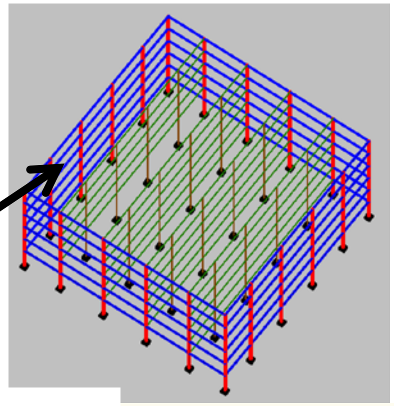
QuickTime™ and a
decompressor
are needed to see this picture.

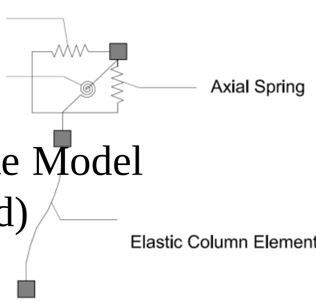
NEES NEEScomm NSF

Current Simulation Examples

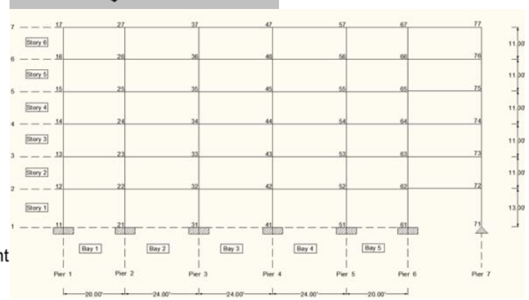
Perimeter Moment Resisting Frame

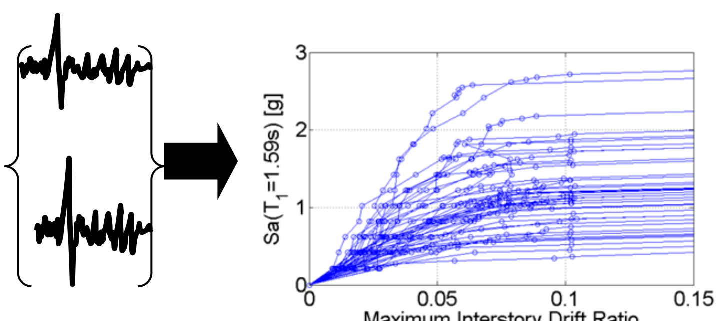
Interior Gravity Frame





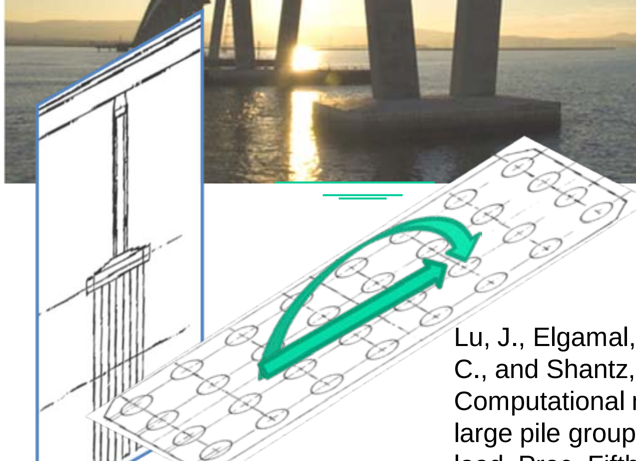
Limit-State Model (K.Elwood)

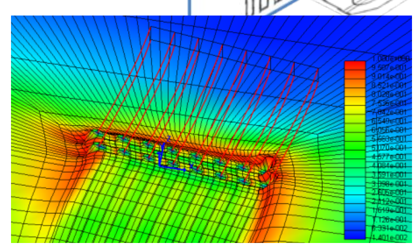


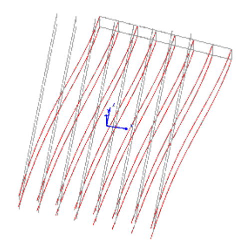


Panagiotis Galanis & Jack Moehle

ATC 78: Assessment of Collapse Risk of Existing Reinforced Concrete Buildings

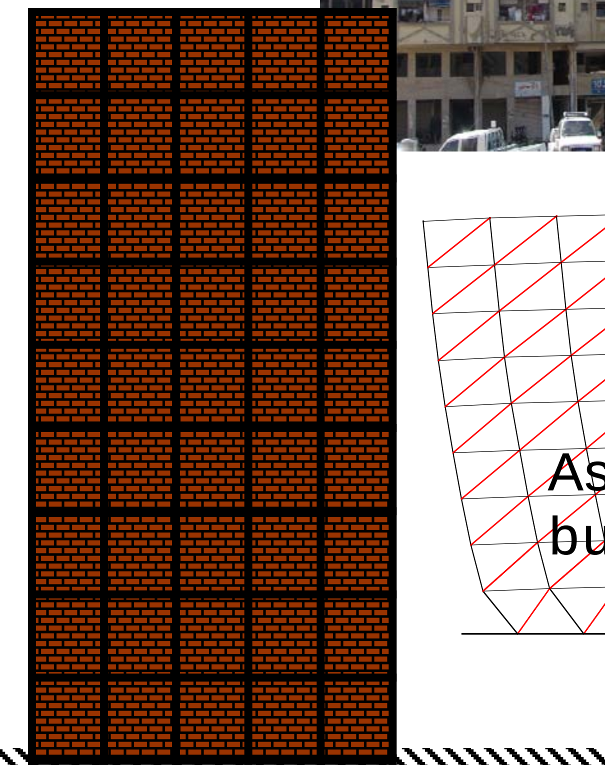


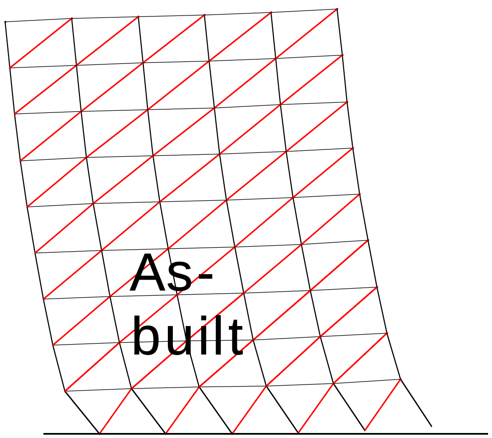


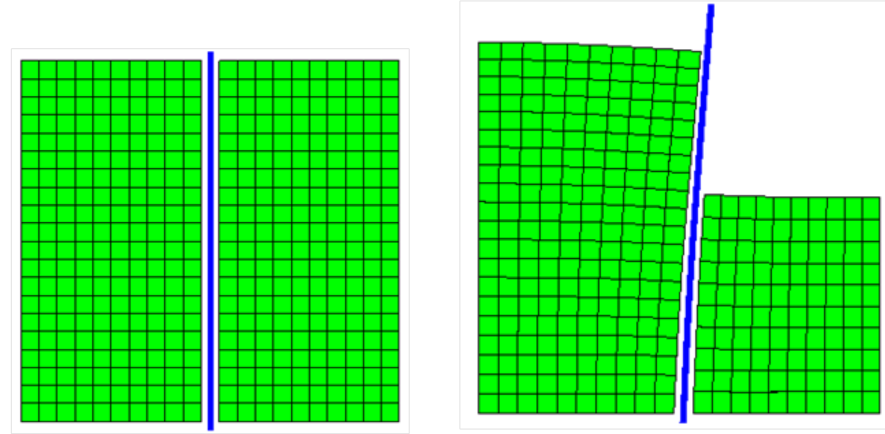


Lu, J., Elgamal, A., Sikorsky, C., and Shantz, T. (2010). Computational modeling of a large pile group under lateral load, Proc. Fifth Intl. Conf. on ent Advances in ›technical Earthquake ineering and Soil Dynamics, ' 24-29, San Diego, CA

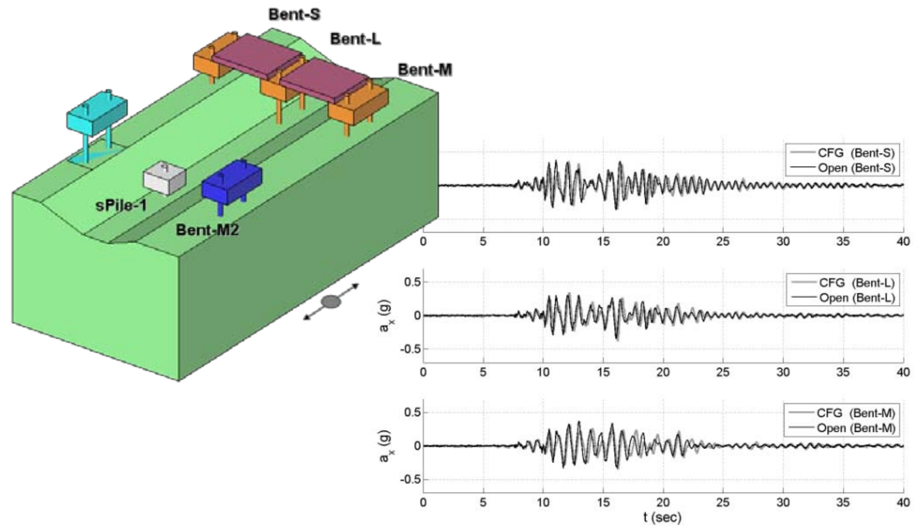
Jinchi Lu & Ahmed Elgamal

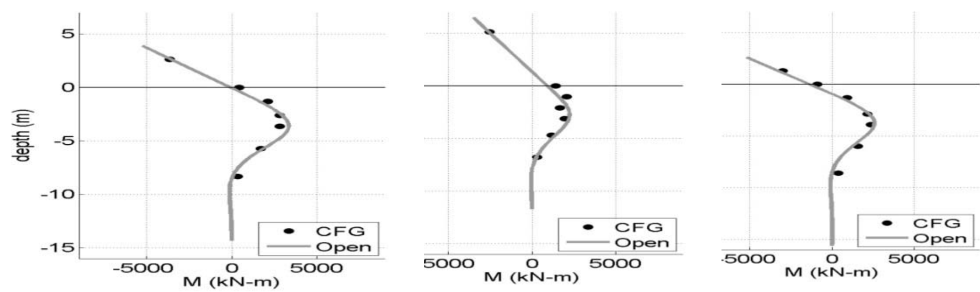






Pedro Arduino

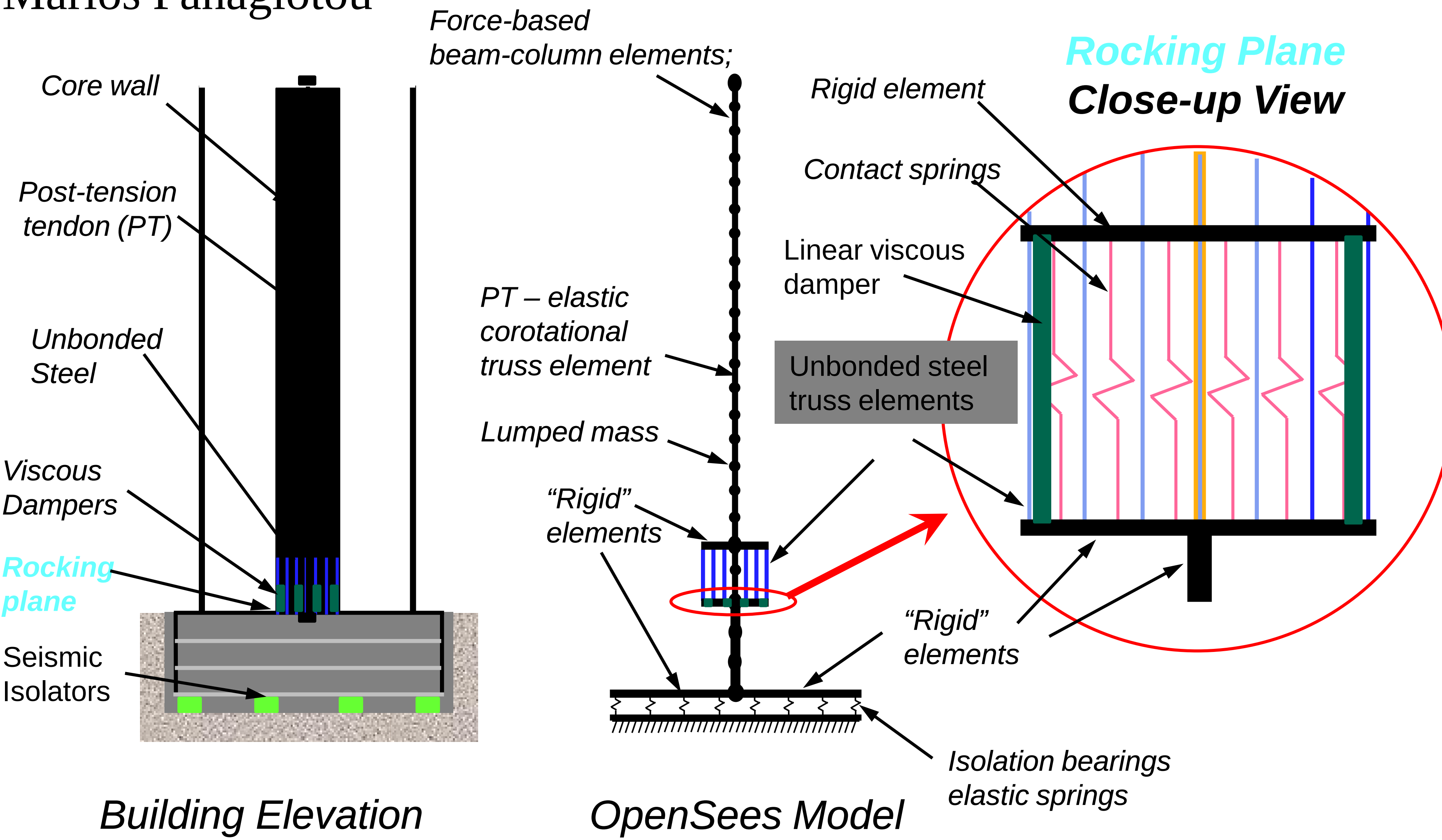




M.Talaat & K.Mosalam

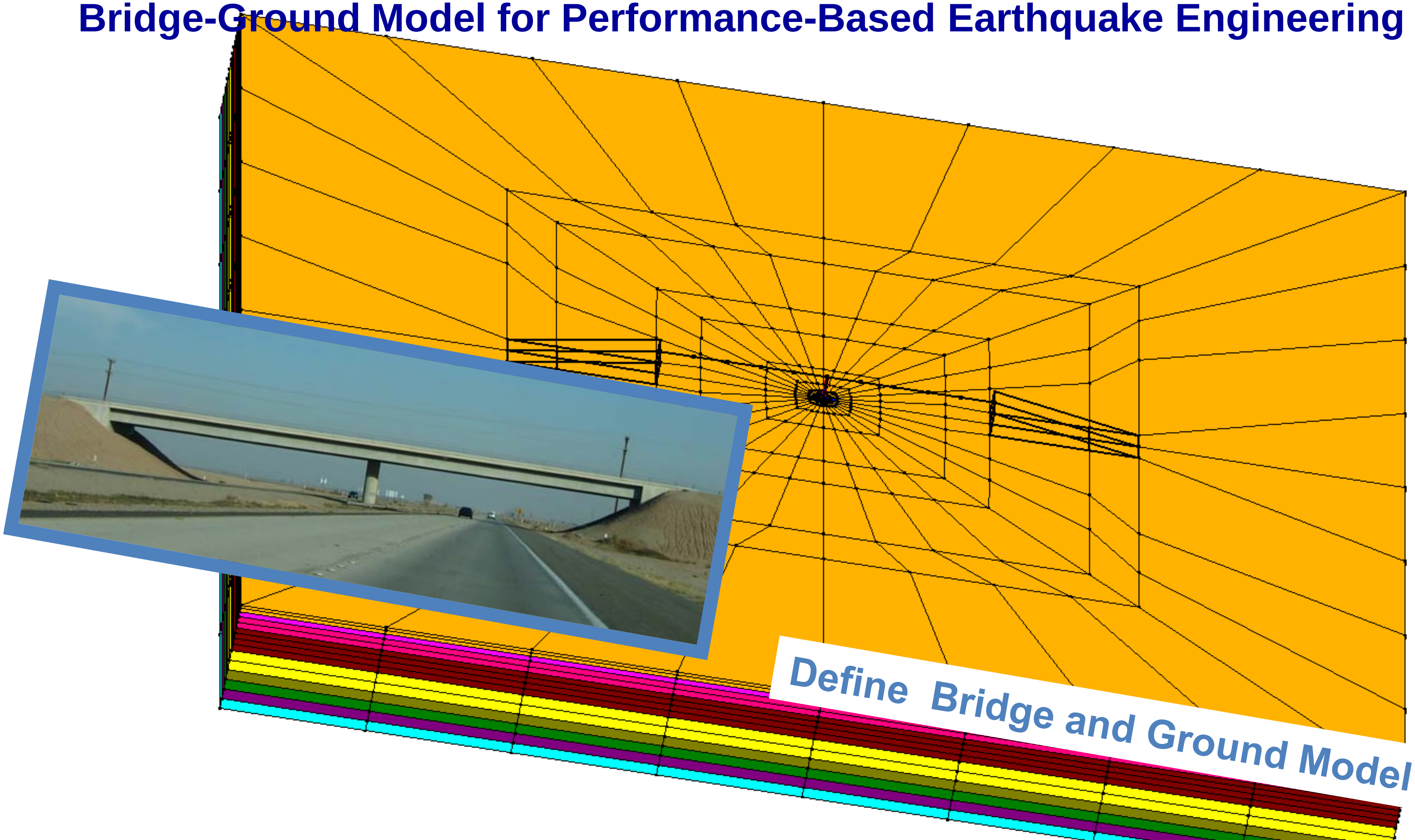
20-story Building with Base Isolation and Rocking Core Wall

Marios Panagiotou



OpenSeesPBEE

Bridge-Ground Model for Performance-Based Earthquake Engineering



Mackie, K., Lu, J., and Elgamal, A. (2010). User interface for performance-based earthquake engineering: a single-bent bridge pilot investigation, 9th US National and 10 Canadian Conference on Earthquake Engineering, July 25-29, Toronto, Canada

Lu, J., Mackie, K., and Elgamal, A. (2010). Performance-based earthquake evaluation of a single column bridge system, Joint conference proceedings, 7th International Conference on Urban Earthquake Eng (7CUEE) & 5th Intl Conf on Earthquake Eng (5ICEE), March 3-5, 2010, Tokyo Institute of Technology, Tokyo, Japan.

OpenSees
Open System for Earthquake Engineering Simulation
Pacific Earthquake Engineering Research Center

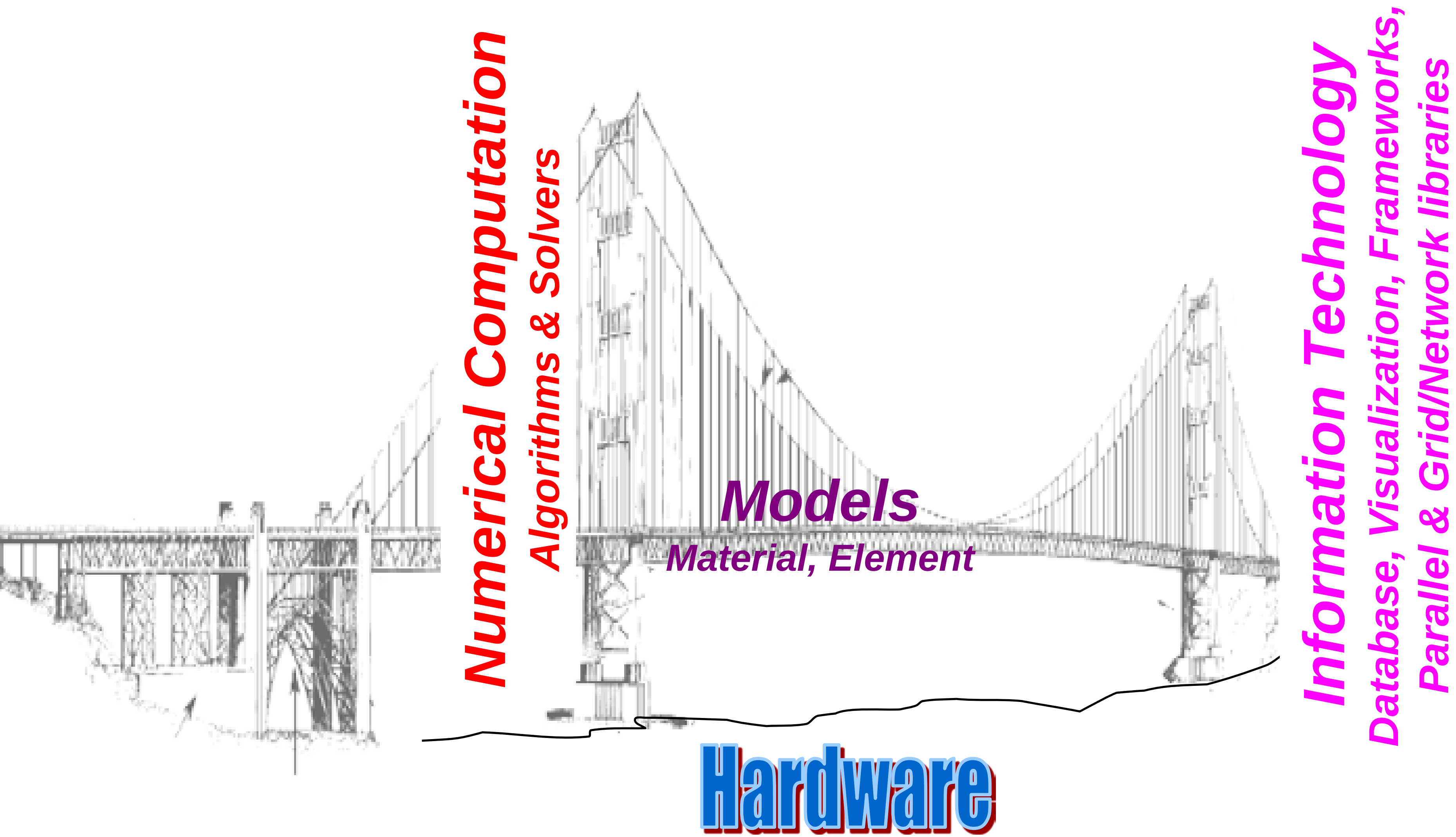
- OpenSees has been under development by PEER since 1998.
- NEES has supported maintenance since 2003.
- OpenSees is Simulation software for structure and geotechnical engineering.
- Large group of developers and users.
- Open-source and royalty free license for non-commercial use and internal commercial use.
- License must be obtained from UC for software developers wishing to including OpenSees code in their applications.

http://opensees.berkeley.edu

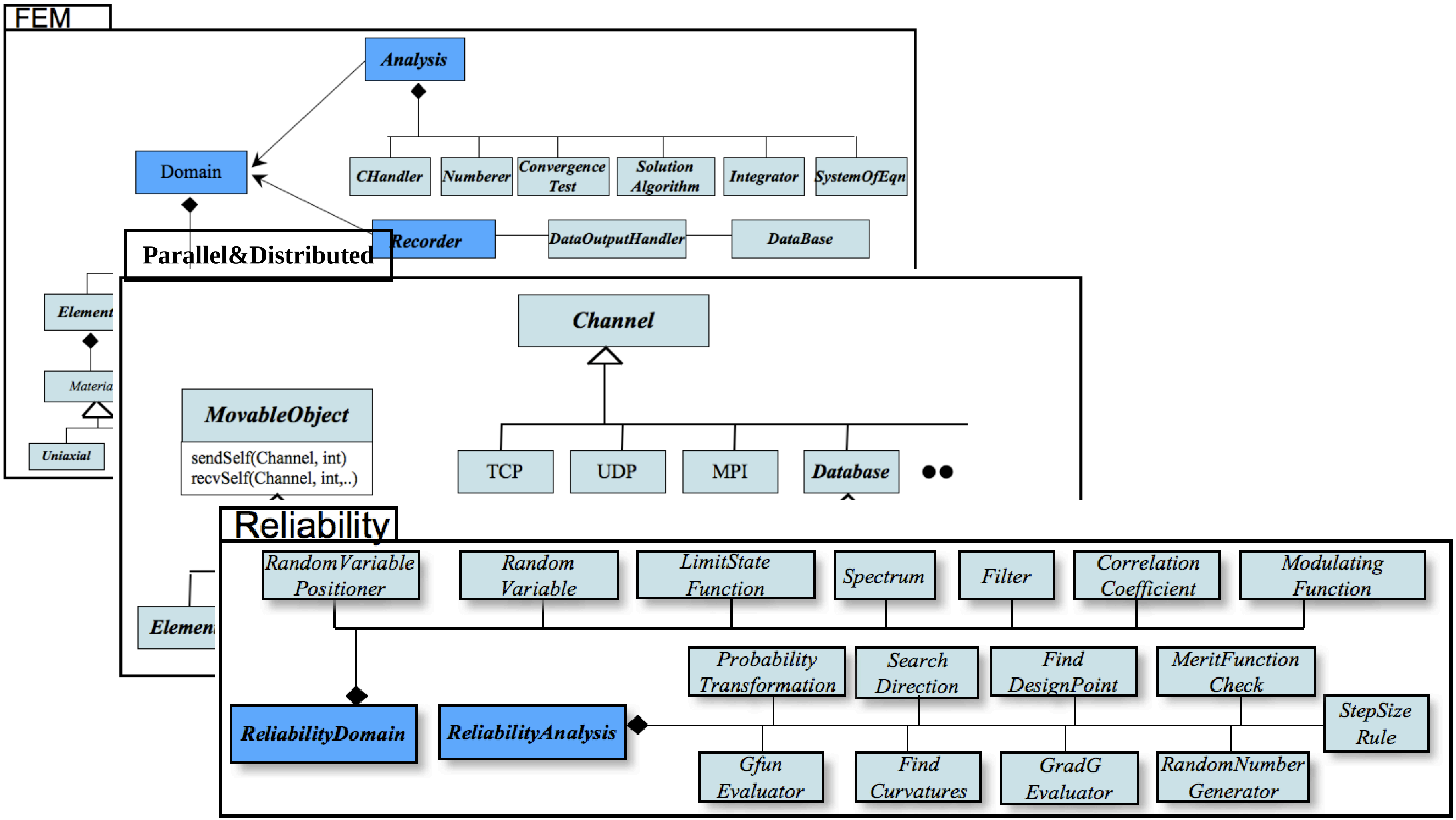
OpenSees Goals:

- To use modern software techniques to evolve an extensible finite element software platform for earthquake engineering that would encompass both structural & geotechnical engineering.
- To provide a common analytical research framework for PEER researchers to educate students & share new knowledge.
- To foster a mechanism whereby new research could be disseminated to industry for testing and implementation.

Building Blocks for Simulation



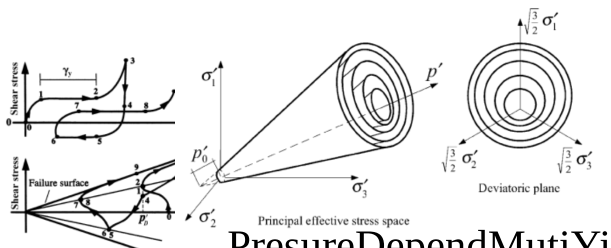
OpenSees Classes



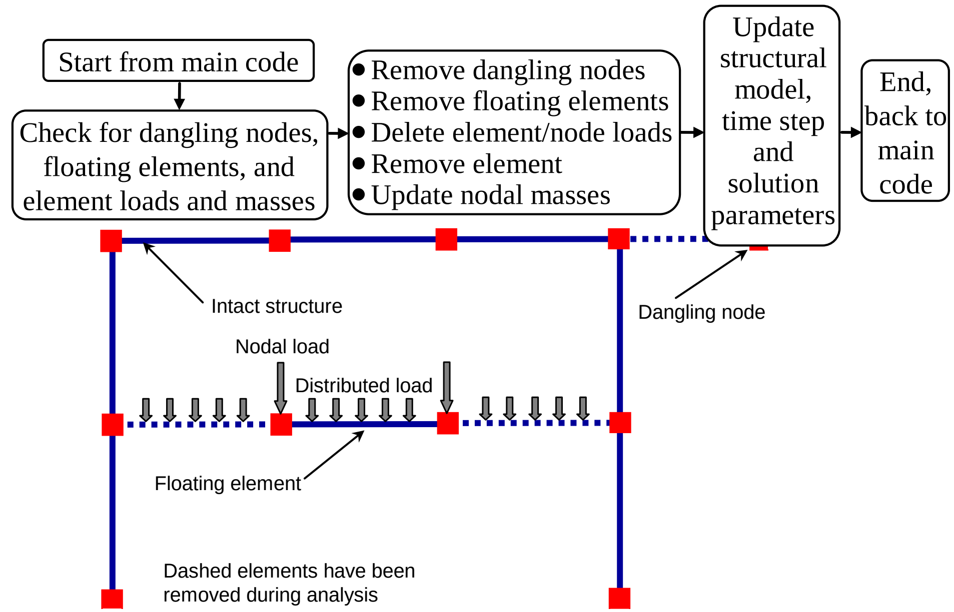
Currently over 1000 classes (modules)

Contributions from Faculty/Students

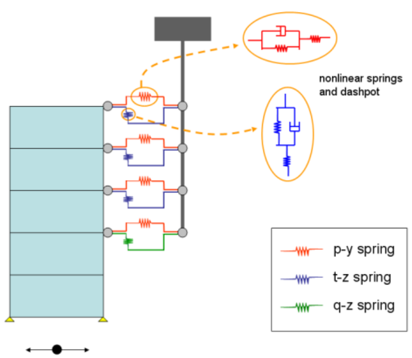
The capabilities in OpenSees are in large part due to the contributions of graduate students & their advisors from PEER affiliated universities (and beyond)



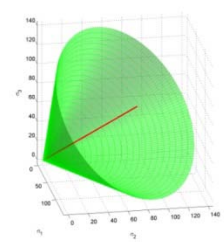
PresureDependMutiYield
Z.Yang & A.Elgamal
UCSD



M.Talaat & K.Mosalam
UC Berkeley



P-Y,T-Z,Q-Z
R. Boulanger
UC Davis



Drucker-Prager
K.Patex, PMcKenzie, & P.Arduino
UWashington

Some Elements:

QuickTime™ and a
decompressor
are needed to see this picture.

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decompressor
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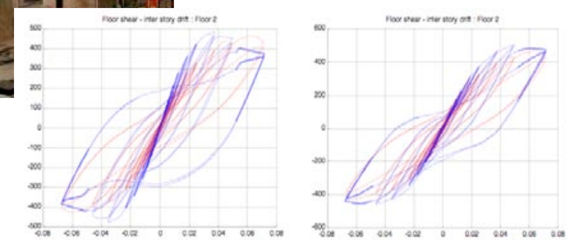
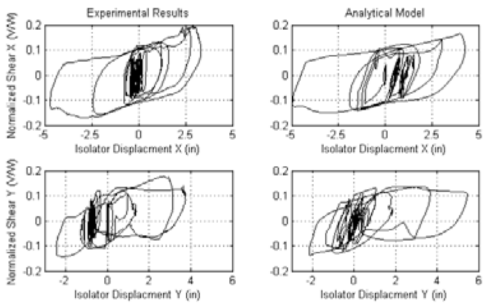




Arash Altoontash & Laura Lowes
Stanford

Tracy Becker & Steve Mahin
UC Berkeley

Many Many More & (apologies)

We are not done -

In addition to the need for new elements & materials, We need new solvers, integration schemes and solution algorithms.

Example: Newton-Raphson (mainstay of all finite element codes) is in theory only good for smooth functions.

We don't have this situation - our surface looks more like this

BUT WE DO NEED HELP SO PLEASE - Don't forget to send us new code for testing & inclusion (C++,C,Fortran, Matlab)

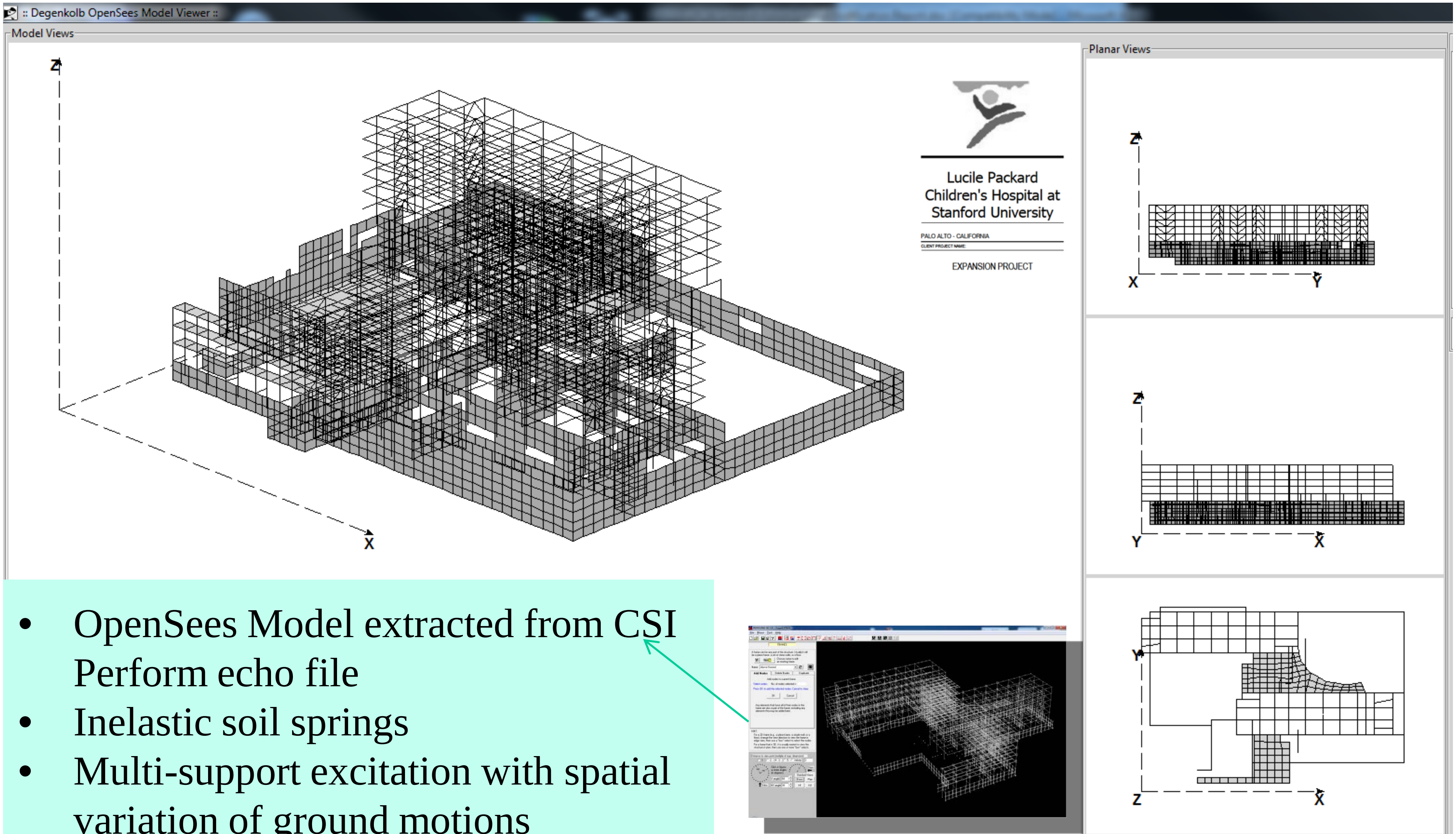
Has It Worked

In last 6 years OpenSees has been downloaded 38,000 times
by users in over 120 Countries

It is being used in Practice (dissemination of research) - WHY?

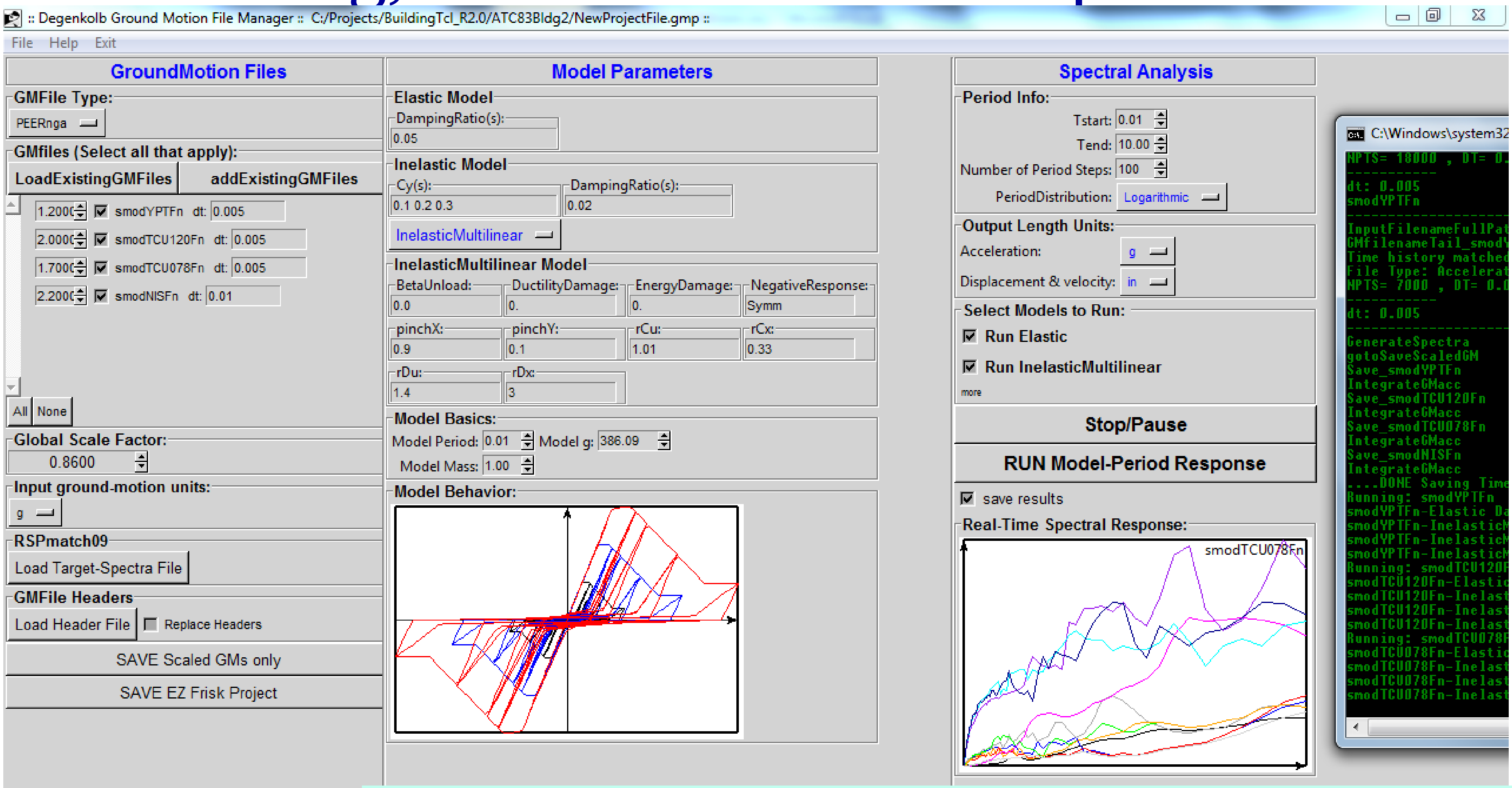
1. It has some routines not found in commercial codes
2. Graduate students learn to love it
3. It is fast

Perform-Echo-File Reader:
Improved modeling of Soil-Structure Interaction



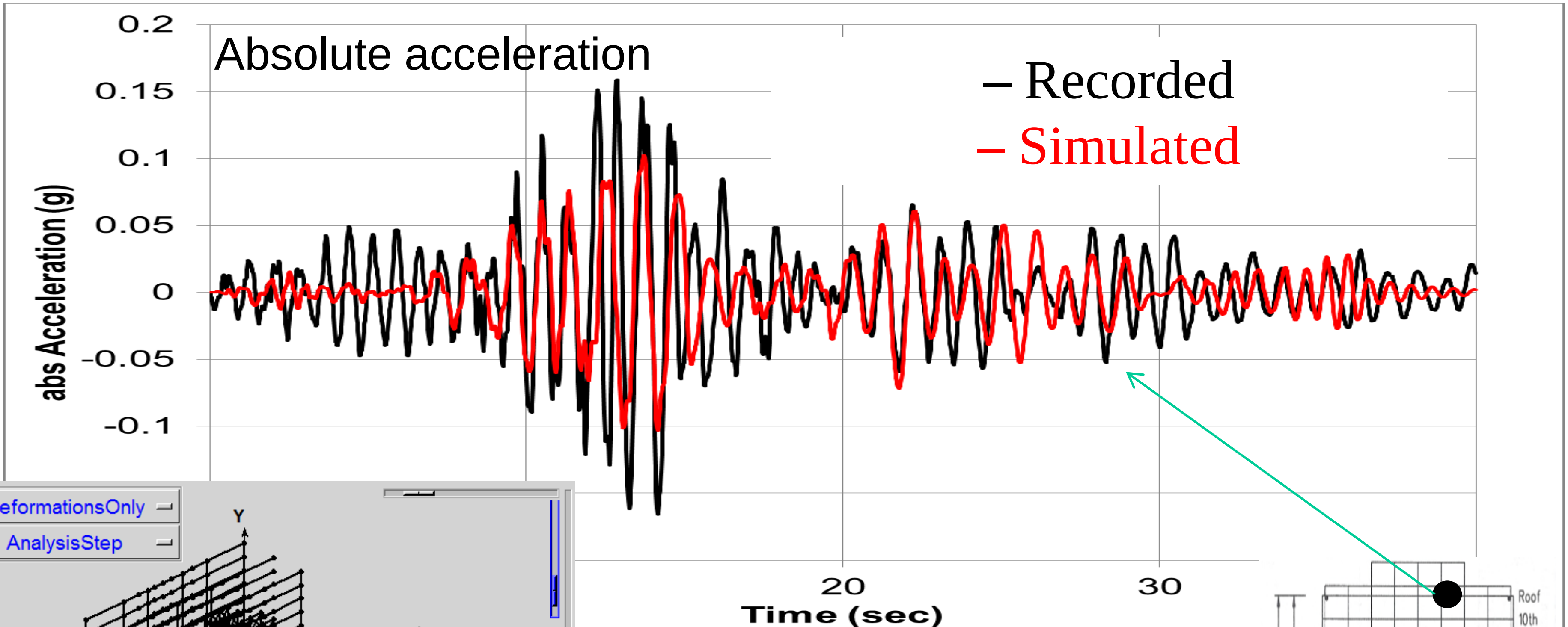
- OpenSees Model extracted from CSI Perform echo file
- Inelastic soil springs
- Multi-support excitation with spatial variation of ground motions

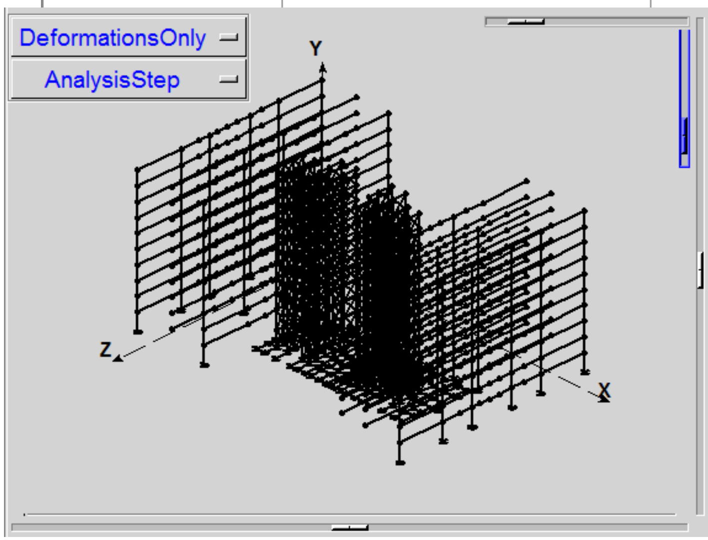
Ground-Motion File Manager: GM scaling, Elastic & Inelastic Spectra



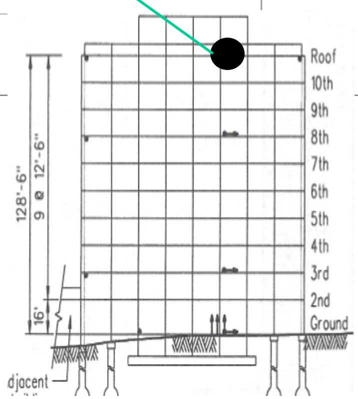
- In-house ground motions scaling and modification
- Processing and interpretation of strong-motion records after relevant seismic events (Mexicali,New Zealand, Japan)

Simulation Validation – Loma Prieta



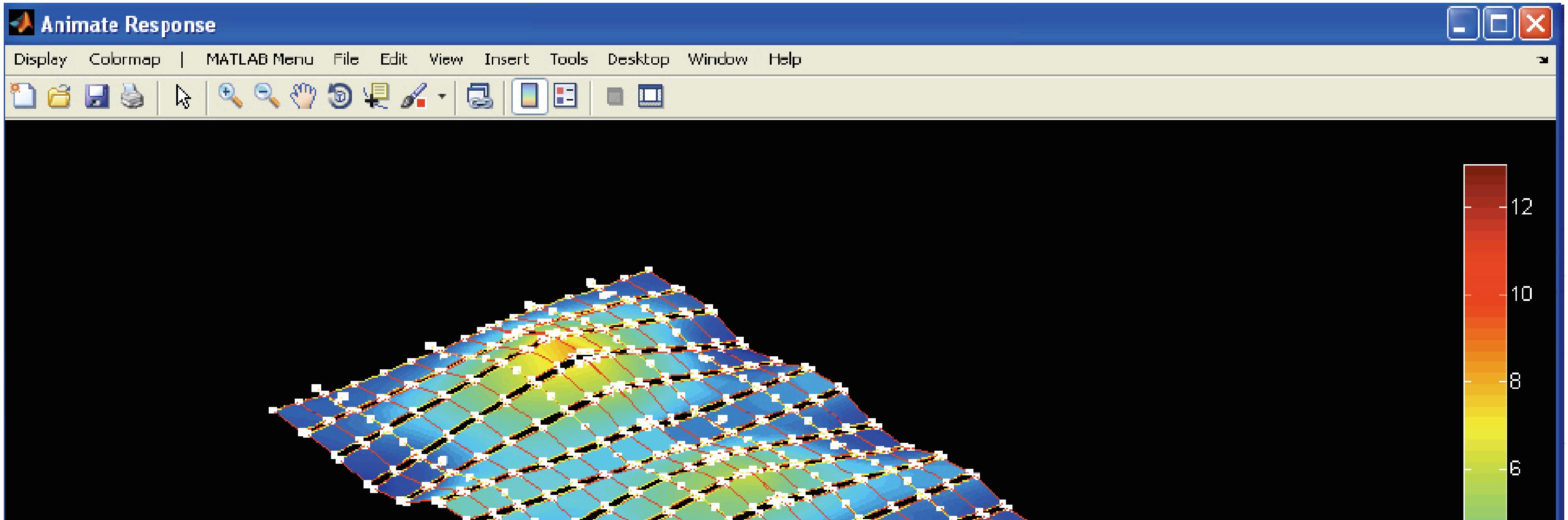


Run as 2D model for efficiency



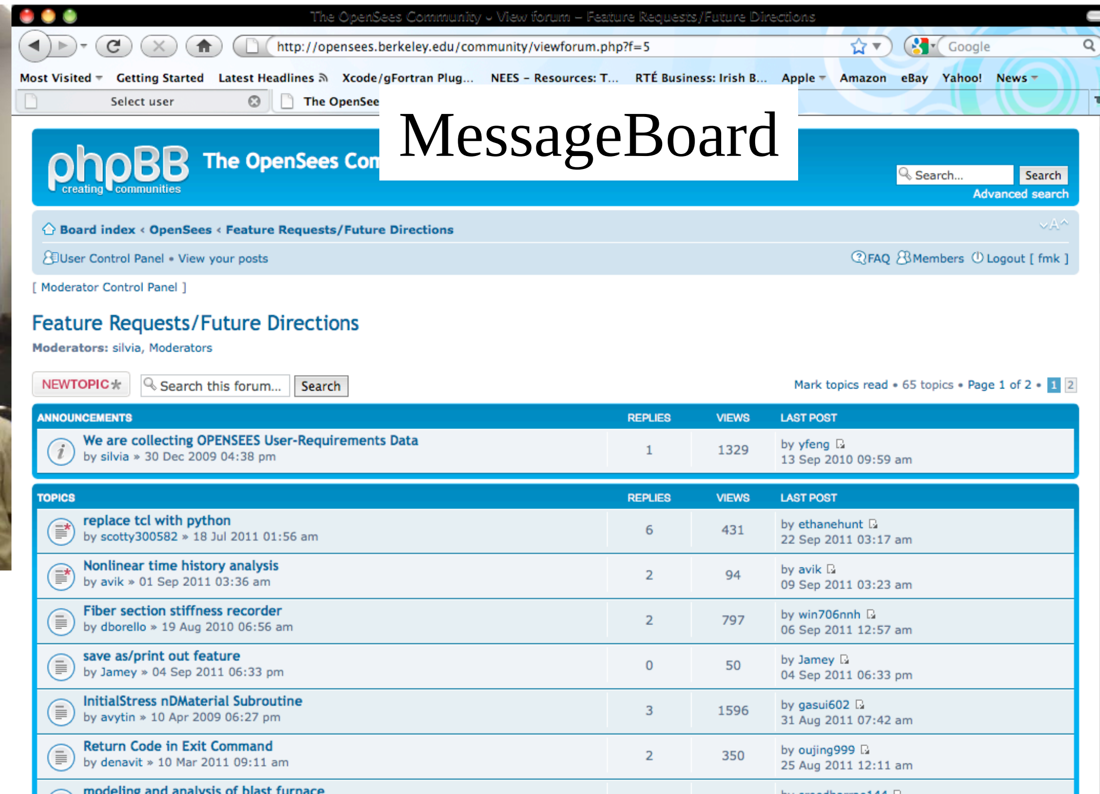
Solar Panels on a Flat Roof

QuickTime™ and a decompressor are needed to see this picture.



"To analyze 5 sec of wind history it took SAP2000 80 hours (and we did not even have the bolted connections modeled then). With OpenSees (not using any parallel processing capabilities yet) we can analyze 10 sec of wind history in ~90 min." [Andreas Schellenberg]

With Success Comes Problems
a.k.a - User & Developer Support

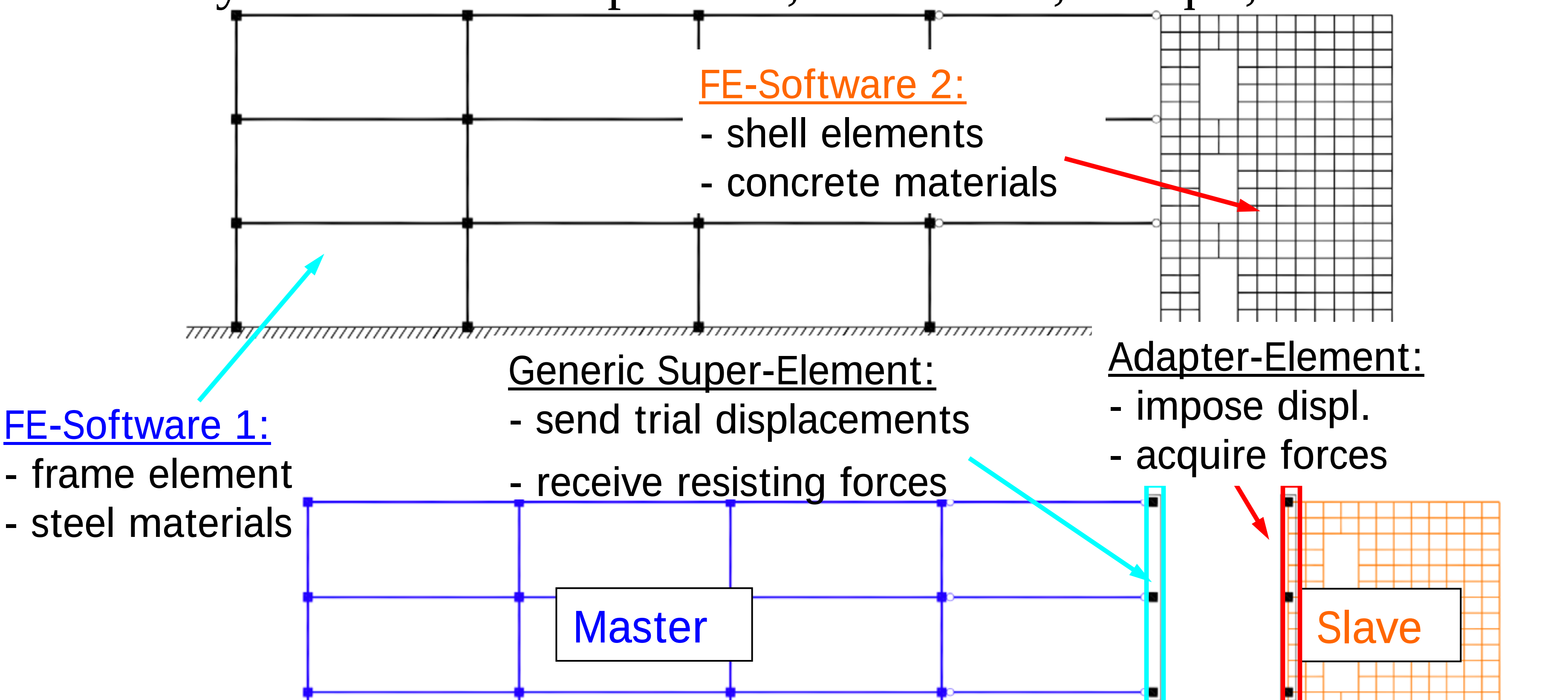


NEW for 2011: Web Based Seminar (http://neesmeetings.webex.com)
“Discovering OpenSees: Surfing the Waves of OpenSees”

WITH TODAY'S TECHNOLOGY IT DOES NOT HAVE TO BE ONE SIMULATION TOOL

OpenFresco (Andreas Schellenberg, Yuli Huang, Steve Mahin)

Allows you to combine OpenSees, LS-DYNA, Abaqus, and ANSYS



ABILITY TO DO MULTIPLE SCALES

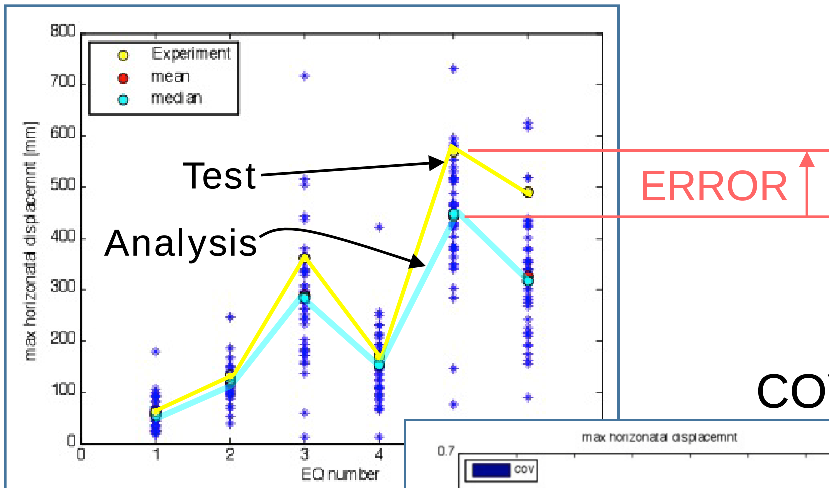
in Master FE-Software

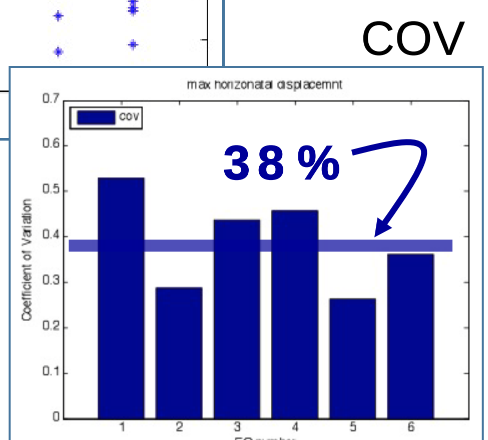
in Slave FE-Software

HOW GOOD ARE OUR SIMULATION TOOLS?

Behavior of Reinforced Concrete Columns

Tests undertaken to validate concepts and numerical models used in PBEE





41 expert teams participated

PEER-NEES RC Column Blind Analysis Contest - 2010

Full-scale 1D tests of circular column - Jose Restrepo, PI (PEER, Caltrans, UNR, FHWA, NEES@UCSD, NEEScomm & NSF)

OUR PREDICTIONS MUST INCLUDE MEASURES OF UNCERTAINTY

And I don't looking at the response of the analysis model when subjected to different ground motions

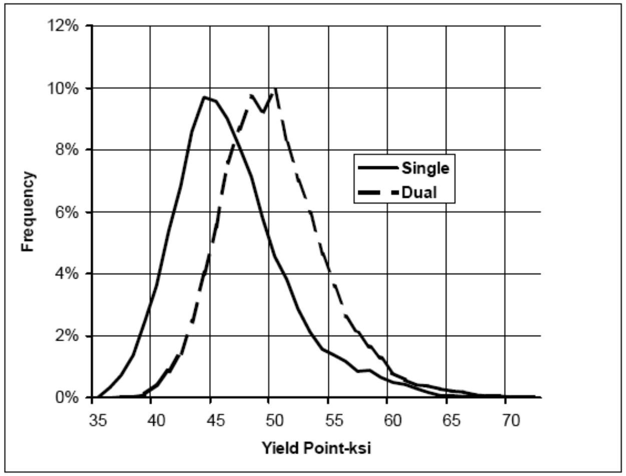


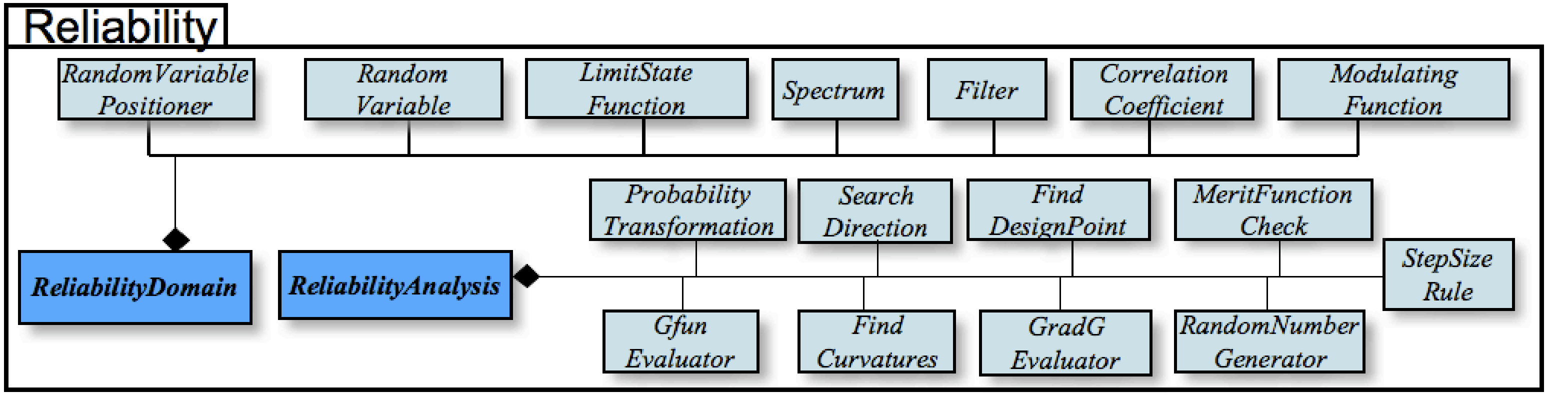
Figure 4-7 Yield Point Histogram of A36 Grade Material

Variation of Yield Strength A36 [FEMA-355A]

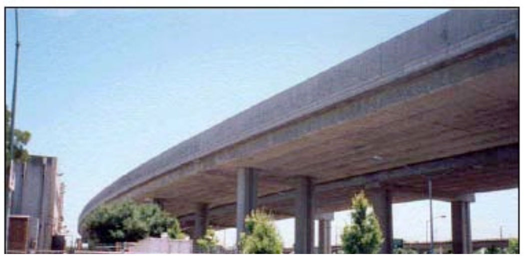
In a digital world I shouldn't need to go to a paper to find this! **Need to share experimental data**.

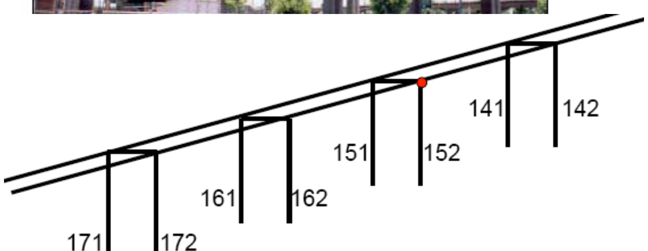
"The uncertainty is as important a part of the result as the estimate itself… An Estimate without a standard error is practically meaningless" [Jeffreys (1967)]

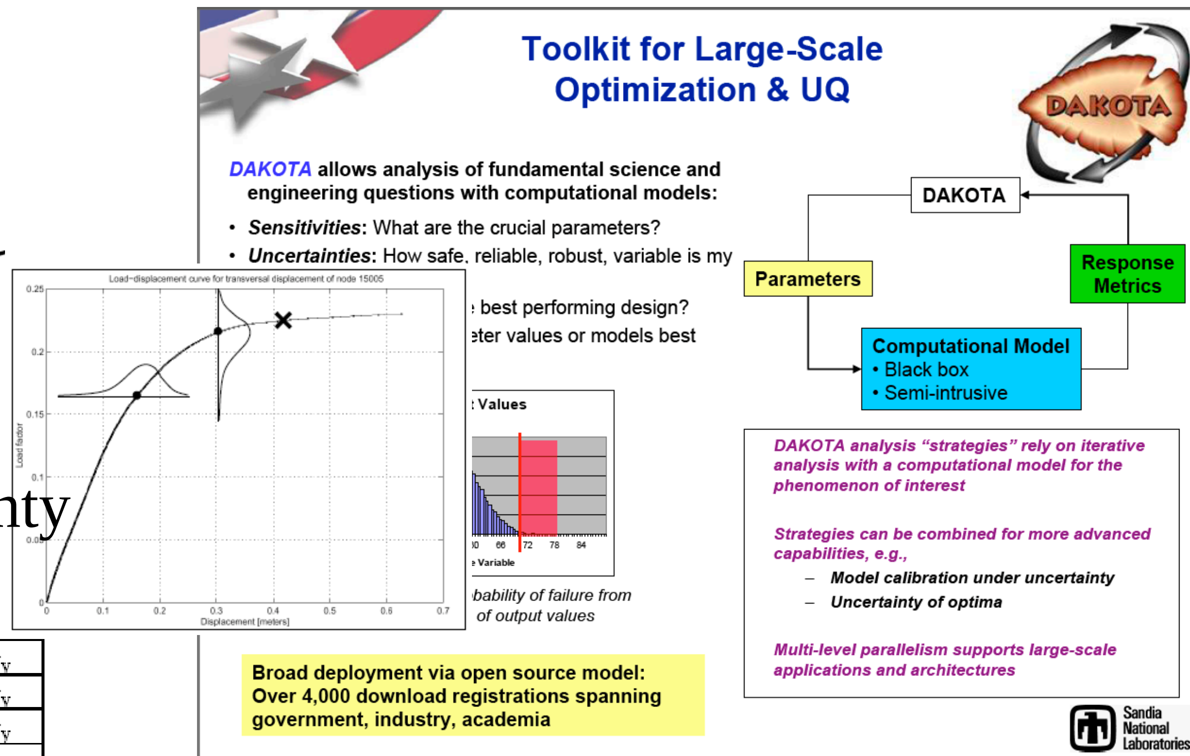
"With such high stakes, we must insist that the predictions include, concrete, quantifiable measures of uncertainty. In other words, we must know how good the predictions are" [Oden, Moser, Ghattas (2011)]



I-880 PEER Testbed project







Uncertainty

Sensitivity

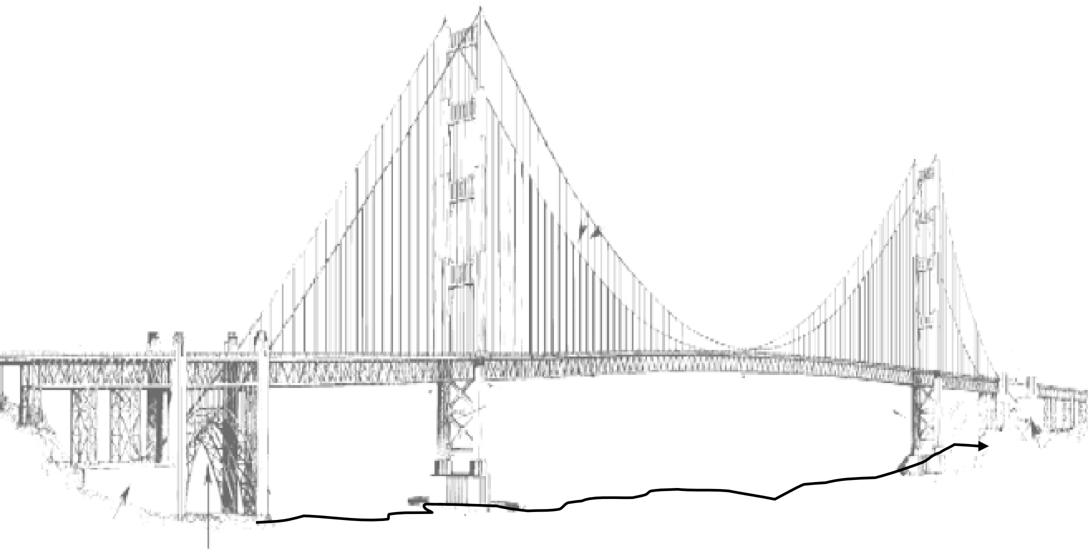
1	-0.603	Element	141	σ_y
2	-0.538	Element	142	σ_y
3	-0.280	Element	151	σ_y
4	0.240	Element	142	f'_c
5	0.232	Element	142	ε_{cu}
6	-0.188	Element	152	σ_y

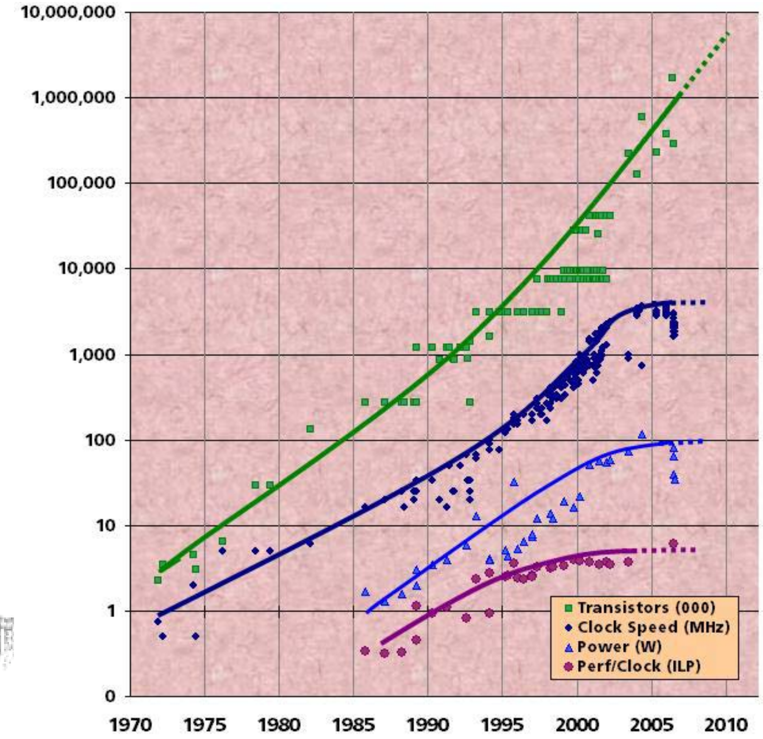
http://dakota.sandia.gov/index.html

The Generation of UQ requires more Computation (& it can be much much more)

I would argue that if your desktop computer represented the state of the art, you are actually only using a slide-rule!

Technology is Changing





Intel Processor Speed

Hardware

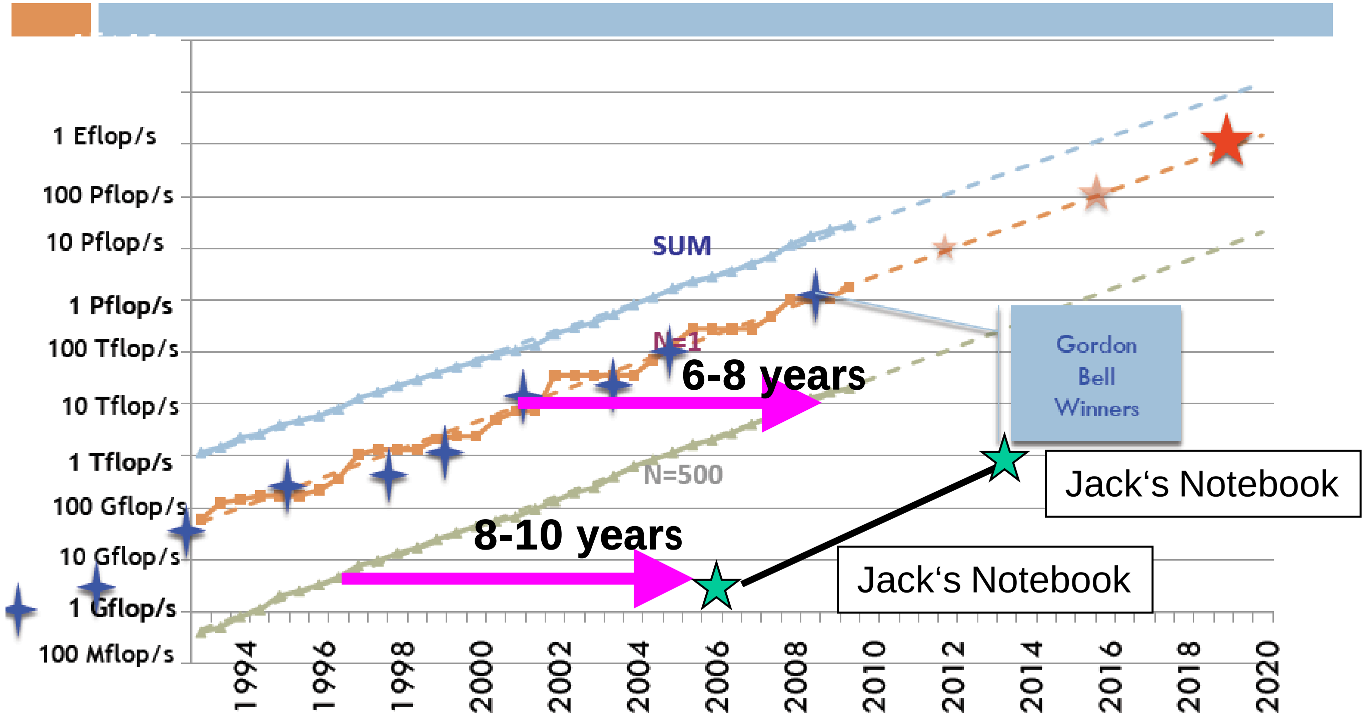
Your childs game (Wii, Xbox Playstation) has more raw numerical processing power than your desktop!

Nintendo Wii	61GFlops
Xbox360	355Glops
Sony PS3	2018Gflops

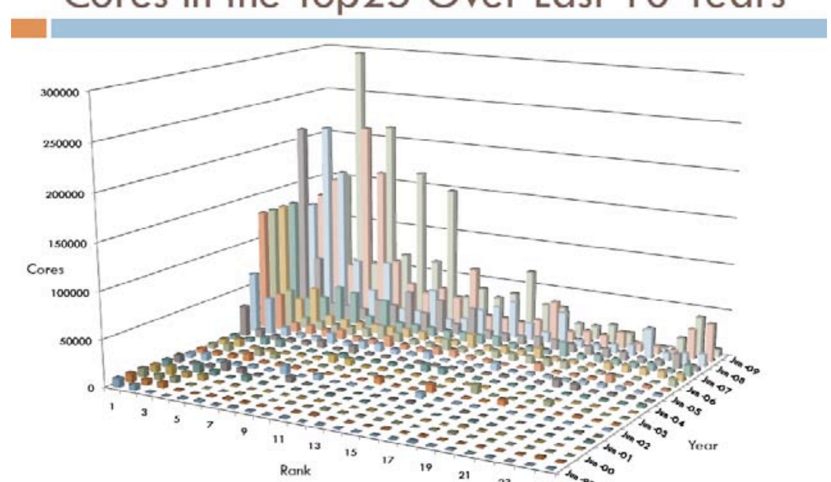
XeonE7Server	72Gflop
i7Desktop	55GFlop
i7Mobile	30GFlop
i5Desktop	40GFlop
i5Mobile	22GFlop
Core2 Extreme	52GFlop
Core2 Quad	48GFlop

Trends in Parallel Computing

(according to Jack)

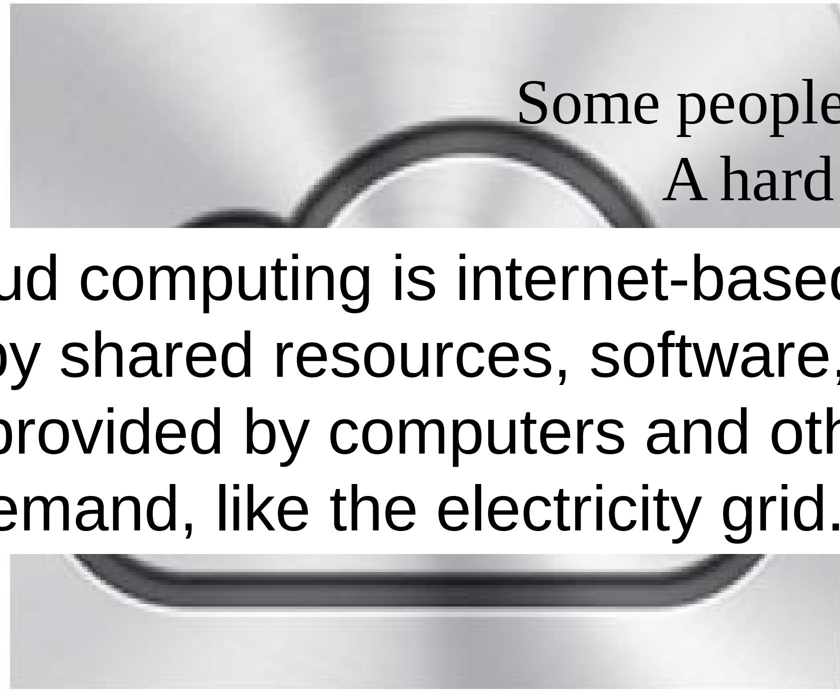


Cores in the Top25 Over Last 10 Years



- Hardware has changed drastically while software ecosystem has remained stagnant
- Community codes unprepared for sea change in architecture

Cloud Computing (according to Steve)



Some people think the cloud is just
A hard drive in the sky!

Cloud computing is internet-based computing , whereby shared resources, software, and information are provided by computers and other devices on demand, like the electricity grid. source: wikipedia

PC and Mac Demoted to a Device”

BEFORE YOU GET ALL EXCITED

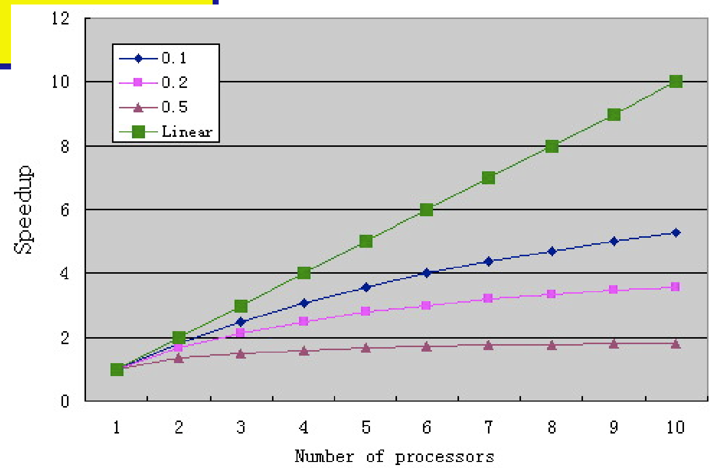
Speedup & Amdahl's Law

$$speedup_{PC}(p) = \frac{Time(1)}{Time(p)}$$

$$Speedup_{PC} = \frac{T_1}{\alpha T_1 + \frac{(1-\alpha)T_1}{n}} \rightarrow \frac{1}{\alpha} \ as \ n \rightarrow \infty$$

Portion of sequential

# of processors



Improving Real Performance

Peak Performance grows exponentially, a la Moore's Law

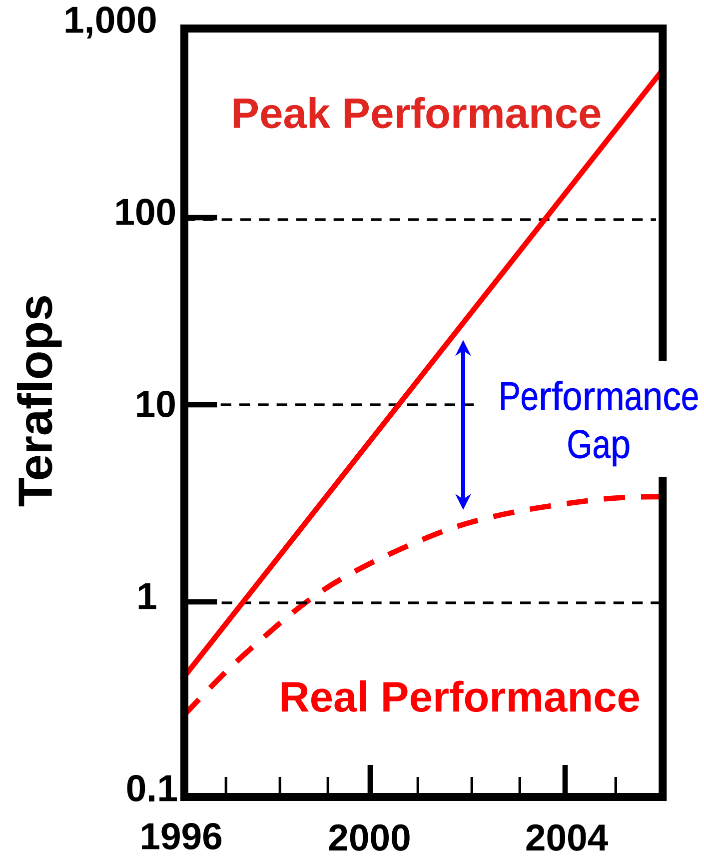
- In 1990's, peak performance increased 100x; in 2000's, it will increase 1000x

But efficiency (the performance relative to the hardware peak) has declined

- was 40-50% on the vector supercomputers of 1990s
- now as little as 5-10% on parallel supercomputers of today

Close the gap through ...

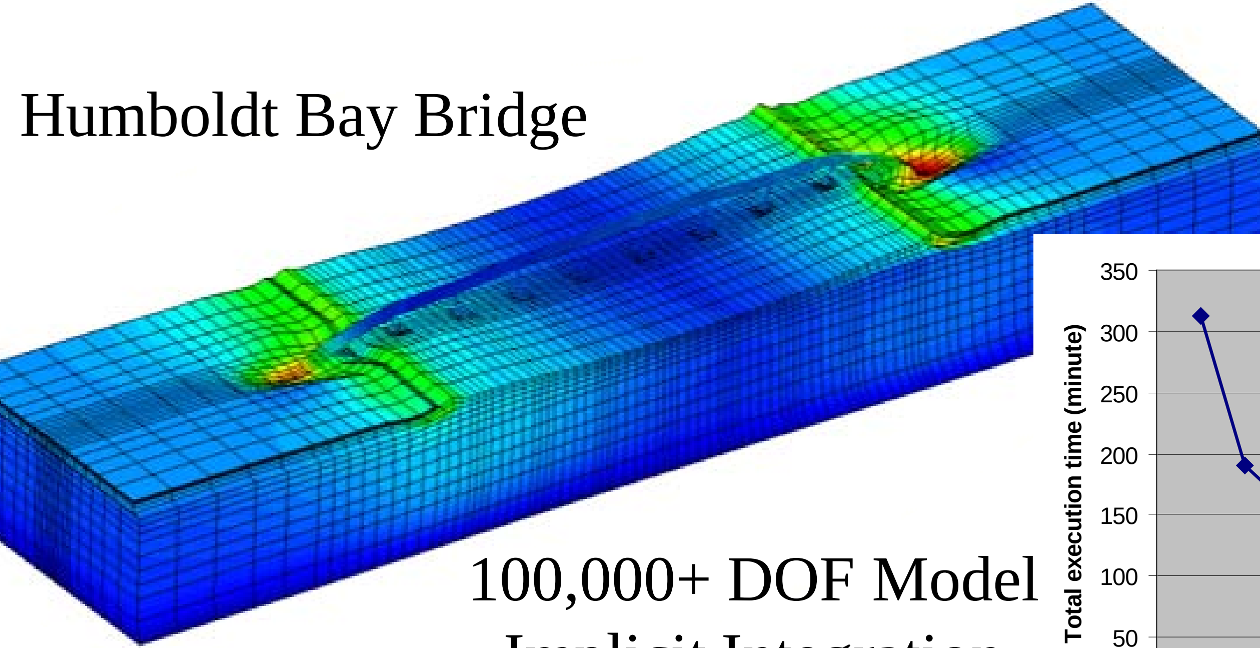
- Mathematical methods and algorithms that achieve high performance on a single processor and scale to thousands of processors
- More efficient programming models and tools for massively parallel supercomputers



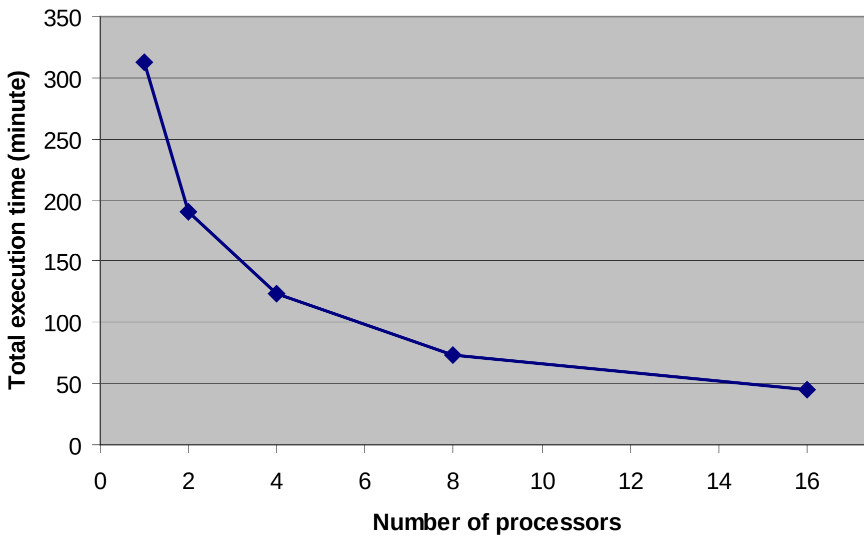
Source: Jim Demmell, CS267 Course Notes

OpenSees Parallel Examples

Humboldt Bay Bridge

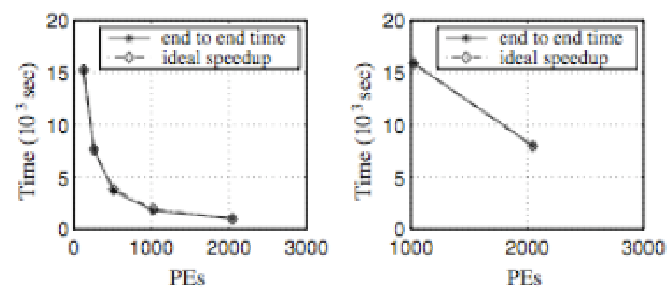


100,000+ DOF Model
Implicit Integration
Mumps Direct Solver



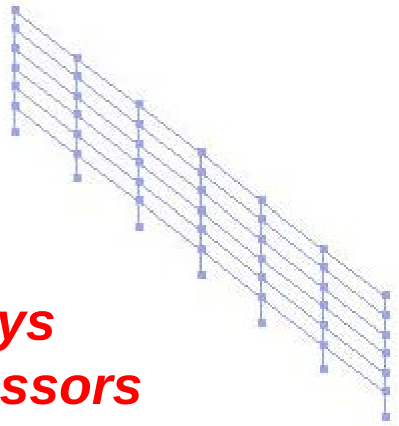
Made Up Continuum Model

Run	el. size (m)	Elements	Nodes	DOFs
A	20	54,026	59,032	156,768
B	10	404,751	424,512	1,193,283
C	5	3,130,301	3,208,822	9,307,563
D	2.5	24,615,801	24,928,842	73,515,123



Steel Building Study

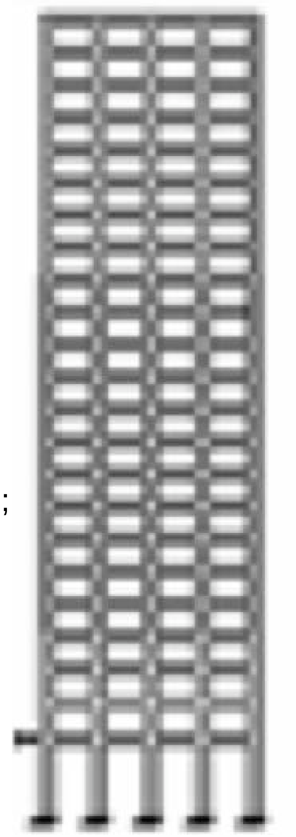
```
set pid [getPID]
set np [getNP]
set recordsFileID [open "peerRecords.txt" r]
set count 0;

foreach gMotion [split [read $recordsFileID] ¥n] {
  if {[expr $count % $np] == $pid} {

  source model.tcl
  source analysis.tcl

  set ok [doGravity]

  loadConst -time 0.0

  set gMotionList [split $gMotion "/"]
  set gMotionDir [lindex $gMotionList end-1]
  set gMotionNameInclAT2 [lindex $gMotionList end]
  set gMotionName [string range $gMotionNameInclAT2 0 end-4 ]

  set Gaccel "PeerDatabase $gMotionDir $gMotionName -accel 384.4 -dT dT -nPts nPts"
  pattern UniformExcitation 2 1 -accel $Gaccel

  recorder EnvelopeNode -file $gMotionDir$gMotionName.out -node 3 4 -dof 1 2 3 disp

  doDynamic [expr $dT*$nPts] $dT

   wipe
  }

  incr count 1;
}
```



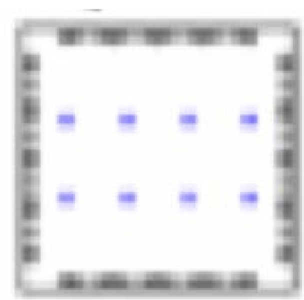
7200 records
2 min a record
240 hours or 10 days
Ran on 2000 processors
on teragrid in less than 15 min.

Concrete Building Study

```
set pid [getPID]
set np [getNP]
set count 0;
source parameters.tcl
source ReadSMDFileNewFormat.tcl;
foreach GMfile $iGMFile {
    foreach Factor1248 $iFactor1248 {

        if {[expr $count % $np] == $pid} {

            set inFile $GMdir/$GMfile.AT2
            set outFile $GMdir/$GMfile.g3;
            ReadSMDFileNewFormat $inFile $outFile dt npts;

            wipe
            source GravityAnalysisScript.tcl

            loadConst -time 0.0;
            wipeAnalysis

            source  EQ_Recorder.tcl
            source EQAnalysisScript.tcl

           if {$ok == 0} {
                puts "Process $pid $GMfile x $Factor1248 FINISHED OK modelTime [getTime]]"
            } else {
                puts "Process $pid $GMfile x $Factor1248 FINISHED FAIL modeTime [getTime] desiredTime $TmaxAnalysis]"
            }
            incr count 1
        }
    }
}
```



113 records, 4 intensities
3 hour a record, would have taken 1356 hours or 56.5 days
Ran on 452 processors of a Teragrid in less than 5 hours.



OpenSees in the clouds using Open Science Grid

André R. Barbosa, Joel P. Conte, and José I. Restrepo, ***UCSD***

❑ Motivation

- Perform parametric studies that involve large-scale nonlinear models of structure or soil-structure systems with large number of parameters and OpenSees runs.

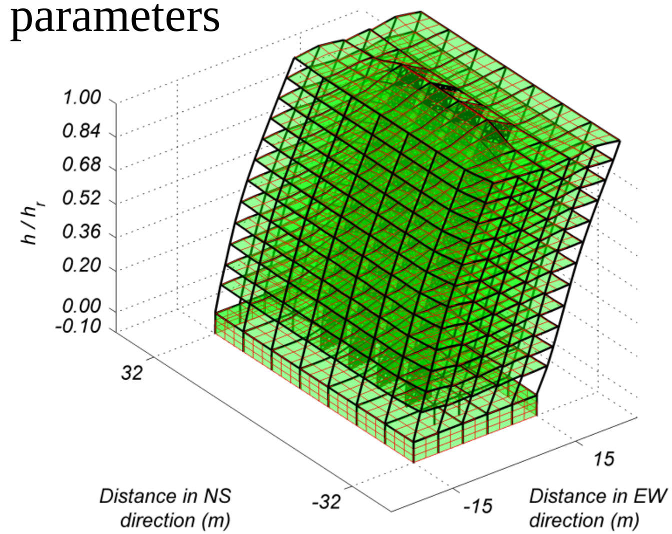
OpenSees

❑ Application example

- Nonlinear time-history (NLTH) analyses of advanced nonlinear FE model of a building
- Probabilistic seismic demand hazard analysis making use of the "cloud method"
  - 90 bi-directional historical earthquake records (unscaled and scaled by a factor of two)
- Sensitivity of probabilistic seismic demand to FE model parameters

❑ Some numbers

Number of NLTH analyses per parameter set realization	180
Average duration of NLTH analysis	12 hours
Average size of output data	1.5 GB
Parameters considered	6
Perturbations considered	4
Estimated clock time (180x12x[(6x4x2)+1])	**106,800 hours (12.2 years)**
Estimated output data (180x1.5x[(6x4x2)+1])	**12 TB**

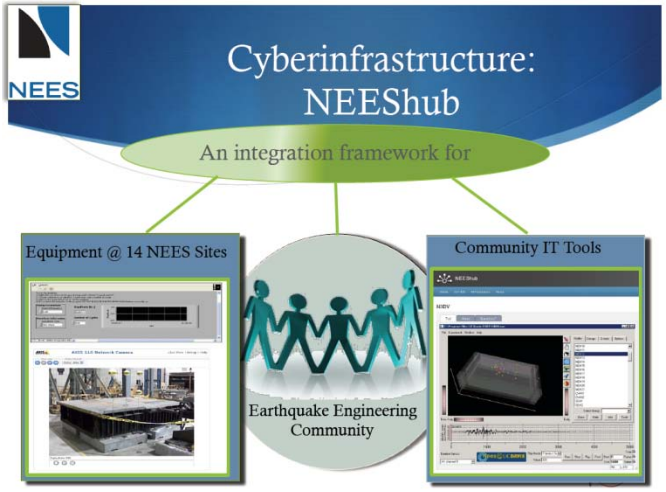


Open Science Grid

30 days on OSG versus 12 years on Desktop!

NEEShub

- The power behind NEES at http://nees.org
- Maintained and developed at Purdue by NEEScomm
- Built using proven HUBzero technology (nanoHUb > 100,000 users)
- A science gateway for education and research in earthquake engineering

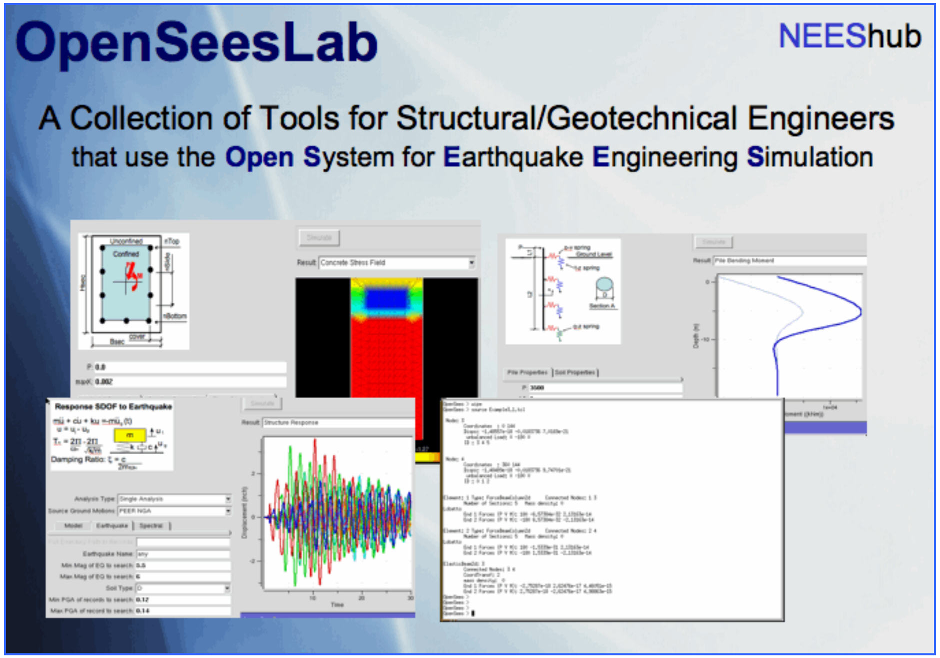


Through a browser engineers can:

- Upload and view experimental data
- Browse online seminars and courses
- Launch sophisticated tools using remote computational resources (OpenSeesLab)

The OpenSeesLab tool:

http://nees.org/resources/tools/openseeslab



Is a suite of Simulation Tools powered by OpnSees for:

1. Submitting OpenSees scripts (input files) to HUB resources
2. Educating students and practicing engineers
3. Performing useful tasks

OpenSees Interpreter Tool

hub

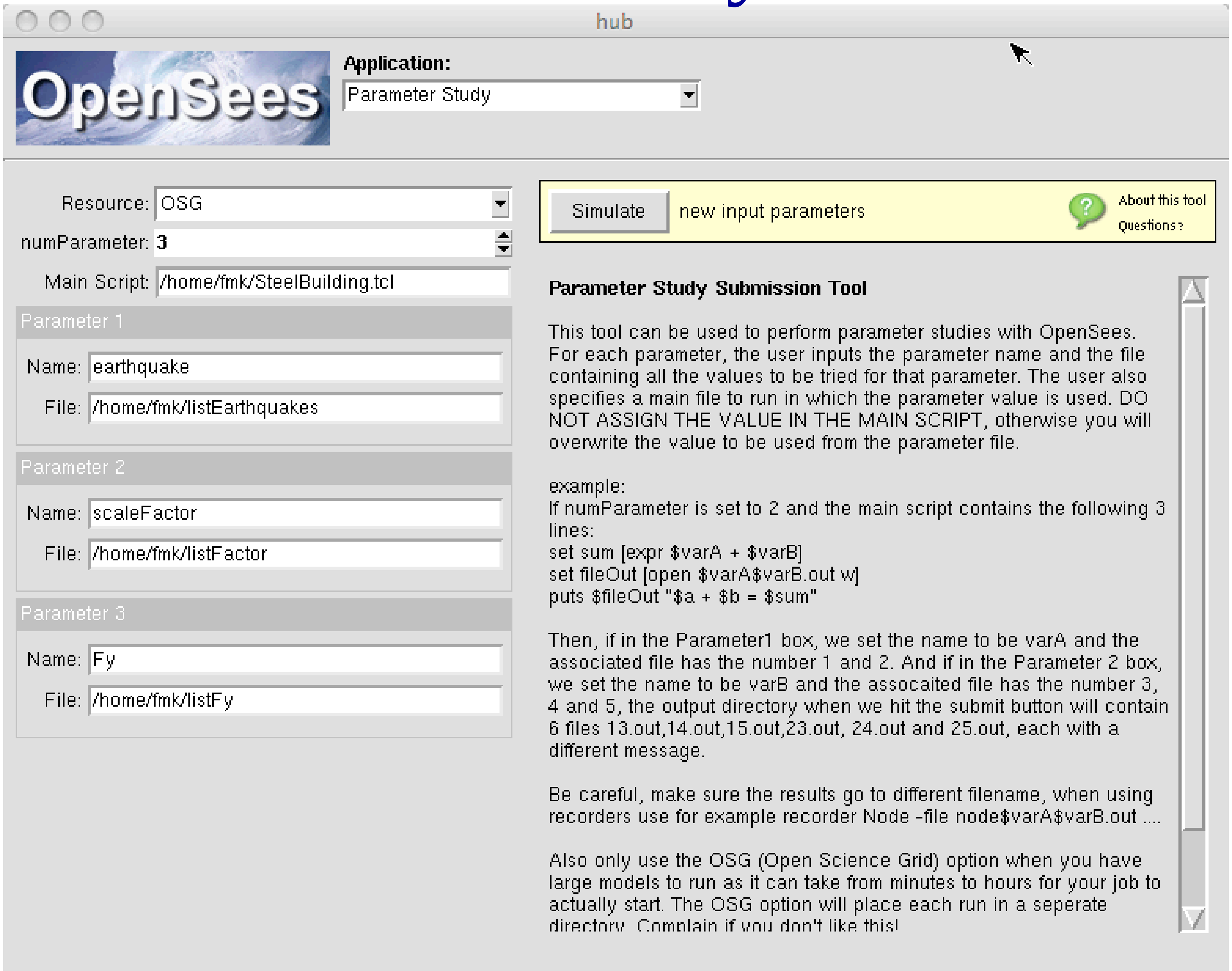
Java Applet Window

OpenSees

Application: OpenSees Interpreter

```
        OpenSees -- Open System For Earthquake Engineering Simulation
       Pacific Earthquake Engineering Research Center -- 2.2.1

           (c) Copyright 1999,2000 The Regents of the University of California
                                 All Rights Reserved
    (Copyright and Disclaimer @ http://www.berkeley.edu/OpenSees/copyright.html)


OpenSees > tar xBf A_Example.tar
OpenSees > cd A_Example
OpenSees > source Ex8.tcl
couldn't read file "Ex8.tcl": no such file or directory
OpenSees > ls
A8.tcl
ExampleSP1.tcl
Node.out
analysis.tcl
model.tcl
peerRecords.txt
OpenSees > source A8.tcl
WARNING analysis Transient dt tFinal - no LinearSOE specified,
 ProfileSPDLinSOE default will be used

 Node: 525
        Coordinates  : 1 1 10
        Disps: 0.00977277 0.00977277 -0.00409793
        Velocities   : 0.0141832 0.0141832 -0.00878414
        commitAccels: 0.128284 0.128284 0.228457
         unbalanced Load: 0 0 0
        ID : 0 1 2

Simulation Time 192
OpenSees > cd ..
OpenSees > tar cBf A_Example.tar A_Example
OpenSees >
```

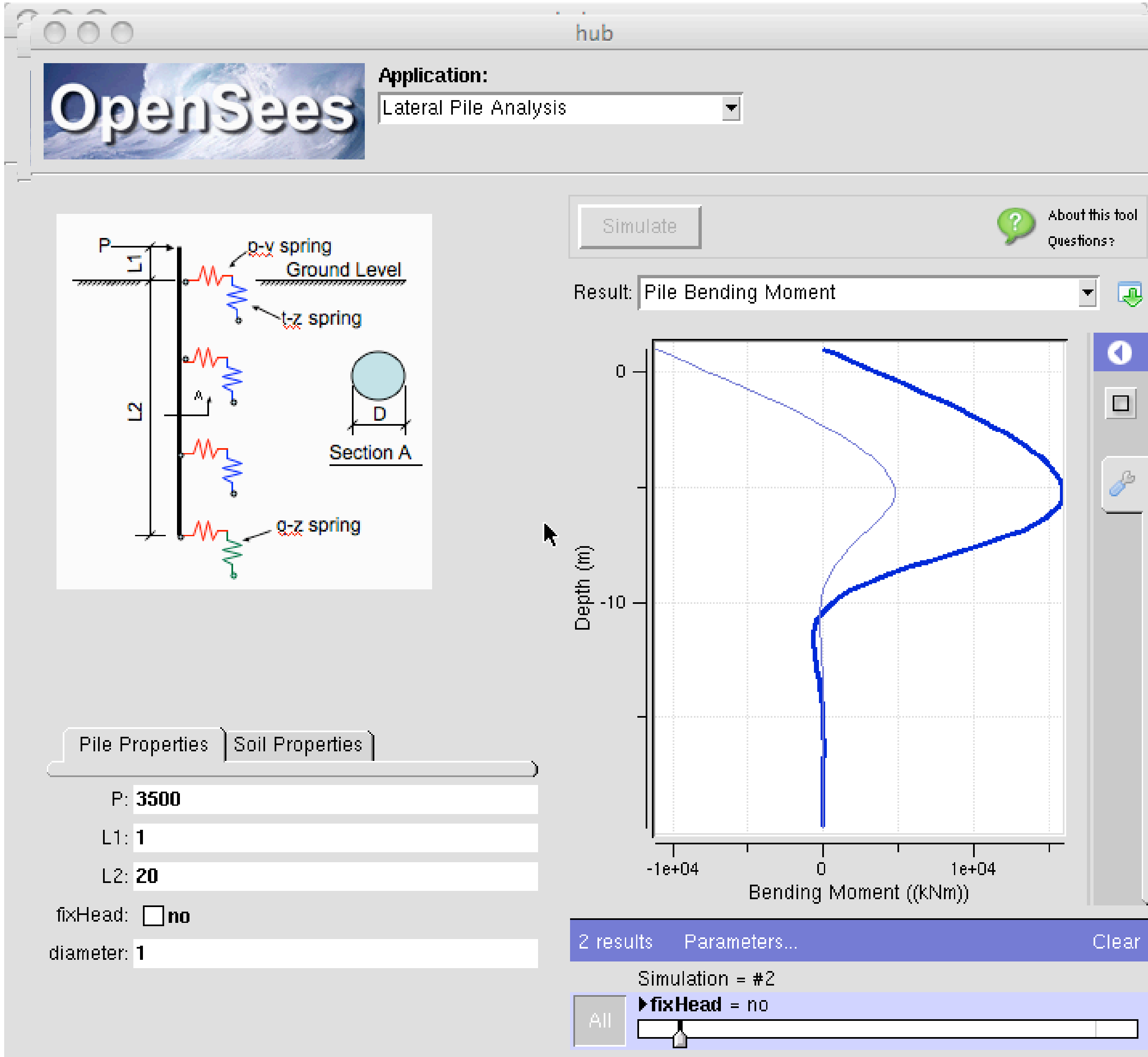
Parameter Study Tool



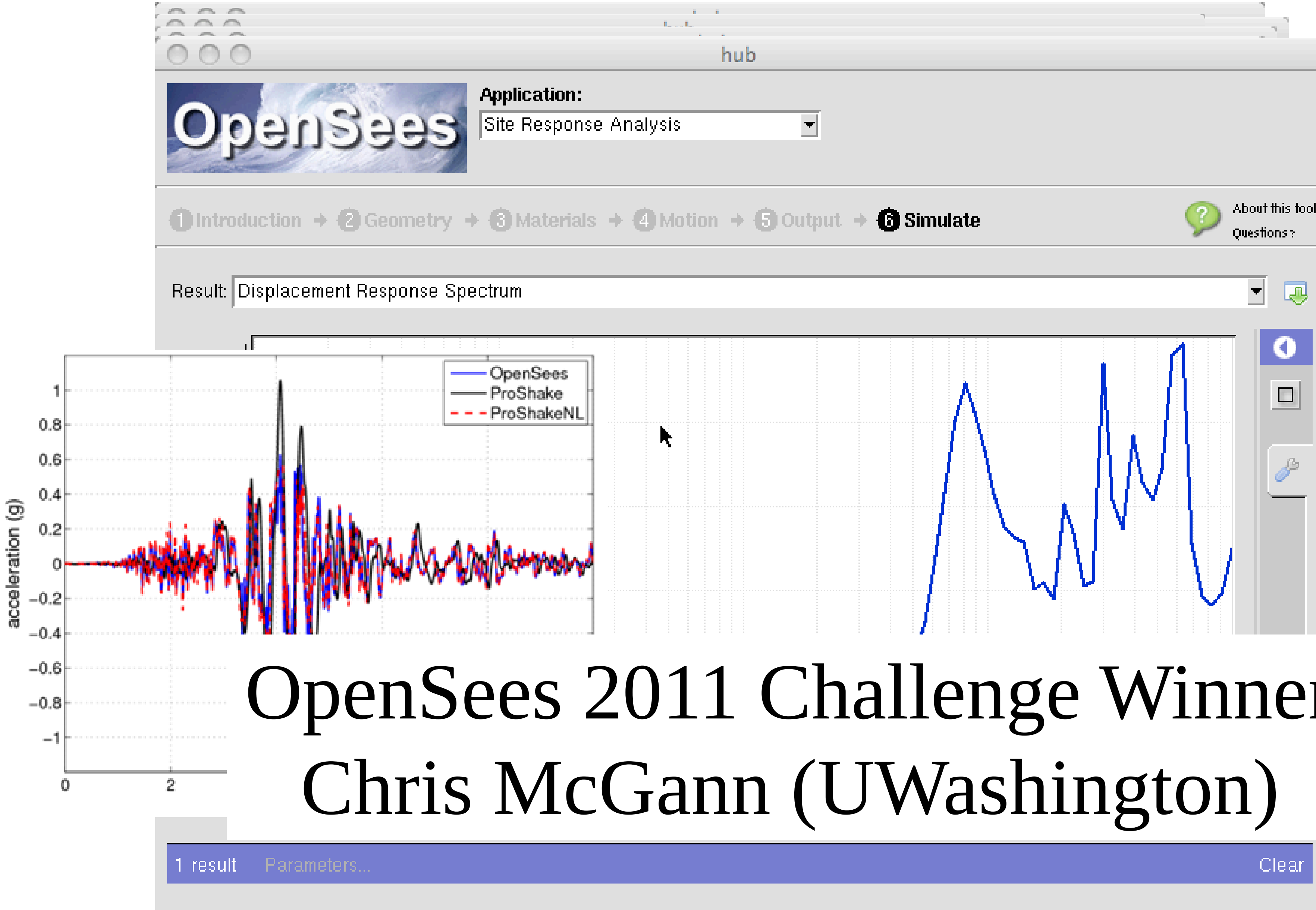
Lateral Pile Analysis

http://opensees.berkeley.edu/wiki/index.php/Laterally-Loaded_Pile_Foundation

Chris McGann U. Washington



Site Response Analysis



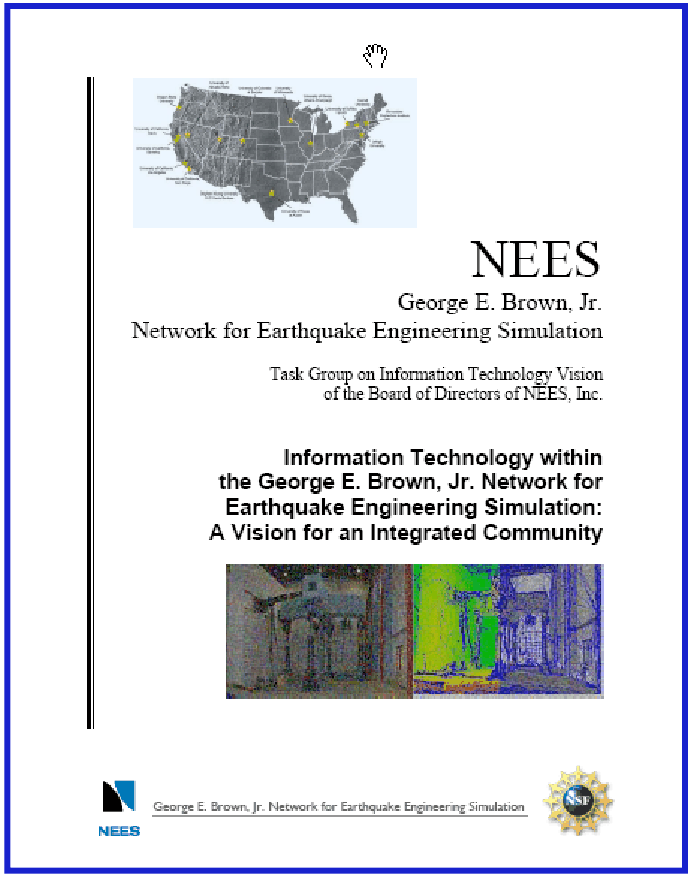
OpenSees 2011 Challenge Winner

Chris McGann (UWashington)

OpenSees Challenge 2012

At next years OpenSees Days Workshop (late August or early Sept), **I** will award an iPod to the person (anyone other than myself) who submits the best **OpenSees powered app** to NEEShub. Winner will be judged by Workshop participants.

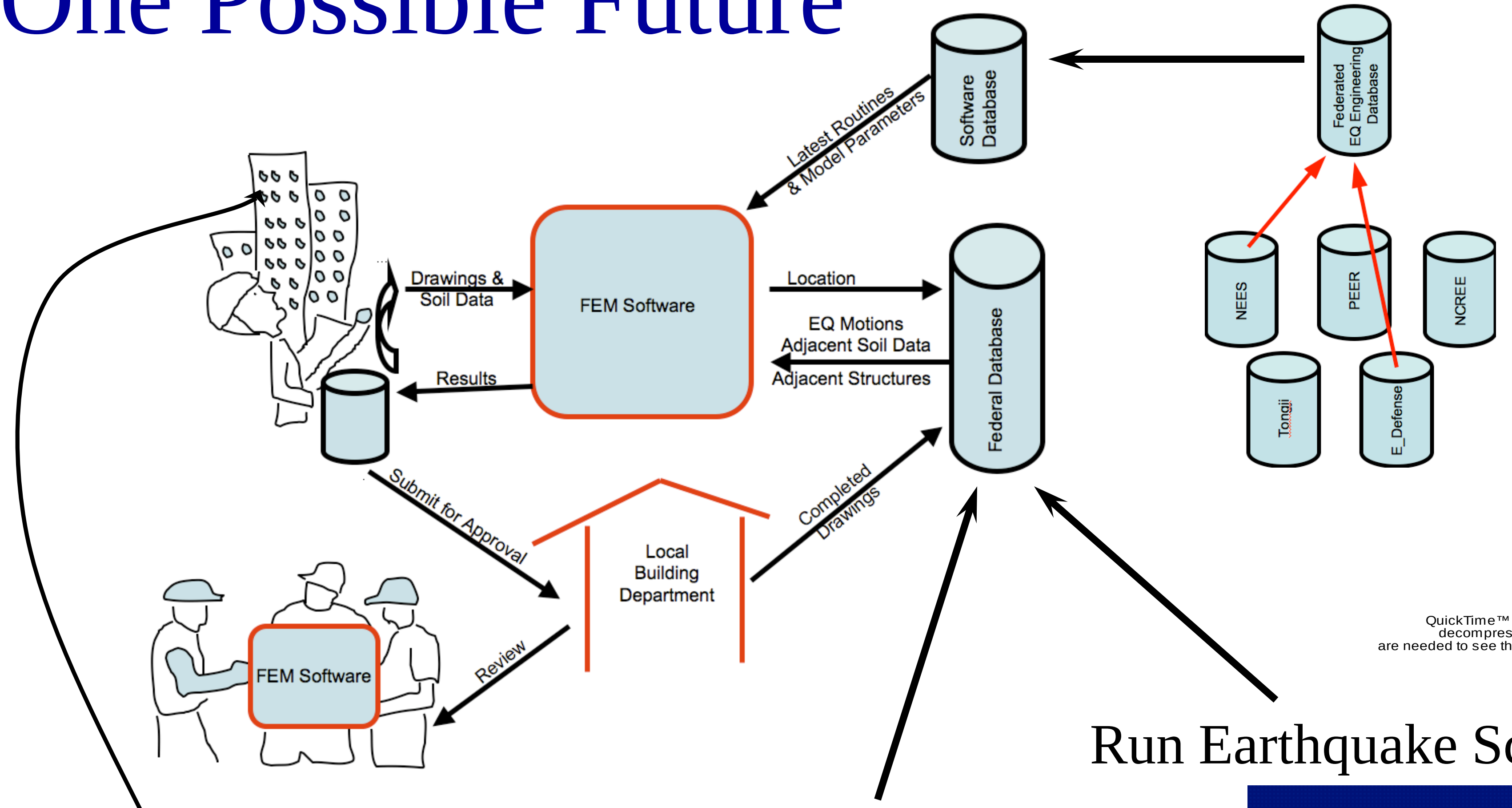
Vision for Computational Simulation



Computational modeling and simulation is central to the vision of NEES to transform the development of new earthquake engineering solutions from being primarily based on experiments to a balanced use of simulation and experimentation using computational models validated by experimental data.

A close integration of modern computational models and simulation software with other NEES applications and services will provide the earthquake engineering community, and broad engineering users, new capabilities for developing innovative and cost-effective solutions.

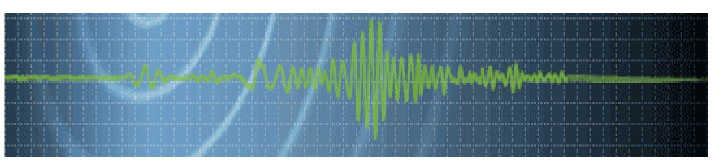
One Possible Future



QuickTime™ and a decompressor are needed to see this picture.

Run Earthquake Scenario

QuickTime™ and a decompressor are needed to see this picture.



Detects EQ - back calculates fault scenario, rupture to rafters analysis & causes EQ alarm in vulnerable buildings to sound!

Simulation Session Tomorrow

1.00-3.30
Boiler Room B

Any Questions?