MTS/PEER Expert Seminar: Hybrid Simulation Technologies & Methods for Civil Engineering, UC Berkeley, 3/20-3/21/2018

Implementation Frameworks: OpenFresco & OpenFresco*Express*

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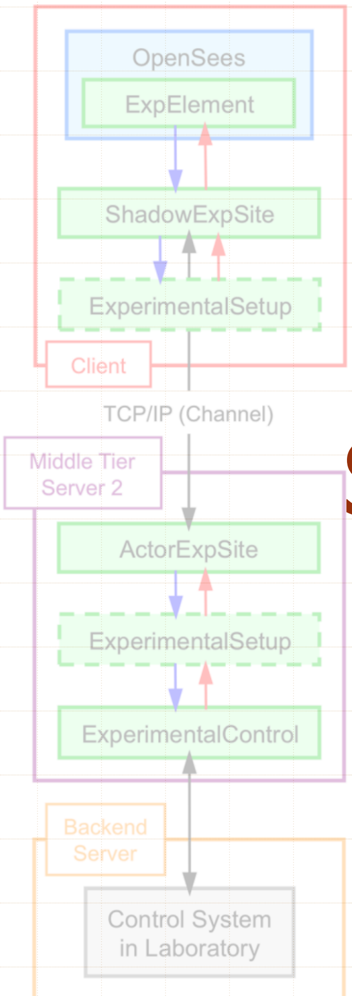
PEER NSF MTS NEES MAFFEI STRUCTURAL ENGINEERING

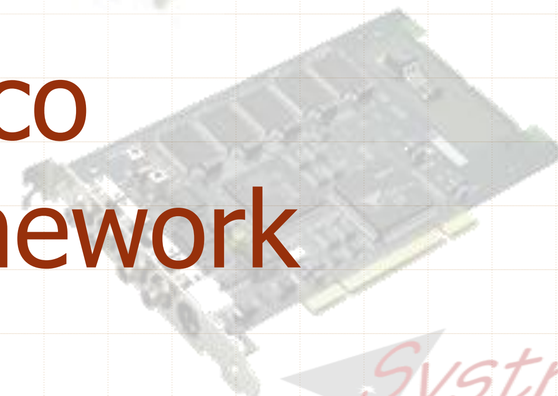
OpenFresco

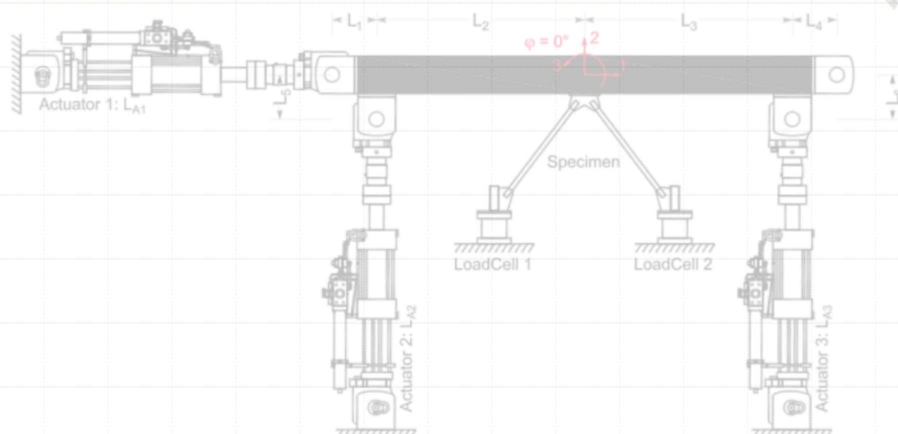
Outline of Presentation

1. OpenFresco Software Framework
2. Unique OpenFresco Features
3. OpenFresco Express GUI
4. Website and Resources
5. Summary & Conclusions



OpenFresco Software Framework





What is OpenFresco?

- Open source Framework for Experimental Setup and Control
- Secure, object oriented, network enabled "middleware" -- Pairs computer analysis software with laboratory control systems and other software to enable hybrid and collaborative computing:

- Computational Drivers
  - OpenSees
  - OpenFresco*Express*
  - Abaqus
  - ANSYS
  - LS-DYNA
  - Matlab
  - Simulink
  - UI-SimCor
- Control Systems
  - dSpace
  - MTS
    - STS family
    - Flextest/CSI
    - Flextest/SCRAMNet
    - 469D
    - SRMD
  - National Instruments
  - Pacific Instruments
  - ADwin

Why a Software Framework?

- Lack of a common framework for development and deployment of HS
- Problem specific implementations which are site and control system dependant
- Such highly customized software implementations are difficult to adapt to different structural problems

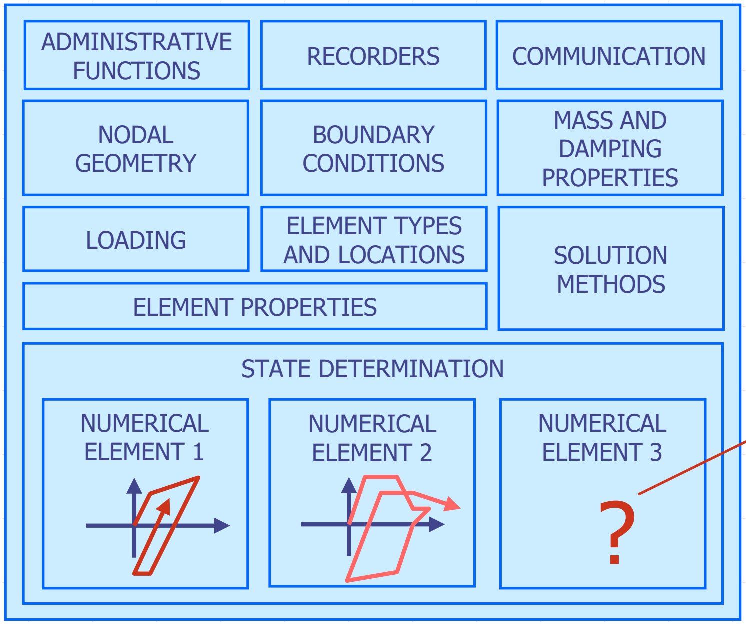
→ Need a robust, transparent, adaptable, and easily extensible software framework for research and deployment

What is a Software Framework?

- A reusable design for a software system, or subsystem
- Defines overall architecture of a software system, meaning its basic components and the relationships among them
- Expressed as a set of abstract classes and the way their instances collaborate
- Loose-coupling of components within the framework is essential for extensibility and reusability

Rethinking implementation strategies

- Embed test specimen(s) in an existing computational framework of user's choice

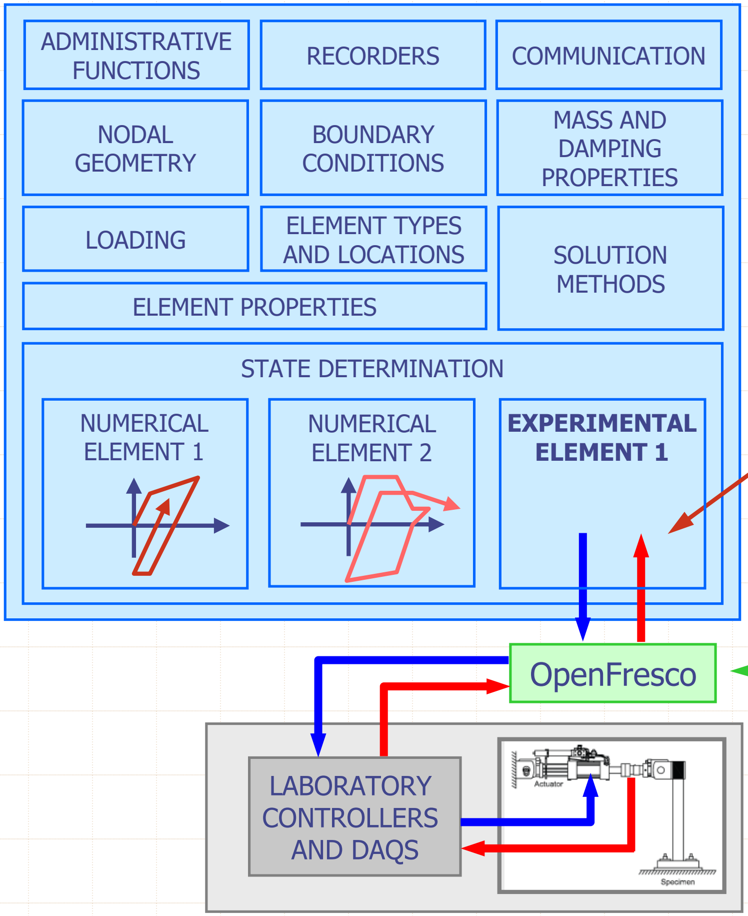


Typical features of an analysis framework

Proper numerical model uncertain

Rethinking implementation strategies

- Embed test specimen(s) in an existing computational framework of user's choice



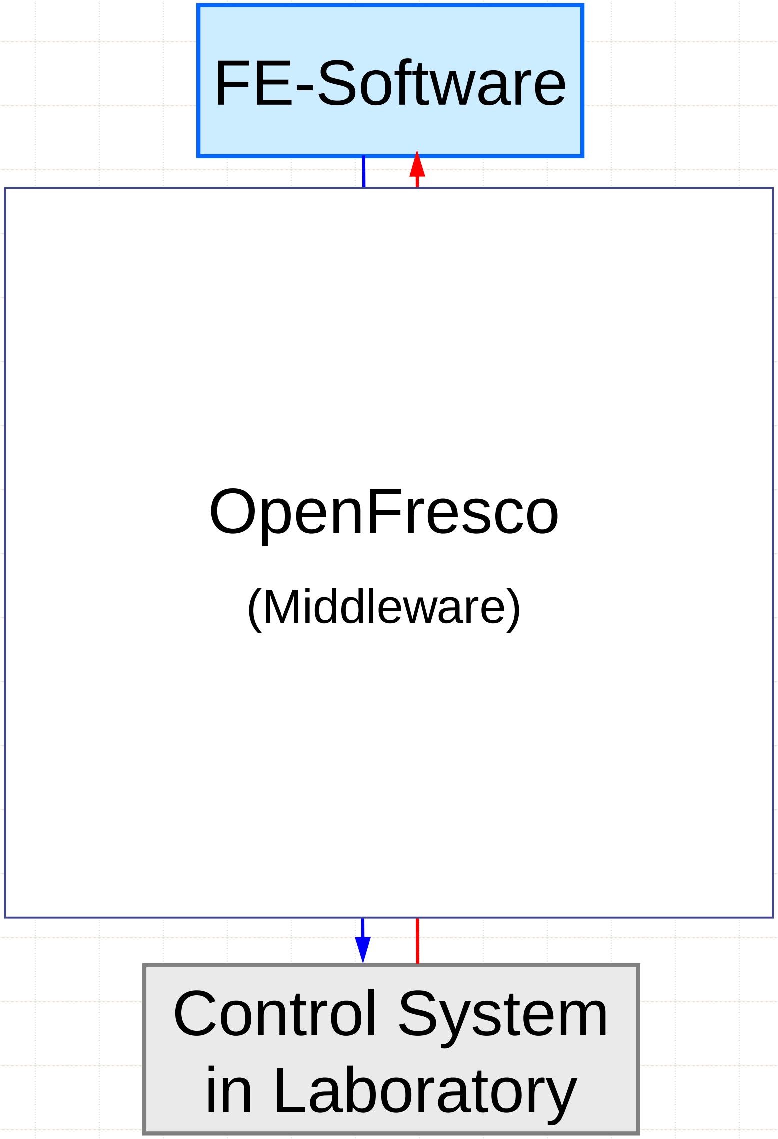
Typical features of an analysis framework

Define element as an "Experimental Element"

OpenFresco

Laboratory

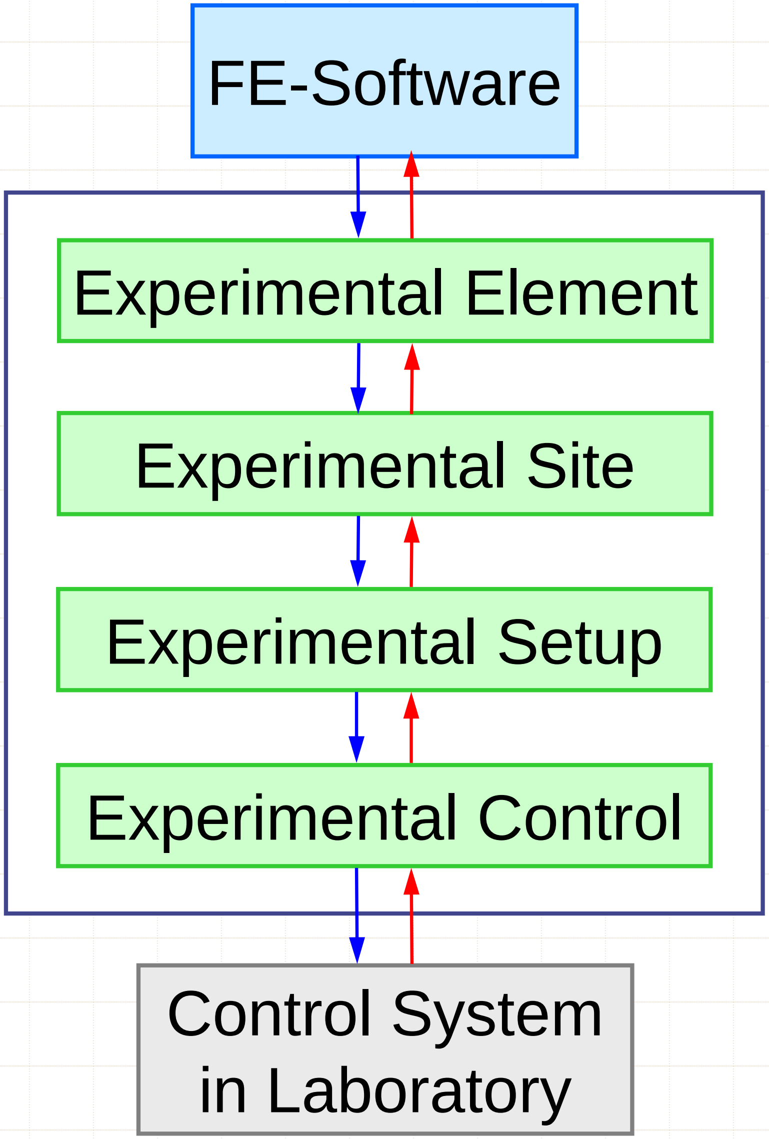
OpenFresco Components



provides all features of unmodified computational framework, including parallel and network computing

provides control of physical actuators as well as data acquisition using physical instrumentation devices

OpenFresco Components



provides all features of unmodified computational framework, including parallel and network computing

represents the part of the structure that is physically tested and provides the interface between the FE-software and the experimental software framework

stores data and provides communication methods for distributed testing

transforms between the experimental element degrees of freedom and the actuator degrees of freedom (linear or non-linear transformations)

interfaces to the different control and data acquisition systems in the laboratories

provides control of physical actuators as well as data acquisition using physical instrumentation devices

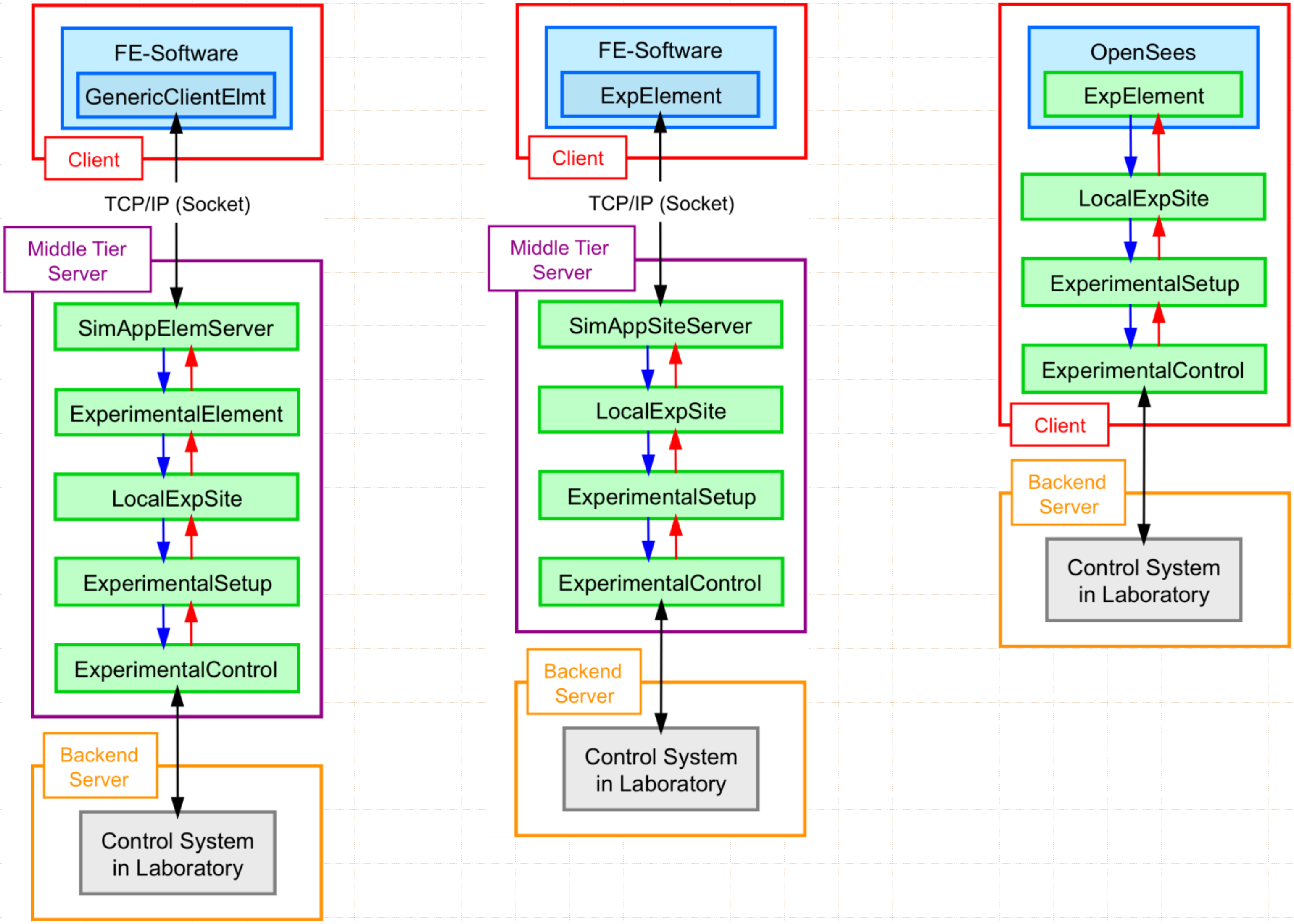
Requirements for Architecture

- Provide connectivity to a wide variety of FE-software (clients), independent of the language, such analysis software is programmed in
- Enable distributed testing and support different communication protocols
- Interface with rapidly evolving control and data acquisition systems deployed at testing facilities all over the world

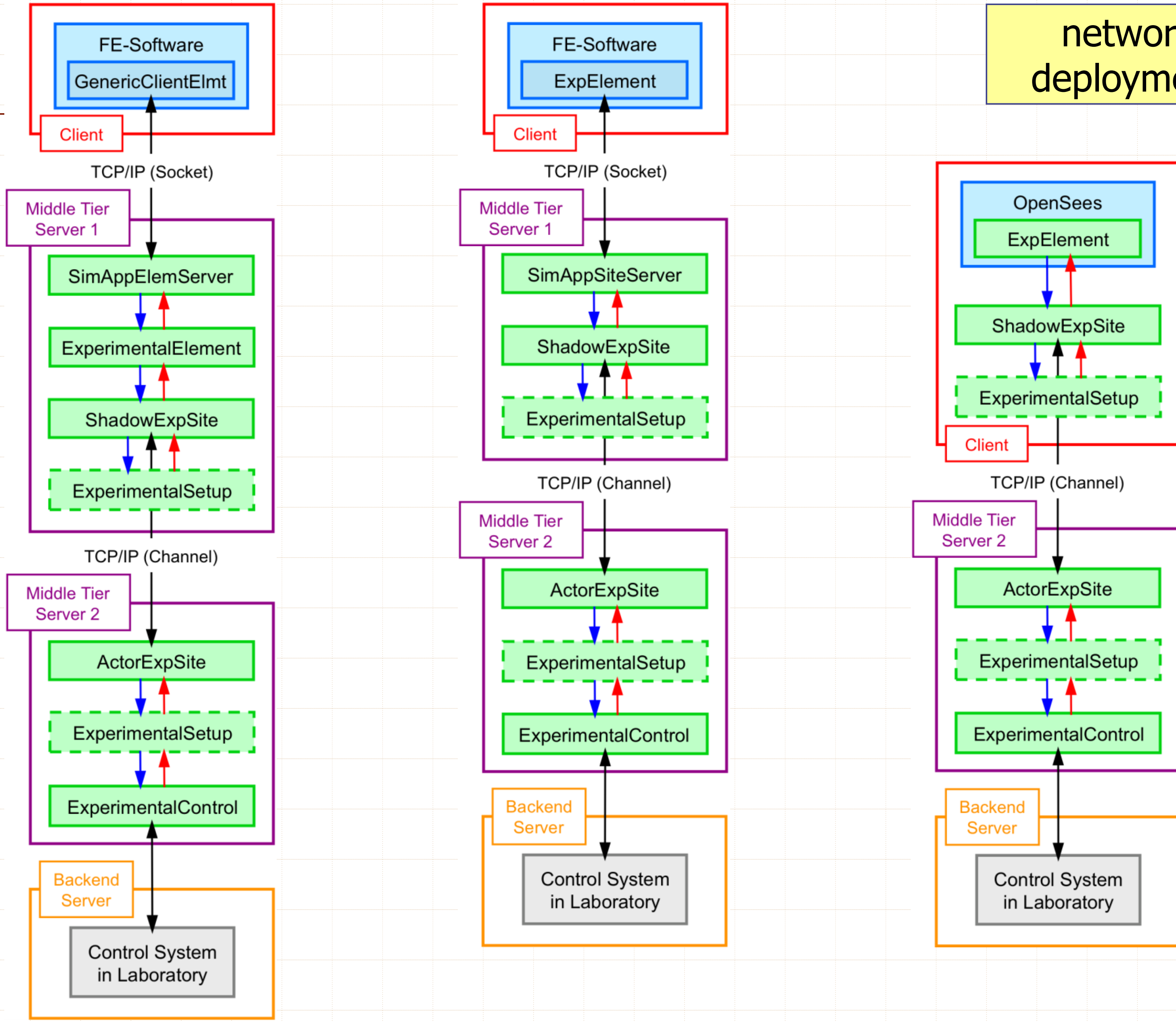
→ Multi/Three-Tier Software Architecture

OpenFresco Components

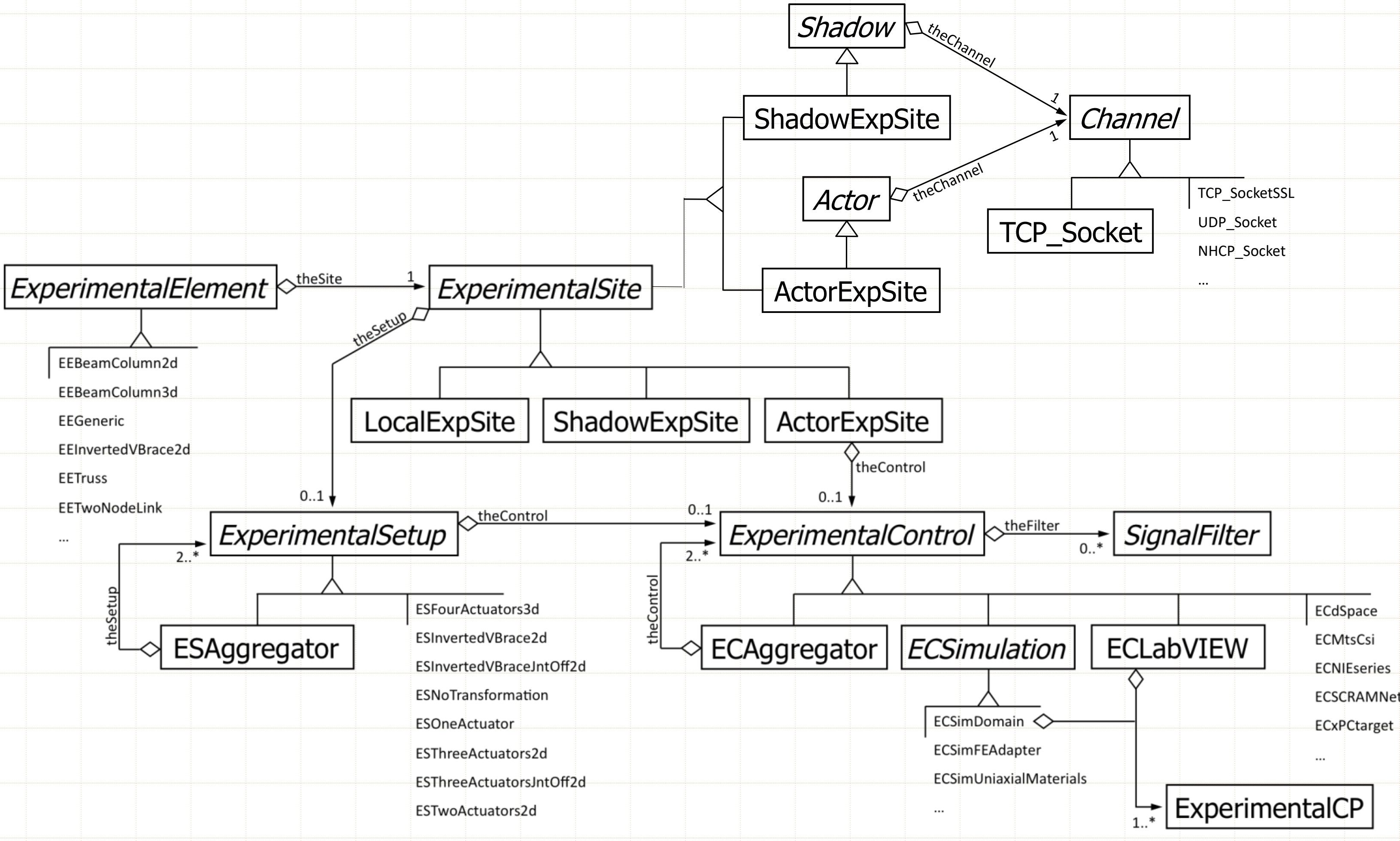
local deployment



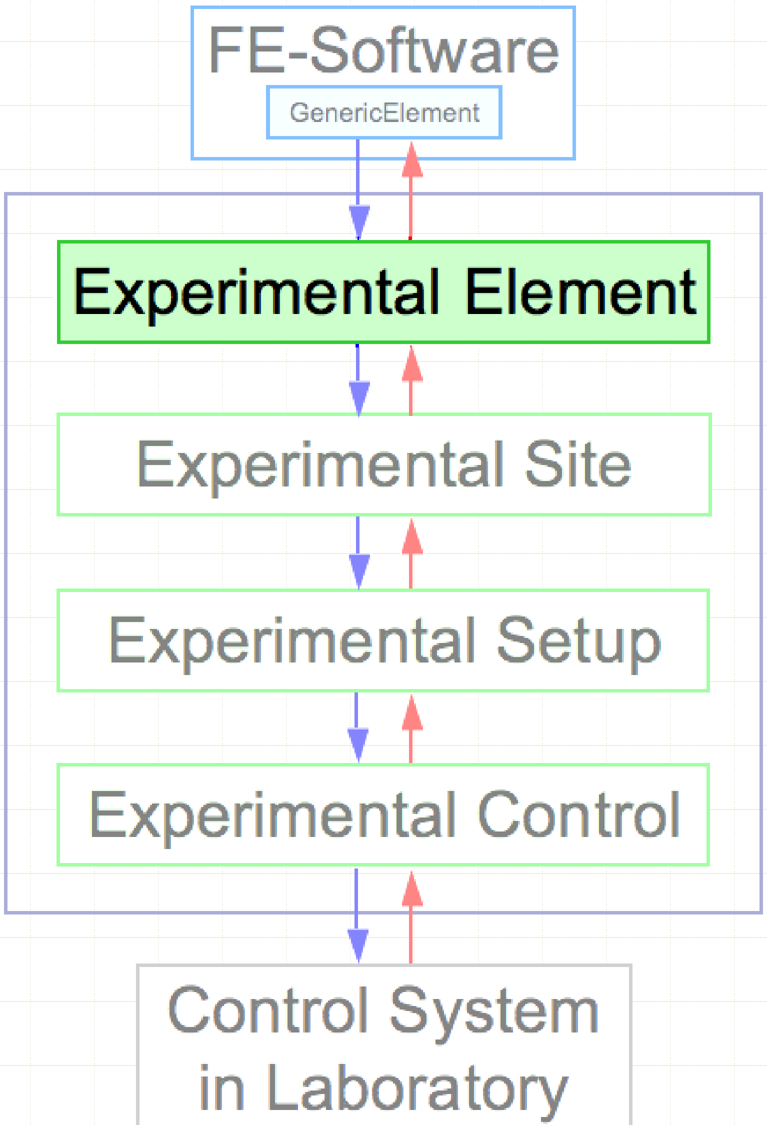
network deployment



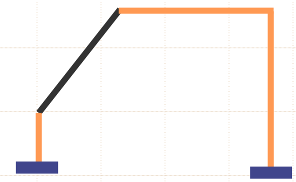
OpenFresco Class Diagram



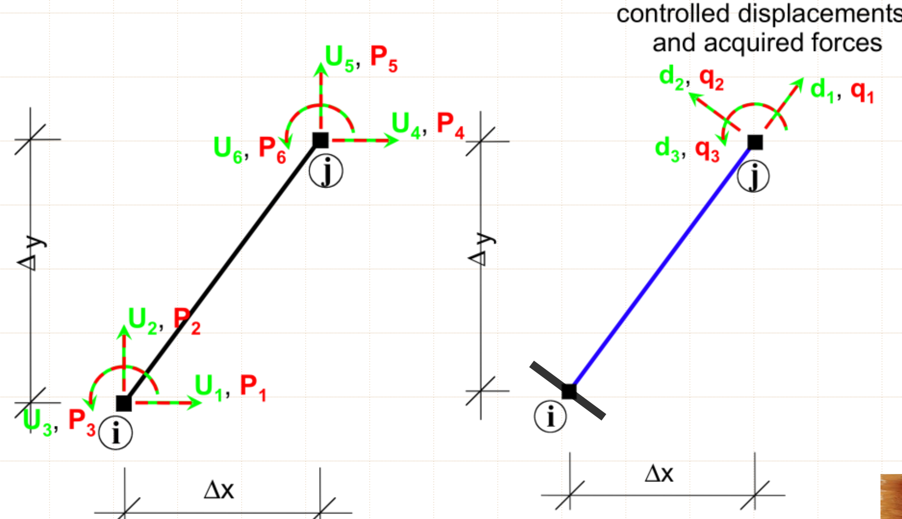
OpenFresco Components



Experimental Element
Transforms between the global element degrees of freedom in the FE-Software and the basic element degrees of freedom in the experimental element

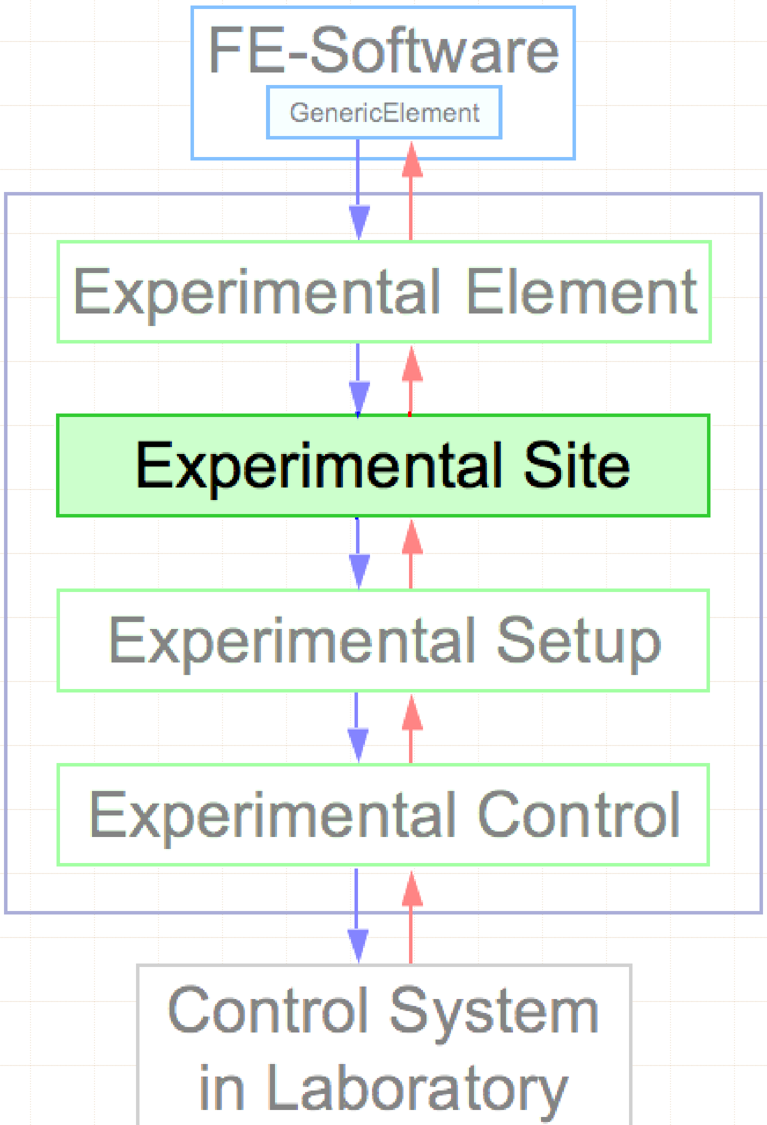


Consider element in structure
- Two coordinate systems used in FE analysis



Global System — Cantilever Basic System

OpenFresco Components

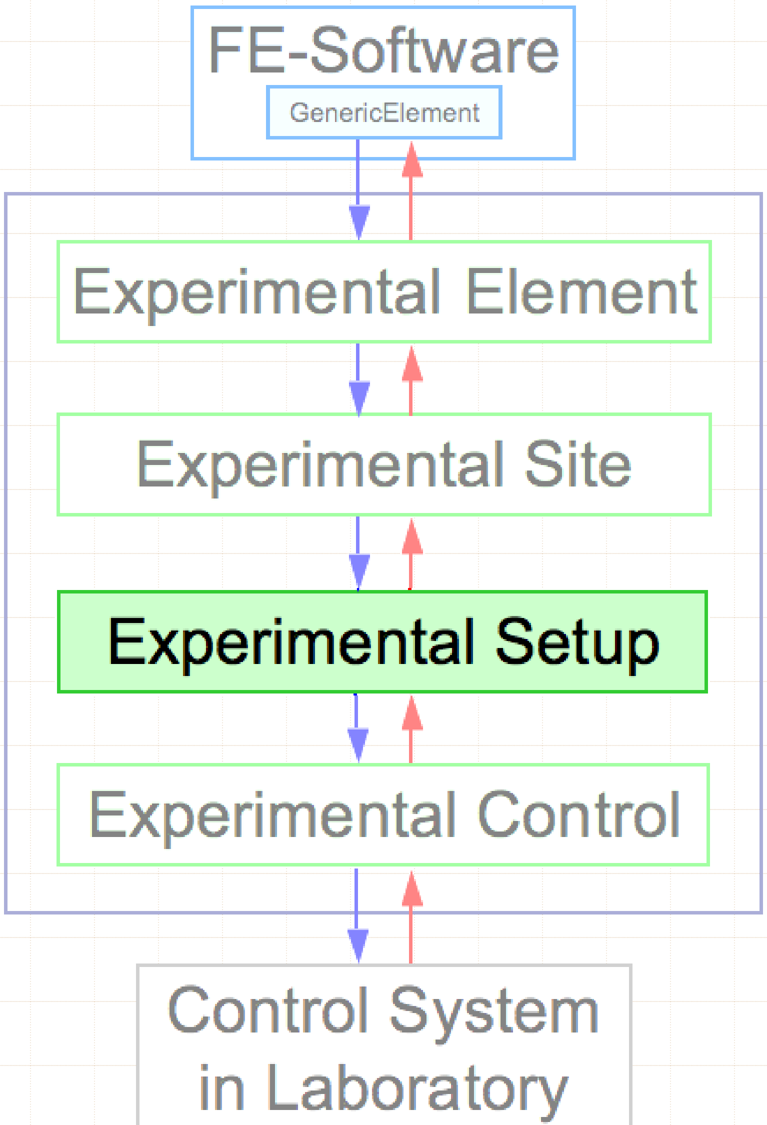


Experimental Site
Stores data and provides communication methods for distributed testing

LocalExpSite available for local testing and RemoteExpSite/ActorExpSite pair available for geographically distributed testing

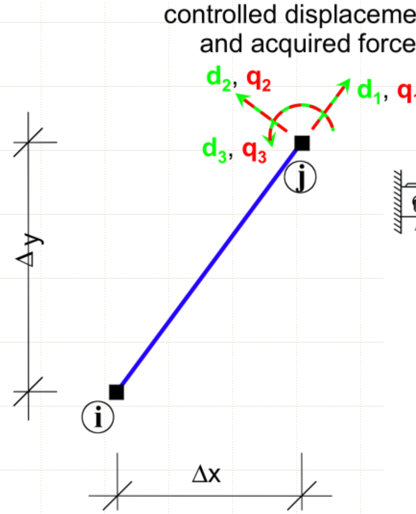
Utilizes communication channels with TCP, TCP+SSL or UDP communication protocols

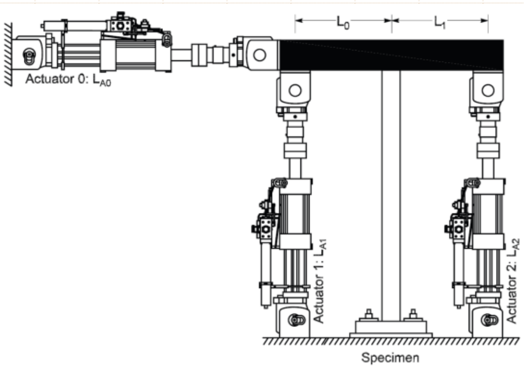
OpenFresco Components



Experimental Setup

Transforms between the basic experimental element degrees of freedom in OpenFresco and the actuator degrees of freedom in the laboratory (linear vs. non-linear transformations are available)



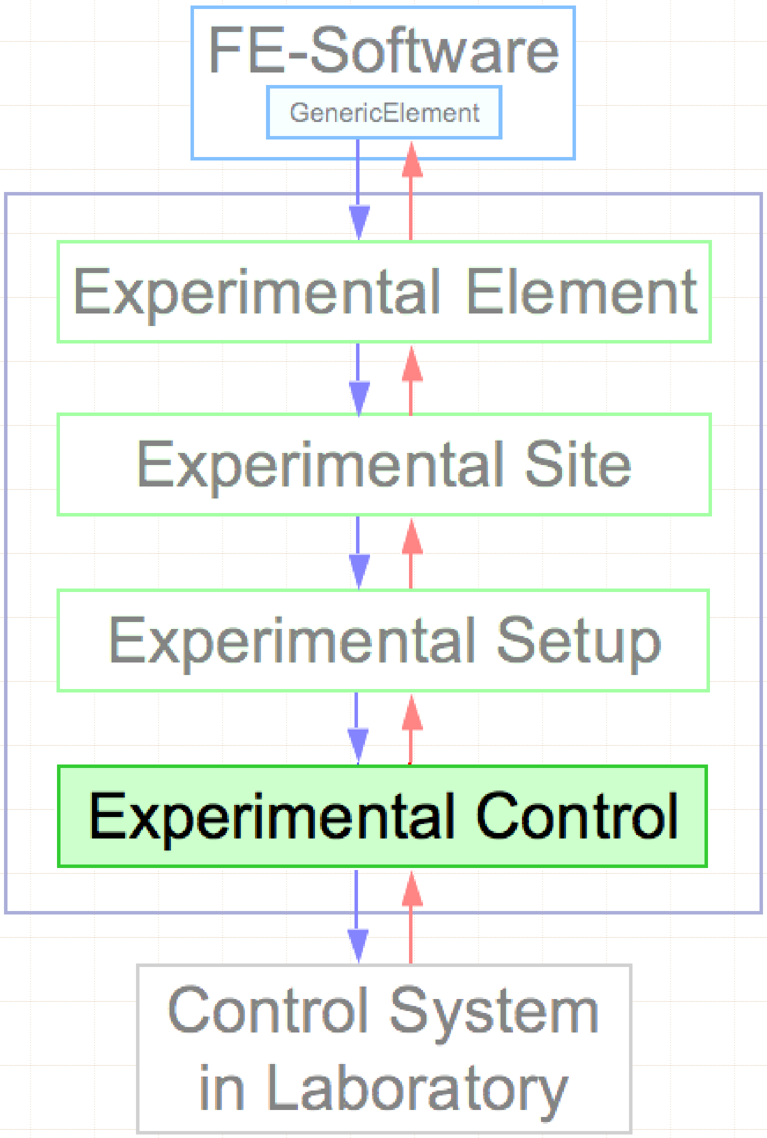


Cantilever Basic System

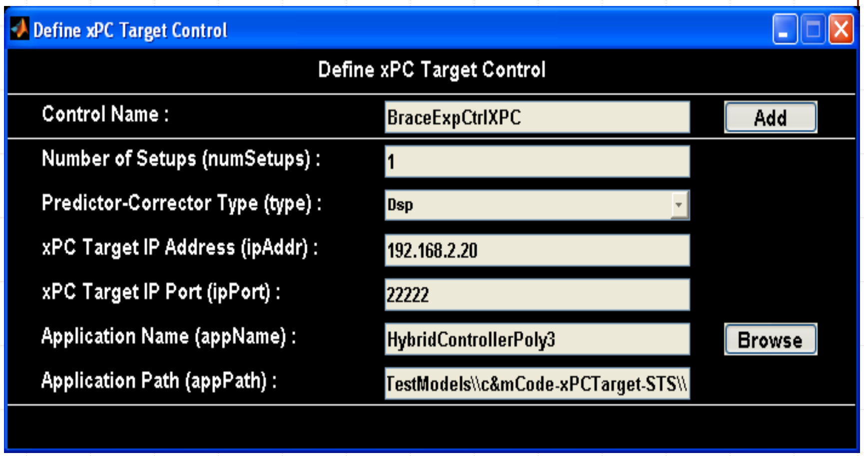
Actuator Setup

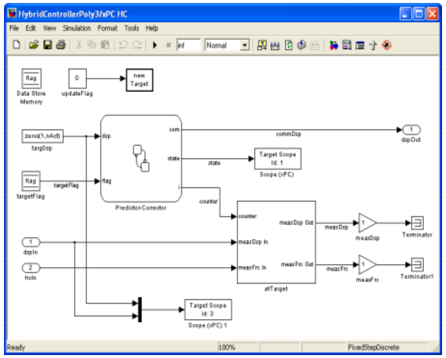
$$T = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & -L_0 \\ 0 & 1 & L_1 \end{bmatrix}$$

OpenFresco Components

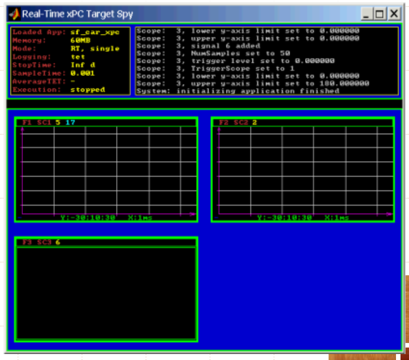


Experimental Control
Interfaces to the different control and data acquisition systems in the laboratories (IP addresses and port numbers)





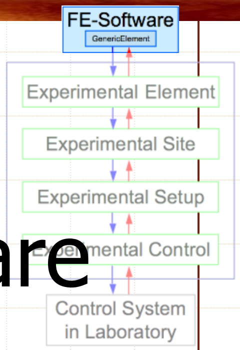
Predictor-Corrector



xPC Target

Computational Drivers

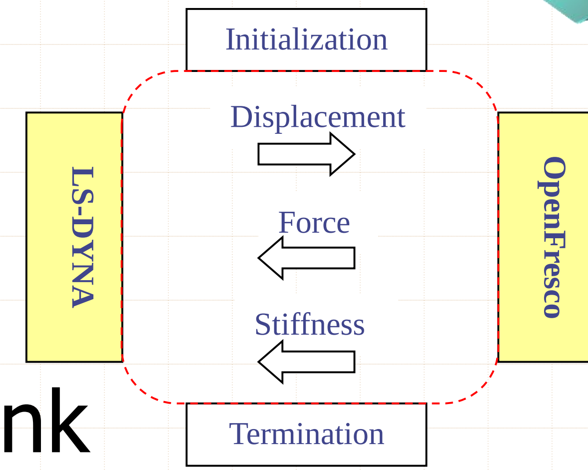
How to Interface

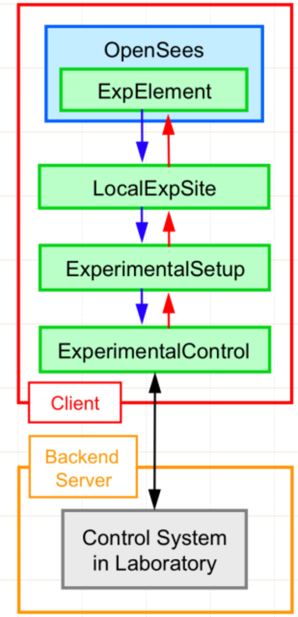


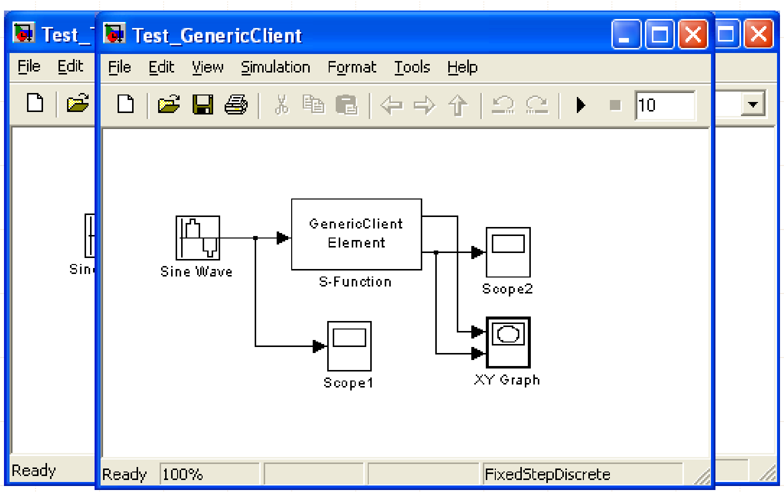
- Two Ways to Interface with FE-Software
  - Generic Client Element
  - Experimental Element Directly in FE-Software
- Generic Client Element to be Programmed by the Developers
- Several generic client elements available: /trunk/SRC/simApplicationClient

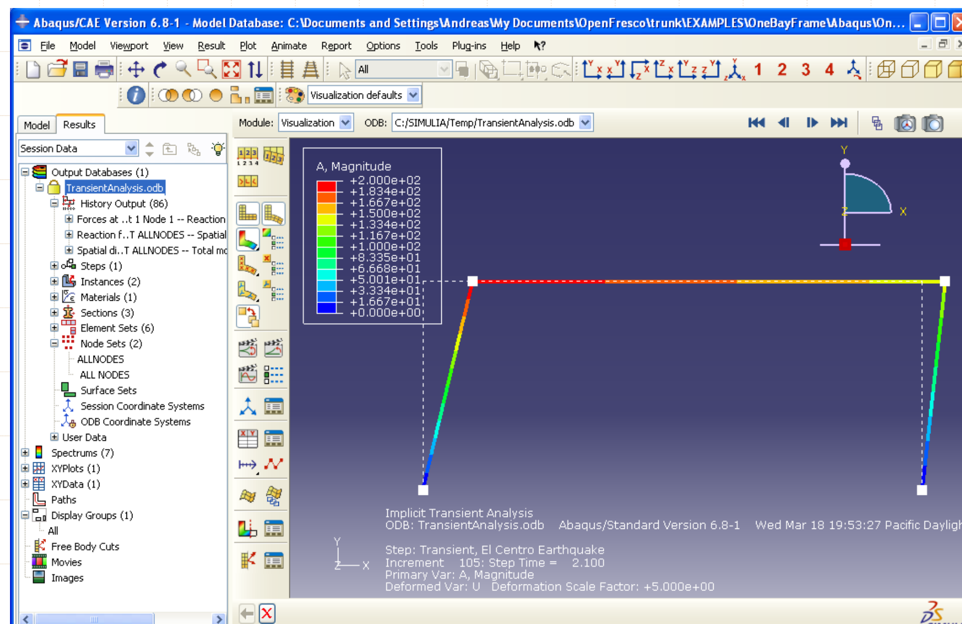
Computational Drivers

- OpenSees
- LS-DYNA
- Abaqus
- Matlab/Simulink
- ANSYS

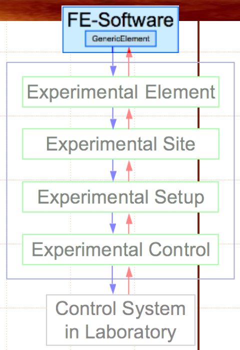








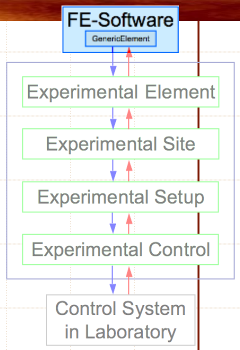
Integration Methods



$$\mathbf{M} \cdot \ddot{\mathbf{u}}_n + \mathbf{C} \cdot \dot{\mathbf{u}}_n + \mathbf{P}_r(\mathbf{u}_n) = \mathbf{P}(t_n)$$

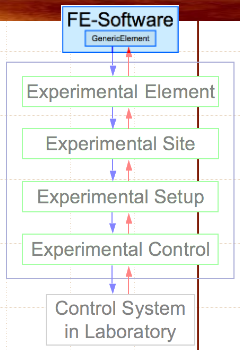
- Mass matrix M is often singular -> second order differential equation infinitely stiff -> fully implicit numerical methods
- Make as few function calls as possible
- Use constant Jacobian in the numerical methods since tangent stiffness is not available

Direct Integration Methods



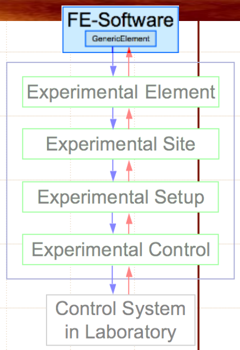
- Explicit Integrators
  - explicit Newmark Method
  - Central-Difference Method
  - explicit Alpha Method
  - explicit Generalized-Alpha Method
  - KR-Alpha Method
- Implicit Integrators (do not use for HS)
  - Newmark Method
  - Alpha Method
  - Generalized-Alpha Method
  - Collocation Method

Direct Integration Methods

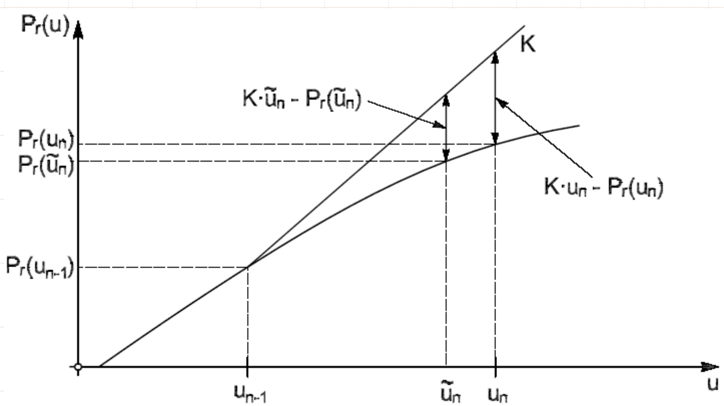


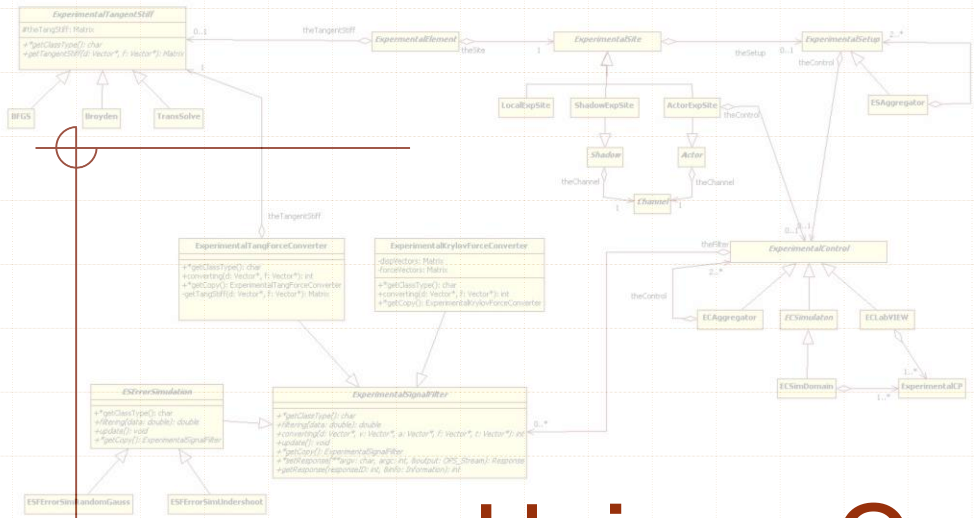
- Implicit Integrators with increment reduction factors
  - Newmark HS IncrReduct Method
  - Generalized-Alpha HS IncrReduct Method
  - Collocation HS IncrReduct Method
- Implicit Integrators with increment limits
  - Newmark HS IncrLimit Method
  - Generalized-Alpha HS IncrLimit Method
  - Collocation HS IncrLimit Method

Direct Integration Methods

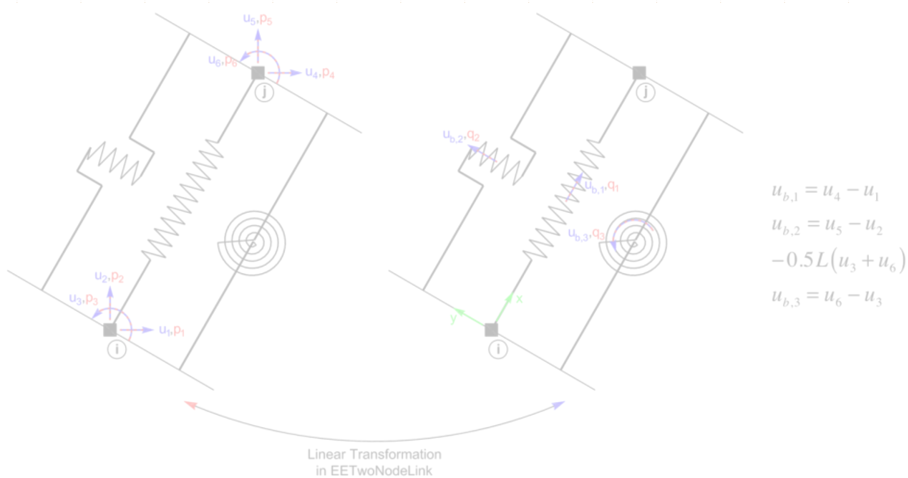


- Implicit Integrators with sub-stepping (constant number)
  - Newmark HS FixedNumIter Method
  - Generalized-Alpha HS FixedNumIter Method
  - Collocation HS FixedNumIter Method
- Predictor-Corrector Integrators
  - Alpha-OS Method
  - Generalized-Alpha-OS Method





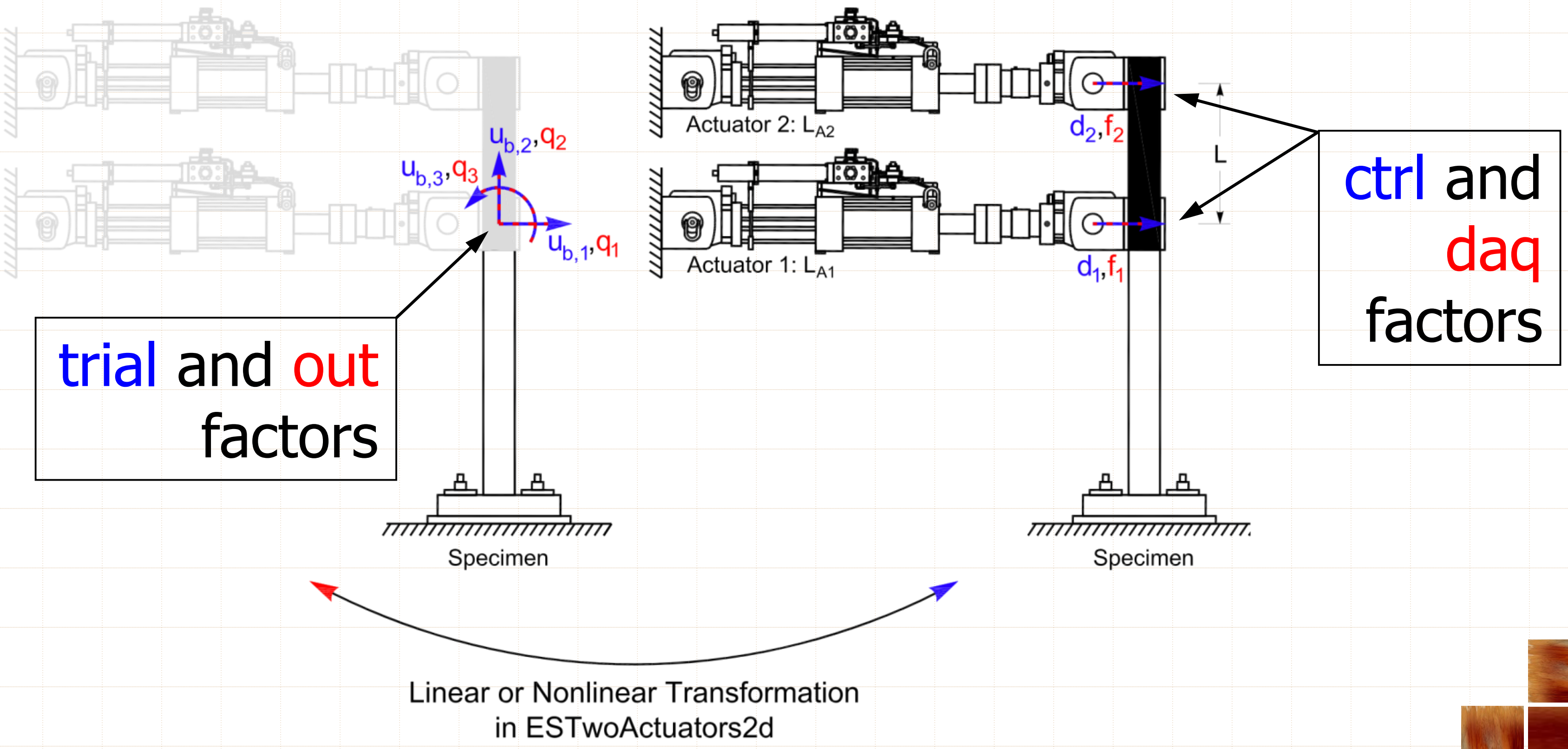
Unique OpenFresco Features



Similitude and Scaling

Response Factors:

factors can now be applied to trial and output response data in addition to control and daq response data

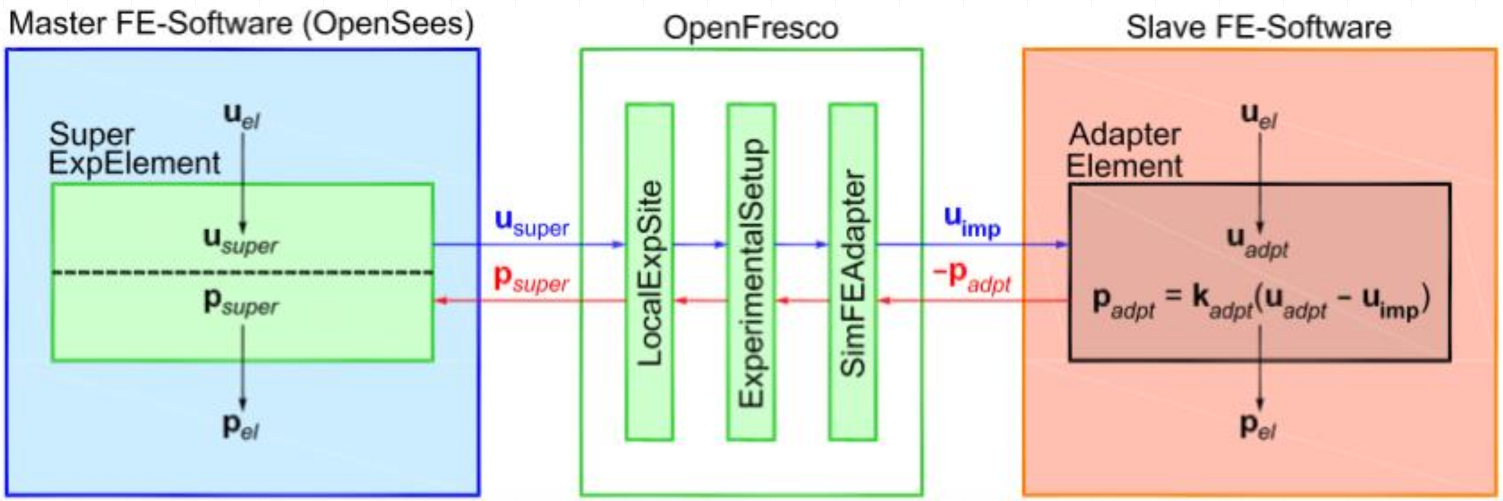


Co-Simulation (Software Coupling)

ECSimFEAdapter

```
expControl SimFEAdapter $tag ipAddr $ipPort
```

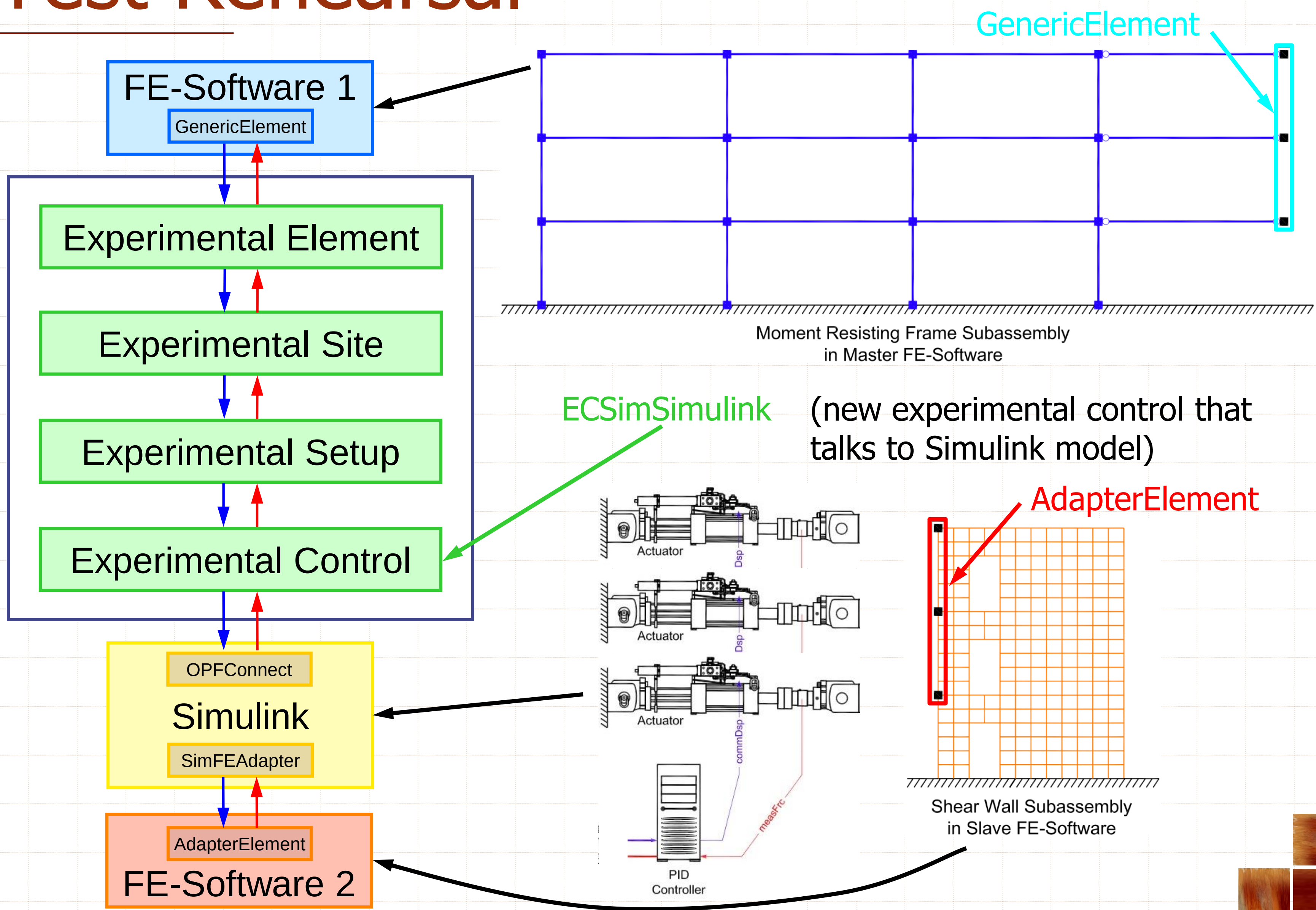
`$tag`	unique control tag
`ipAddr`	IP address of slave process
`$ipPort`	IP port of slave process



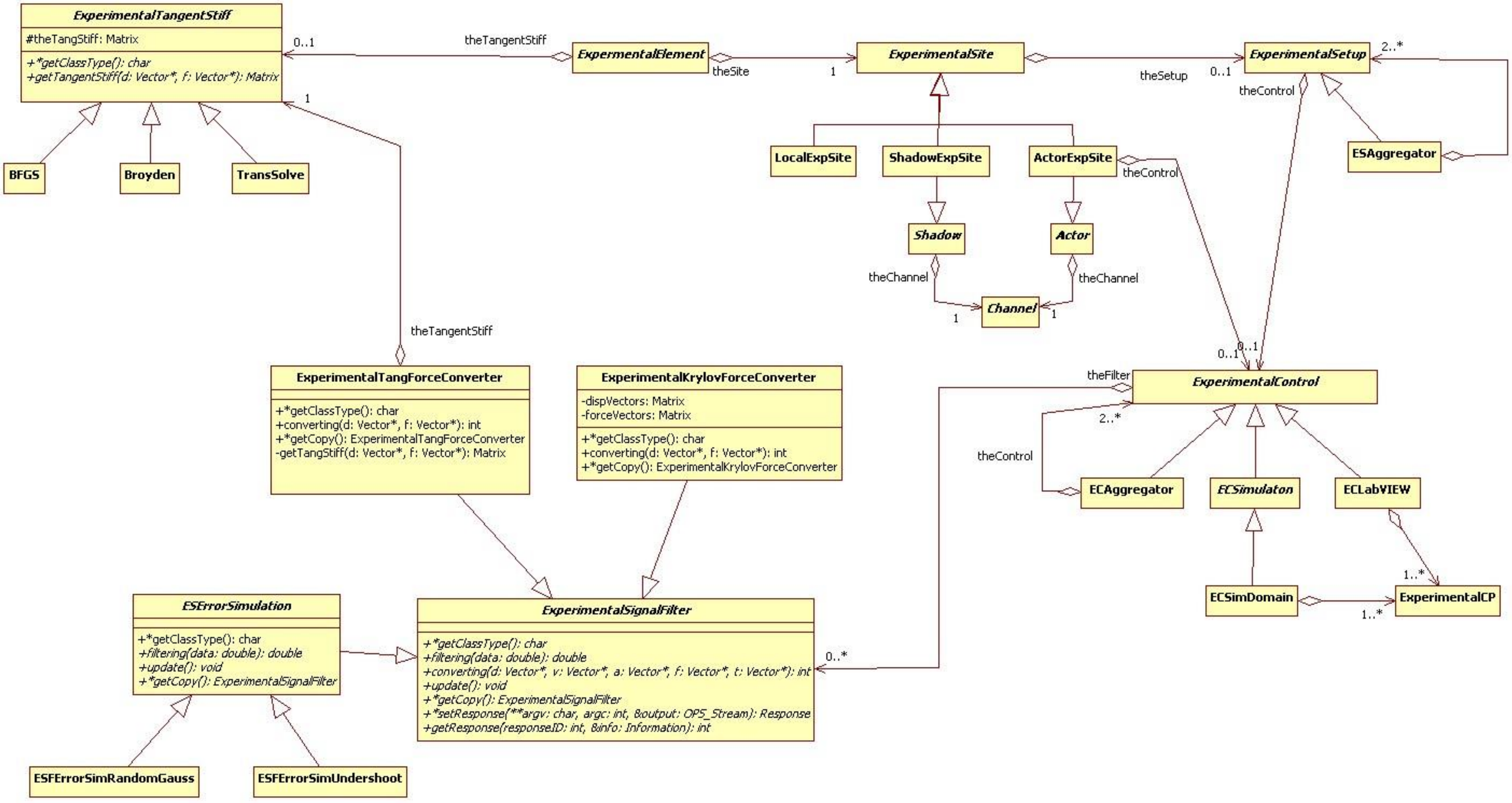
Co-Simulation (Software Coupling)

- Master Programs
  - OpenSees
  - OpenFresco*Express*
  - Abaqus
  - LS-DYNA
  - Matlab
  - Simulink
  - ANSYS
  - UI-SimCor
- Slave Programs
  - OpenSees
  - Abaqus
  - LS-DYNA
  - Matlab
  - Simulink
  - ANSYS

Test Rehearsal



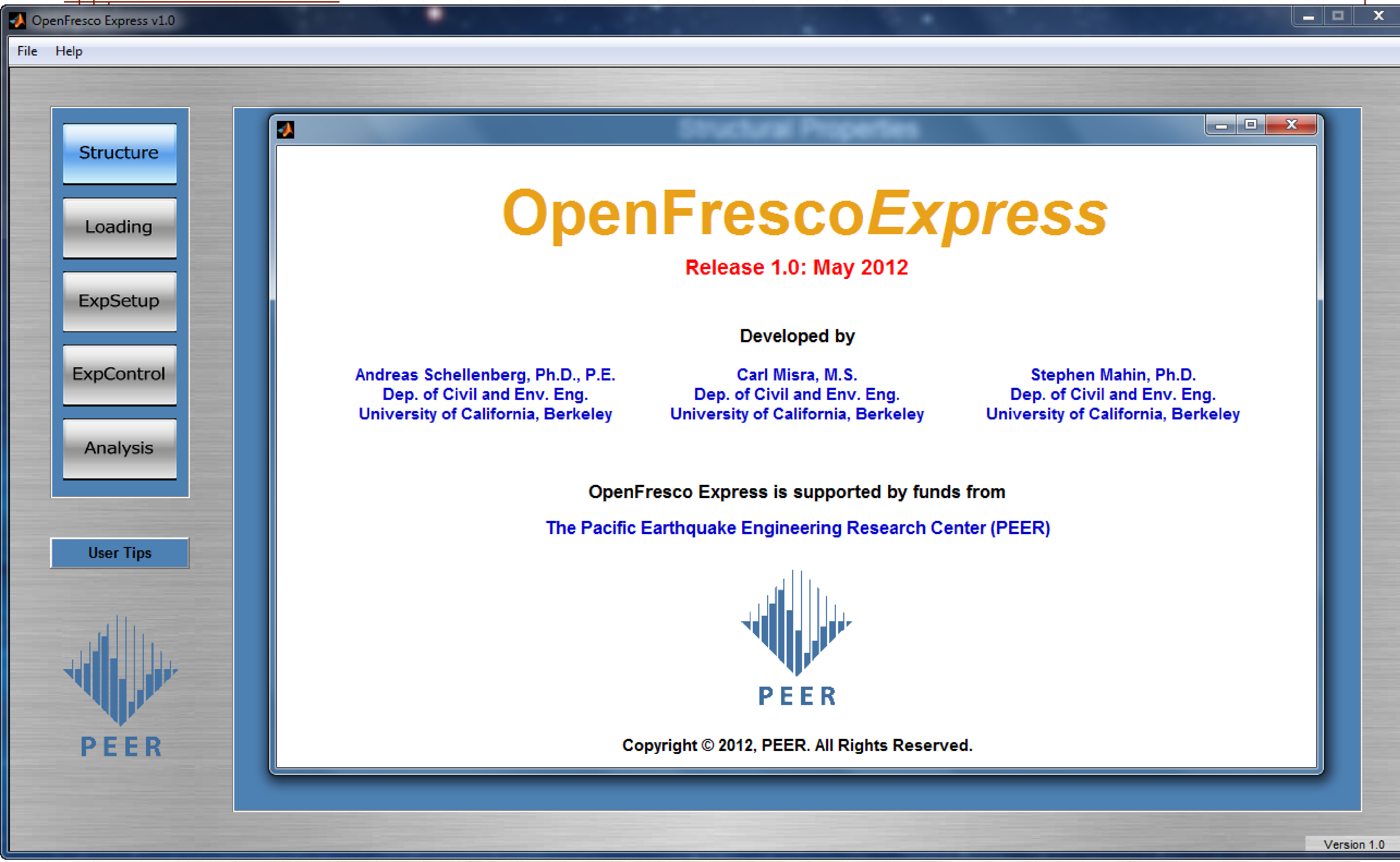
Force and Mixed Control



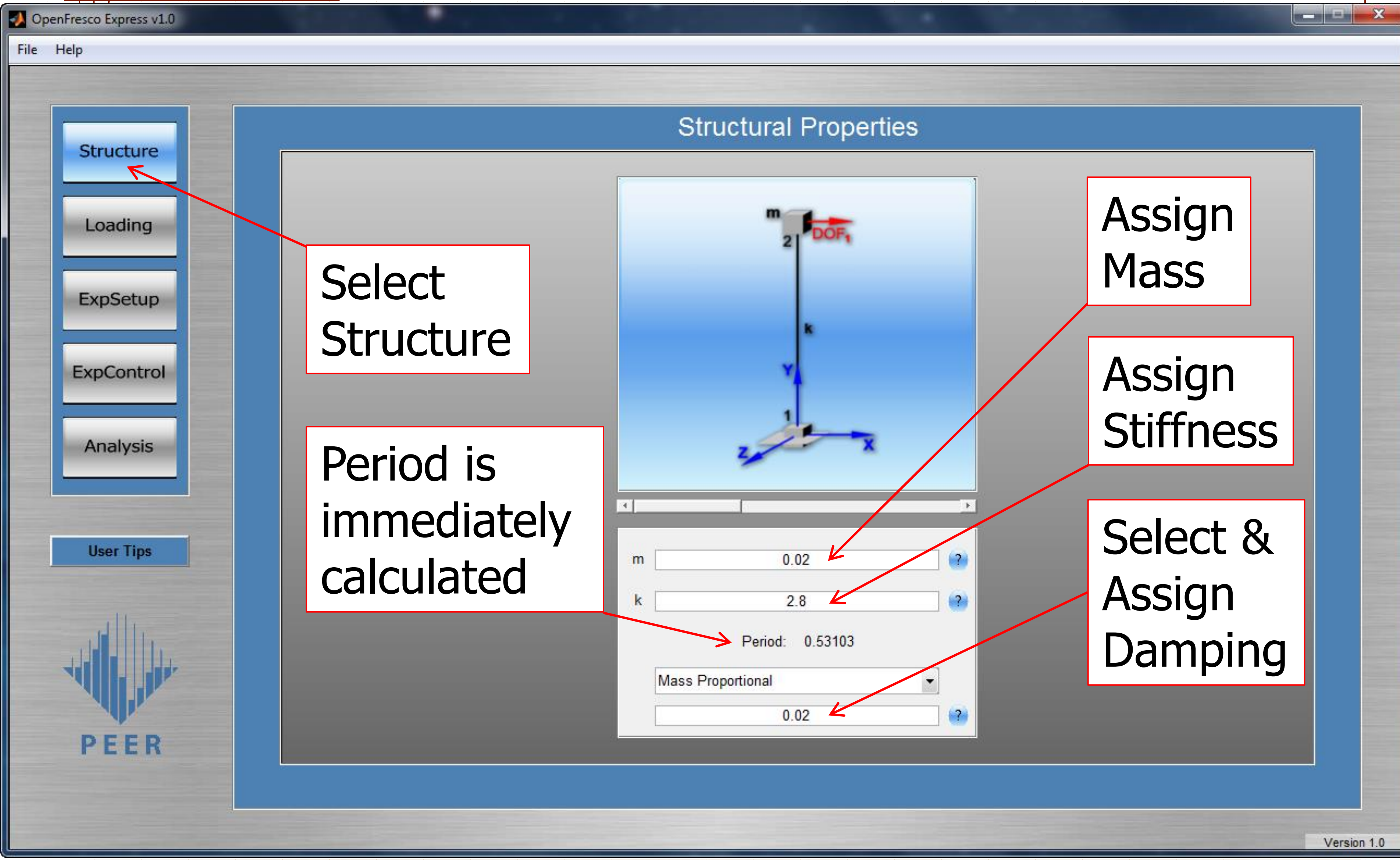
Some useful utility commands

- **logFile $fileName <-append> <-noEcho>**
- **defaultUnits -force $type -length $type -time $type -temp $type**
- **metaData –title $txt –contact $txt –description $txt –modelType $txt –analysisType $txt …**
- **recordExp**
- **removeExp recorder $tag**
- **wipeExp**
- **setupLabServer $siteTag**
- **stepLabServer $siteTag $numSteps**
- **stopLabServer $siteTag**

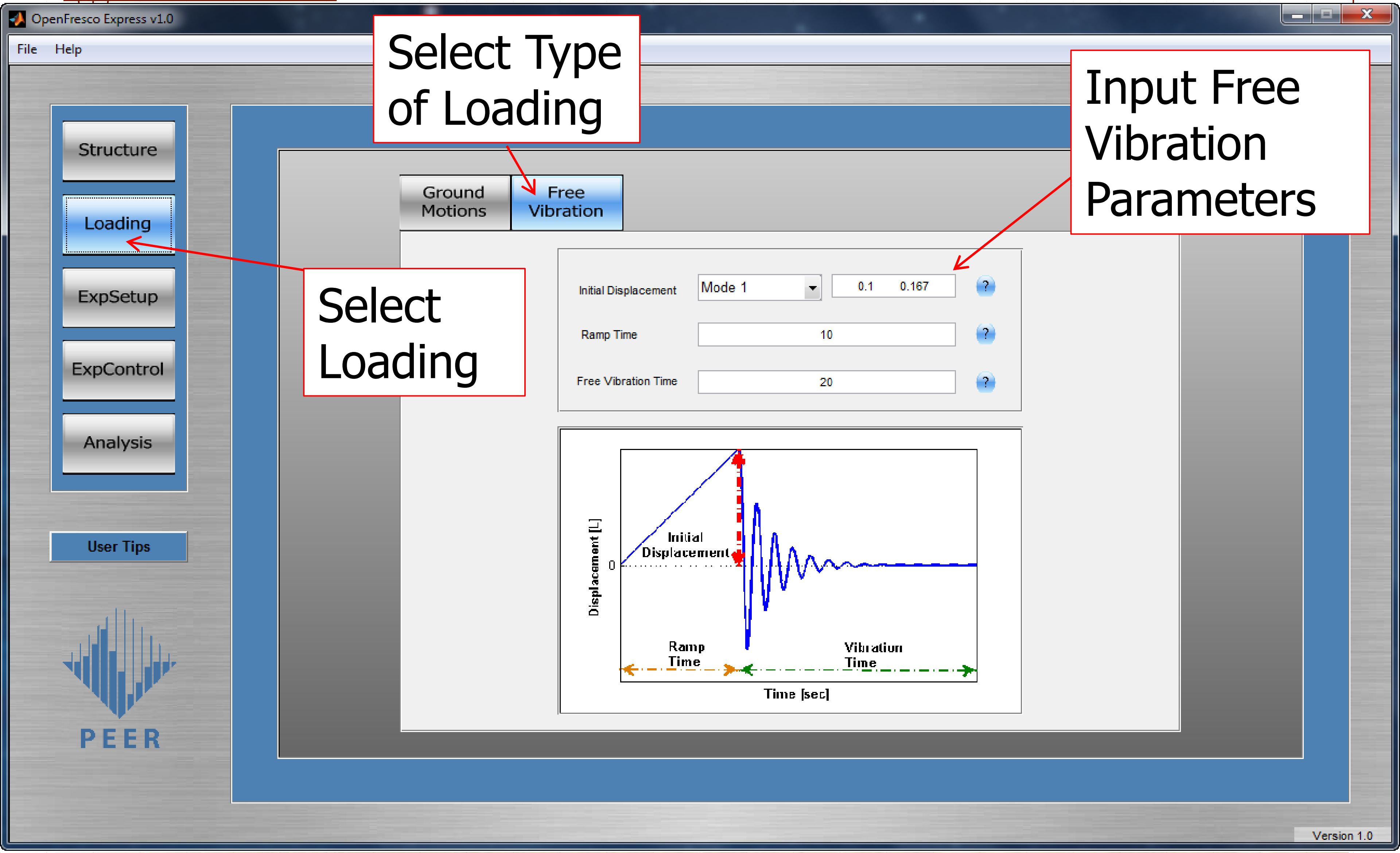
GUI: OpenFresco*Express*



GUI: OpenFresco*Express*



Define Loading: Free Vibration

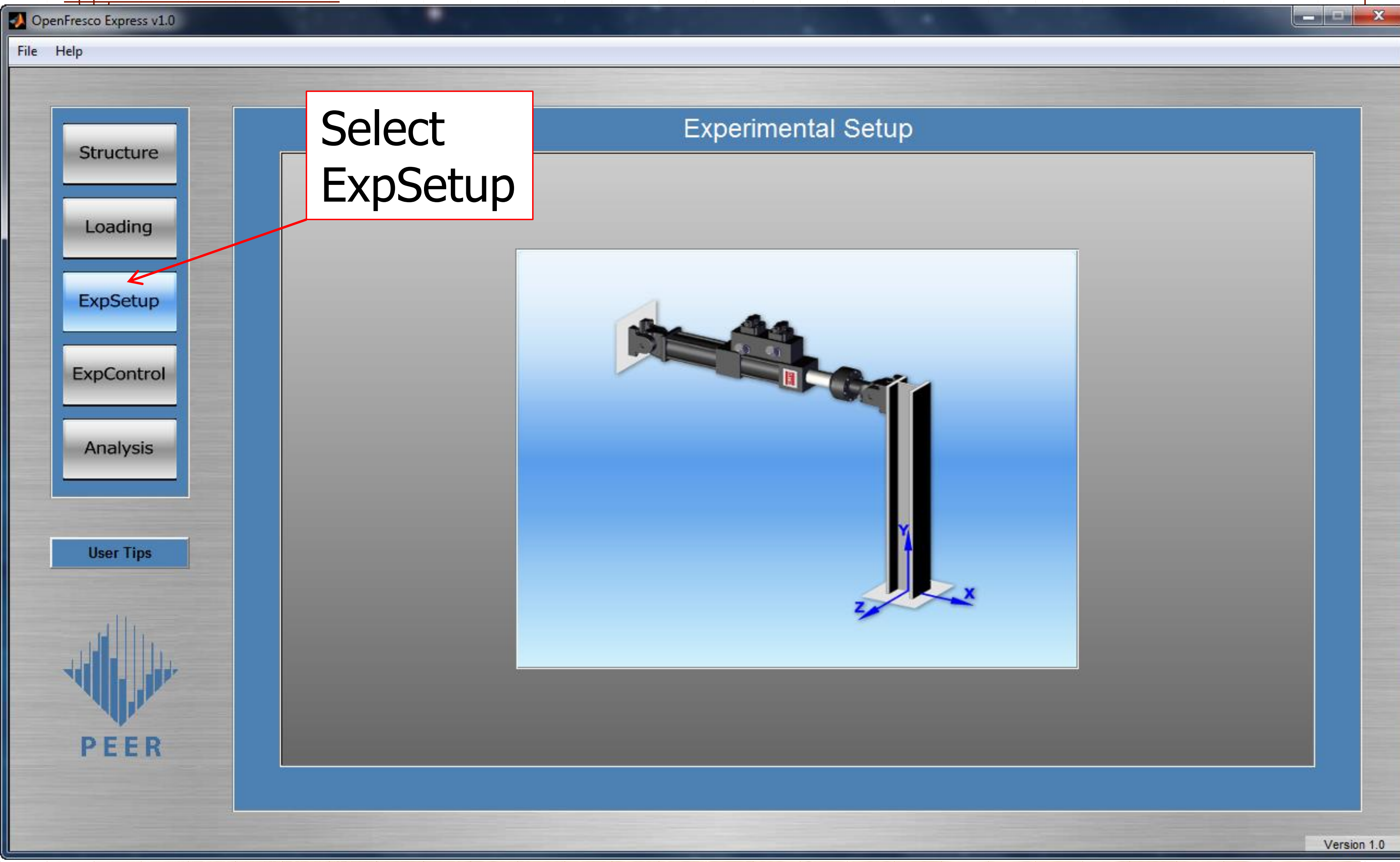


Select Type of Loading

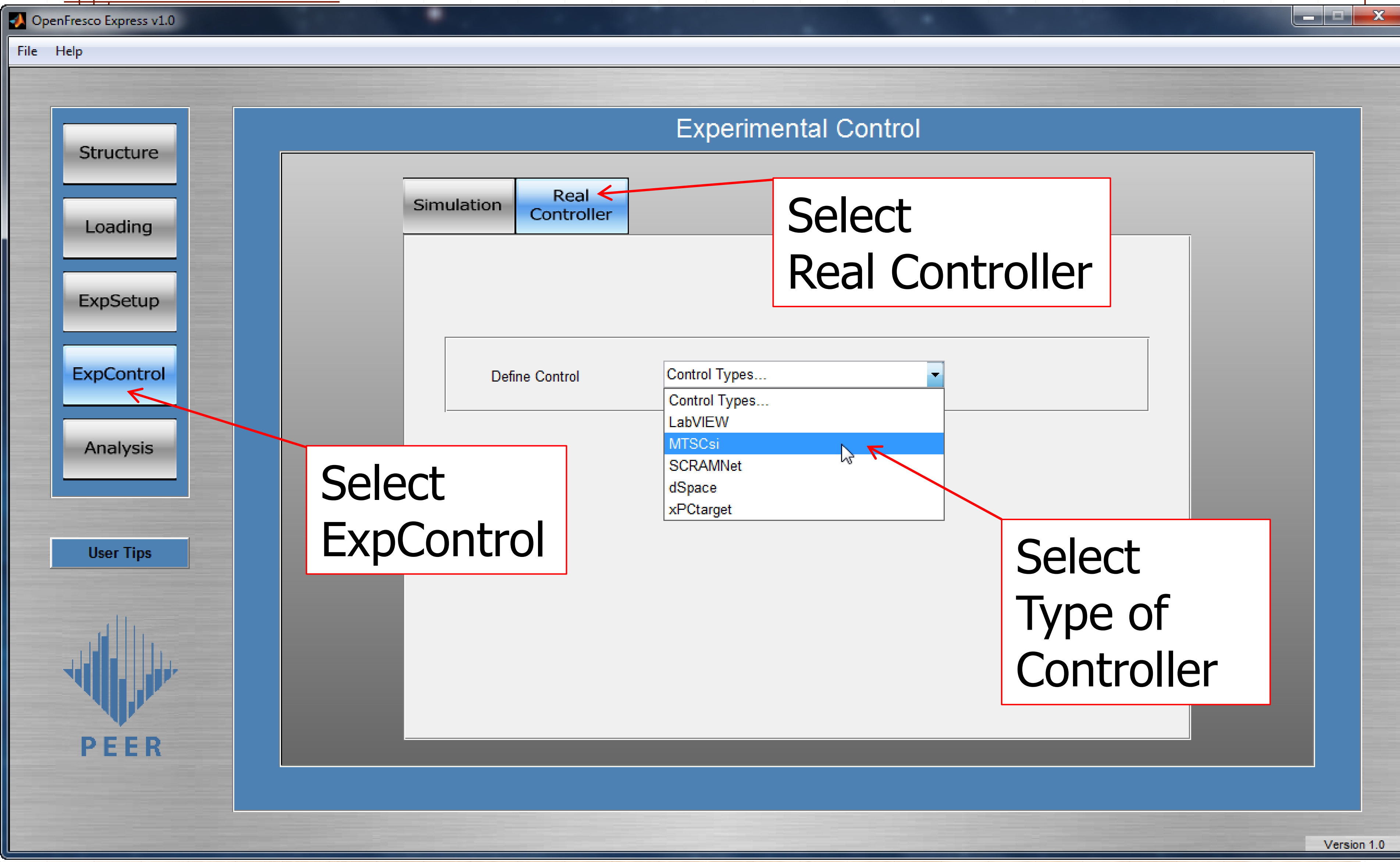
Input Free Vibration Parameters

Select Loading

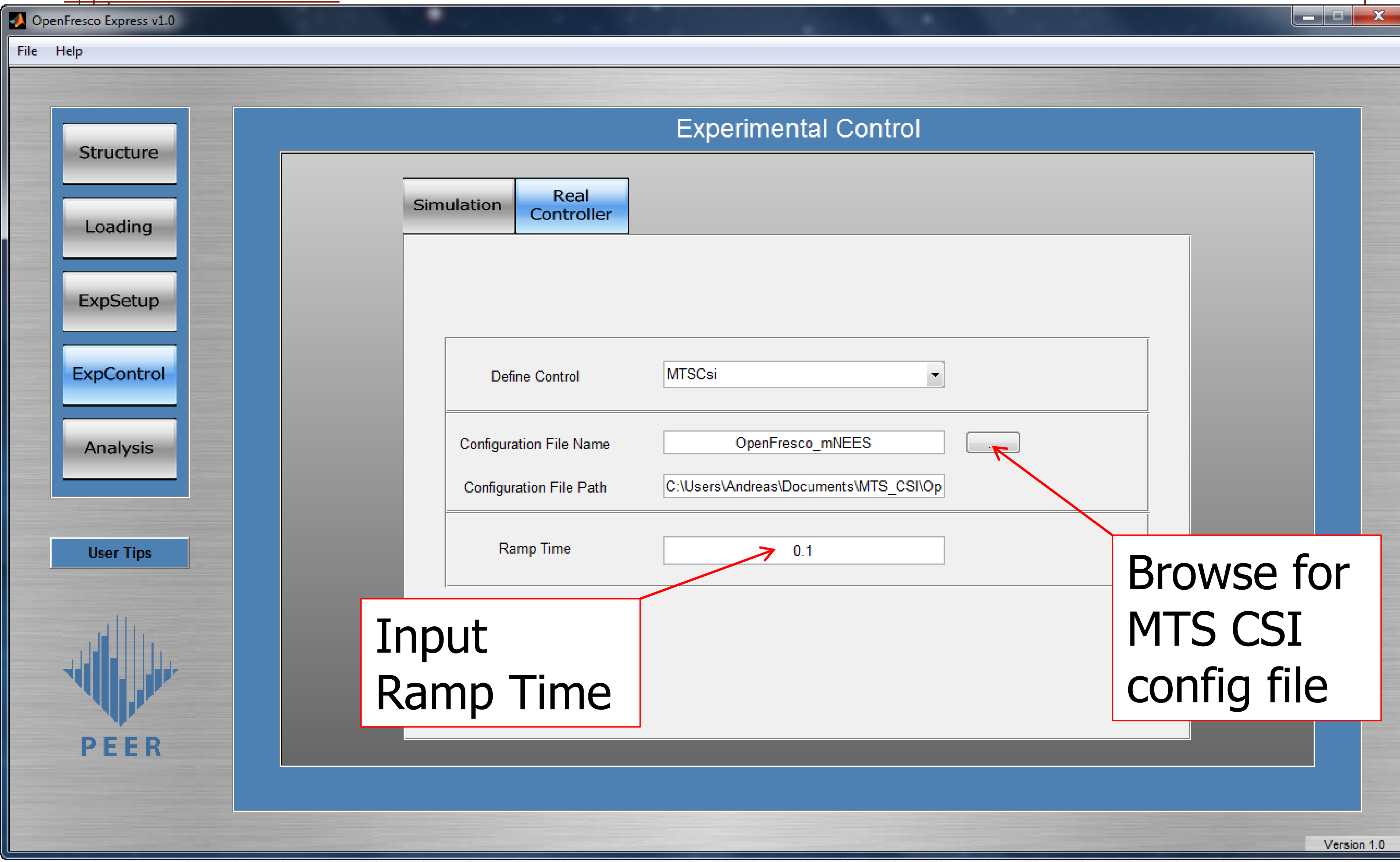
Experimental Setup



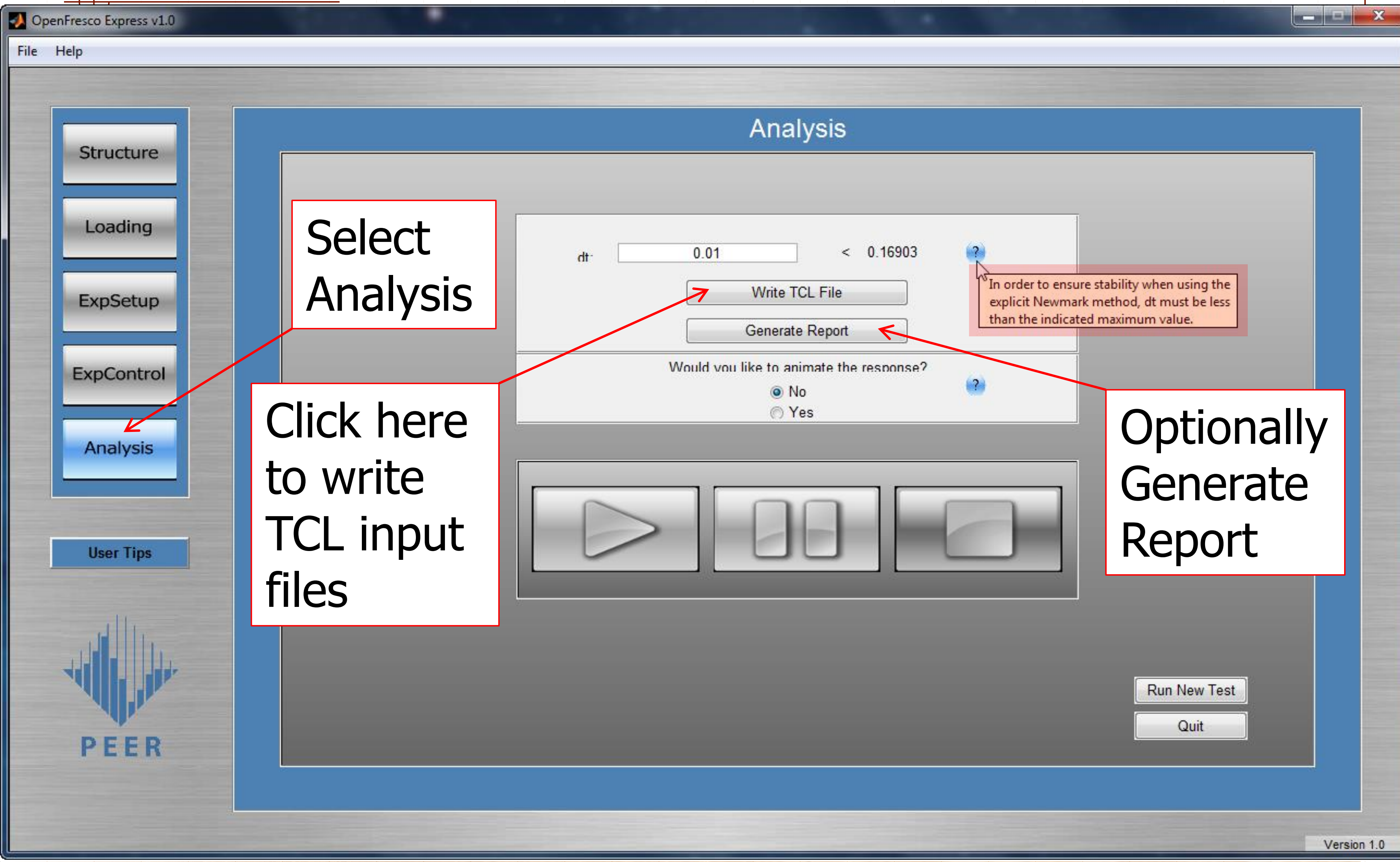
Real Experimental Control



Real Experimental Control

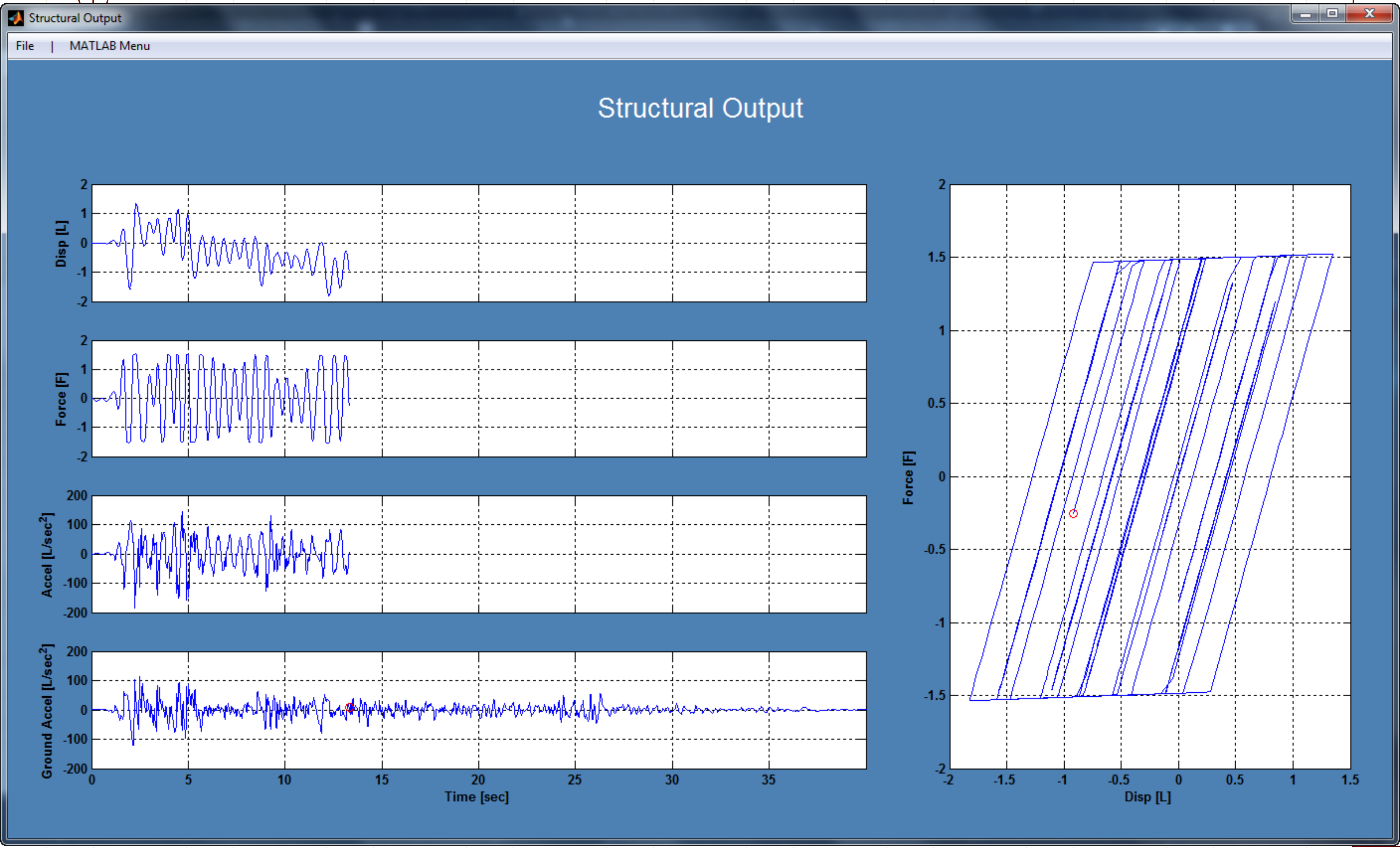


Analysis

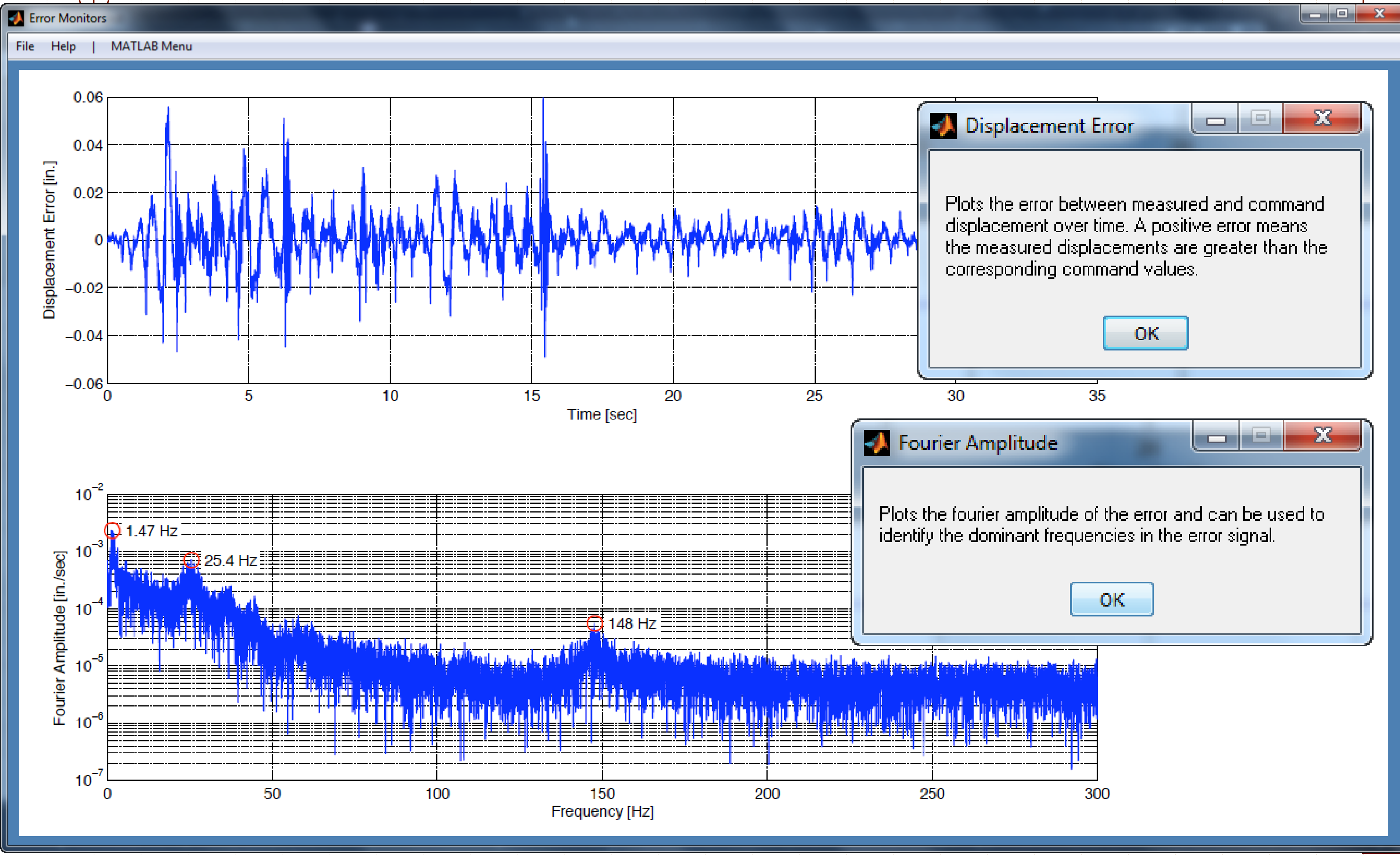


OpenFresco Express v1.0
File
Help
Structure
Loading
ExpSetup
ExpControl
Analysis
User Tips
PEER
Analysis
dt
0.01
< 0.16903
Write TCL File
Generate Report
In order to ensure stability when using the explicit Newmark method, dt must be less than the indicated maximum value.
Would you like to animate the response?
No
Yes
Run New Test
Quit
Version 1.0
Select Analysis
Click here to write TCL input files
Optionally Generate Report

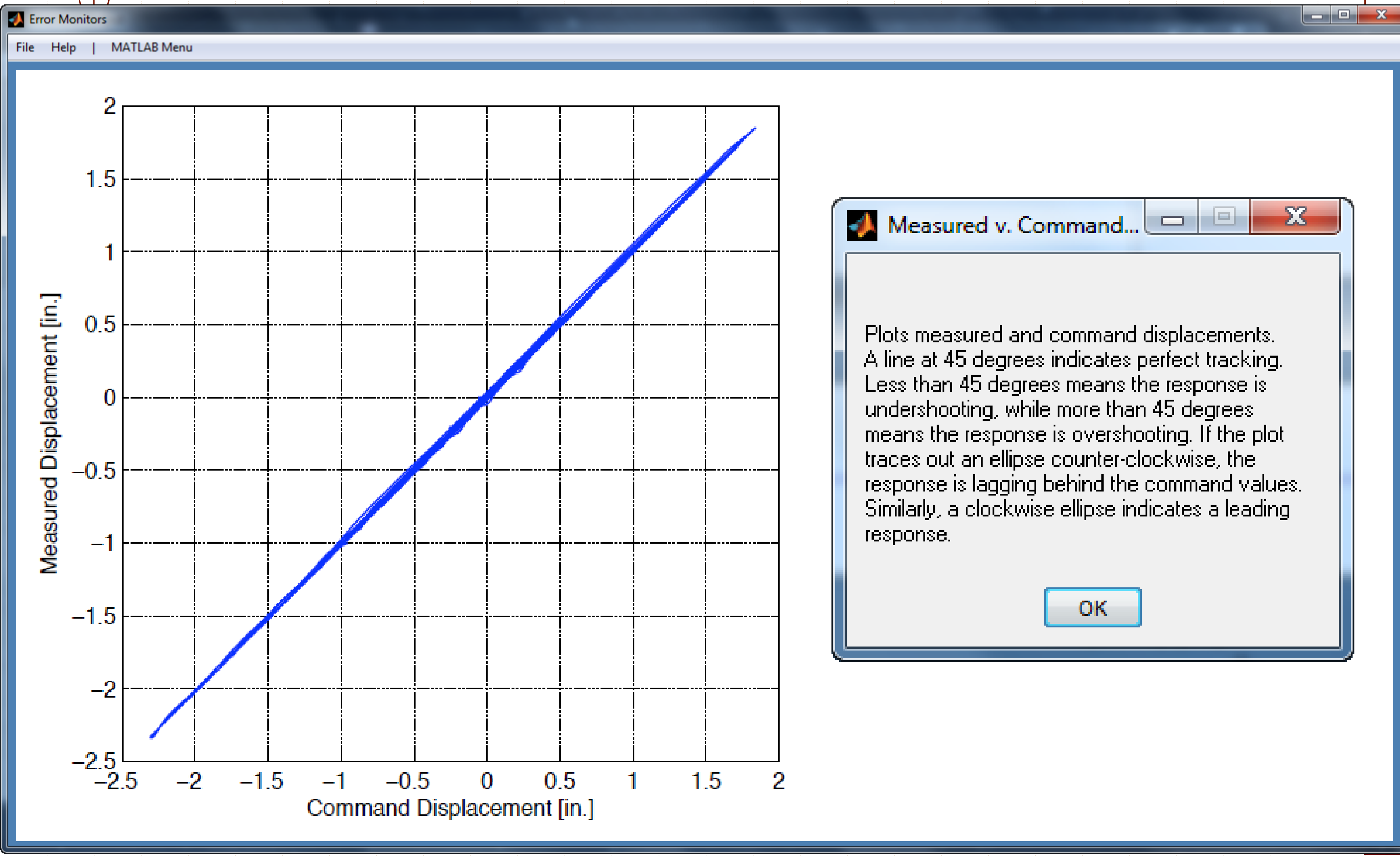
Structural Output



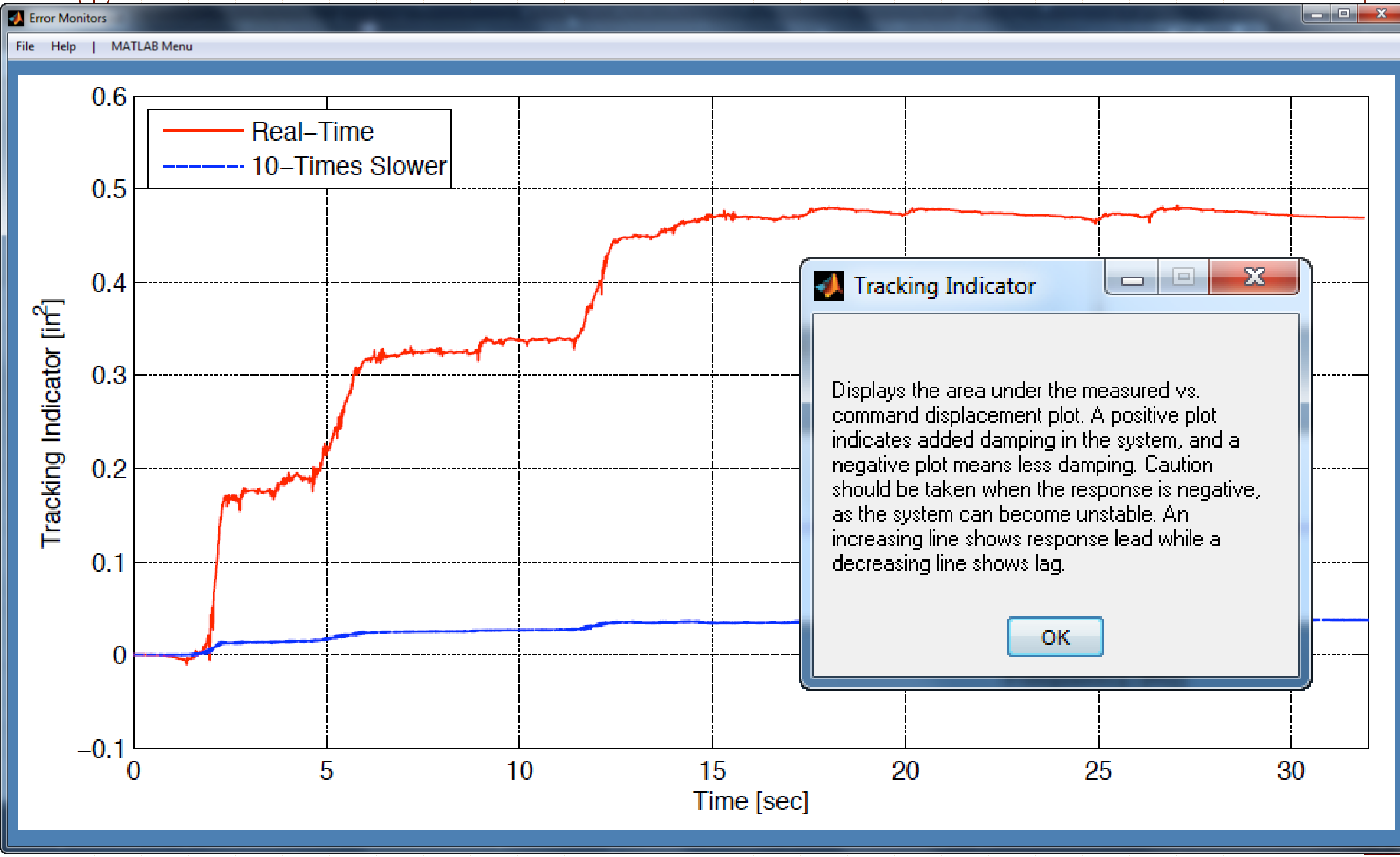
Error Monitors: dispError and FFT



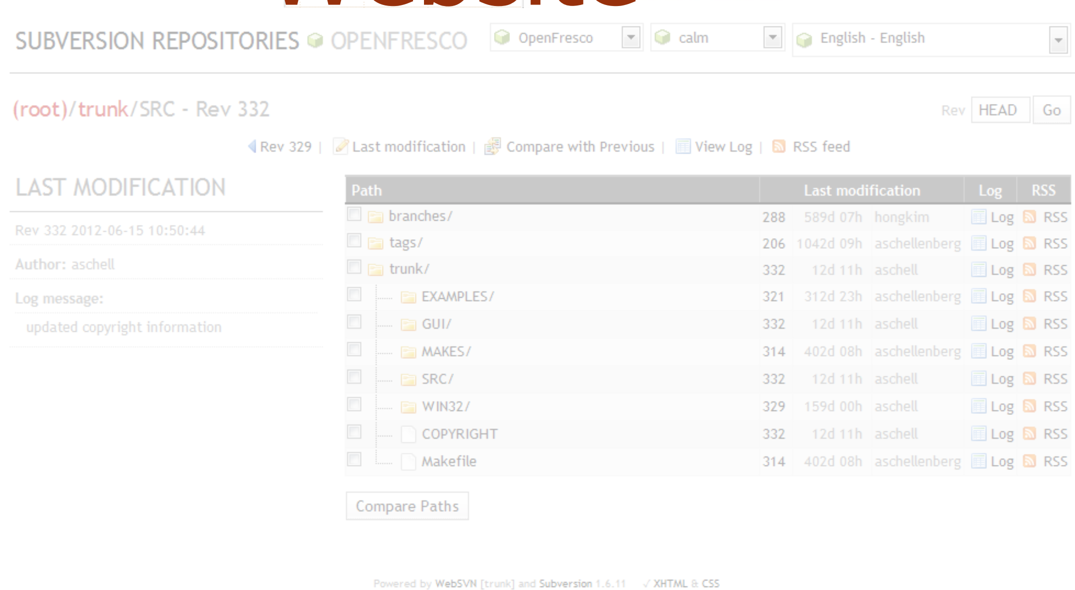
Error Monitors: Subspace Plot



Error Monitors: Tracking Indicator



OpenFresco Website



http://openfresco.berkeley.edu

OpenFresco

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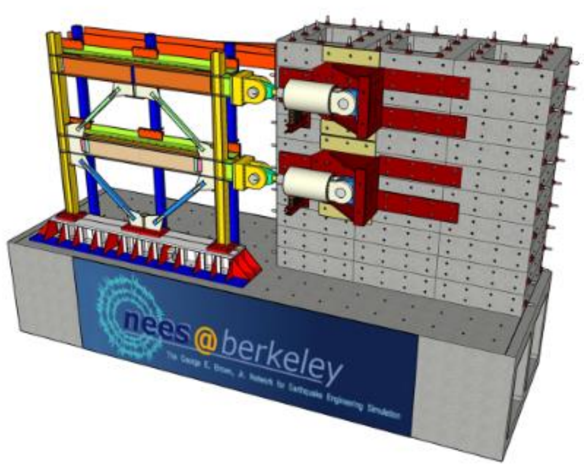
HOME

OpenFresco (the Open-source Framework for Experimental Setup and Control) is an environment-independent software framework, that connects finite element models with control and data acquisition systems in laboratories to facilitate hybrid simulation of structural and geotechnical systems.

Hybrid simulation is an experimental testing technique where a test is executed based on a step-by-step numerical solution of the governing equations of motion for a hybrid model, formulated considering both the numerical and physical portions of a structural system. In order for the earthquake engineering community to take full advantage of this technique, OpenFresco standardizes the deployment of hybrid simulation and extends its capabilities to applications where advanced numerical techniques are utilized, boundary conditions are imposed in real-time, and dynamic loading conditions caused by wind, blast, impact, waves, fire, traffic, and, in particular, seismic events are considered. Accordingly, the architecture of the OpenFresco software package provides a great deal of flexibility, extensibility, and re-usability to the researcher or developer interested in hybrid simulation.



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OpenFresco
OpenFresco*Express*
OpenSees Navigator

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OpenFresco*Express*
OpenFresco
Examples
Feedback

USERS

OpenFresco and OpenFresco ...loped to allow users to conduct hybrid simulation tests. Both ... connect finite element models with laboratory control and data ... extensible manner to facilitate performing local and geogra... simulations of structural systems.

OpenFresco*Express* is a self-contained software package, including a easy-to-use graphical user interface, that facilitates hybrid testing of systems having up to two degrees of freedom. OpenFresco*Express* addresses the needs of a wide range of users including:

- laboratory staff and research students learning about hybrid simulation and starting to use this experimental testing method.
- staff and students at laboratories that regularly use hybrid simulation but desire a tool for quick demonstration of the hybrid simulation testing method.
- researchers who are conducting simple tests and would like to take advantage of a graphical user interface that quickly and easily displays useful real-time test data.
- graduate students and researchers who are not at a laboratory but wish to run the software as a pure simulation tool to learn more about hybrid simulation and how it works.

OpenFresco is a robust middleware software package for performing hybrid simulations involving numerical models, test specimens, experimental setups and loading conditions that are larger and more complex than those considered by OpenFresco*Express*. It targets researchers, graduate students and laboratory staff that are more experienced in the concept and application of the hybrid simulation method. It is suited for advanced hybrid simulation when the users have analytical model and/or experimental specimen configurations that exceed the capabilities of the OpenFresco*Express* version, and/or have the desire and need to create their own custom graphical user interface.

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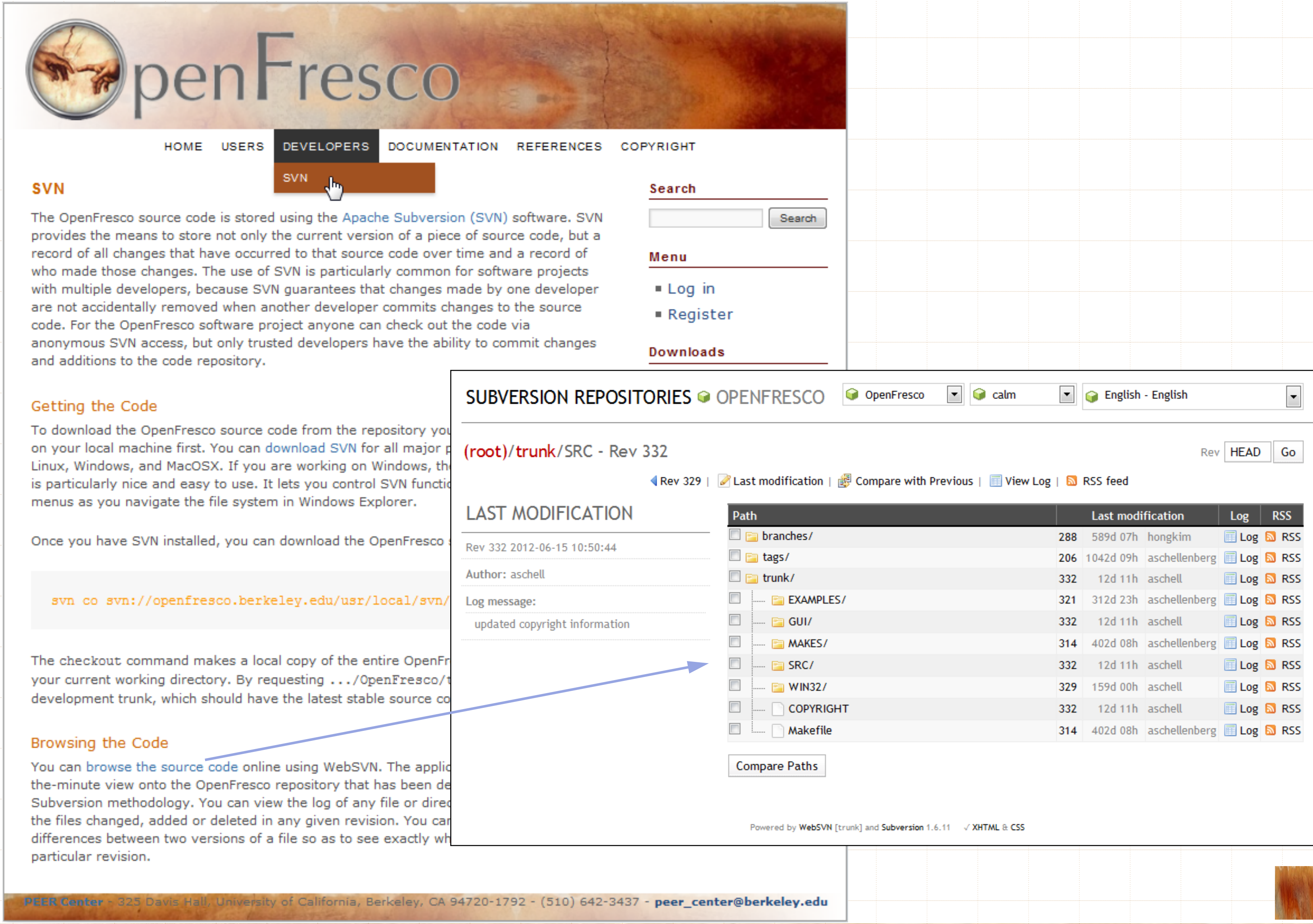
Developers


OpenFresco
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SVN
SVN
The OpenFresco source code is stored using the Apache Subversion (SVN) software. SVN provides the means to store not only the current version of a piece of source code, but a record of all changes that have occurred to that source code over time and a record of who made those changes. The use of SVN is particularly common for software projects with multiple developers, because SVN guarantees that changes made by one developer are not accidentally removed when another developer commits changes to the source code. For the OpenFresco software project anyone can check out the code via anonymous SVN access, but only trusted developers have the ability to commit changes and additions to the code repository.
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Getting the Code
To download the OpenFresco source code from the repository yo
on your local machine first. You can download SVN for all major p
Linux, Windows, and MacOSX. If you are working on Windows, th
is particularly nice and easy to use. It lets you control SVN functi
menus as you navigate the file system in Windows Explorer.
Once you have SVN installed, you can download the OpenFresco
svn co svn://openfresco.berkeley.edu/usr/local/svn/
The checkout command makes a local copy of the entire OpenFr
your current working directory. By requesting .../OpenFresco/t
development trunk, which should have the latest stable source co
Browsing the Code
You can browse the source code online using WebSVN. The appli
the-minute view onto the OpenFresco repository that has been de
Subversion methodology. You can view the log of any file or direc
the files changed, added or deleted in any given revision. You ca
differences between two versions of a file so as to see exactly wh
particular revision.
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updated copyright information
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tags/ 206 1042d 09h aschellenberg Log RSS
trunk/ 332 12d 11h aschell Log RSS
EXAMPLES/ 321 312d 23h aschellenberg Log RSS
GUI/ 332 12d 11h aschell Log RSS
MAKES/ 314 402d 08h aschellenberg Log RSS
SRC/ 332 12d 11h aschell Log RSS
WIN32/ 329 159d 00h aschell Log RSS
COPYRIGHT 332 12d 11h aschell Log RSS
Makefile 314 402d 08h aschellenberg Log RSS
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Command Language Manual

OpenFresco

HOME NEWS USERS DEVELOPERS DOCUMENTATION

DOCUMENTATION

General Manuals

- OpenFresco Installation & Getting Started Manual 2.6
- OpenFresco Command Language Manual 2.6
- OpenSSL How To

Example Manuals

- OpenFresco Example Manual 2.6 – LabVIEW
- OpenFresco Example Manual 2.6 – LS-DYNA
- OpenFresco Example Manual 2.6 – Matlab
- OpenFresco Example Manual 2.6 – OpenSSL
- OpenFresco Example Manual 2.6 – PortalFrame
- OpenFresco Example Manual 2.6 – SignalFilter
- OpenFresco Example Manual 2.6 – SimDomain
- OpenFresco Example Manual 2.6 – SimFEAdapter
- OpenFresco Example Manual 2.6 – UI-SimCor
- OpenFresco Example Manual 2.6 – xPCTarget

Workshop Presentations 2009

- OPFW 2009 – Agenda
- OPFW 2009 – Opening Remarks (Mahin)
- OPFW 2009 – Installing OpenFresco (Kim)
- OPFW 2009 – Architecture & Tcl (Schellenberg)
- OPFW 2009 – Hands-on Exercise (Whyte)
- OPFW 2009 – Class APIs (Schellenberg)
- OPFW 2009 – GenericClient & Adapter (Kim, Schellenberg)
- OPFW 2009 – Experiences (Terzic)

Workshop Presentations 2008

- OPFW 2008 – Agenda
- OPFW 2008 – Opening Remarks (Mahin)
- OPFW 2008 – Installing OpenFresco (Kim)
- OPFW 2008 – Architecture & Tcl (Schellenberg)
- ...-on Exercise (Whyte)

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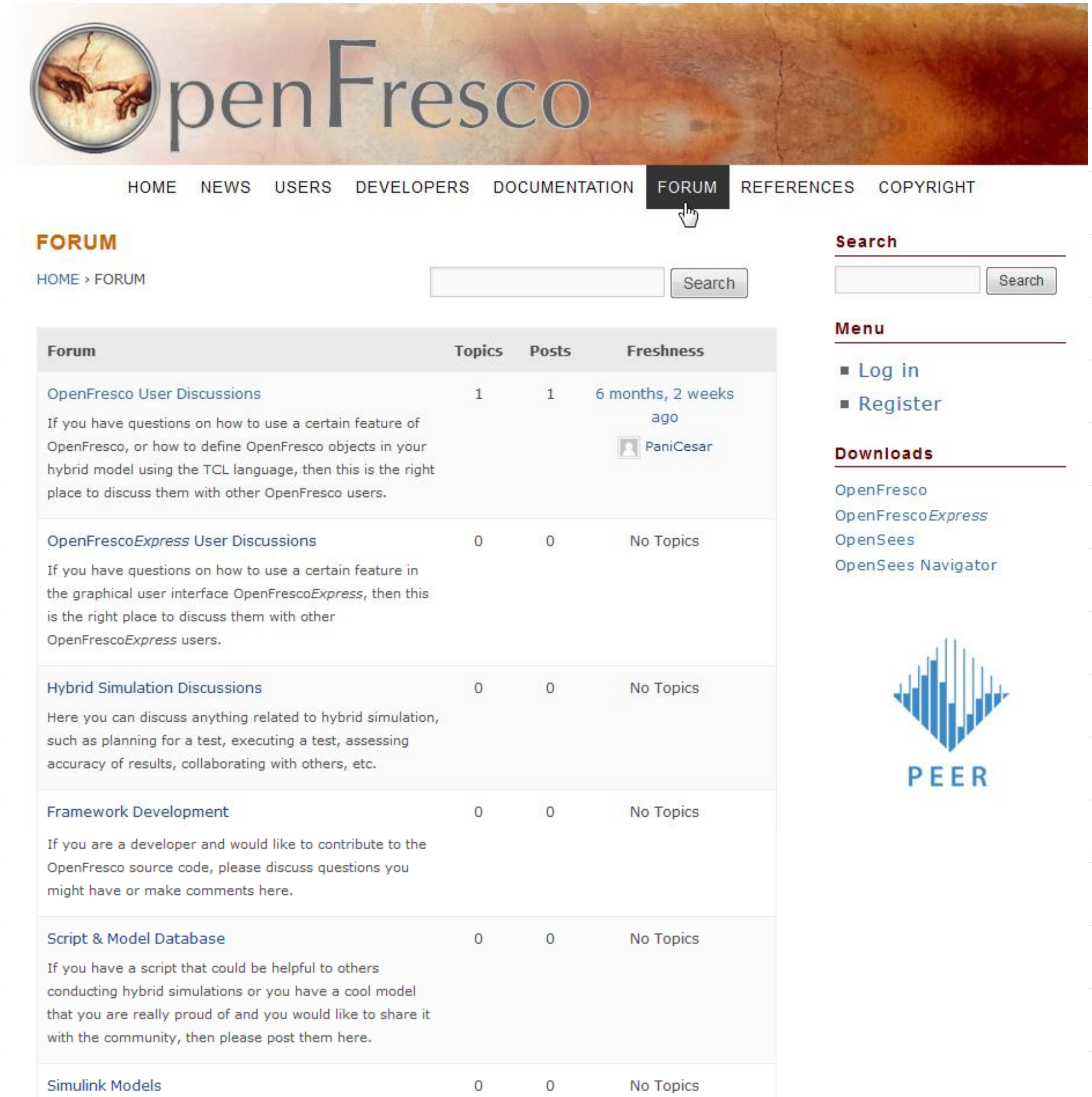
PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Advanced Implementation of Hybrid Simulation

Andreas H. Schellenberg
Stephen A. Mahin
Gregory L. Fenves
University of California, Berkeley

PEER 2009/104
NOVEMBER 2009

Forum



- OpenFresco User Discussions
- OpenFresco*Express* User Discussions
- Hybrid Simulation Discussions
- Framework Development
- Script & Model Database
- Simulink Models
- Documentation
- Bug Reports
- Brainstorming & Ideas

Summary & Conclusions

- Hybrid simulation inherently requires close collaboration amongst experts from many different fields.
  - Structural behavior
  - Laboratory testing and control
  - Computational simulation
  - Information technology
- Hence, hybrid simulation fosters collaboration and communication among distant researchers in different labs.

Summary & Conclusions

- OpenFresco, the environment-independent software framework for the development and deployment provides an excellent platform for this collaboration (on-site and geographically distributed)
- The modularity and transparency of the framework permits existing components to be modified and new components to be added without much dependence on other objects.
- Speed up HS from beginning of planning until end of testing

Summary & Conclusions

- Large libraries of hybrid simulation direct integration methods, experimental elements, experimental setups, controller models, and event-driven solution strategies are available to the researchers to choose or adapt from.
- Needs:
  - More user feedback on refinements and new features
  - Developer contributions to extend libraries

Questions?
Thank you!

http://openfresco.berkeley.edu/

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OpenFresco