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

NEEScomm

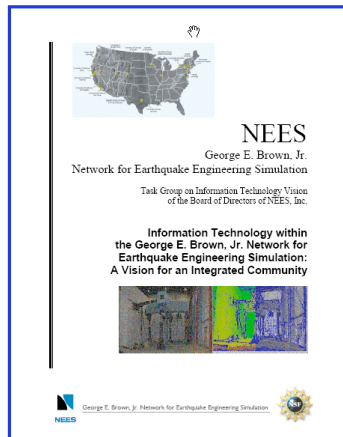NEES

PEER / NEES
OpenSees Days 2010

Presented by the OpenSees Community
September 2-3, 2010

Sponsored by:
NEEScomm
Pacific Earthquake Engineering Research Center
National Science Foundation

Simulation in Earthquake Engineering

- Research and practice is moving towards Performance-Based Seismic Engineering, which depends on high-fidelity models and simulation to assess performance.

- Simulation models capture knowledge from tests to leverage investment in limited experimentation.

- Community-based, open-source software for simulation promotes innovation in research and advanced applications for practice.

- NEES is supporting OpenSees to provide simulation capability and integration with NEEScomm services for NEES research.
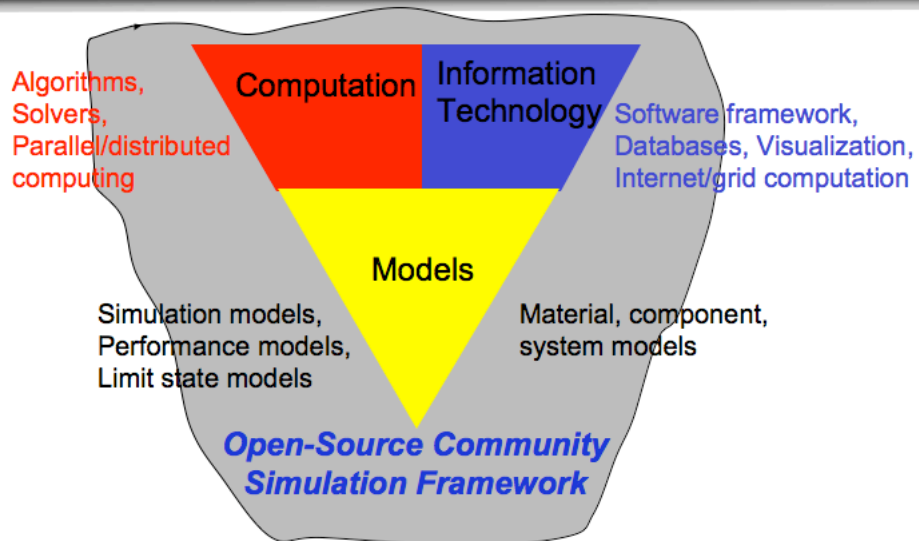
Vision for Simulation

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.

NEES
George E. Brown, Jr.
Network for Earthquake Engineering Simulation

Task Group on Information Technology Vision
of the Board of Directors of NEES, Inc.

Information Technology within
the George E. Brown, Jr. Network for
Earthquake Engineering Simulation:
A Vision for an Integrated Community

George E. Brown, Jr. Network for Earthquake Engineering Simulation

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Observations on Current Situation

- Tight binding of models in research and commercial codes is an impediment to new research and implementation of models for professional practice.
- Embedding of computational procedures in codes makes it difficult to experiment and take advantage of computing technology:
  - Parallel and distributed computers
  - Computational grids
- "Closed-source" is the norm, whereas other fields have adopted "open-source" software for communities users.

Conceptual Approach for Simulation

What is OpenSees?

- A software *framework* for simulation applications in earthquake engineering using finite element methods. OpenSees is not a code.

- A communication mechanism for exchanging and building upon research accomplishments.

- As open-source software, it has the potential for a community code for earthquake engineering.

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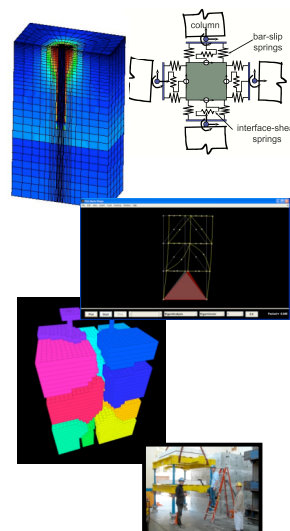
http://opensees.berkeley.edu

- OpenSees has been under development by PEER since before 1997.
- Large group of developers and user.
- NEES has supported integration and extension since 2003.
- Open-source and royalty free license for non-commercial use and royalty free for internal commercial use.
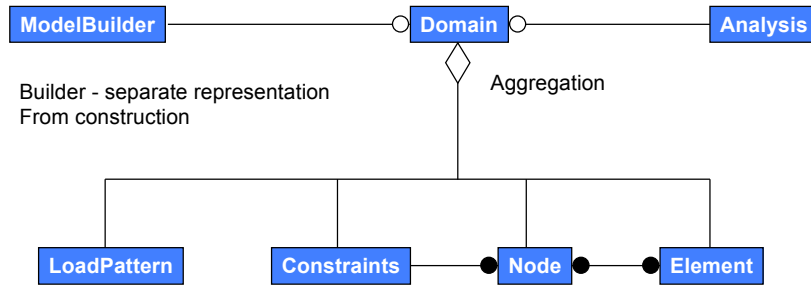

OpenSees Approach to Simulation

- Basic approach:
  - Modular software design for implementing and integrating modeling, numerical methods, and IT for scalable, robust simulation
  - Focus on capabilities needed for performance-based engineering
  - Programmable interfaces
- <u>Most users</u>: a "code" for nonlinear analysis. Fully scriptable.
- <u>Generally</u>: a software framework for developing simulation applications.

Structural Models as Aggregation Pattern

ModelBuilder ——————○ Domain ○————————— Analysis

Builder - separate representation
From construction

Aggregation

LoadPattern   Constraints ——●— Node —●— Element
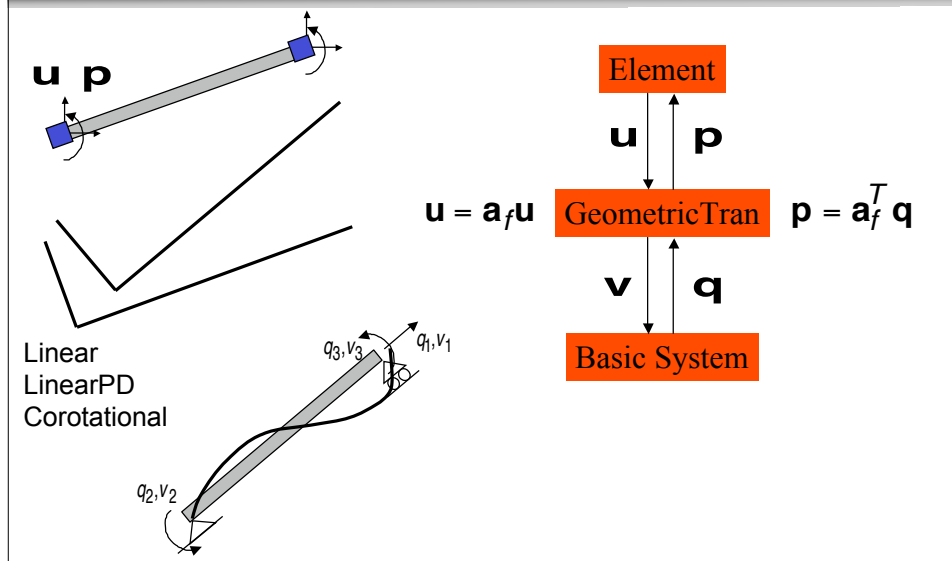

Analysis Class for Simulation

Analysis class is responsible
for performing an analysis on a
domain and is formed by
Aggregation.

Analysis ————————○ Domain
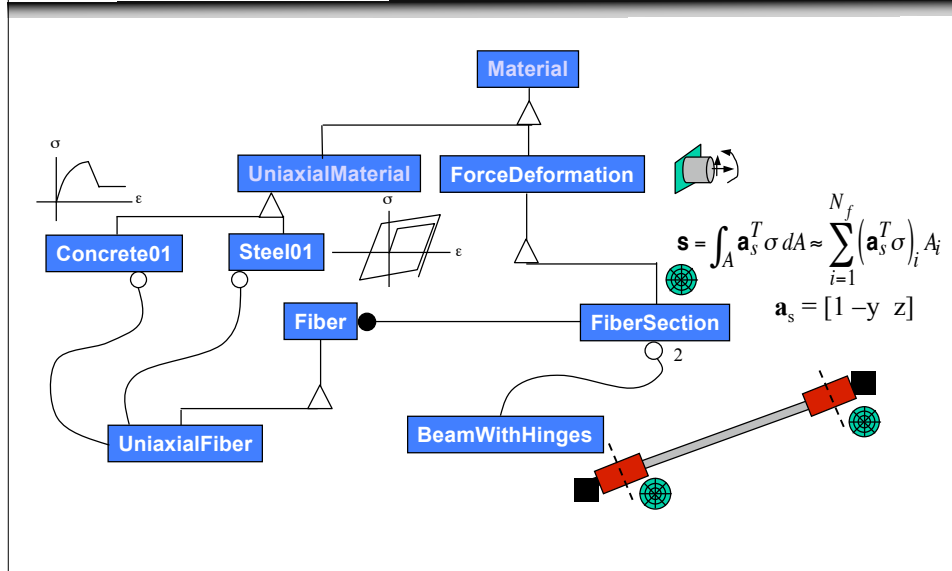
DO_Numberer   ConstraintHandler   Integrator   AnalysisModel

SystemofEqs   SolutionAlg

Beam-Column Models I

u p

Linear
LinearPD
Corotational

q_3, v_3 q_1, v_1

q_2, v_2

Element

u p

$u = a_f u$ GeometricTran $p = a_f^T q$

v q

Basic System

Beam-Column Models II

q_3, v_3 q_1, v_1 **Displacement**

q_2, v_2

$$e = av$$

$$q = \int_0^L a^T s \, dx$$

e, s

σ

ε

$$\varepsilon = a_s e$$

v q

Basic System

e s

Section

ε σ

Material

Force

$$s = bq$$

$$v = \int_0^L b^T e \, dx$$

$$s = \int_A a_s^T \sigma dA$$

$$\sigma = \sigma(\varepsilon)$$

No assumptions are made on section or material behavior;
each level in the hierarchy can be defined independently of
other levels

Form Follows Mechanics

Material

UniaxialMaterial   ForceDeformation

Concrete01   Steel01

Fiber   FiberSection

UniaxialFiber   BeamWithHinges

$$\mathbf{s} = \int_A \mathbf{a}_s^T \sigma \, dA \approx \sum_{i=1}^{N_f} \left(\mathbf{a}_s^T \sigma \right)_i A_i$$

$$\mathbf{a}_s = [1 \;\; -y \;\; z]$$

OpenSees Scripting

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

5.   foreach Xframe $iXframe Hco $iHcol Lcol $iLcol Lbeam $iLbeam            FRAME
                  Glblc $iGlblc GrhoCol $iGrhoCol GPco $iGPcol GMfact $iGMfact {
6.     source Static.tcl; # load procedure for static analysis
7.     source Dynamic.tcl;           # load procedure for dynamic analysis
8.     puts FRAME$Xframe........FRAME$Xframe........
9.     puts STATIC_ANALYSIS
10.    Static $Xframe $Hcol $Lcol $Lbeam $Glblc $GrhoCol $GPcol $GMfact ;
11.    puts DYNAMIC_ANALYSIS
12.    foreach GroundFile $iGroundFile {                    GROUND MOTION
13.        puts GroundMotion$GroundFile
14.        Dynamic $Xframe $Hcol $Lcol $Lbeam $Glblc $GrhoCol $GPcol $GMfact $GroundFile;
15.    }
16. }
```
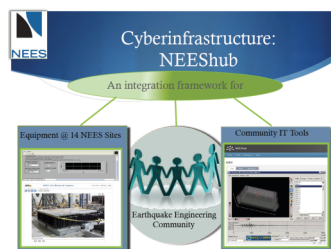
NEES

The Network for Earthquake Engineering Simulation (NEES) is a shared national network of 14 experimental facilities, collaborative tools, a centralized data repository, and earthquake simulation software.
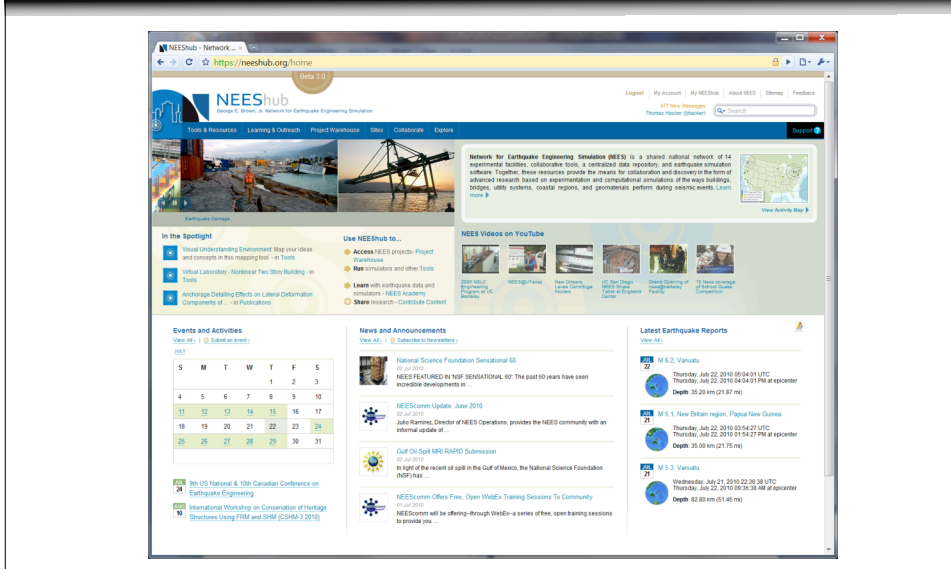

NEEShub

- The power behind NEES at http://nees.org
- Maintained and developed at Purdue by NEEScomm
- 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)

NEEShub (First Release July 2010)

NEEShub Tools and Resources

Simulation

Data Management

Objective of OpenSees Days

- Describe modeling and analysis capability, including hierarchy of system, element, section, material
- Overview of applications, structural and geotechnical
- Show specific examples of nonlinear analysis
- Provide hands-on starting-point for simulation tools
- Introduce NEEShub capabilities using OpenSees
- Motivation to use OpenSees for your simulation problems….

Day 1 – Getting Started

- Getting Started with OpenSees, Frank McKenna
- Nonlinear Analysis Theory, Filip Fillippou
- OpenSeees Analysis, Frank McKenna
- Lunch
- Structural Modeling with Examples, Silvia Mazzoni
- Geotechnical Modeling with Examples, Pedro Arduino
- Recorders, Frank McKenna
- Hands-On, Frank McKenna

Day 2 – Advanced Tools and Topics

- Parallel Processing & OpenSees, Frank McKenna
- Cloud Computing with NEEShub & OpenSees, Greg Rodgers
- NEEShub Hands-On, Greg Rodgers
- Lunch
- Reliability/Sensitivity, Armen Der Kiureghian
- Reliability/Sensitivity in OpenSees, Micheal Scott
- BuildingTcl, Silvia Mazzoni
- OpenSeesPL, Ahmed Elgamal/Jinchi Lu
- OpenFresco, Andreas Schellenberg

What Should be Your Expectations?

- OpenSees is a research tool at this time, but fairly stable for regular use
- As with any nonlinear analysis, it requires careful consideration of model and interpretation of results
- It is under continual development by students, faculty and other researchers
- User interface development lags behind computational technology
- It is not bullet-proof
- An investment of time and learning is required
- The OpenSees *open-source community* requires contributions for the community to succeed.

Thanks to:

- PEER staff (Heidi, Marcos, Veronica, & Yolanda)
- Silvia Mazzoni & Degenkolb Engineers
- Vesna Terzik
- Greg Rogers
- *All the presenters*