

Computational Simulation

Frank McKenna
UC Berkeley

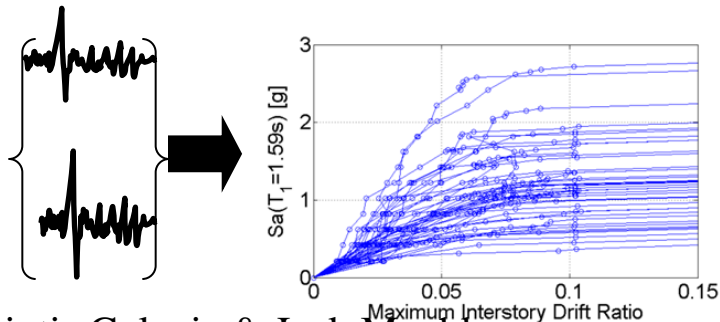
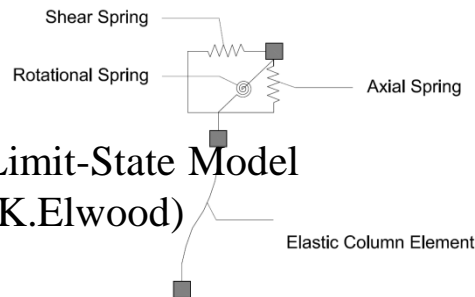
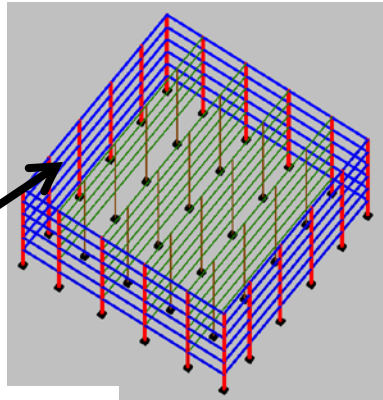
QuickTime™ and a
decompressor
are needed to see this picture.



Current Simulation Examples

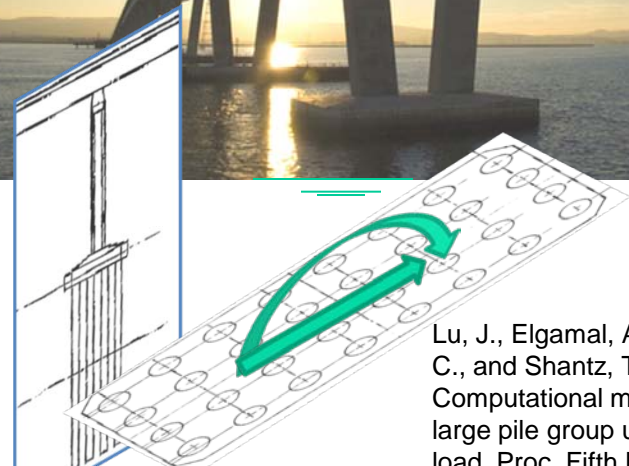
Perimeter
Moment
Resisting
Frame

Interior
Gravity
Frame

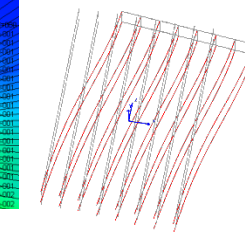
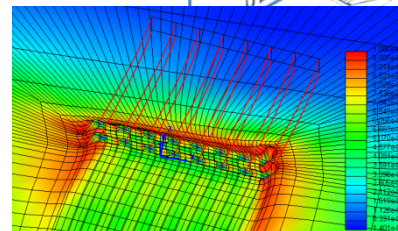


Panagiotis Galanis & Jack Moehle

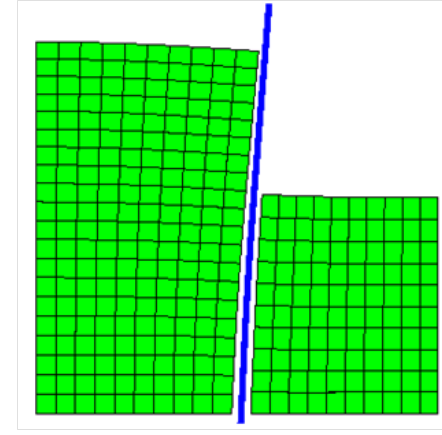
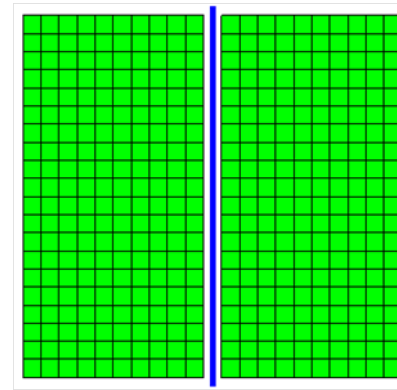
ATC 78: Assessment of Collapse Risk of Existing Reinforced Concrete Buildings



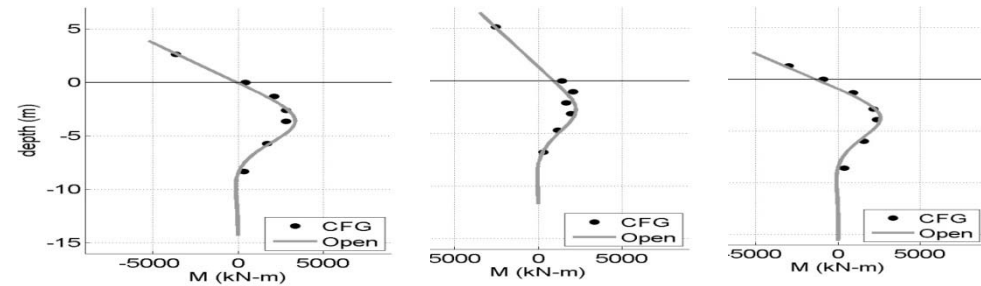
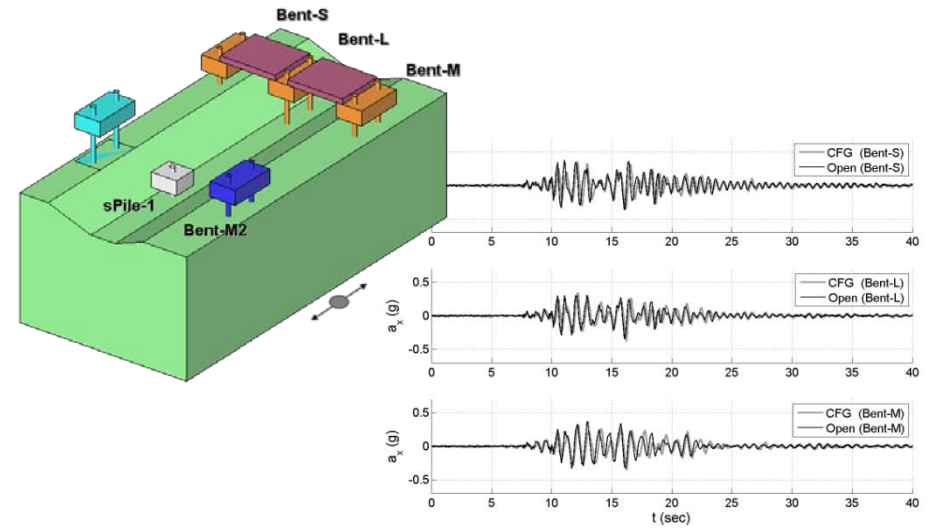
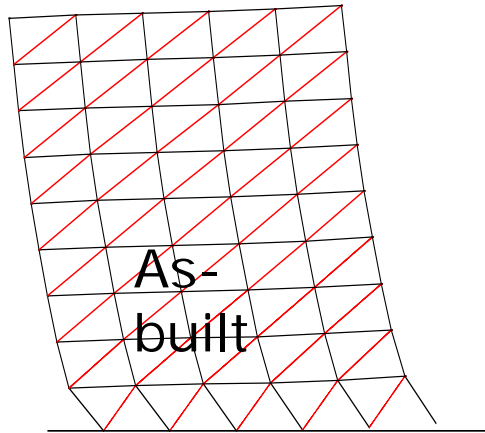
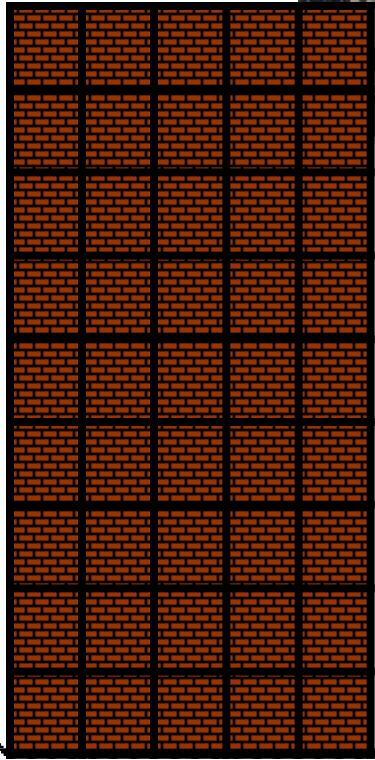
Lu, J., Elgamal, A., Sikorsky, C., and Shantz, T. (2010). Computational modeling of a large pile group under lateral load, Proc. Fifth Intl. Conf. on Recent Advances in Technical Earthquake Engineering and Soil Dynamics, 24-29, San Diego, CA



Jinchi Lu & Ahmed Elgamal



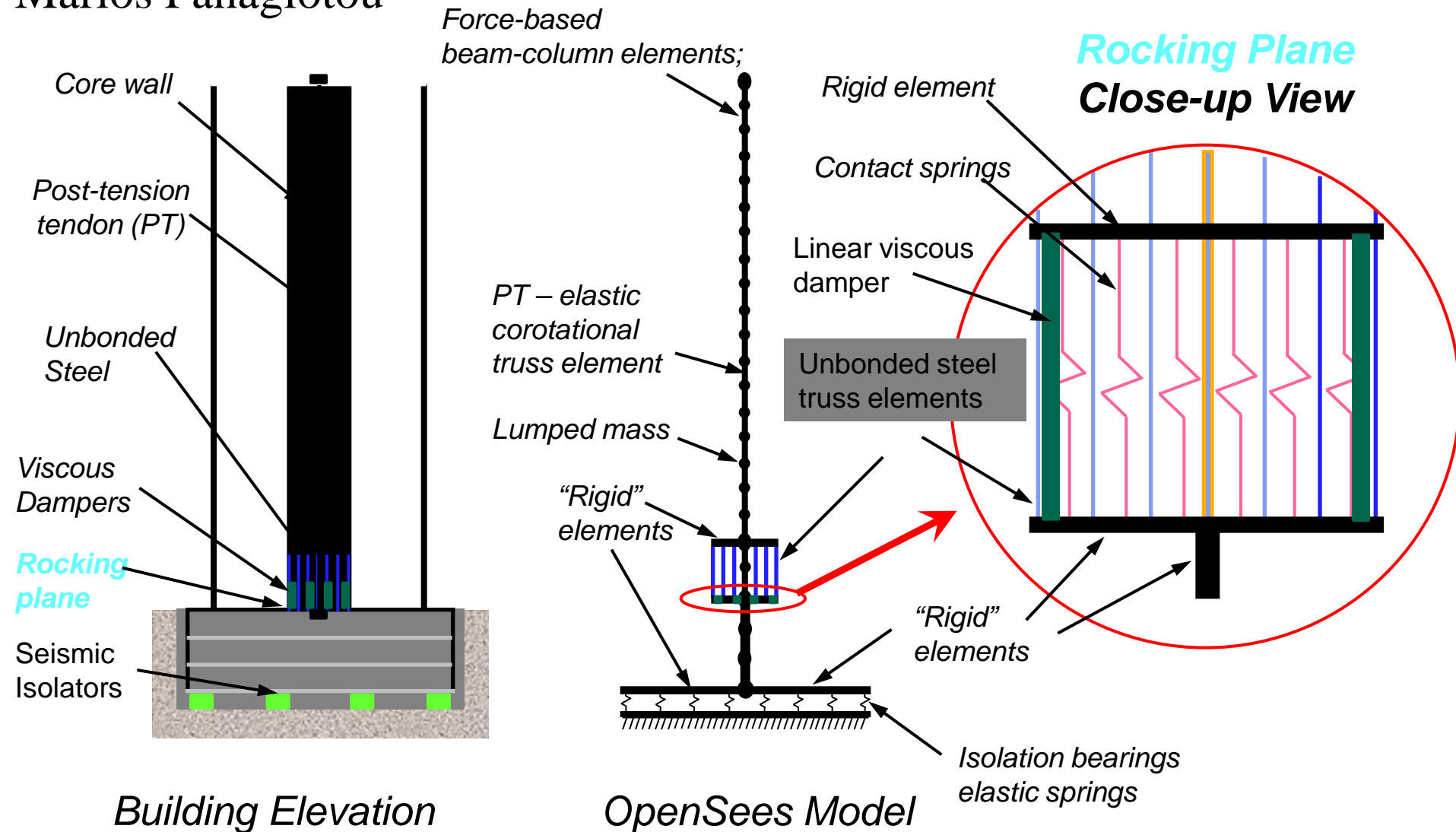
Pedro Arduino



M.Talaat & K.Mosalam

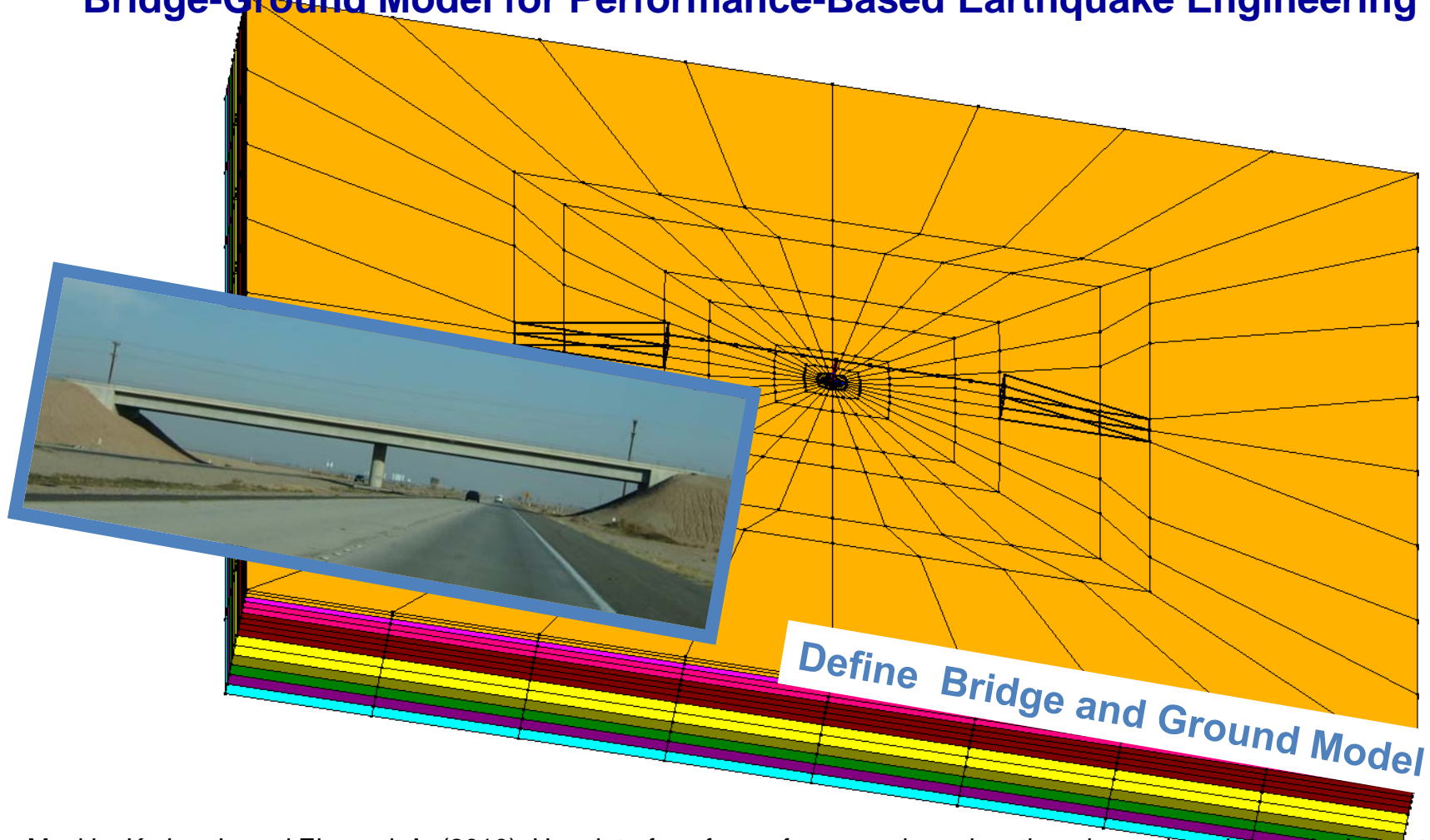
20-story Building with Base Isolation and Rocking Core Wall

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 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>

The screenshot shows the OpenSees website homepage. At the top, there is a navigation bar with links: HOME, USER, DEVELOPER, PROJECTS, SUPPORT, and SITE MAP. Below this is a secondary navigation bar with links: About, News, Calendar, and Registration. The main content area is divided into three columns. The left column contains links: HOME, MESSAGE BOARD, USER DOC, DOWNLOAD, SOURCE CODE, and BUG REPORT. The middle column contains a 'Welcome' section with a paragraph about the software framework, a paragraph about the goal of the development, a paragraph about the continual development and updates, and a paragraph about the development and application of OpenSees. The right column contains a 'Register' section with a paragraph about new releases and a 'News' section with a list of recent updates. The footer contains logos for PEER and NEES.

OpenSees PEER NEES NEESit

HOME USER DEVELOPER PROJECTS SUPPORT SITE MAP

About News Calendar Registration

HOME

MESSAGE BOARD

[USER DOC](#)

[DOWNLOAD](#)

[SOURCE CODE](#)

[BUG REPORT](#)

To customize the quicklinks, go to [Site Map](#)

PEER

NEESit NEES

Welcome

Welcome to the website for OpenSees, a software framework for developing applications to simulate the performance of structural and geotechnical systems subjected to earthquakes.

The goal of the OpenSees development is to improve the modeling and computational simulation in earthquake engineering through open-source development.

OpenSees is in under continual development, so users and developers should expect changes and updates on a regular basis. In this sense, all users are developers so it is important to [register](#). More information on [Open Source](#) is available.

The development and application of OpenSees is sponsored by the [Pacific Earthquake Engineering Research Center](#) through the [National Science Foundation](#) engineering and education centers program.

OpenSees has been selected as the simulation component for the [George E. Brown, Jr. Network for Earthquake Engineering Simulation](#) in the [NEESgrid System Integration Project](#). Ongoing work to integrate OpenSees into NEESgrid includes a web-based portal for simulation services

Register

For information about new releases we encourage you to register with us at the [OpenSees Registration Center](#).

News

2006-12-01 [New Examples Manual](#) released.

2006-09-01 [Version 1.7.3 Released](#).

2006-08-25 [Workshop Presentation Material Node Available](#).

2006-06-06 [Version 1.7.2 Released](#)

2006-05-15 [Copyright Revised](#).

2006-02-18 [Version 1.7.1 Released](#).

2005-11-01 [Server Running Again](#).

Calendar

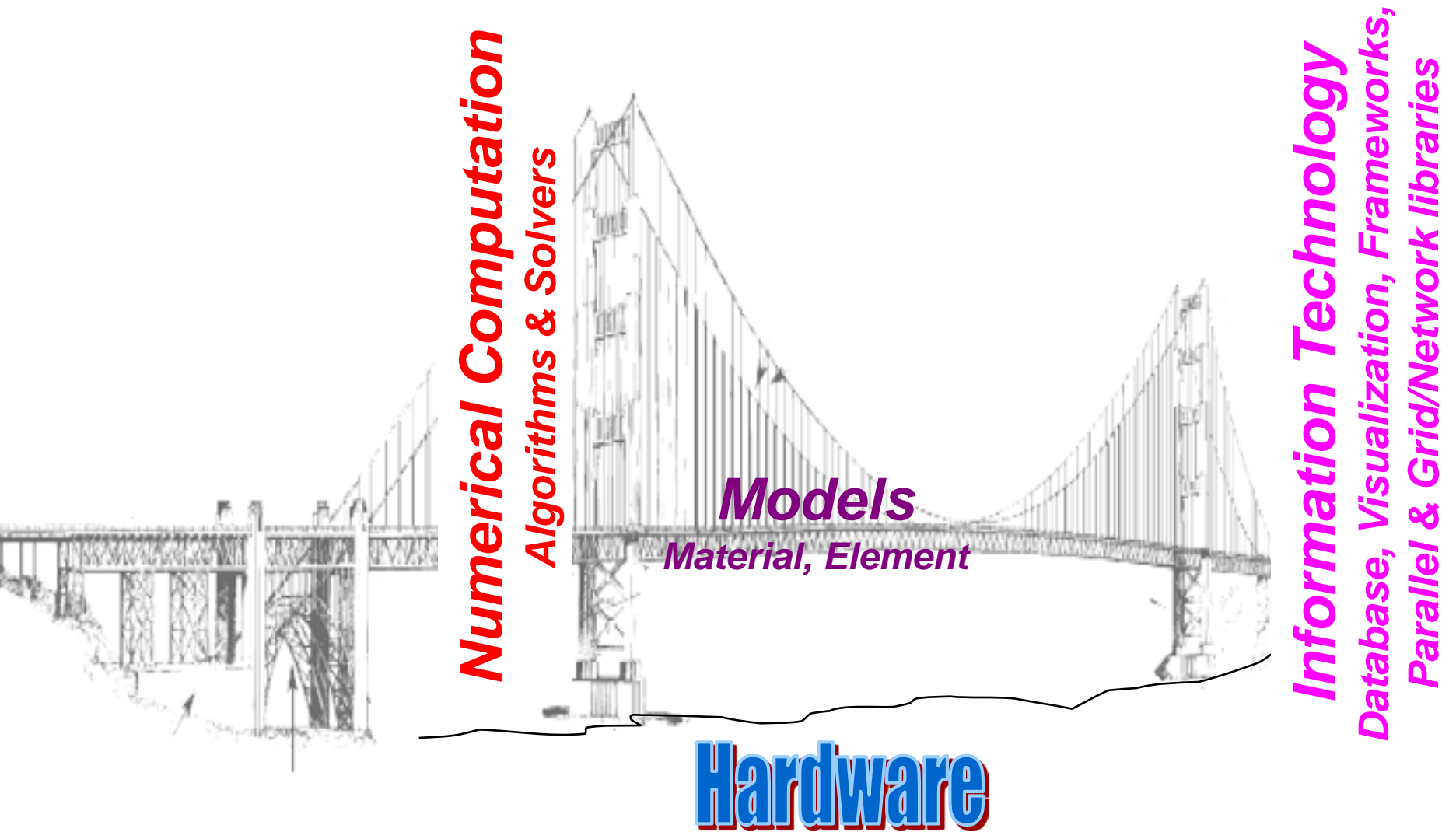
2006-09-16 [OpenSees Symposium](#)

2006-09- [OpenSees Developer](#)

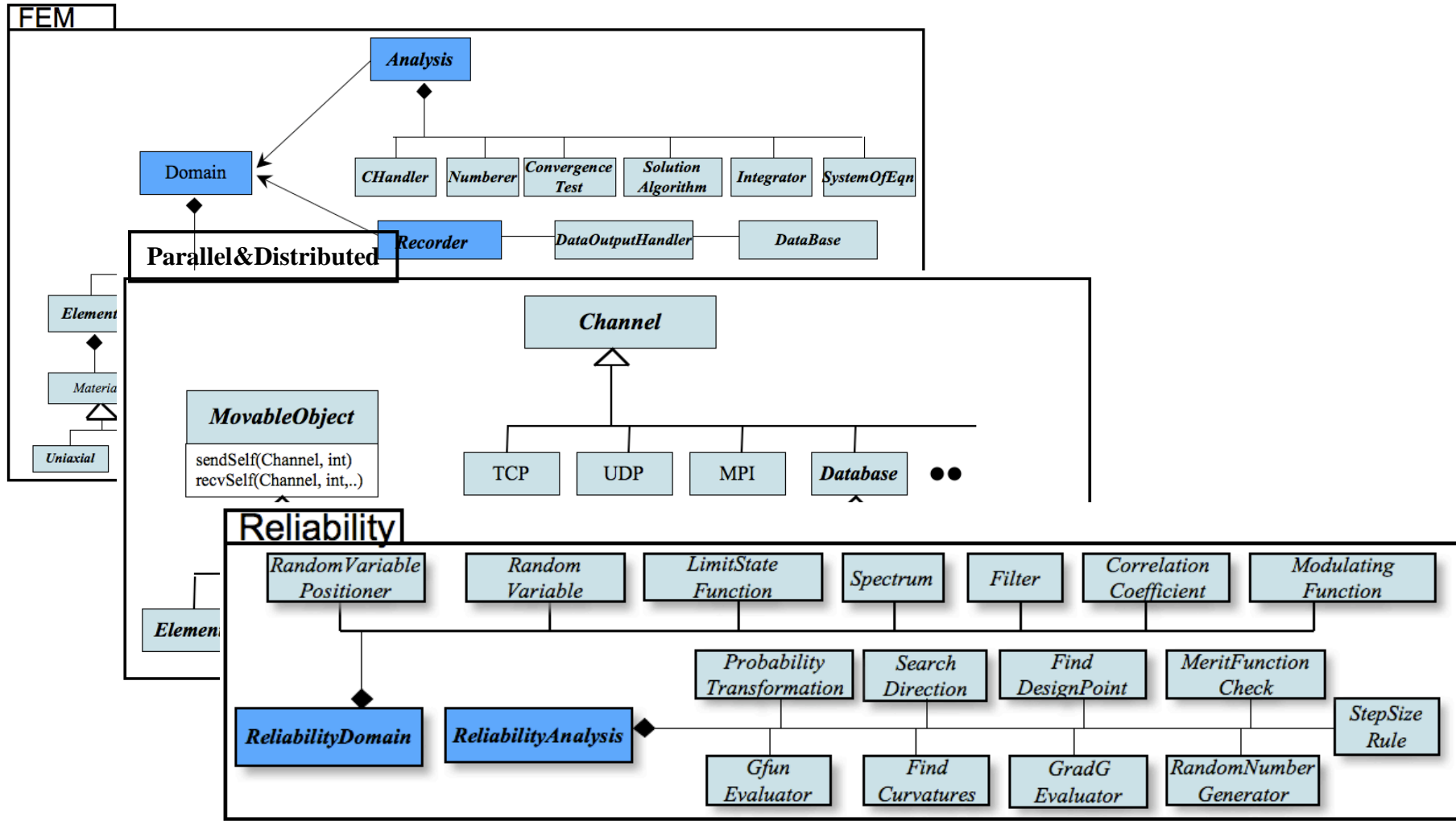
OpenSees Goals:

- 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



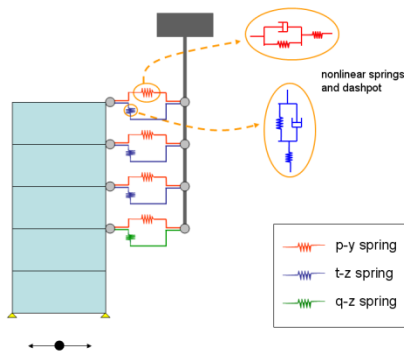
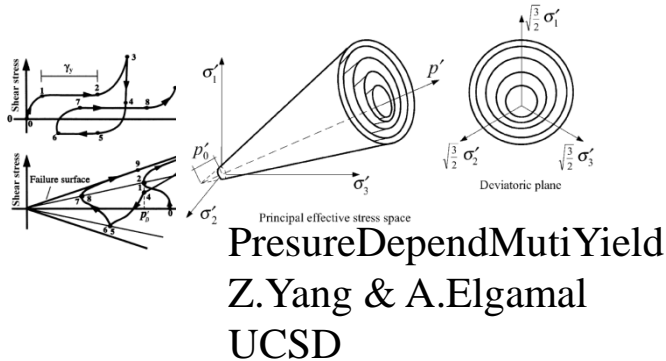
OpenSees Classes



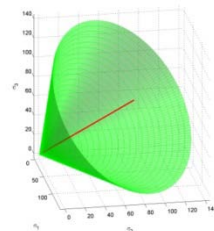
Currently over 1000 classes (modules)

Contributions from Faculty/Students

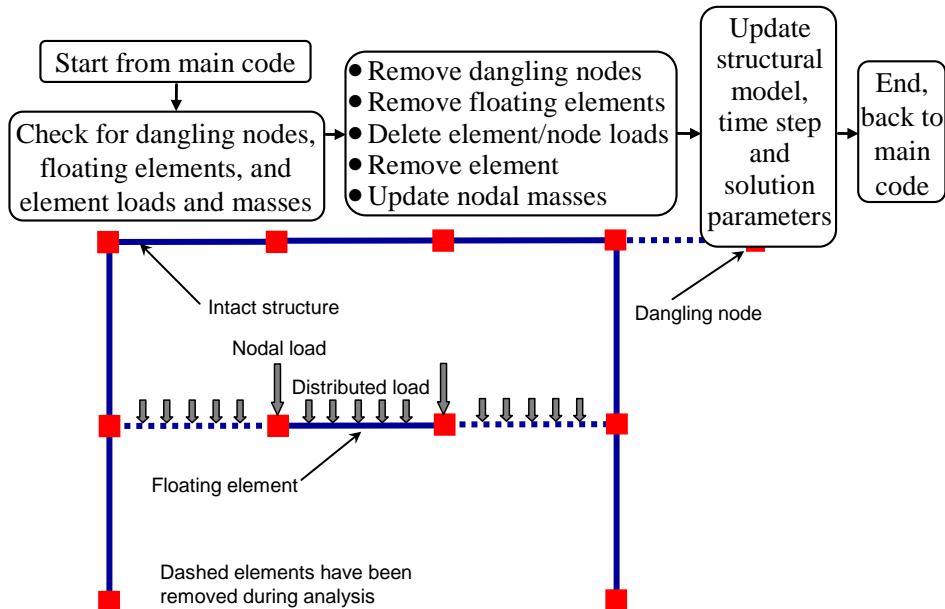
The capabilities in OpenSees are in large part due to the contributions of graduate students & their advisors from PEER affiliated universities (and beyond)



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



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

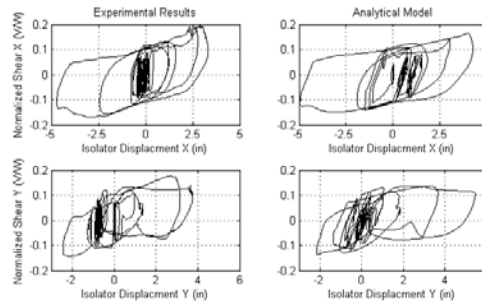


M. Talaat & K. Mosalam
UC Berkeley

Some Elements:

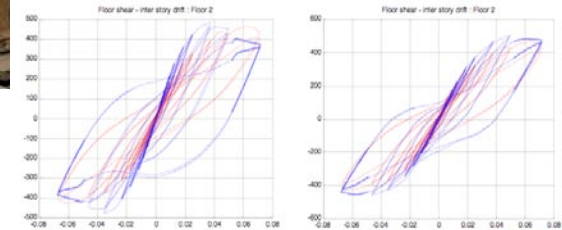


QuickTime™ and a
decompressor
are needed to see this picture.



Tracy Becker & Steve Mahin
UC Berkeley

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



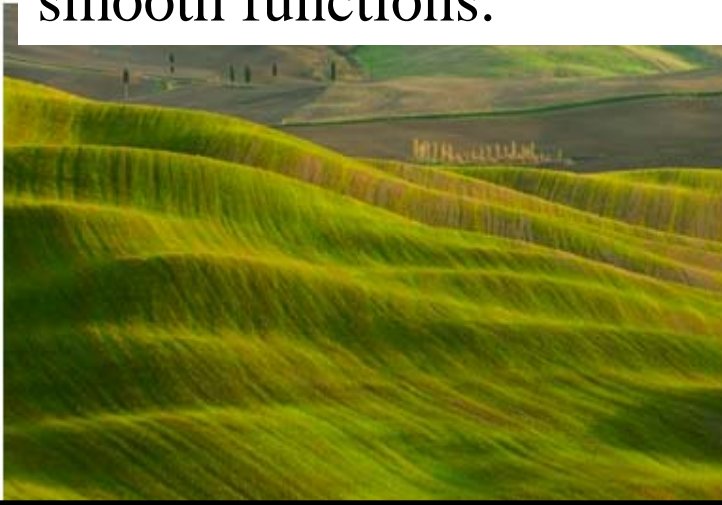
Arash Altoontash & Laura Lowes
Stanford

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)

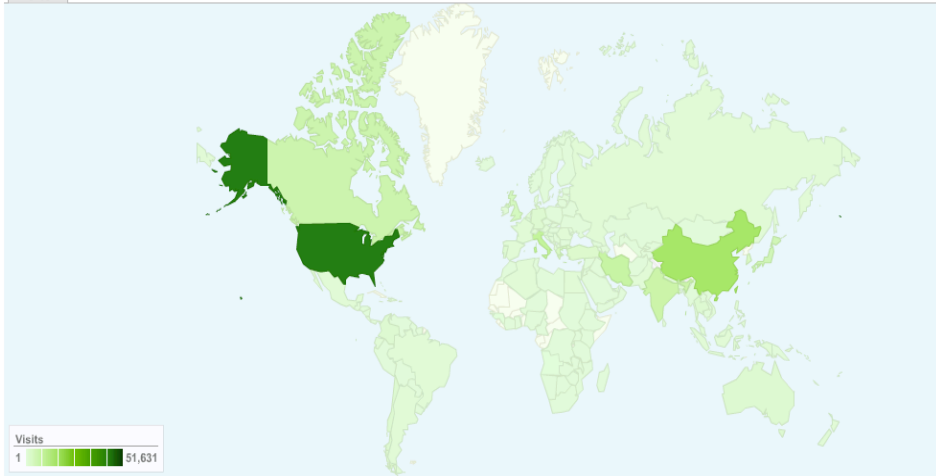
Has It Worked

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

Map Overlay

22 Sep 2010 - 22 Sep 2011

Visits

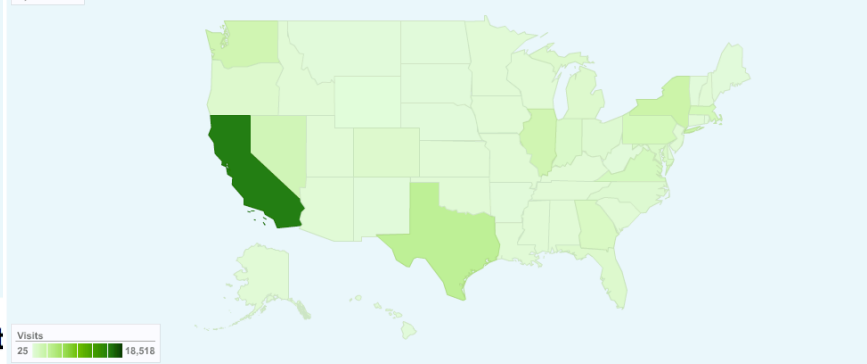


Country/Territory Detail:
United States

22 Sep 2010 - 22 Sep 2011

Visits

Zoom Out



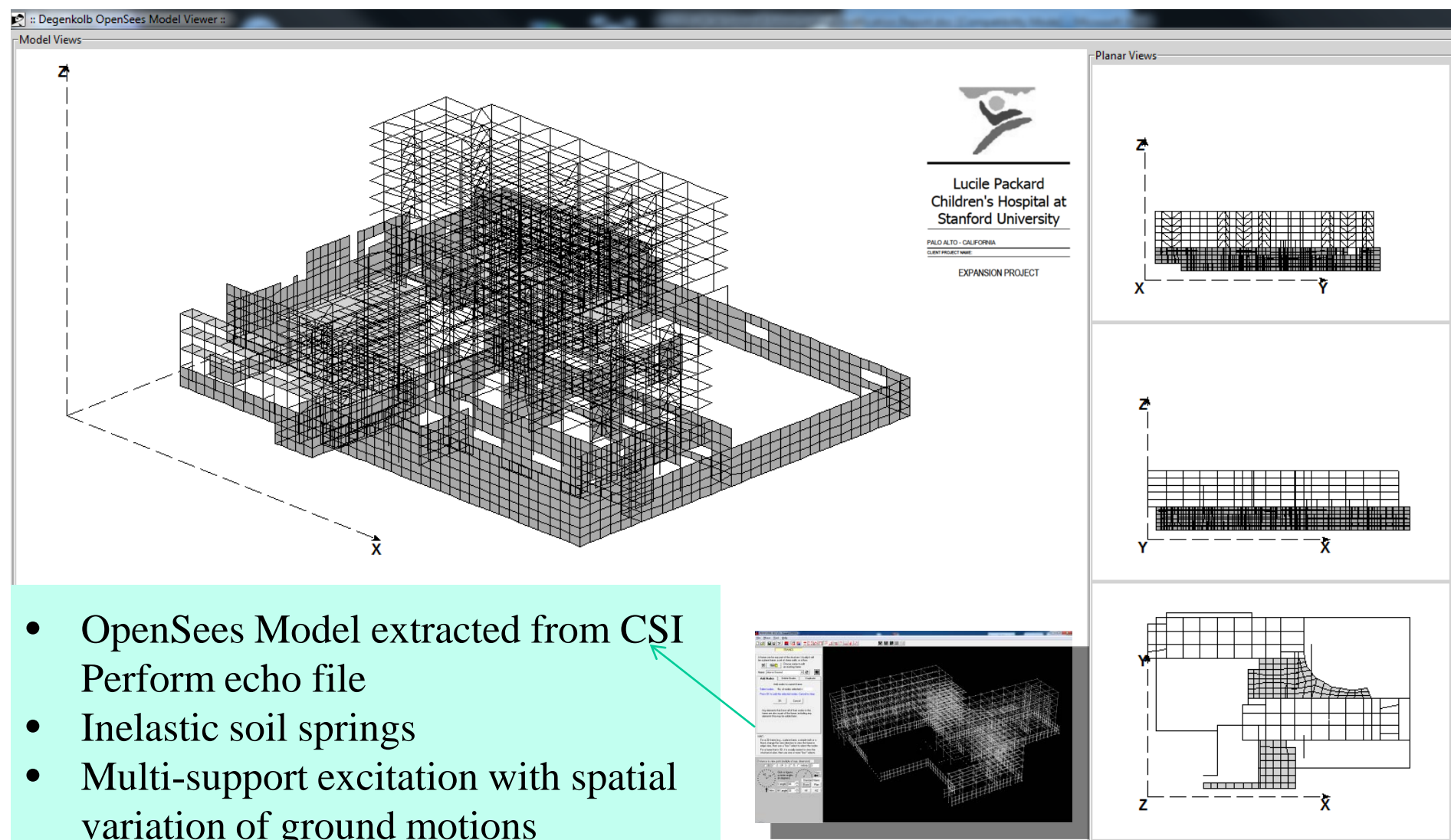
This country/territory sent 51,631 visits via 52 regions

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



Ground-Motion File Manager:

GM scaling, Elastic & Inelastic Spectra

Ground-Motion File Manager :: C:/Projects/BuildingTcl_R2.0/ATC83Bldg2/NewProjectFile.gmp ::

File Help Exit

GroundMotion Files

GMFile Type:
PEERnga

GMfiles (Select all that apply):

LoadExistingGMFiles addExistingGMFiles

1.200 [g] ☒ smodYPTFn dt: 0.005

2.000 [g] ☒ smodTCU120Fn dt: 0.005

1.700 [g] ☒ smodTCU078Fn dt: 0.005

2.200 [g] ☒ smodNISFn dt: 0.01

All None

Global Scale Factor:
0.8600

Input ground-motion units:
g

RSPmatch09

Load Target-Spectra File

GMFile Headers

Load Header File ☐ Replace Headers

SAVE Scaled GMs only

SAVE EZ Frisk Project

Model Parameters

Elastic Model

DampingRatio(s):
0.05

Inelastic Model

Cy(s):
0.1 0.2 0.3

DampingRatio(s):
0.02

InelasticMultilinear

InelasticMultilinear Model

BetaUnload: 0.0 DuctilityDamage: 0.0 EnergyDamage: 0.0 NegativeResponse: Symm

pinchX: 0.9 pinchY: 0.1 rCu: 1.01 rCx: 0.33

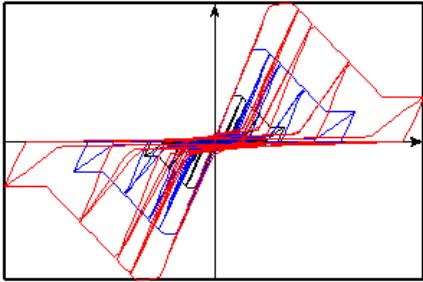
rDu: 1.4 rDx: 3

Model Basics:

Model Period: 0.01 Model g: 386.09

Model Mass: 1.00

Model Behavior:



Spectral Analysis

Period Info:

Tstart: 0.01

Tend: 10.00

Number of Period Steps: 100

PeriodDistribution: Logarithmic

Output Length Units:

Acceleration: g

Displacement & velocity: in

Select Models to Run:

☒ Run Elastic

☒ Run InelasticMultilinear

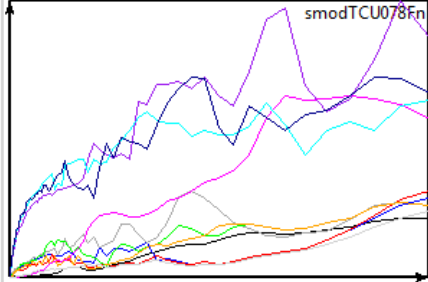
more

Stop/Pause

RUN Model-Period Response

☒ save results

Real-Time Spectral Response:



```

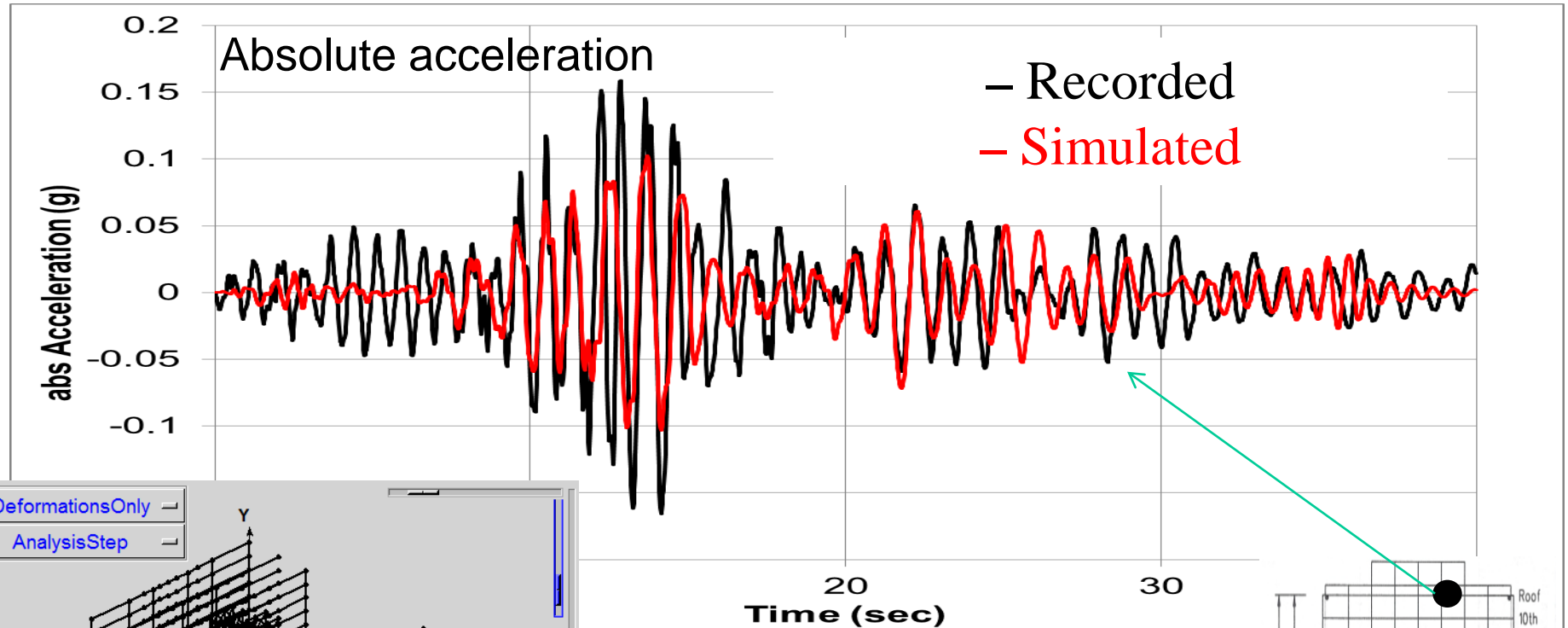
C:\Windows\system32
NPTS= 18000 , DT= 0.005
dt: 0.005
smodYPTFn
InputFilenameFullPa
GMFilenameTail_smod
Time history matche
File Type: Accelerat
NPTS= 7000 , DT= 0.005
dt: 0.005
GenerateSpectra
gotoSaveScaledGM
Save_smodYPTFn
Integrate6Macc
Save_smodTCU120Fn
Integrate6Macc
Save_smodTCU078Fn
Integrate6Macc
Save_smodNISFn
Integrate6Macc
...DONE Saving Time
Running: smodYPTFn
smodYPTFn-Elastic Da
smodYPTFn-Inelastic
smodYPTFn-Inelastic
Running: smodTCU120F
smodTCU120Fn-Elastic
smodTCU120Fn-Inelas
smodTCU120Fn-Inelas
Running: smodTCU078F
smodTCU078Fn-Elastic
smodTCU078Fn-Inelas
smodTCU078Fn-Inelas
smodTCU078Fn-Inelas

```

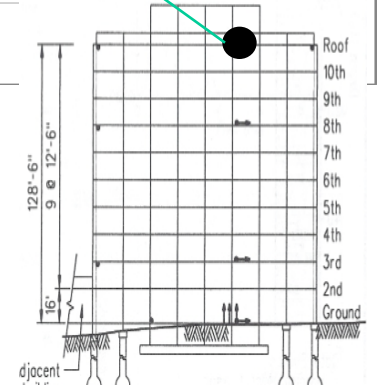
Running: smodTCU078Fn
Running: smodTCU120Fn
Running: smodYPTFn
...DONE Saving TimeSeries Files in the following Directory:
C:/Projects/BuildingTcl_R2.0/ATC83Bldg2/DegenGMFMoutput_...
...Saving TimeSeries Files

- 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

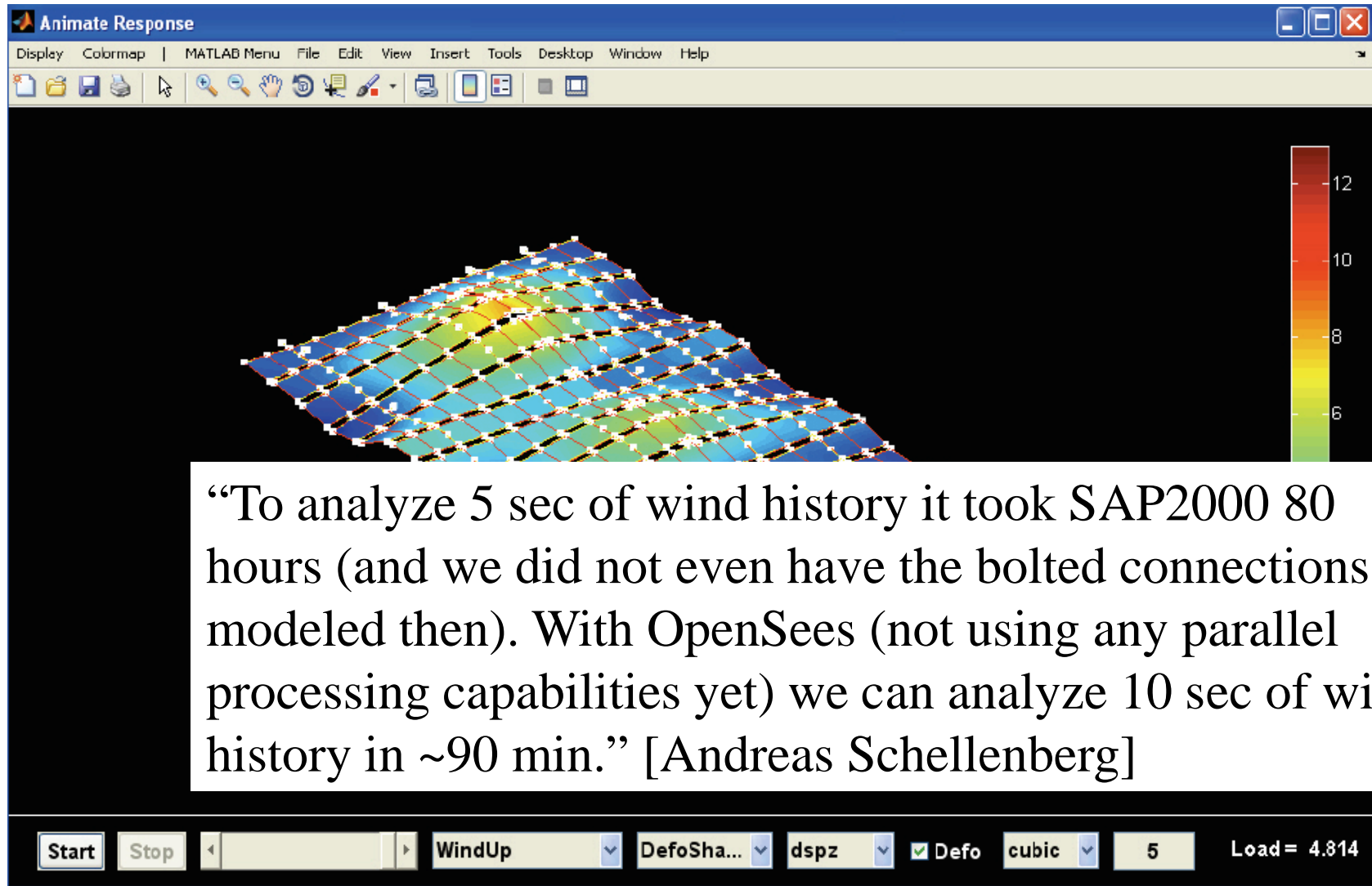


Run as 2D model for efficiency



Solar Panels on a Flat Roof

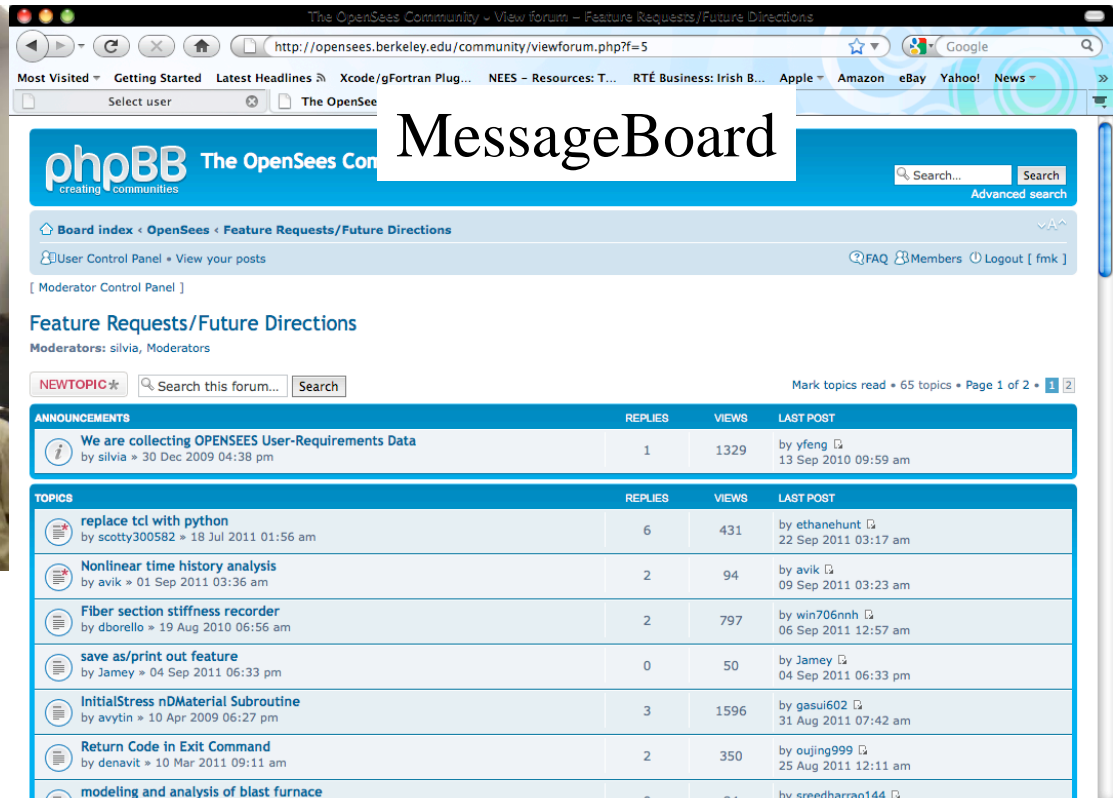
QuickTime™ and a
decompressor
are needed to see this picture.



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



Workshops

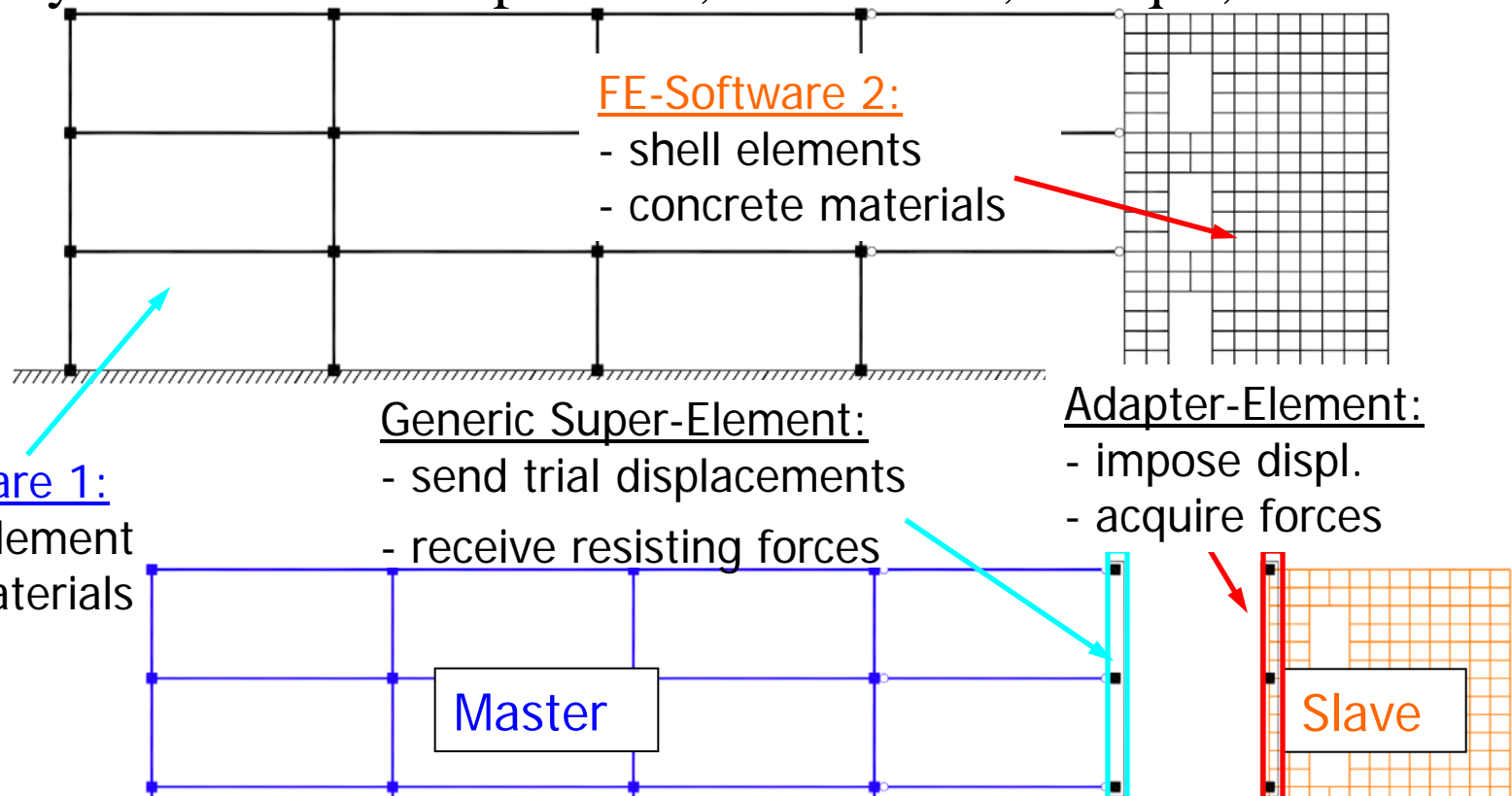


**NEW for 2011: Web Based Seminar (<http://neesmeetings.webex.com>)
“Discovering OpenSees: Surfing the Waves of OpenSees”**

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

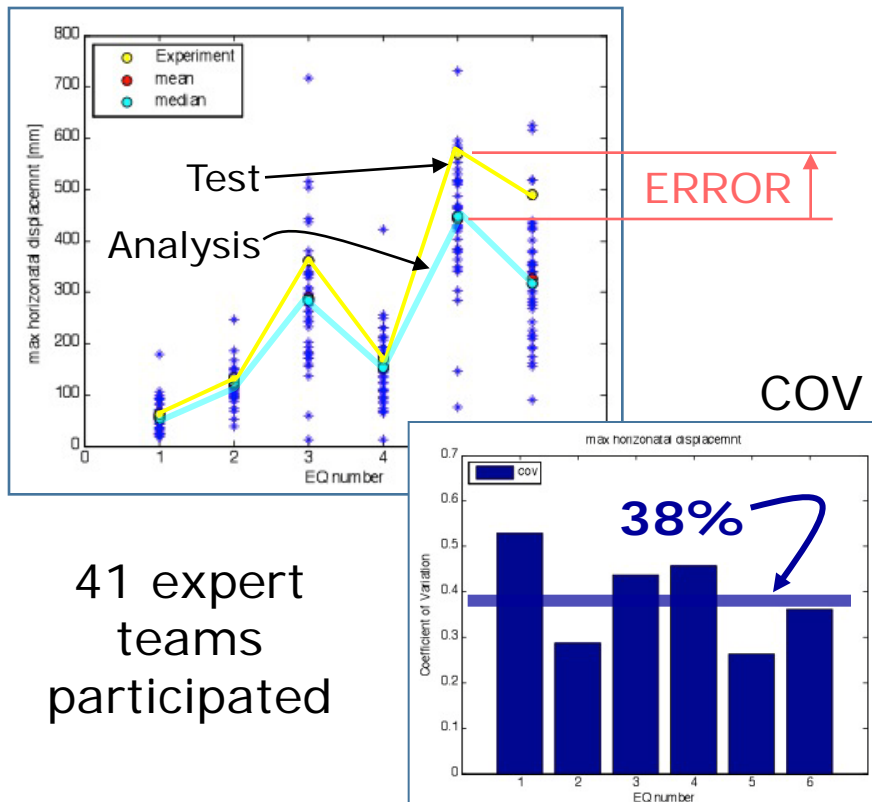


ABILITY TO DO MULTIPLE SCALES

HOW GOOD ARE OUR SIMULATION TOOLS?

Behavior of Reinforced Concrete Columns

Tests undertaken to validate concepts and numerical models used
in PBEE



**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

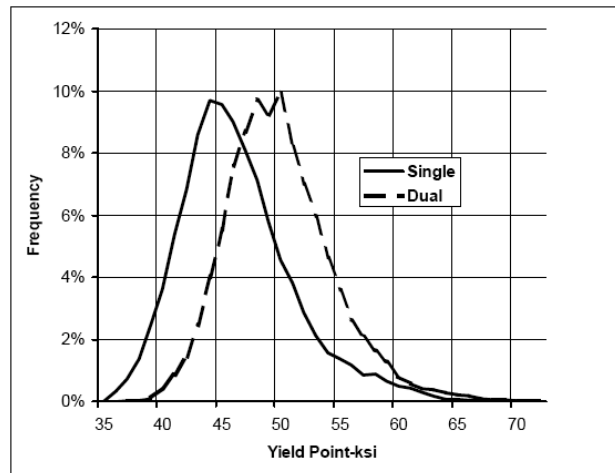


Figure 4-7 Yield Point Histogram of A36 Grade Material

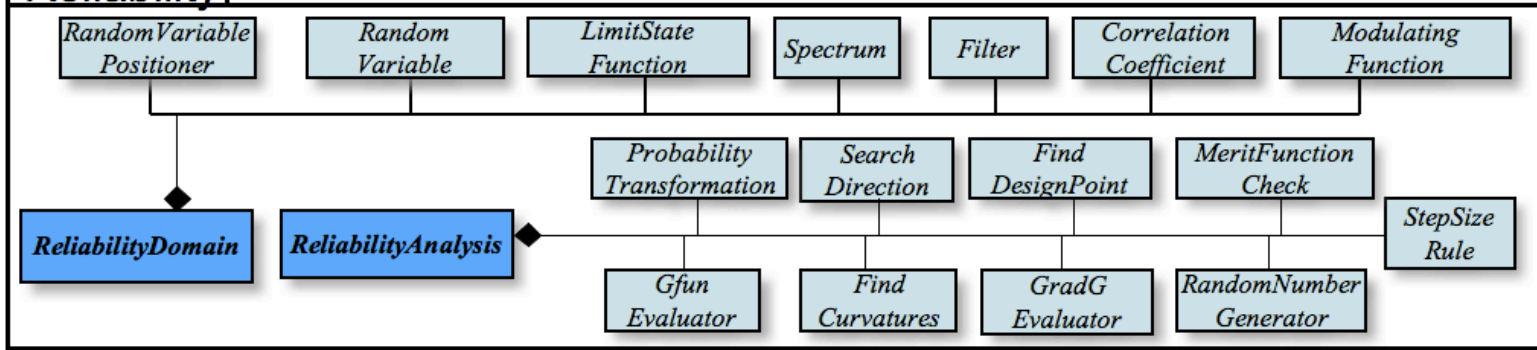
Variation of Yield Strength A36
[FEMA-355A]

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

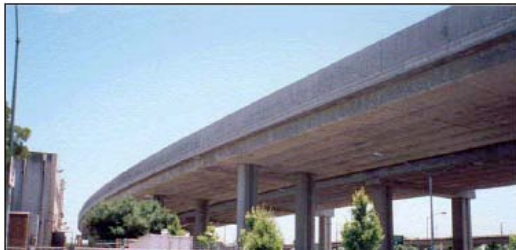
“The uncertainty is as important a part of the result as the estimate itself... An Estimate without a standard error is practically meaningless” [Jeffreys (1967)]

“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)]

Reliability



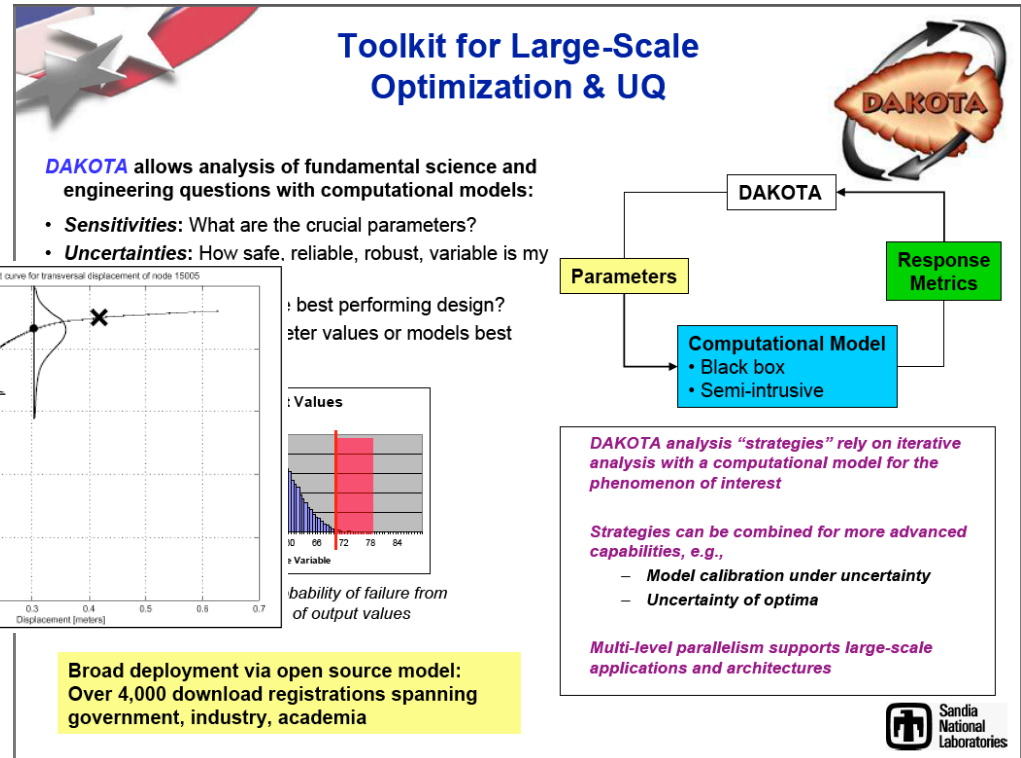
I-880 PEER Testbed project



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	ρ_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



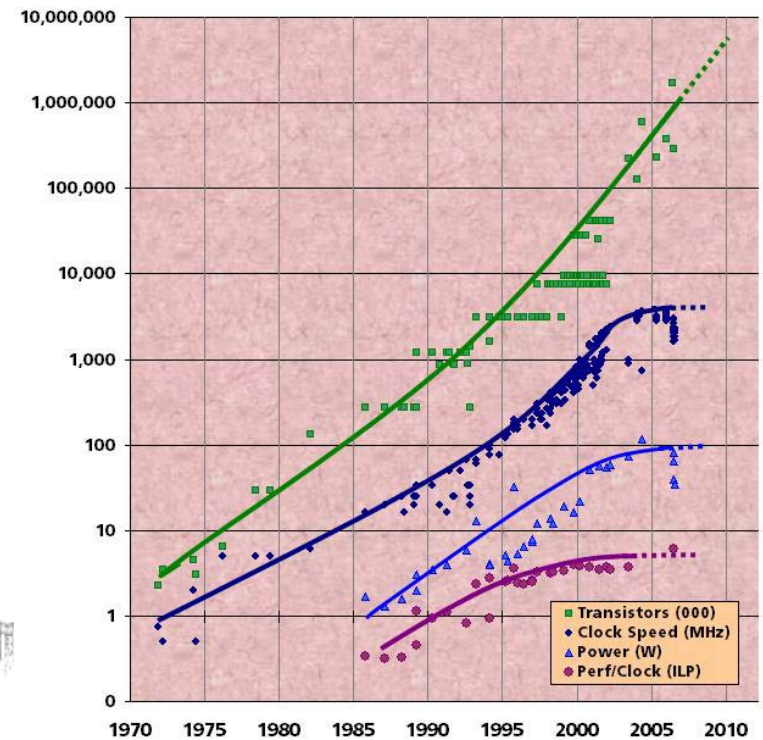
Hardware

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

Nintendo Wii 61GFlops

Xbox360 355GFlops

Sony PS3 2018GFlops

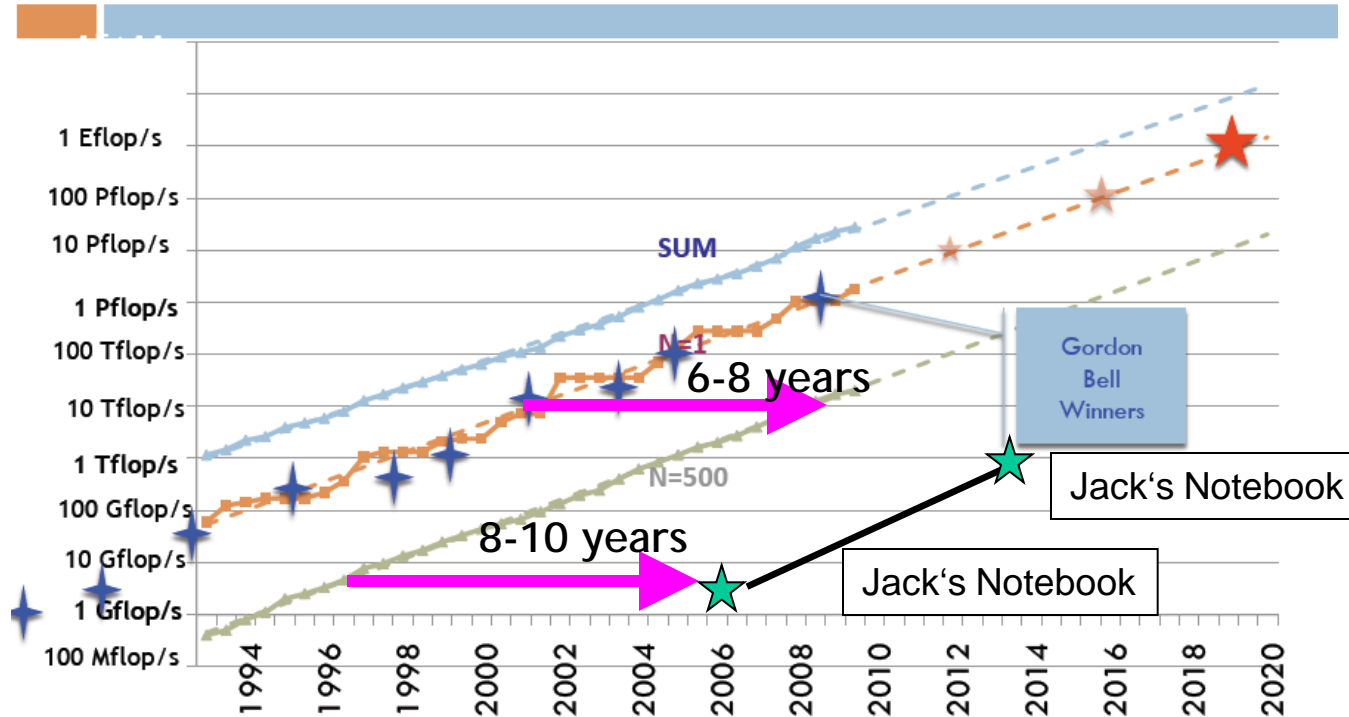


Intel Processor Speed

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

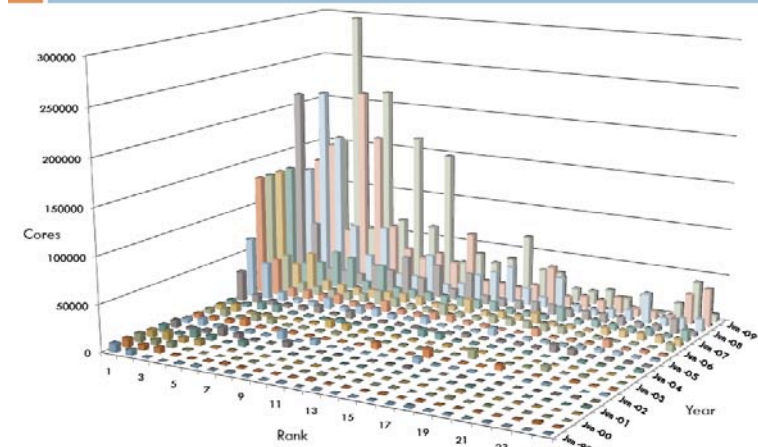
Trends in Parallel Computing

(according to Jack)



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

Cores in the Top25 Over Last 10 Years



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

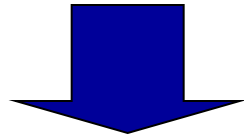


PC and Mac Demoted to a Device”

BEFORE YOU GET ALL EXCITED

Speedup & Amdahl's Law

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



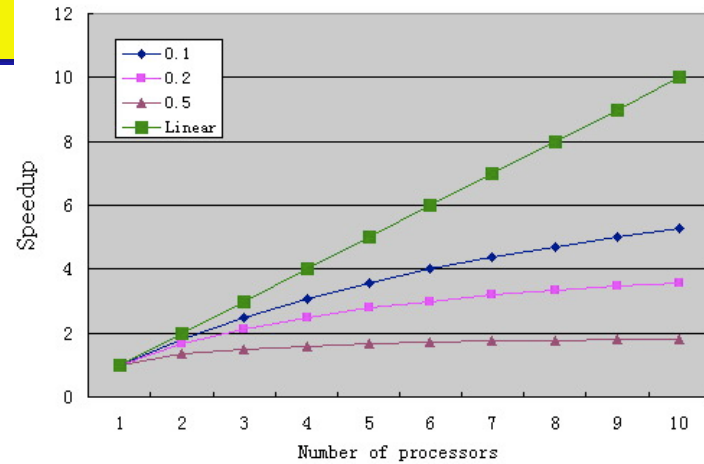
$$Speedup_{PC} = \frac{T_1}{\alpha T_1 + \frac{(1-\alpha)T_1}{n}} \rightarrow \frac{1}{\alpha} \text{ as } n \rightarrow \infty$$

αT_1

n

Portion of sequential

of processors



Improving Real Performance

Peak Performance grows exponentially, a la Moore's Law

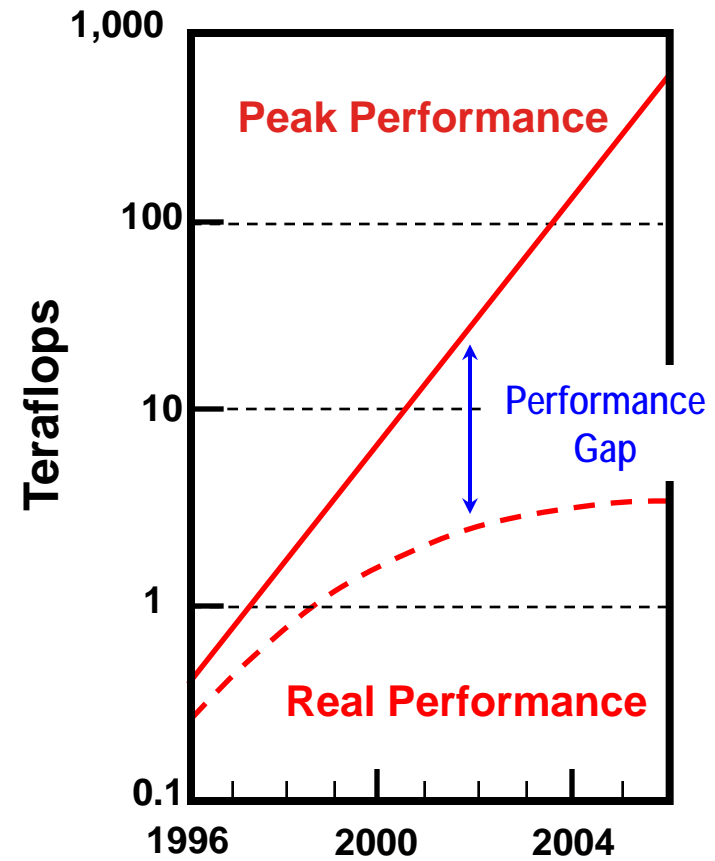
- In 1990's, peak performance increased 100x;
in 2000's, it will increase 1000x

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 ...

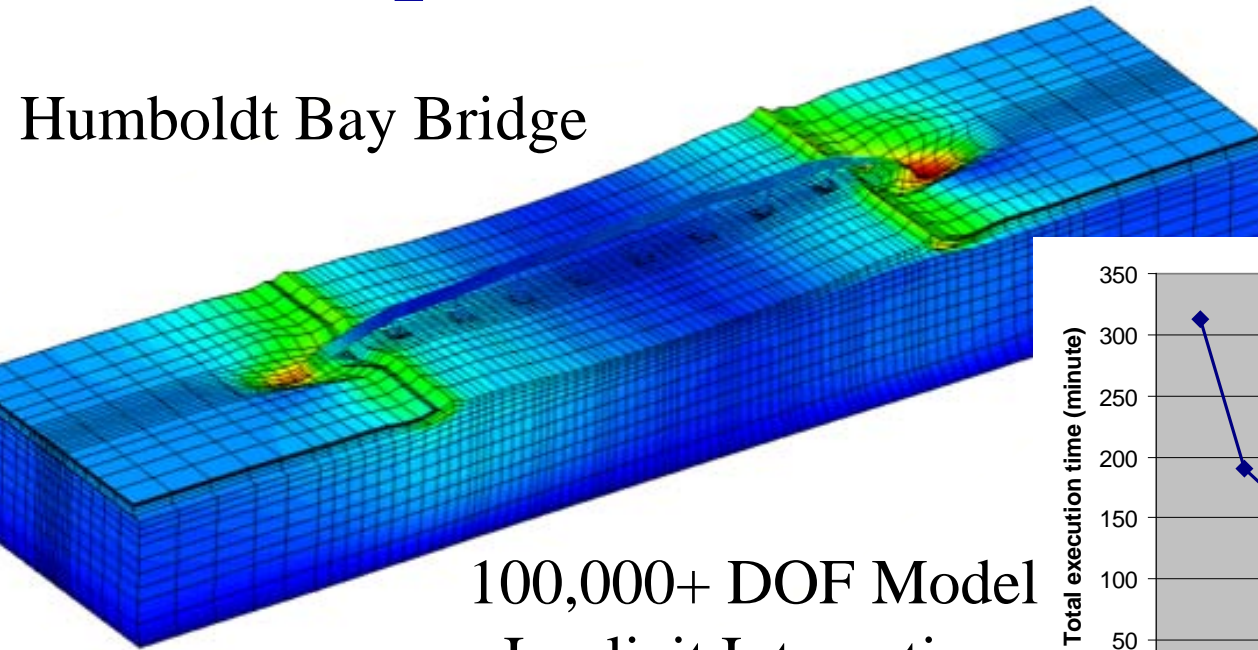
- Mathematical methods and algorithms that
achieve high performance on a single
processor and scale to thousands of
processors
- More efficient programming models and tools
for massively parallel supercomputers



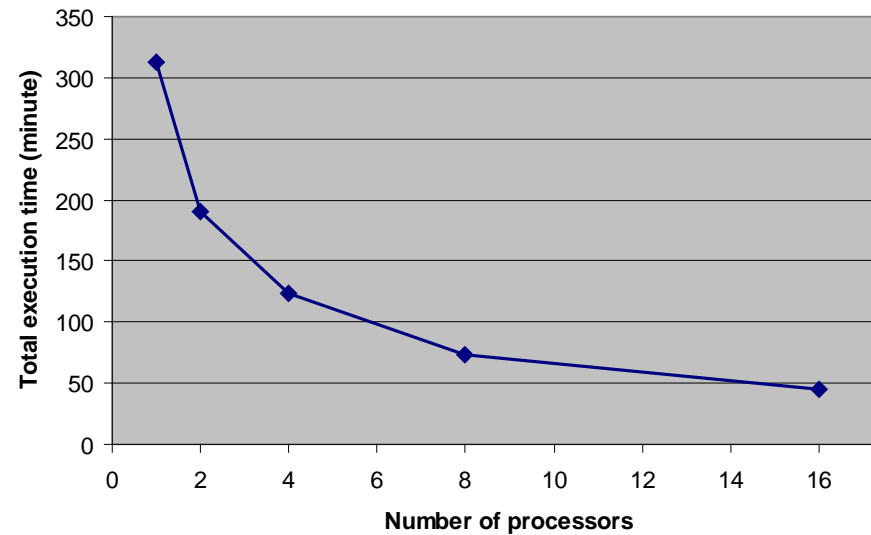
Source: Jim Demmell, CS267
Course Notes

OpenSees Parallel Examples

Humboldt Bay Bridge

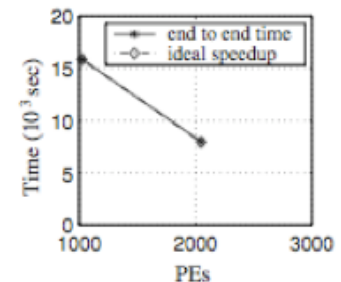
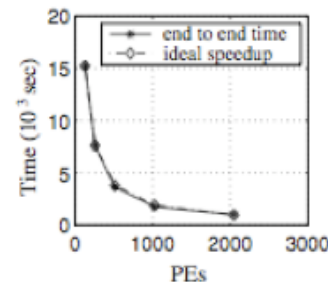


100,000+ DOF Model
Implicit Integration
Mumps Direct Solver



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
```

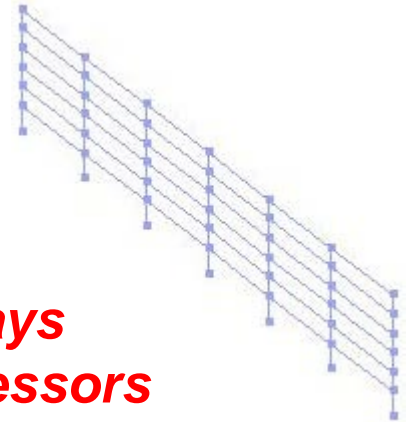
```
    doDynamic [expr $dT*$nPts] $dT
```

```
    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} {

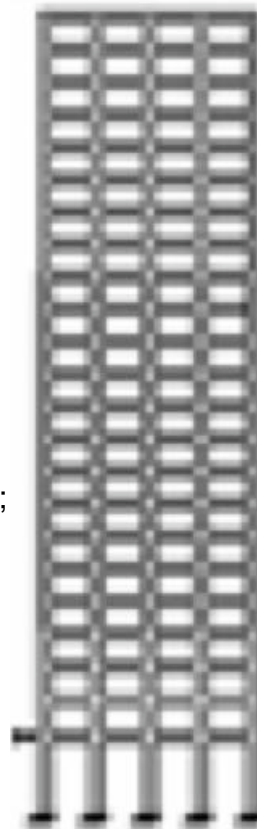
      set inFile $GMdir/$GMfile.AT2
      set outFile $GMdir/$GMfile.g3;
      ReadSMDFileNewFormat $inFile $outFile dt npts;

      wipe
      source GravityAnalysisScript.tcl

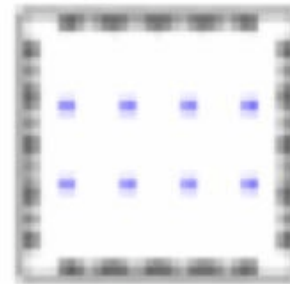
      loadConst -time 0.0;
      wipeAnalysis

      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.

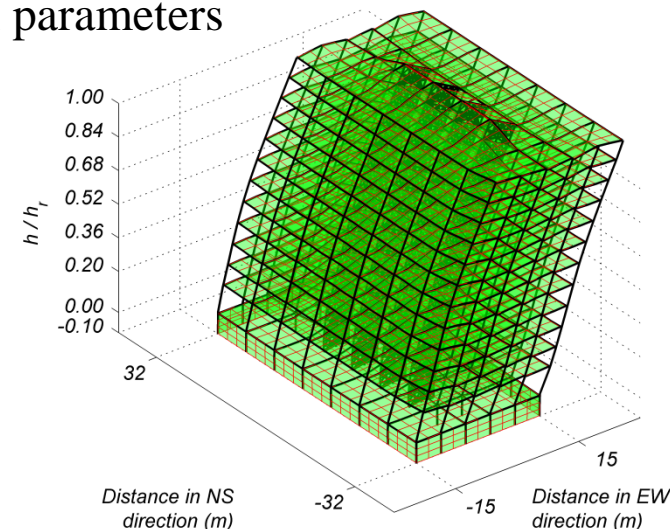


□ Application example

- 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



**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

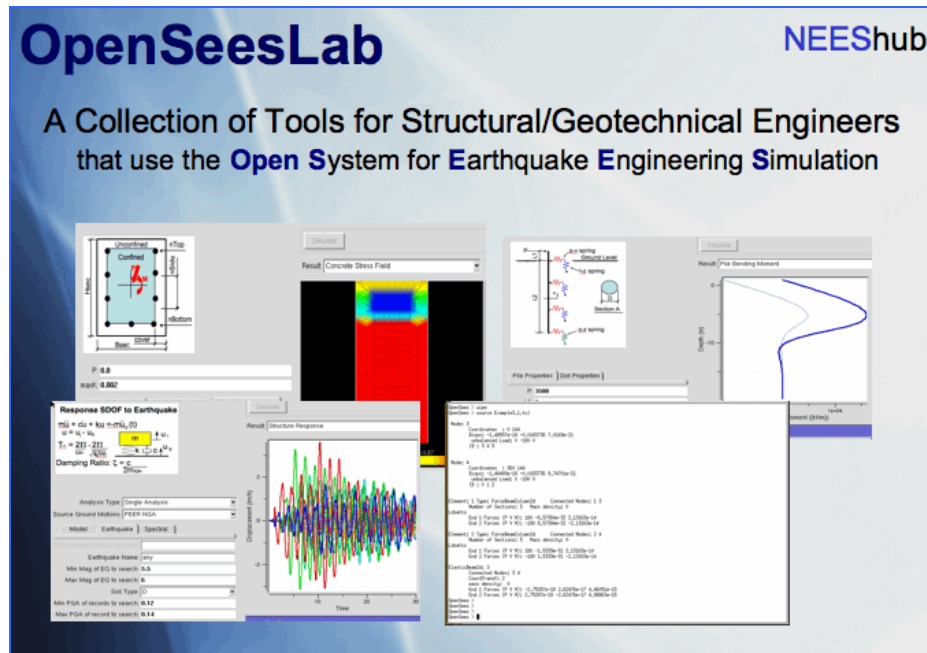


Through a browser engineers can:

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

The OpenSeesLab tool:

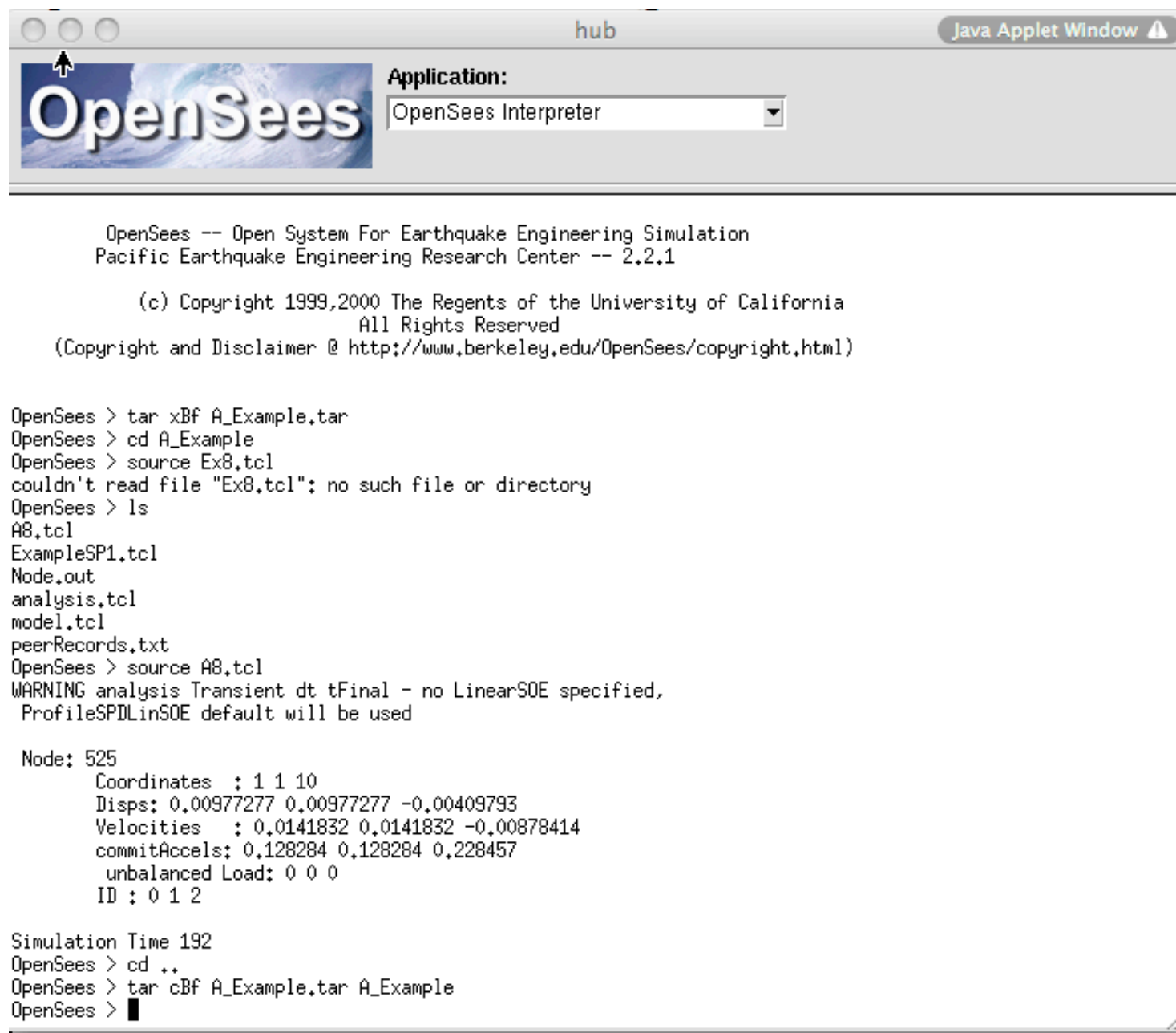
<http://nees.org/resources/tools/openseeslab>




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



Parameter Study Tool



Application:
Parameter Study

Resource: OSG

numParameter: 3

Main Script: /home/fmk/SteelBuilding.tcl

Simulate

new input parameters

? About this tool
Questions?

Parameter 1

Name: earthquake

File: /home/fmk/listEarthquakes

Parameter 2

Name: scaleFactor

File: /home/fmk/listFactor

Parameter 3

Name: Fy

File: /home/fmk/listFy

Parameter Study Submission Tool

This tool can be used to perform parameter studies with OpenSees. For each parameter, the user inputs the parameter name and the file containing all the values to be tried for that parameter. The user also specifies a main file to run in which the parameter value is used. DO NOT ASSIGN THE VALUE IN THE MAIN SCRIPT, otherwise you will overwrite the value to be used from the parameter file.

example:
If numParameter is set to 2 and the main script contains the following 3 lines:

```
set sum [expr $varA + $varB]
set fileOut [open $varA$varB.out w]
puts $fileOut "$a + $b = $sum"
```

Then, if in the Parameter1 box, we set the name to be varA and the associated file has the number 1 and 2. And if in the Parameter 2 box, we set the name to be varB and the associated file has the number 3, 4 and 5, the output directory when we hit the submit button will contain 6 files 13.out,14.out,15.out,23.out, 24.out and 25.out, each with a different message.

Be careful, make sure the results go to different filename, when using recorders use for example recorder Node -file node\$varA\$varB.out

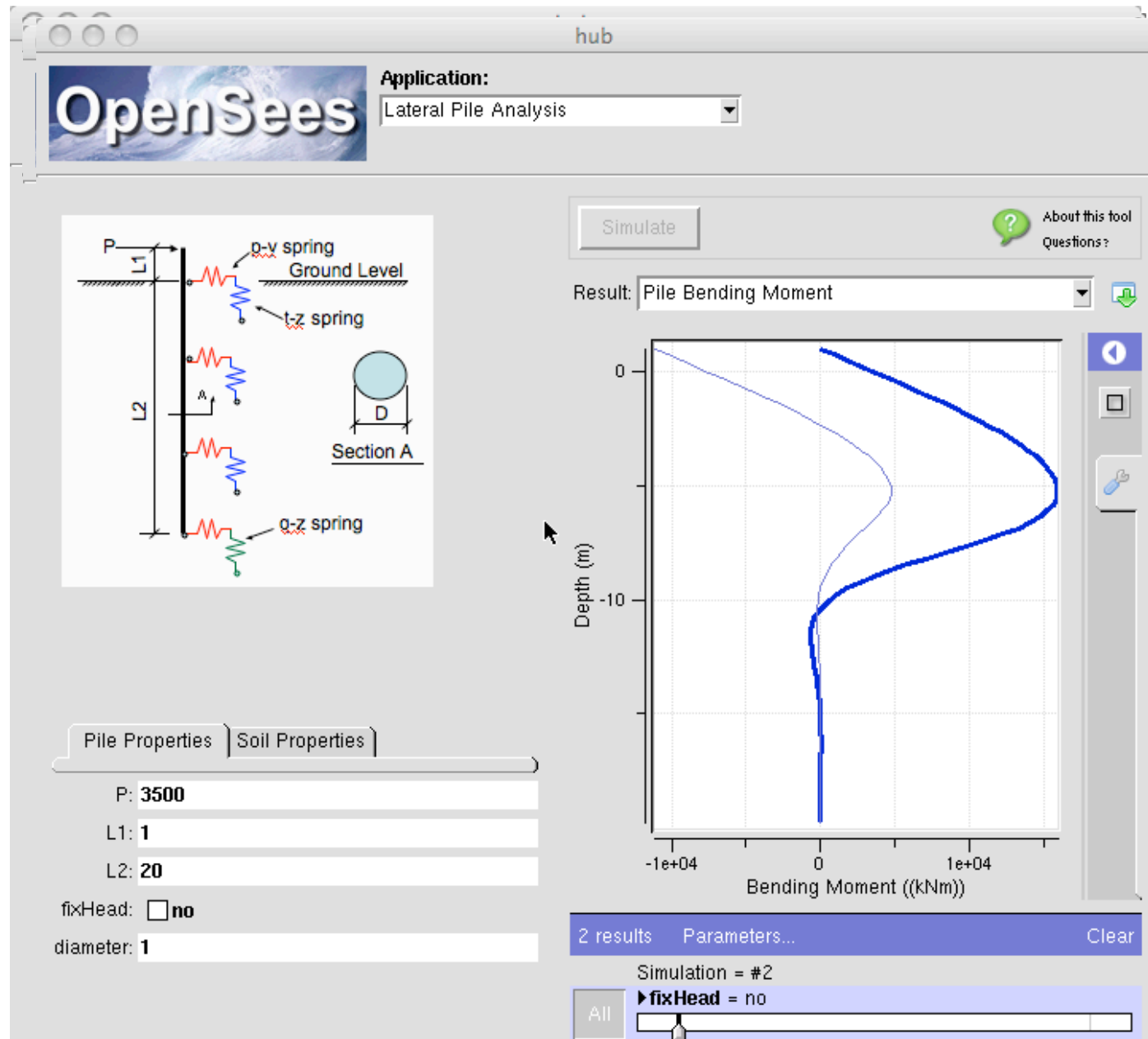
Also only use the OSG (Open Science Grid) option when you have large models to run as it can take from minutes to hours for your job to actually start. The OSG option will place each run in a separate directory. Complain if you don't like this!

Lateral Pile Analysis

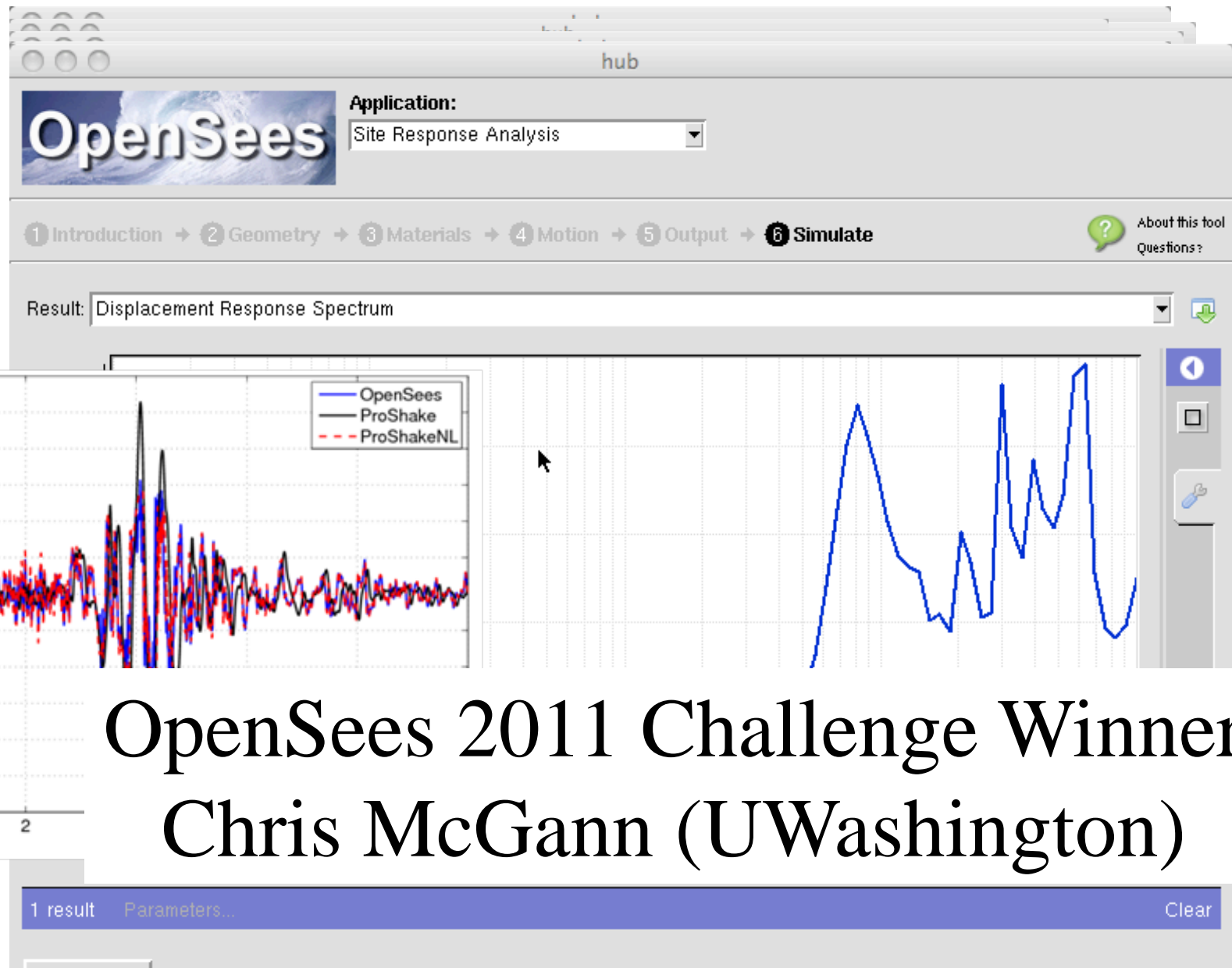
<http://opensees.berkeley.edu/wiki/index.php/>

Laterally-Loaded Pile Foundation

Chris McGann U. Washington



Site Response Analysis

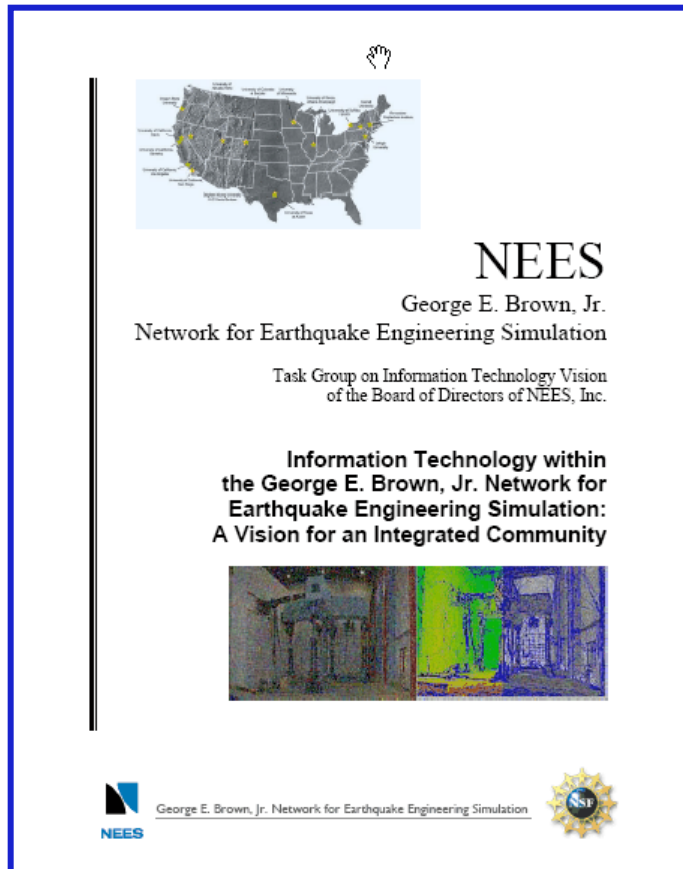


OpenSees 2011 Challenge Winner
Chris McGann (UWashington)

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.

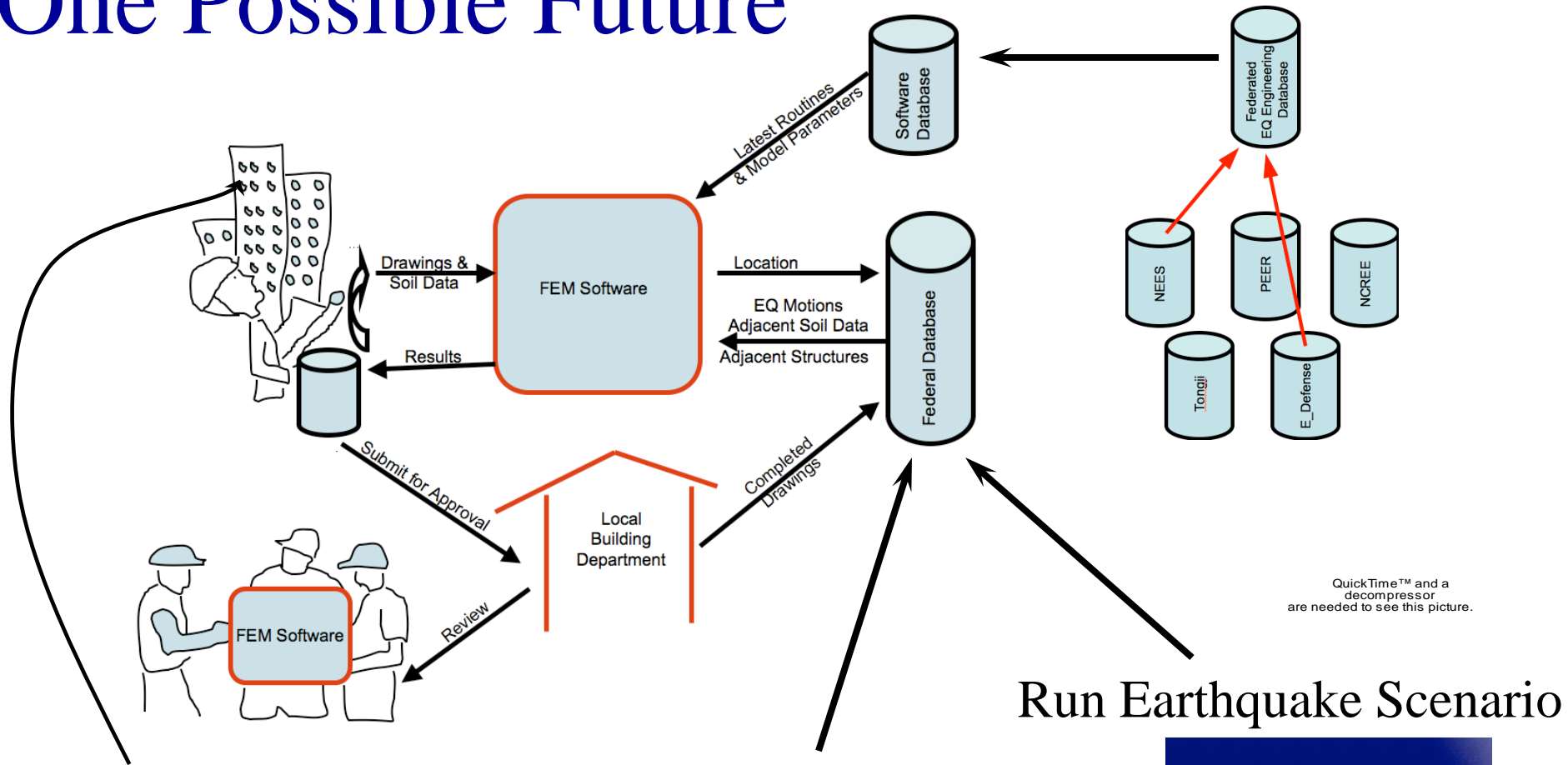
Vision for Computational Simulation



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



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?