Earthquake Simulations of Large Scale Structures using OpenSees Software on Grid and High Performance Computing in India

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ABSTRACT :

The Open System for Earthquake Engineering Simulation (OpenSees) is one of the many projects under development, as part of the Pacific Earthquake Engineering Research Center (PEER). Breaking the barriers of traditional methods and software development protocols, PEER has embarked on a completely new approach in the earthquake engineering community by developing an open-source, object-oriented software framework. Tthe rapid advances in information technology can be used in developing the next generation of earthquake engineering simulation applications and also in educating the next generation of earthquake engineers. These advances include high-end computers for solving large-scale problems; databases for searching for new information from experimental data, simulation data, or observed data such as ground motion and field data; and visualization technology for providing engineers, design professionals, understanding about the performance of their systems. The capabilities of OpenSees include Modeling, Analysis and Structural Reliability. In this investigation, OpenSees software has been implemented on different HPC system in India and its performance has been evaluated using simulation studies. The OpenSees model has a Bridge and the effects of permanent displacements on the performance of these structures with impact of long period ground motions in an earthquake. The Simulation study is carried out using our Supercomputing facility - Param Padma system. The earthquake engineering analysis and simulations demand high computational requirements. A study on the time performance has been carried out and the effectiveness of parallel Opensees, to handle large size simulations is demonstrated taking advantage of the latest developments in databases, reliability methods, scientific visualization, and high-end computing

KEYWORDS:

OpenSees, High Performance Computing, Simulations, nonlinear finite element analysis

1. INTRODUCTION

One of the best features of OpenSees is its suitability to support a multidisciplinary approach to Performance Based Earthquake Engineering simulation problems. The modular design allows researchers from different disciplines to combine their software implementations. As one example, OpenSees is linking new models in structural and soil behavior for affecting a complete soil-foundation-structure interaction analysis. As another, parallel and distributed equation solvers developed by computer scientists and mathematicians are integrated into the framework for the simulation of very large models. The framework has been combined with advanced ground motion simulation software to investigate the earthquake behavior of structures distributed through an urban region. Researchers are developing reliability modules using the framework. In another example, other researchers are using OpenSees to develop computational reliability modules for performance-based earthquake engineering.

Structural models have been developed with a general representation of shear behavior in reinforced concrete. An accurate assessment of reinforced concrete building damage must include shear and shear-flexure modes of behavior in order to capture nonductile failure modes that can occur and to track the degradation of shear strength and stiffness during an earthquake.

One of the major objectives of the OpenSees Processor is to provide a user-friendly mechanism to researchers and engineers so that they can employ the renowned computational technology and handle the complex problems in an efficient manner. Therefore, the functions available in the OpenSees toolbox must be accessible. Firstly OpenSees user can use any available tools, such as GID, SAP2000, to gather information regarding to the coordinates of the nodes and elements. Secondly, by inputting these coordinate data, users can easily create tcl files that accurately represent the shape and the load conditions of the structures by using OpenSees Model Builder. Thirdly, the users can query the results and download the output files in the local machine after submitting the completed OpenSees model to the collaborative framework or High performance Computing Facility. Thereafter, users can also examine the analytical results by plotting the deformation time history, displacement plot, acceleration plot, the stress-strain contour and numerous other types of plots.

2. BRIDGE EXAMPLE

2.1 Example Problem

A Model of Hollow pier Bridge was selected in the ongoing development of a performance-based earthquake engineering design and assessment methodology at the Pacific Earthquake Engineering Research (PEER) Center. A two- imensional, advanced nonlinear computational model of the structure-foundation system of bridge has been developed using OpenSees, the new PEER software framework for seismic response simulation of structural systems. This paper presents and discusses a simplified, yet improved definition of the seismic excitation along the boundaries of the soil domain included in the finite element model of the structure-foundation system. This seismic excitation assumes vertically incident shear waves and a linear elastic, undamped, the nonlinear soil region modeled. The proposed treatment of the boundary conditions includes transmitting/absorbing boundaries in order to limit the occurrence of spurious seismic wave reflections along the boundaries of the modeled soil medium. Using simple (single wavelet) incident wave motions, the dynamic response of the bridge-foundation system obtained using the above modeling assumptions is obtained.

The OpenSees Example includes

```
# Hollow High Pier 3 Nos.
#   Reinforced concrete bridge with 30m tall pier
# Length of Deck slab 40 m
# Foundation 1 m in length
# No of spans 3
#   Nonlinear beam-column elements
# Perform the transient analysis
# Create the convergence test, the norm of the residual with a tolerance of
     1e-12 and a max number of iterations of 10 test EnergyIncr 1.0e-12 15 0
# Create the solution algorithm, a Newton-Raphson algorithm algorithm Newton
# Create the integration scheme, Newmark with gamma = 0.5 and beta =    0.25
     integrator Newmark    0.5    0.25
# Create the system of equation, a banded general storage scheme system UmfPack
# Create the constraint handler, a plain handler as homogeneous boundary conditions
    constraints Transformation
# Create the DOF numberer, the reverse Cuthill-McKee algorithm numberer RCM
# Create the analysis object analysis Transient
# Define materials for nonlinear columns
# CONCRETE                    tag     f'c        ec0     f'cu         ecu
# Core concrete (confined)
uniaxialMaterial Concrete01 1   -44540.0   -0.0051   -28500.0    -0.0254
```

```
# Cover concrete (unconfined)
uniaxialMaterial Concrete01 2   -34000.0   -0.002    0.0       -0.006
#Linear elastic torsion
uniaxialMaterial Elastic   101   [expr 11.6942*13000000.0]
# STEEL
# Reinforcing steel
set fy 340000.0;         # Yield stress
set E 200000000.0;       # Young's modulus
#                                tag   fy E0      b
uniaxialMaterial Steel01   3   $fy $E 0.001
# Define cross-section for nonlinear columns
# set some paramaters
set y    1.55
set y2 1.25
set z    1.55
set z2 1.25
set cover   0.05
set As      0.000490625;        # area of 25mm bars
```

3. MODELING

A two-dimensional nonlinear model of the Bridge, including the superstructure, piers, and supporting piles was developed using *OpenSees*.The bridge piers are modeled using 2-D nonlinear material, fiber beam-column elements formulated using the flexibility approach based on the exact interpolation of the internal forces The column cross-section is discredited into concrete and steel fibers. A sinusoidal incident wave is applied at the base through a set of nodal equivalent forces.

3.1 Analysis on Param Padma

The Bridge is analysed and simulated on C-DACs HPC facility Param Padma and the simulation is carried out using two aspects.

1. The no of iterations for the simulations keeps on changing and the simulation time counted for the same.
2. The no. of iteration kept constant as 2000 and the No. of processors varied accordingly and the simulation time counted for the same.

The Simulation Results on Param Padma using earthquake as Tabas fp as input.

Table 1

Sr. No.	No. of Iterations	No of Processors	Time Taken for Simulation in sec
1.	200	36	661
2.	500	36	710
3.	1000	36	730
4.	1500	36	850
5.	2000	36	990
6.	2200	36	1280
7.	2500	36	1290

Table 2

Sr. No.	No. of Iterations	No of Processors	Time Taken for Simulation in sec
1.	2000	4	1710
2.	2000	8	1660
3.	2000	12	1400
4.	2000	16	1250
5.	2000	24	1060
6.	2000	30	1150
7.	2000	36	1280

CONCLUSIONS

This paper briefly describes a 2D nonlinear finite element model of the structure-foundation-soil system for the assumed Bridge. This model was developed using OpenSees, the new software framework for seismic response simulation of structural and geotechnical systems developed by the Pacific Earthquake Engineering Research (PEER) Center. This paper especially focuses on the simulations and energy transmitting/absorbing boundary for this bridge model. The results for the displacements and strains and forces (Stresses) are collected for the tabas fp earthquake. It is found that nonlinearity of the bridge has a significant effect on the wave propagation through the Pier and deck slab. This methodology initiates the simulations studies using High performance computing of C-DAC for structural systems and can be useful for integrating probabilistic seismic hazard analysis, advanced computational modeling of the bridge ground system, probabilistic seismic demand analysis, and probabilistic damage analysis or fragility analysis.

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