Simulation Practice and Research Prior to PEER

Simulation in practice:
- Little use of pushover analysis, almost no use of nonlinear dynamic analysis
- Models based on simple hinge representation
- Very little consideration of soil-structure interaction

Simulation in research:
- Embedding of computational procedures in codes makes it difficult to use new models and Information Technology
- “Closed-source” was the norm creating islands of software
- Poor integration between structural and geotechnical simulation
- Very little incorporation of probabilistic methods in simulation

Combination of two impeded progress and both were inadequate for PBEE
Approach for Simulation in PEER

Open-Source Community Simulation Framework

Computation
- Algorithms, Solvers, Parallel/distributed computing

Information Technology
- Software framework, Databases, Visualization, Internet/grid computation

Models
- Simulation models, Performance models, Limit state models
- Material, component, system models
OpenSees has been under development by PEER since before 1997

Large group of developers and users

Open-source and license for non-commercial use

The only widely used community-based simulation software in CEE

NEES has adopted OpenSees for the NEESit simulation component

http://opensees.berkeley.edu
OpenSees Approach to Simulation

- **Basic approach:**
  - Modular software design for implementing and integrating modeling, numerical methods, and IT for scalable, robust simulation.
  - Open-source software for building a community of users and developers.
  - Focus on capabilities needed for PBEE.

- **Most users:** a “code” for nonlinear analysis.

- **Generally:** a software framework for developing simulation applications.
Form Follows Mechanics

Use of design patterns.

\[ s = \int_A a_s^T \sigma dA \approx \sum_{i=1}^{N_f} (a_s^T \sigma) A_i \]

\[ a_s = [1 \quad -y \quad z] \]
Framework Design/Source for Developers

Source Code Viewing/Updating

Class Specification
Application Program Interface

OpenSees

Click on a directory to enter that directory. Click on a file to display its revision history and to get a chance to display diffs between revisions.

Current directory: [local] / OpenSees / SRC / element / 20nbrick

<table>
<thead>
<tr>
<th>File</th>
<th>Rev.</th>
<th>Age</th>
<th>API</th>
<th>Last log entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent Directory</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Makefile</td>
<td>1.2</td>
<td>2 years</td>
<td></td>
<td>2.yang - adding 20 node brick element that is not tensor based</td>
</tr>
<tr>
<td>TcfTwentyNodeBrickCommand.cpp</td>
<td>1.5</td>
<td>4 years</td>
<td></td>
<td>small changes, mostly on top... Boris Jeremic (@bdavis.edu)</td>
</tr>
<tr>
<td>TcfTwentyNodeBrickCommand.cpp</td>
<td>1.2</td>
<td>10 months</td>
<td></td>
<td>fmk - changes for vc 2005 compiler; problems with understanding some end-of-line...</td>
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<td>3 months</td>
<td>api</td>
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<td>api</td>
<td>removing unused Information argument from setResponse</td>
</tr>
</tbody>
</table>

Show only files with tag: All tags / default branch □ Module path or alias: OpenSees/SRC/element Go

#include <TwentyNodeBrick.h>

Inheritance diagram for TwentyNodeBrick:

```
    TaggedObject
       ↑
       ↑
    MovableObject
       ↑
       ↑
    DomainComponent
       ↑
       ↑
    Element
       ↑
       ↑
    TwentyNodeBrick
```

List of all members

Public Member Functions

```
TwentyNodeBrick (int element_number, int node_num_1, int node_num_2, int node_num_3, int node_num_4, int node_num_5, int node_num_6, int node_num_7, int node_num_8, int node_num_9, int node_num_10, int node_num_11, int node_num_12, int node_num_13, int node_num_14, int node_num_15, int node_num_16, int node_num_17, int node_num_18, int node_num_19, int node_num_20); #Material *GlobalModel, double b1, double b2, double b3, double r, double p);
TwentyNodeBrick ()
```

const char * getClassName (void) const

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OpenSees Framework Applications

Tall Building Analysis

Advanced Visualization

Seismic Performance of Urban Regions
NEESit: High-Performance Computing

- OpenSees implementations
  - Domain decomposition
  - High-fidelity site response by DRM
  - Large-scale parameter studies

- Teragrid allocation and usage
  - NEES wide 50,000 SU’s (OpenSees, ABAQUS, Adina, LS-Dyna)
  - 22 projects have access to allocation

- NEESsphere interfaces for HPC jobs
OpenSees Integration with NEESit
What Has Been Accomplished by PEER in Simulation/IT for Practice and Research?

**Simulation in practice:**
- Much more robust and validated models for R/C
- Dynamic analysis for suite of ground motions used more widely, provide improved understanding of EDP distributions for PBEE
- Recognition of importance of SSFI on many structures

**Simulation in research:**
- The first open-source software for earthquake engineering; developed an enabling technology for the community
- Introduced a new generation of students to modern IT
- Tackled more complex problems using teams of researchers to develop models, computational procedures, and model validations
- Improved coordination between structural and geotechnical simulation
- Created new opportunities for IT and cyberinfrastructure advances in earthquake engineering through NEES and other NSF initiatives

**Combination of two accelerated advances for simulation in PBEE, incorporated modern IT, and created a community of users.**