Interfacing FE-Software: Generic Client Element and Adapter Element

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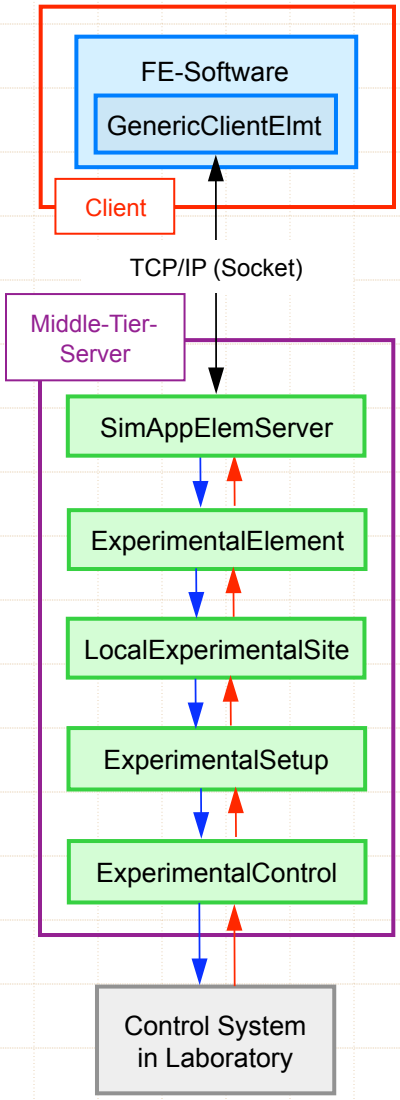
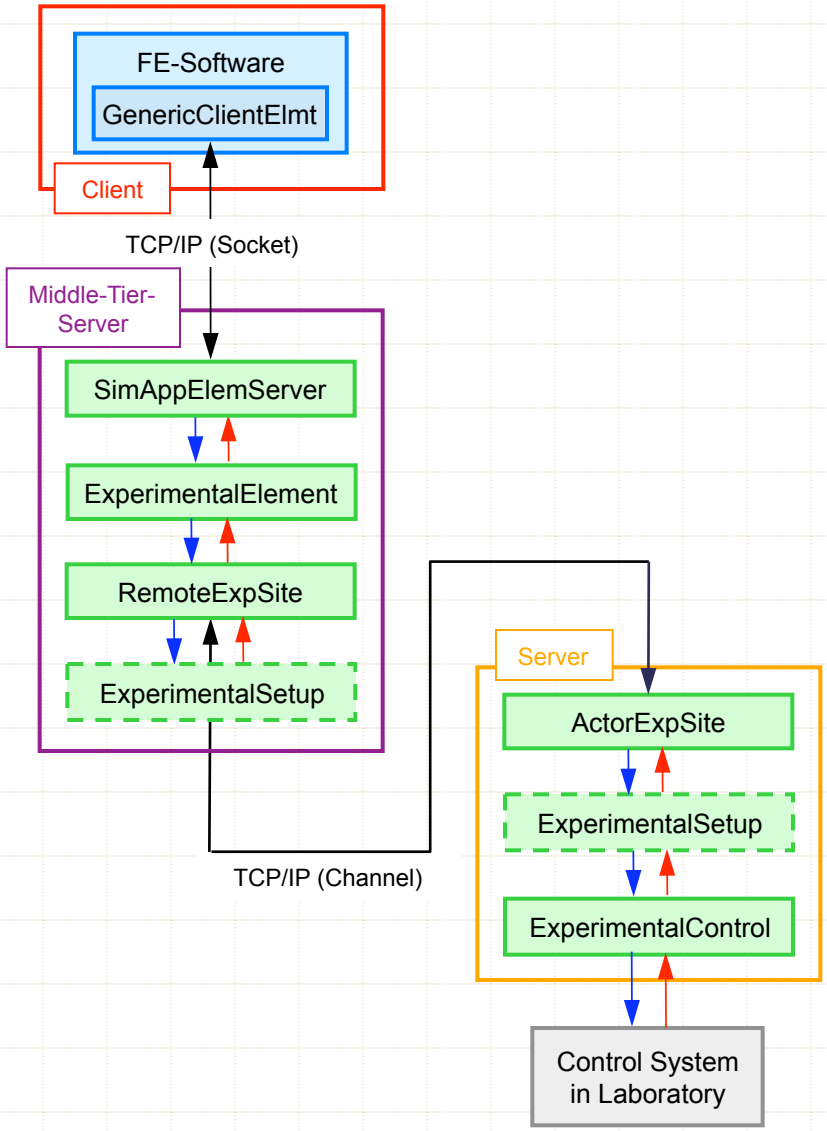
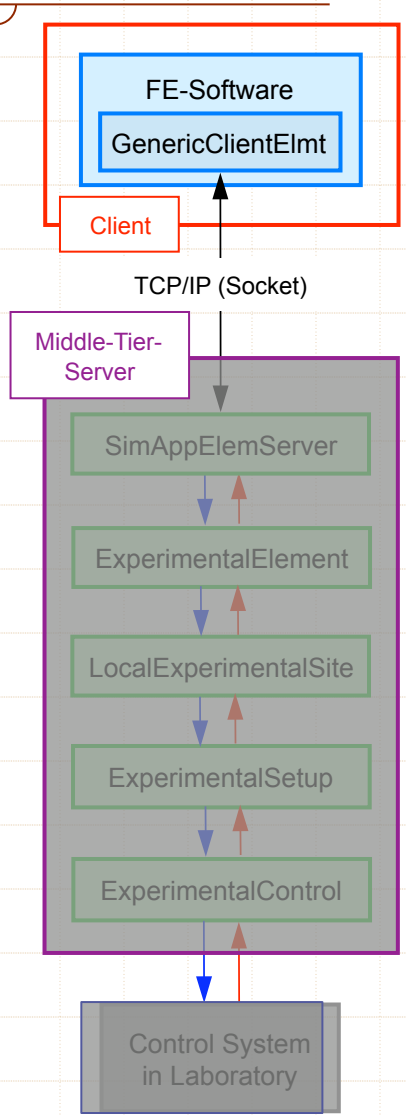
OpenFresco

OpenFresco Architecture



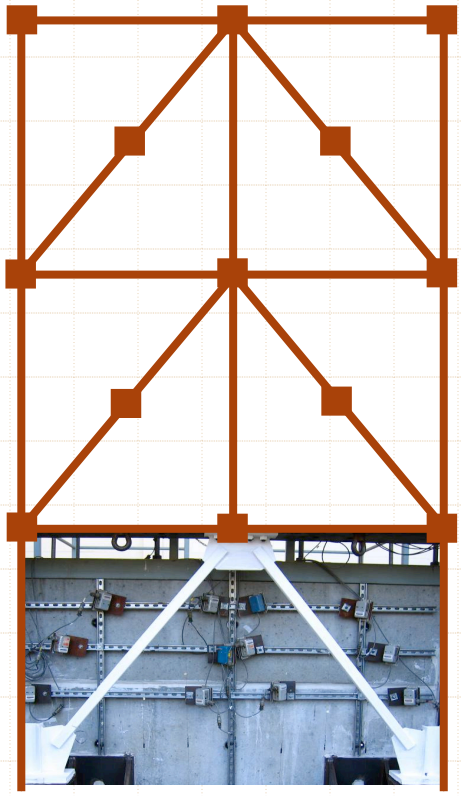


Generic Client Element (1)



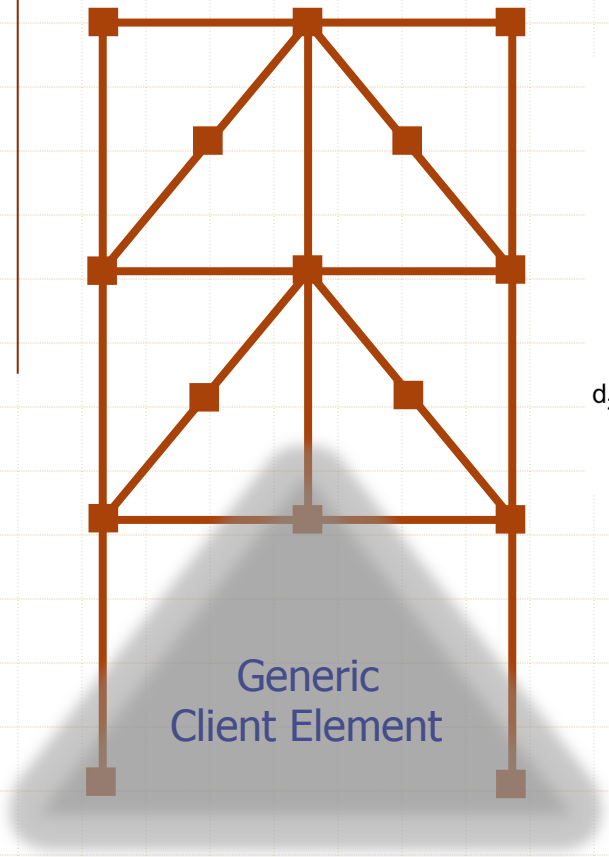
- FE-Software must have user-defined elements
- Generic Client Element is an interface to OpenFresco
- Has arbitrary number of nodes and degrees of freedom
- Uses TCP sockets for communication
- Makes use of Experimental Elements already in OpenFresco
- Generic Client Element is programmed once for a specific FE-Software

Generic Client Element (2)

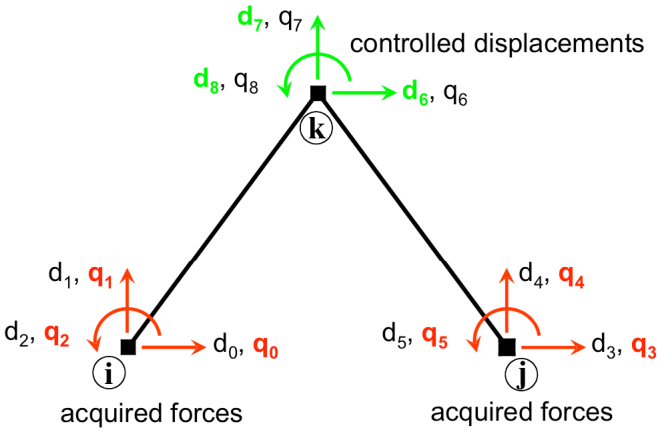


- analytical model of structural energy dissipation and inertia
- physical model of structural resistance

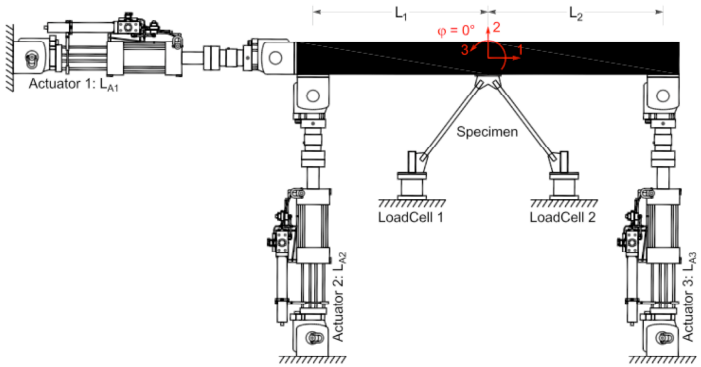
Generic Client Element (3)



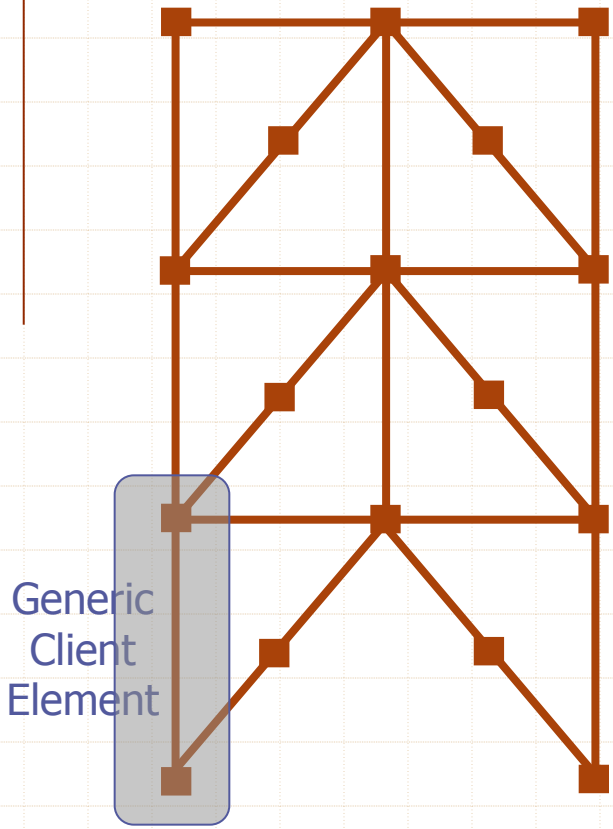
OpenFresco Experimental Element: invertedVBrace (2D)



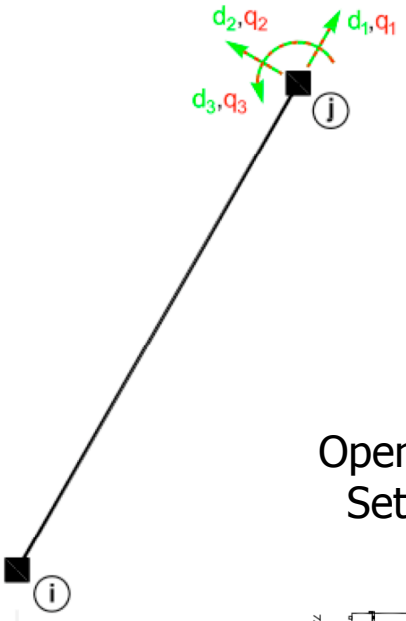
OpenFresco Experimental Setup: invertedVBrace



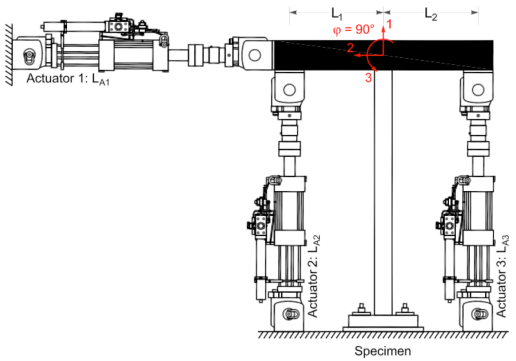
Generic Client Element (4)



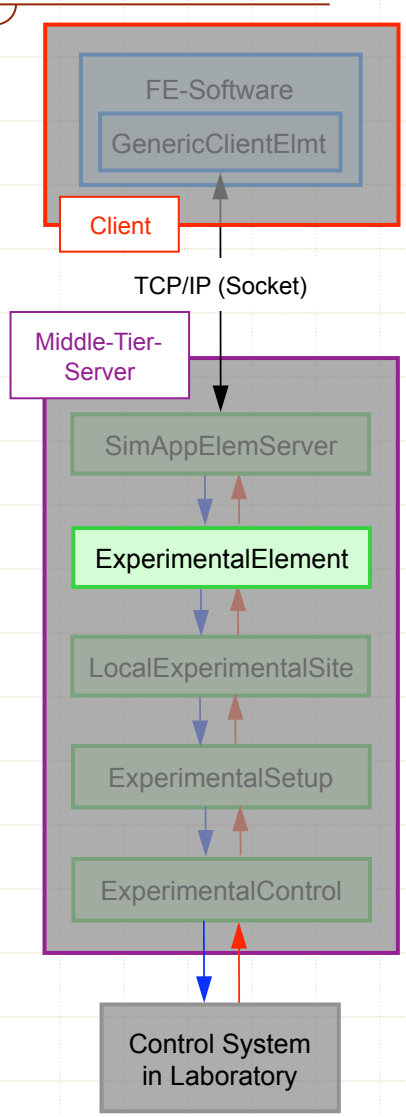
OpenFresco Experimental
Element: beamColumn (2D or 3D)



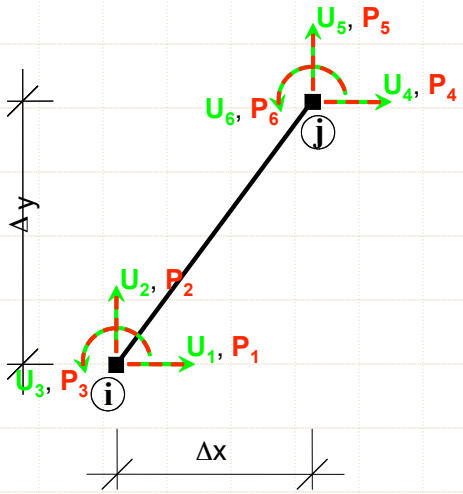
OpenFresco Experimental
Setup: ThreeActuators



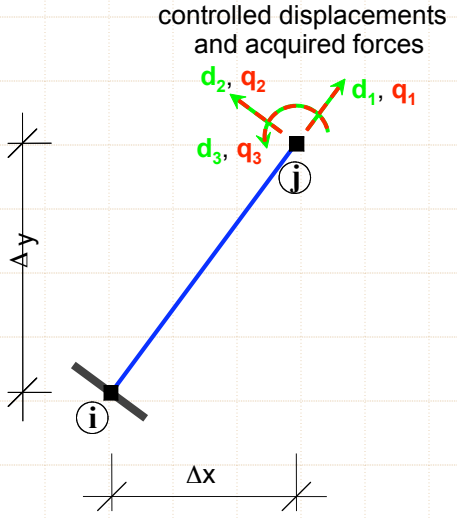
Experimental Element



- Transforms between global element DoF in FE-Software and basic element DoF in experimental element
- Experimental Element Tcl commands are in the Command Language Manual
- Recorder command available for each element



Global System



Cantilever Basic System

OpenFresco Experimental Elements

- beamColumn (2D or 3D)
- generic (1D, 2D, or 3D)
- invertedVBrace (2D)
- truss (1D, 2D, or 3D)
- corotTruss (1D, 2D, or 3D)
- twoNodeLink (1D, 2D, or 3D)

LS-DYNA genericClient_1d Element (1)

- NEESforge website: OpenFresco LS-Dyna Example Manual
- /trunk/SRC/simApplicationClient/lsDyna
  - Trial Displacements Being sent

```
c ...   send trial response to experimental site
c
        sData(1) = 3
        do 5, j = 1,4
          sData(1+j) = hsv(i,2+j)
    5   continue
c
        dataTypeSize = sizeDouble
        nleft        = sizeSendData
        call senddata(socketID, dataTypeSize, sData, nleft, stat)
```

LS-DYNA genericClient_1d Element (2)

- Get Measured Force

```
c ...   get measured resisting forces
c
        sData(1) = 10
        dataTypeSize = sizeDouble
        nleft        = sizeSendData
        call senddata(socketID, dataTypeSize, sData, nleft,
stat)
c
        dataTypeSize = sizeDouble
        nleft        = 4
        call recvdata(socketID, dataTypeSize, r, nleft, stat)
c
        do j=1,2
           force(i,j)   = r(j)
           force(i,j+6) = r(j+2)
        enddo
```

- socket.c using socketf.c

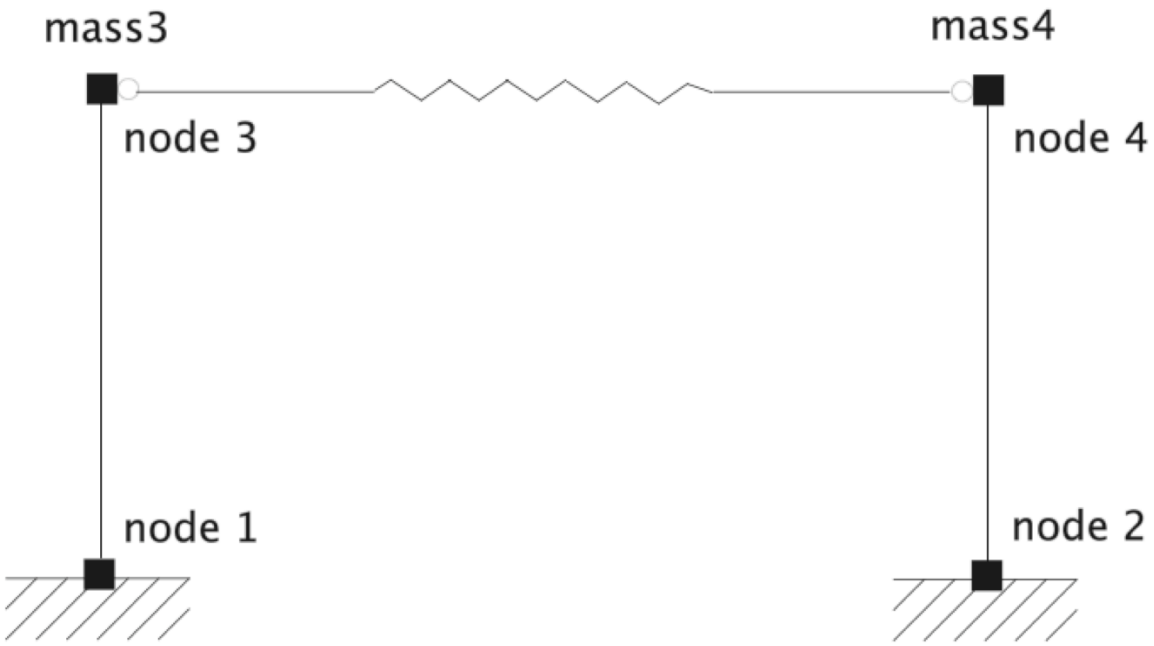
sData(1) actions (FrescoGlobals.h)

- /trunk/SRC/

  - 1 = start server process (optional).
  - 2 = setup test (not used here).
  - 3 = set trial response.
  - 4 = execute (obsolete).
  - 5 = commit state.
  - 6 = get DAQ response.
  - 7 = get displacement.
  - 8 = get velocity.
  - 9 = get acceleration.
  - 10 = get force.
  - 11 = get time.
  - 12 = get initial stiffness.
  - 13 = get tangent stiffness.
  - 14 = get damping values.
  - 15 = get mass values.
  - 99 = end server process.

LS-DYNA OneBayFrame Example

- /trunk/EXAMPLES/OneBayFrame/LSDyna
  - OneBayFrame_LSDyna.k
- Structural Model



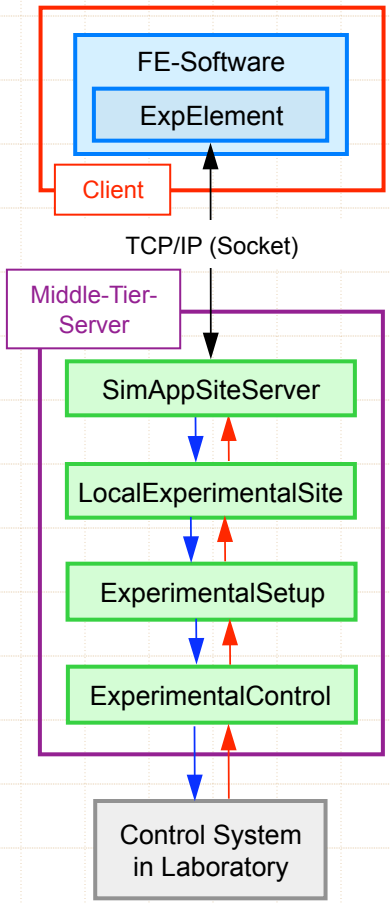
OpenSees genericClient Element

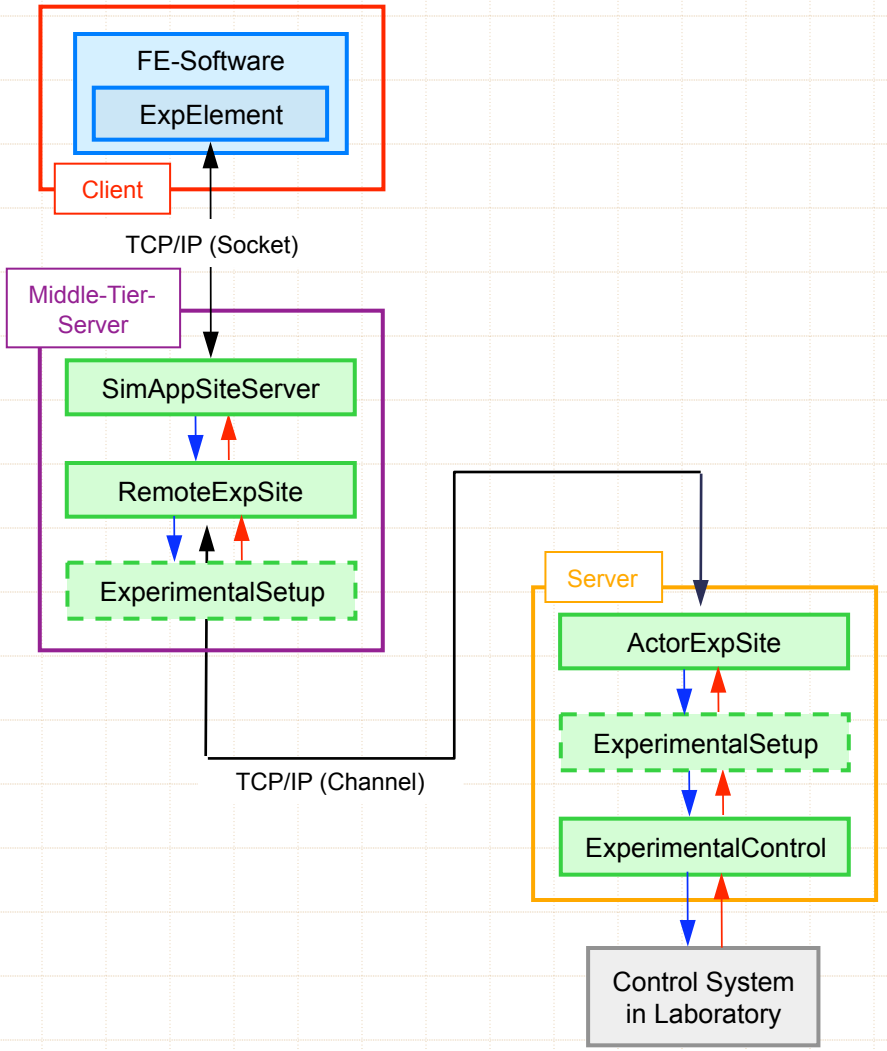
- Included in OpenSees 2.1.1
- Tcl command:

element genericClient $tag –node $Ndi $Ndj…
–dof $dofNdi … –dof $dofNdj … –server
$ipPort <$ipAddr> <-ssl> <-datasize $size>

- /trunk/EXAMPLES/OneBayFrame
  - Local Test Files: OneBayFrame_Local_Client.tcl and OneBayFrame_Local_SimAppServer.tcl
  - Distributed Test Files: OneBayFrame_Distr_Client.tcl, OneBayFrame_Distr_SimAppServer.tcl, and OneBayFrame_Distr_LabServer.tcl

Experimental Element Directly in FE-Software



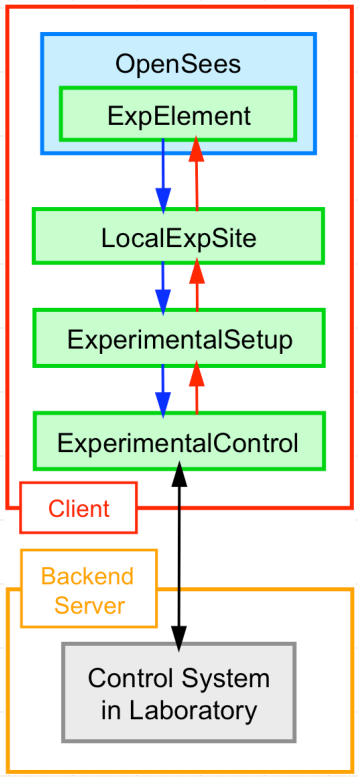


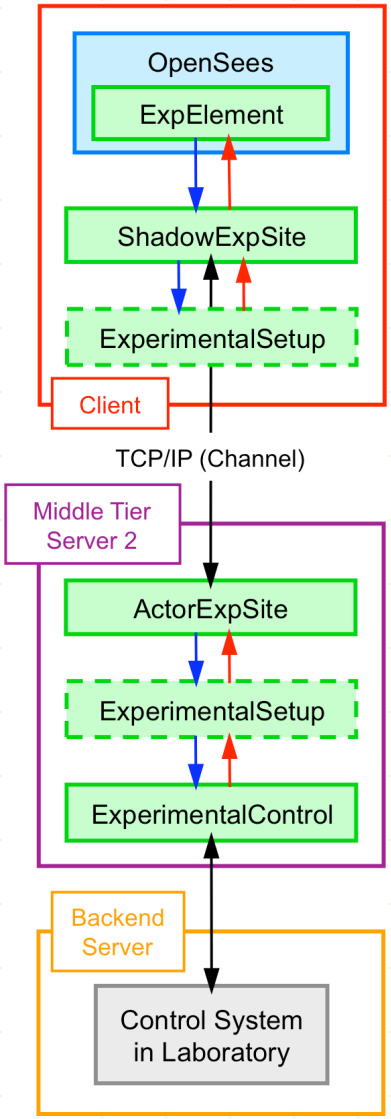
Matlab Experimental Element

- OpenFresco Matlab Example Manual
- /trunk/EXAMPLES/OneBayFrame/Matlab
- Experimental.m, 1D element, uses a TCPSocket.mex file

```
% send trial response to experimental sites
Data(1) = 3;
sData(2) = u;
TCPSocket('sendData',socketID,sData,dataSize);

% get measured resisting forces
sData(1) = 10;
TCPSocket('sendData',socketID,sData,dataSize);
rData = TCPSocket('recvData',socketID,dataSize);

% commit state
sData(1) = 5;
TCPSocket('sendData',socketID,sData,dataSize);
```

Experimental Element In OpenSees





OpenSees OneBayFrame Example

- /trunk/EXAMPLES/OneBayFrame
- Local Test File: OneBayFrame_Local.tcl
- Distributed Test Files: OneBayFrame Client1.tcl, OneBayFrame_Server1a.tcl (Left Column), and OneBayFrame_Server1b.tcl (Right Column)

Abaqus genericClient_exp Element (1)

- NEESforge website: OpenFresco Abaqus Example Manual (available soon)
- /trunk/SRC/simApplicationClient/abaqus
  - build instructions.txt
  - genericClient_exp.for
  - genericClient_exp.obj
  - vaba_param.inc
- /trunk/SRC/simApplicationClient/c
  - socket.c
- /trunk/SRC/simApplicationClient/fortran
  - socketf.c

Abaqus genericClient_exp Element (2)

```
                if (time(iTotalTime) .gt. 0.0) then
                   if (nint(svars(kblock,1)) .eq. 0) then
                      port = jprops(1)
                      sizeMachineInet = 9+1
                      call setupconnectionclient(port,
     * * *                                       '127.0.0.1'//char(0),
     * * *                                       sizeMachineInet,
     * * *                                       socketID)
                      if (socketID .le. 0) then
                         write(*,*) 'ERROR - failed to setup connection'
                         call xplb_exit
                      endif
                      svars(kblock,1) = socketID

c                     set the data size for the experimental element
c                     sizeCtrl(disp)
                      iData(1)  = ndofel
c                     sizeCtrl(vel)
                      iData(2)  = ndofel
c                     sizeCtrl(accel)
                      iData(3)  = ndofel
c                     sizeCtrl(force)
                      iData(4)  = 0
c                     sizeCtrl(time)
                      iData(5)  = 1
c                     sizeDaq(disp)
                      iData(6)  = 0
c                     sizeDaq(vel)
                      iData(7)  = 0
c                     sizeDaq(accel)
                      iData(8)  = 0
c                     sizeDaq(force)
                      iData(9)  = ndofel
c                     sizeDaq(time)
                      iData(10) = 0
c                     dataSize
                      iData(11) = dataSize

                      call senddata(socketID, sizeInt,
     *                              iData, 11, stat)
                   else
                      socketID = nint(svars(kblock,1))
                   endif
```

Abaqus genericClient_exp Element (3)

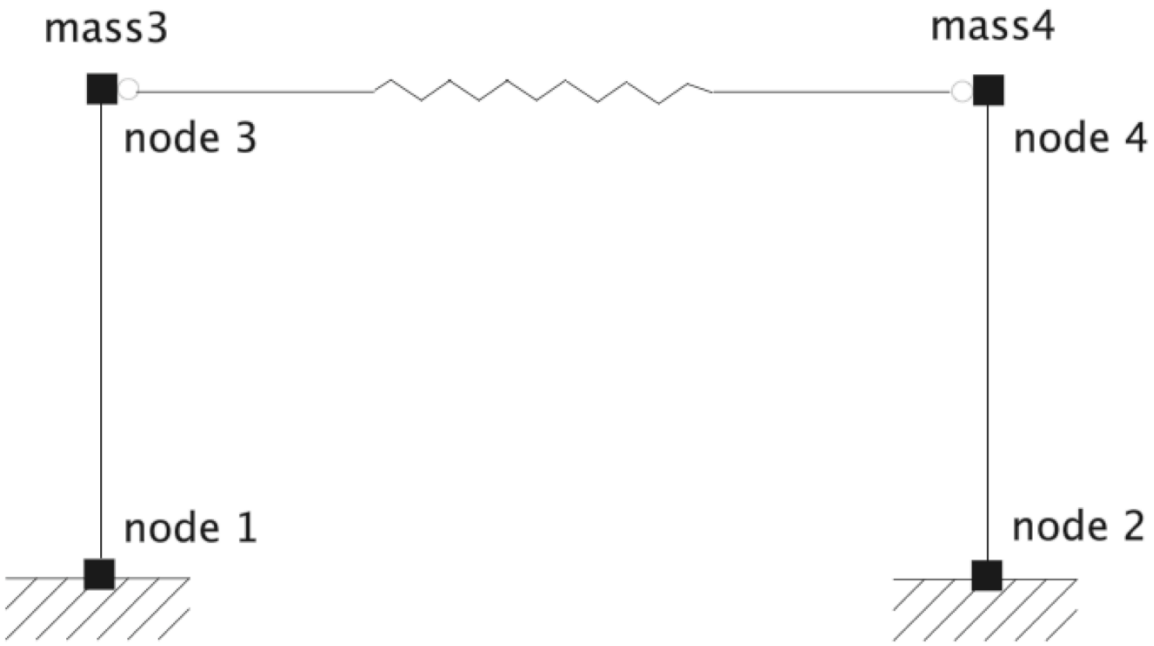
```
c                  commit state
                   if (time(iTotalTime) .gt. svars(kblock,2)) then
                      sData(1) = 5
                      call senddata(socketID, sizeDouble,
     *                                 sData, dataSize, stat)
                      svars(kblock,2) = time(iTotalTime)
                   endif
```

```
c                  send trial response to experimental element
                   sData(1) = 3
                   do i = 1, ndofel
                      sData(1+i) = u(kblock,i)
                      sData(1+ndofel+i) = v(kblock,i)
                      sData(1+2*ndofel+i) = a(kblock,i)
                   enddo
                   sData(1+3*ndofel+1) = time(iTotalTime)

                   call senddata(socketID, sizeDouble,
     *                           sData, dataSize, stat)
```

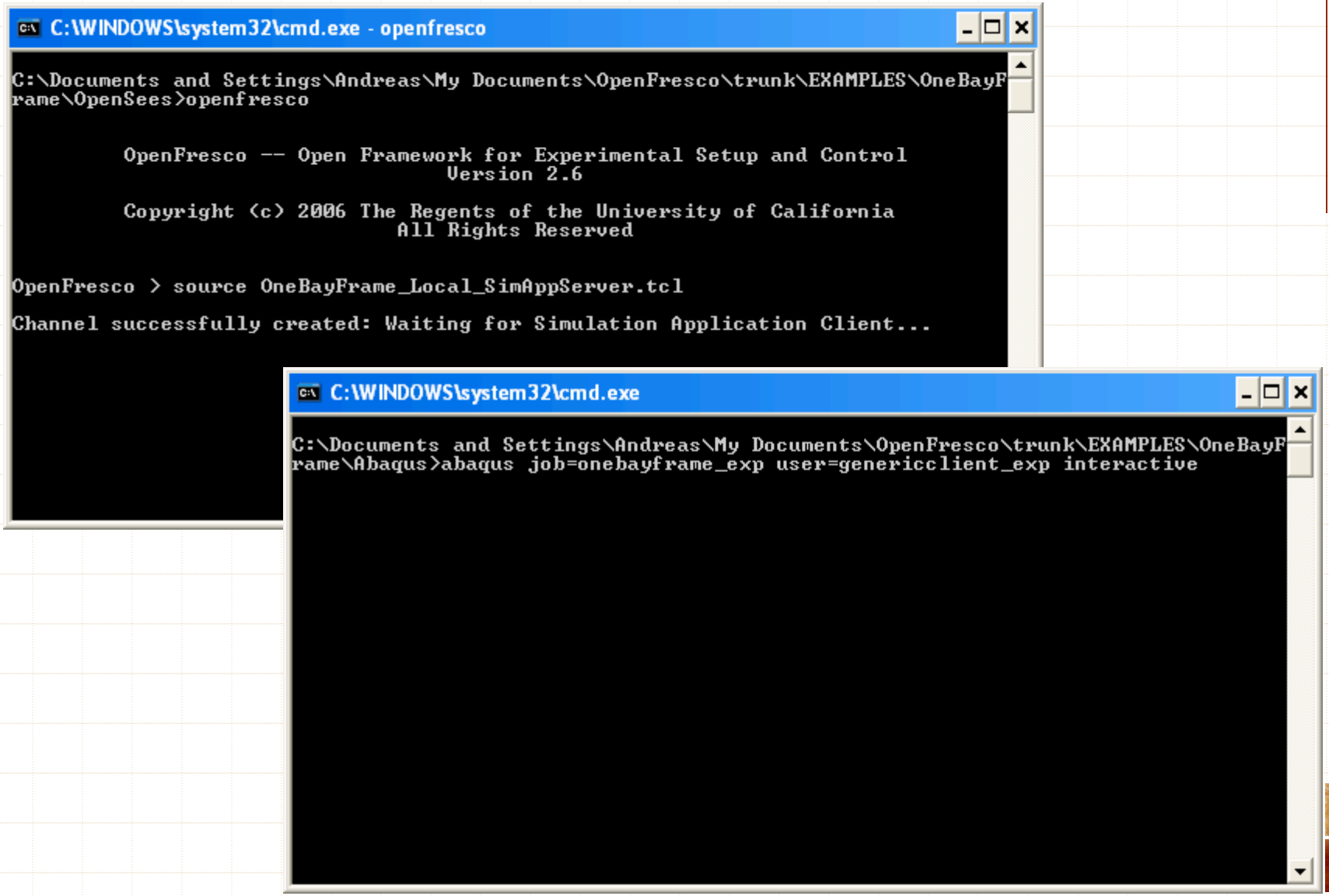
```
c                  get measured resisting forces
                   sData(1) = 10
                   call senddata(socketID, sizeDouble,
     *                           sData, dataSize, stat)

                   call recvdata(socketID, sizeDouble,
     *                           rData, dataSize, stat)

                   do i = 1, ndofel
                      rhs(kblock,i) = rData(i)
                   enddo
```

Abaqus OneBayFrame Example (1)

- /trunk/EXAMPLES/OneBayFrame/Abaqus
  - OneBayFrame_Exp.inp
- Structural Model

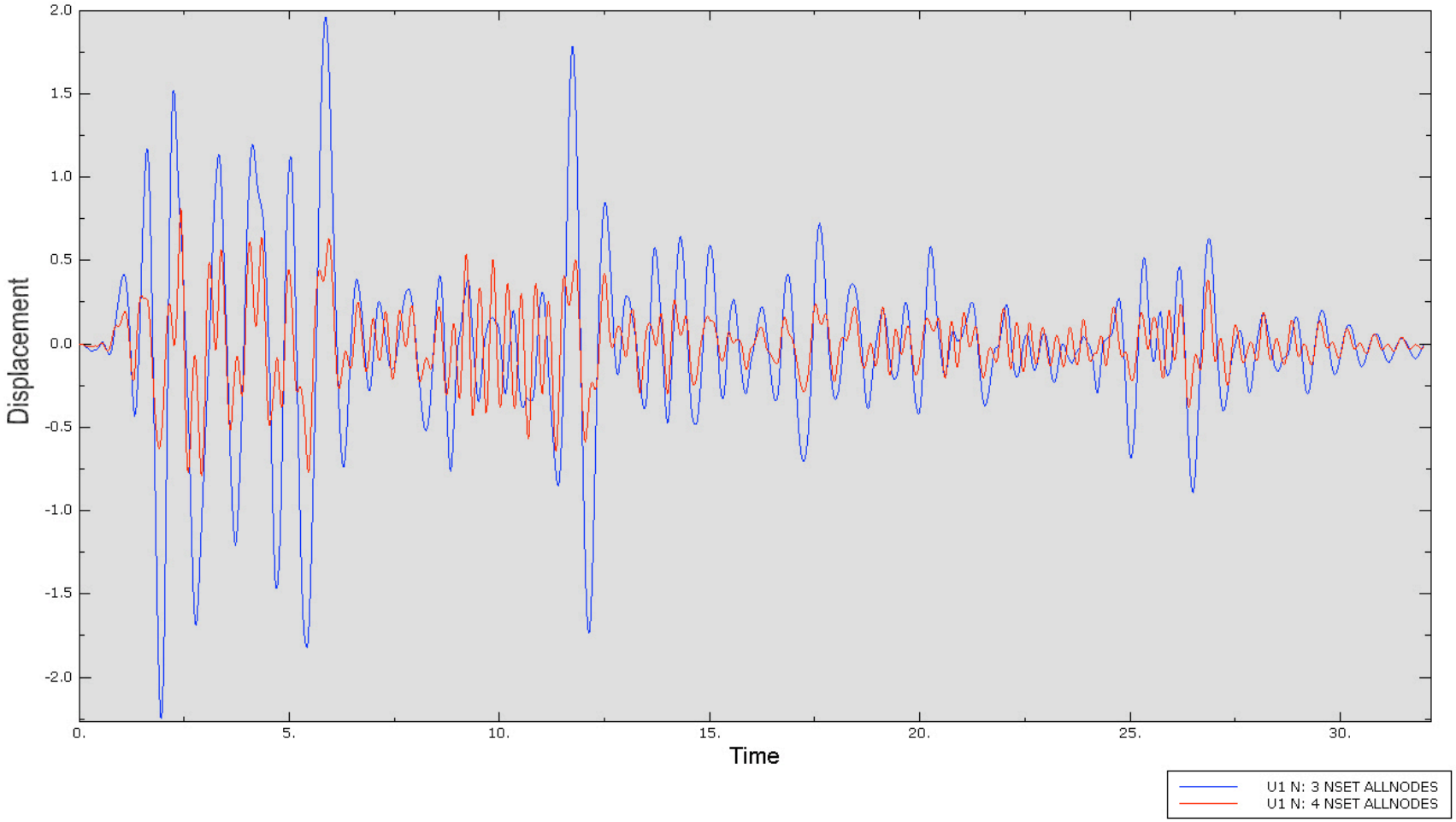


Abaqus OneBayFrame Example (2)

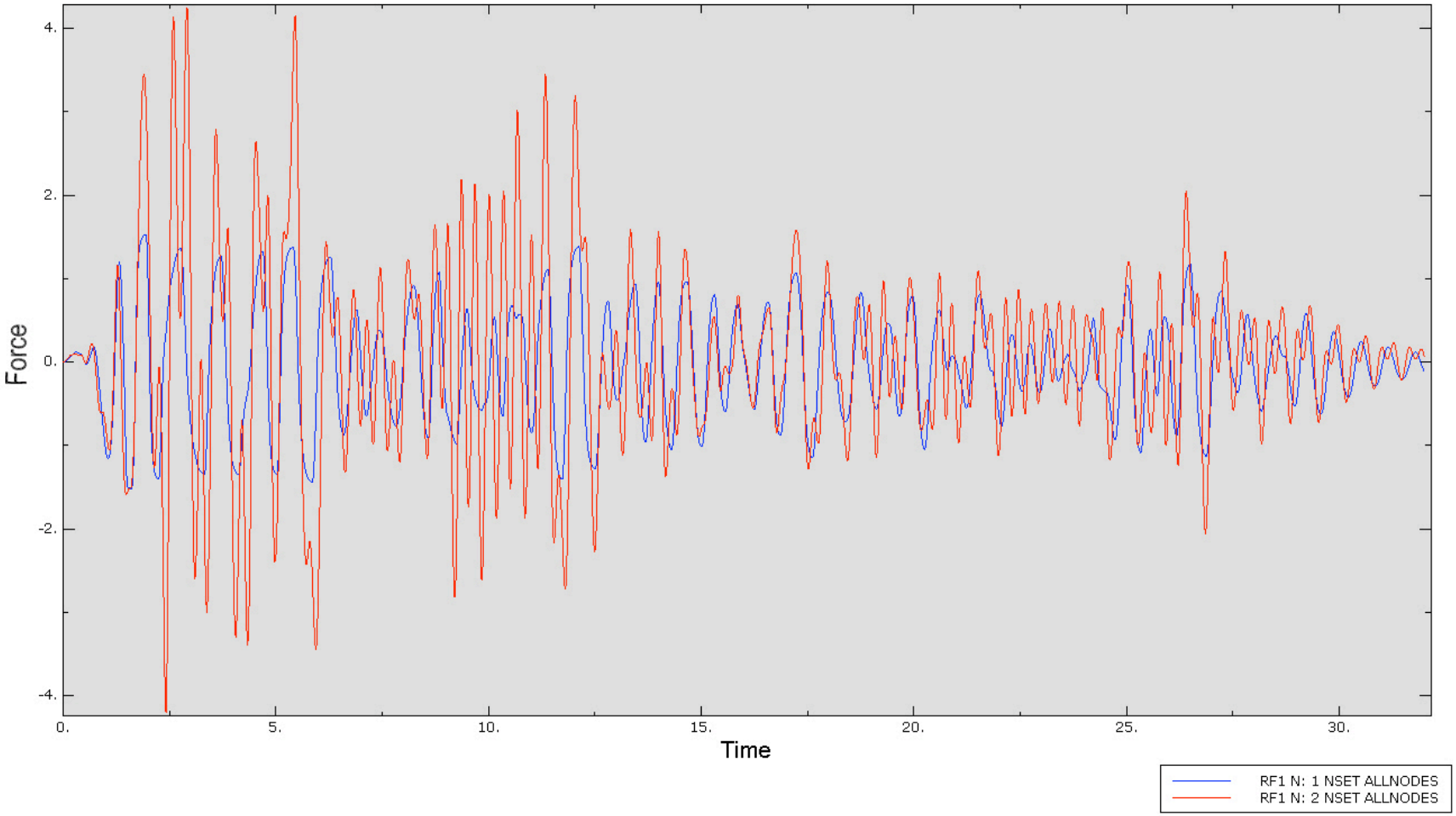


Abaqus OneBayFrame Example (3)

Abaqus OneBayFrame Example (4)



Abaqus OneBayFrame Example (5)



Conclusion

- Two Ways to Interface FE-Software
  - Generic Client Element
  - Experimental Element Directly in FE-Software
- Generic Client Element to be Programmed by the Developers
- OpenFresco works with Matlab/Simulink, LS-Dyna, Abaqus, OpenSees, UI SimCor

Structural FE-Software Coupling through the Experimental Software Framework, OpenFresco

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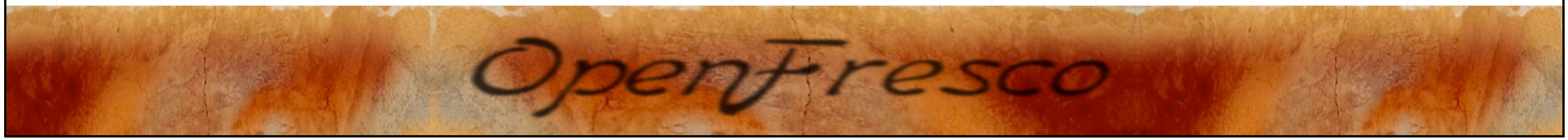
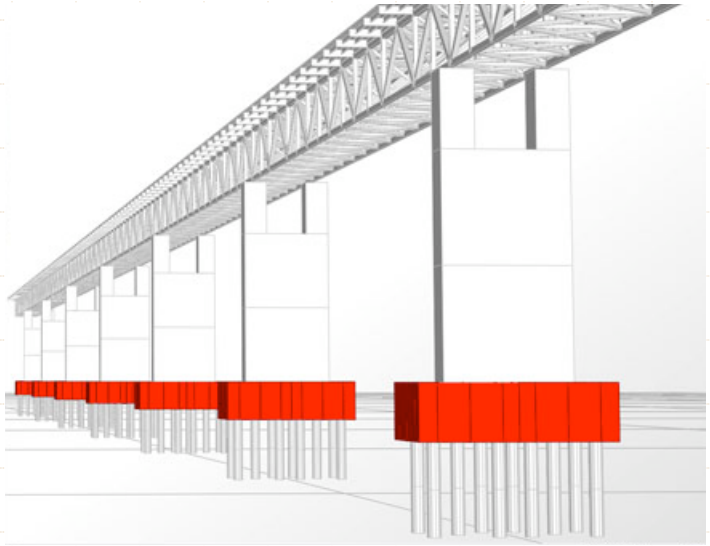
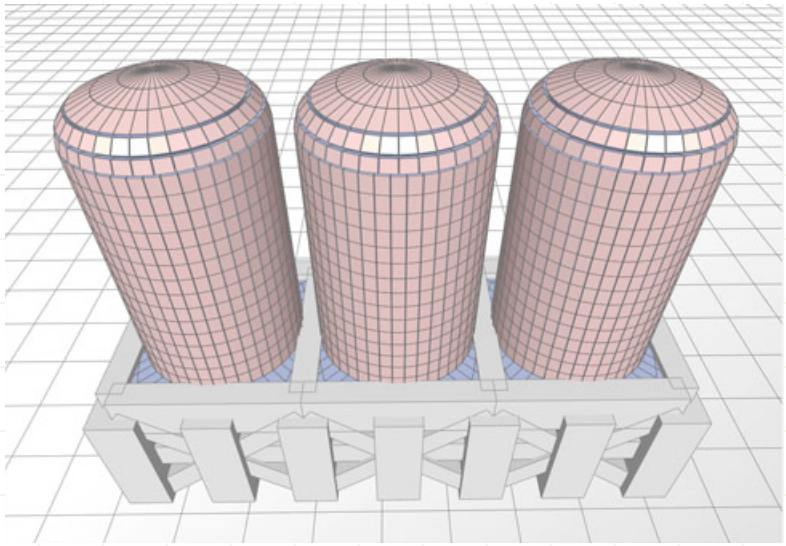


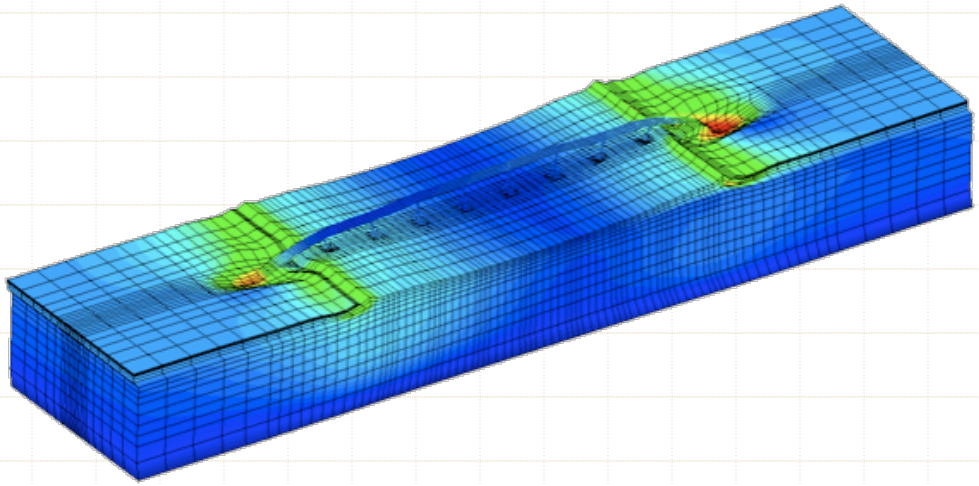
Motivation

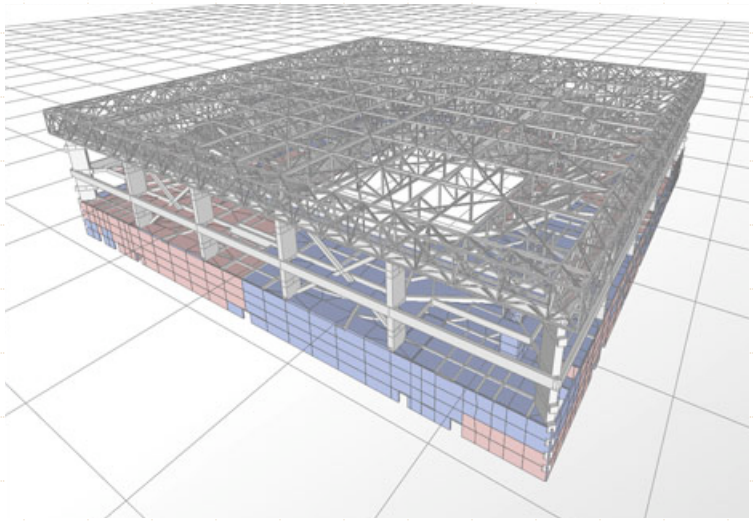
- Model and simulate entire systems and not just isolated structures or components
- FE-software packages are often highly specialized for some areas, but might lack necessary features in others
- Thus, couple specialized software packages together to take advantage of unique modeling and analysis capabilities
- This provides more flexibility and greater realism in simulating large systems

Motivation Cont.









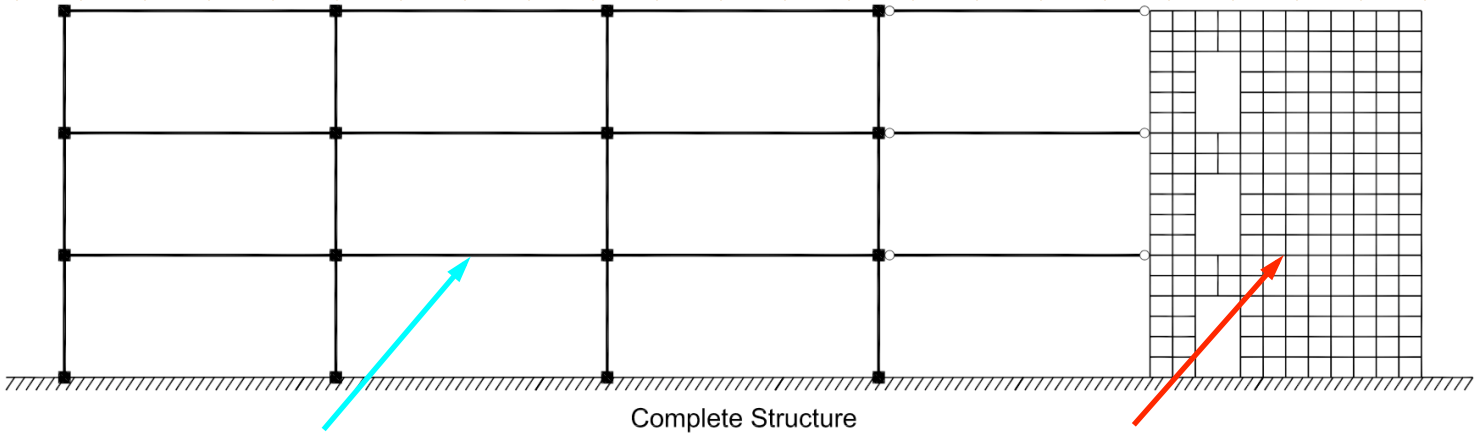
Outline of Presentation

1. Software Coupling Concept
2. Adapter Element Theory
3. Implementation Details
4. Three-Story Five-Bay Frame Example
5. Summary and Conclusions

Concept

- Select one program to act as the master solving the complete system
- Select remaining programs to act as slaves modeling different subassemblies
  - Subassemblies act as super-elements
  - Connected to master via interface DOFs
- Generic adapter elements provide interfaces in slave programs
- Generic super-elements provide interfaces in master program

Concept Cont.

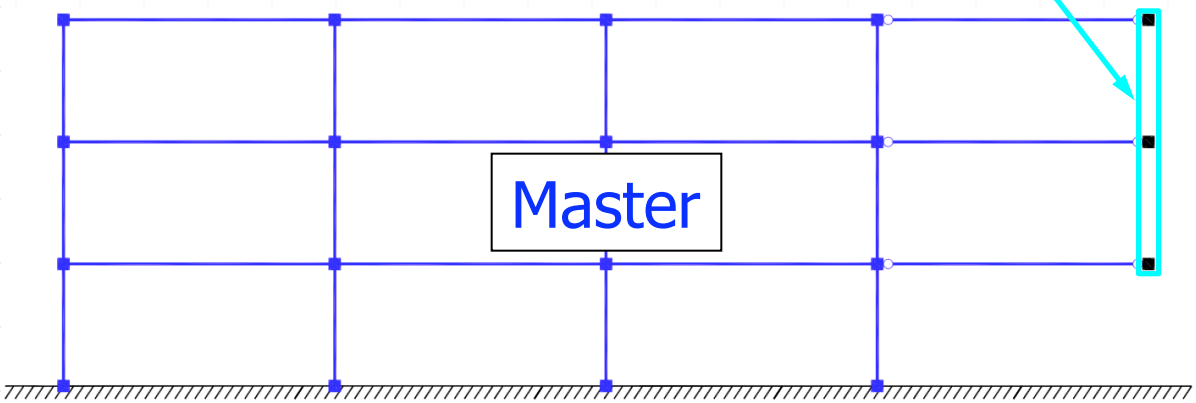


FE-Software 1: Generic Super-Element:
- frame element
- steel materials

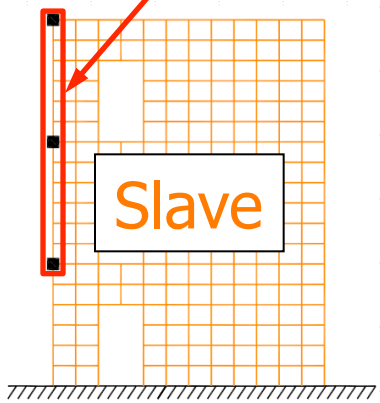
FE-Software 2: Adapter-Element:
- shell element
- concrete materials

- trial displacements
- resulting forces

- impose displ.
- acquire forces

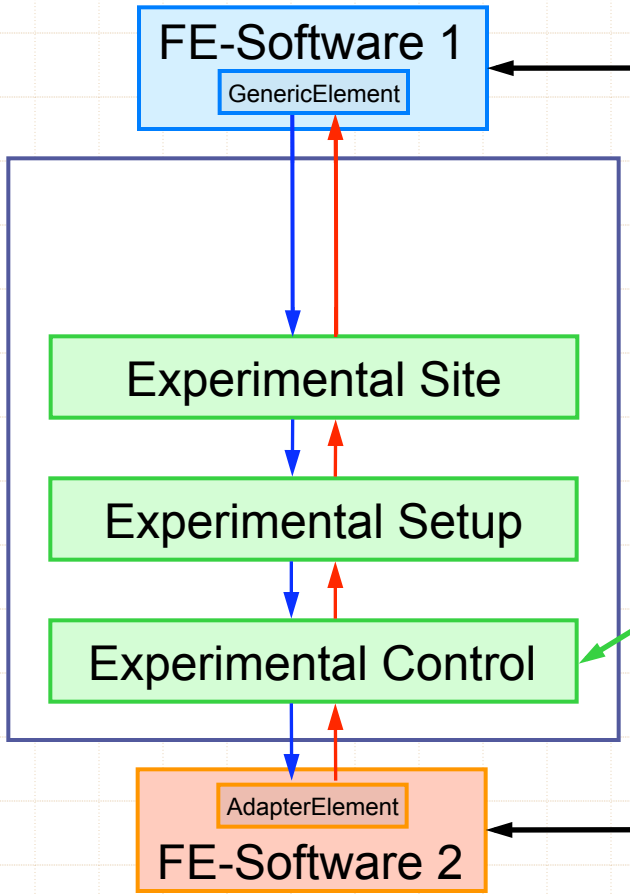


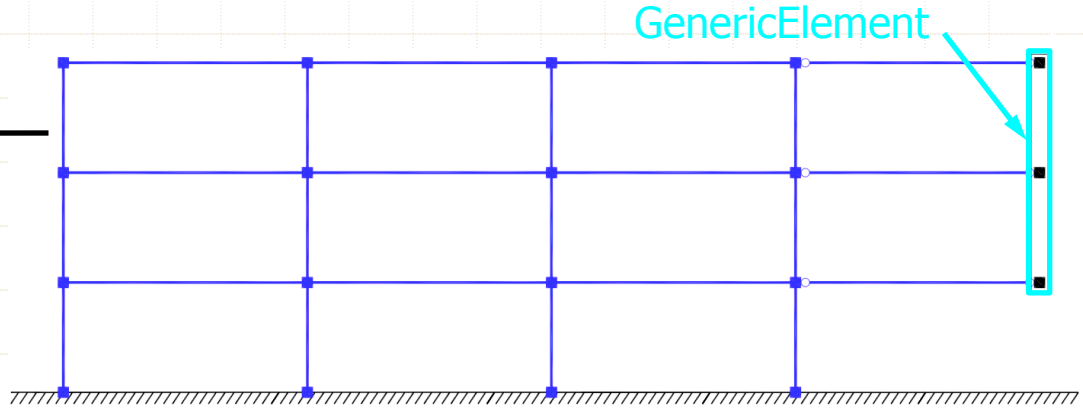
Moment Resisting Frame Subassembly
in Master FE-Software



Shear Wall Subassembly
in Slave FE-Software

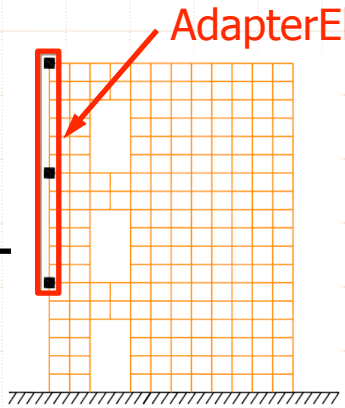
Middleware: OpenFresco





Moment Resisting Frame Subassembly
in Master FE-Software

ECSimFEAdapter (new experimental control that talks to Adapter element)



Shear Wall Subassembly
in Slave FE-Software

Advantages

- No file system is utilized to exchange data among the different software packages
- Runs continuously and concurrently
- No program-specific modifications need to be made to achieve the coupling
- This means that no access to the entire source-code of a FE-software is required
- A published programming interface (e.g. user-defined elements) is the only requirement

Adapter Element Theory

$$\mathbf{M}\ddot{\mathbf{U}}(t)+\mathbf{P}_{\mathbf{r}}\left(\mathbf{U}(t),\dot{\mathbf{U}}(t)\right)=\mathbf{P}(t)-\mathbf{P}_{\mathbf{0}}(t)$$

where:

$$\mathbf{M}=\mathbf{M}_{\mathbf{nd}}\ddot{\mathbf{U}}(t)+\mathop{\mathbf{A}}_{el}\mathbf{m}_{el}\ddot{\mathbf{u}}_{el}(t)$$

$$\mathbf{P}_{\mathbf{r}}=\mathop{\mathbf{A}}_{el}\mathbf{p}_{\mathbf{r},el}\left(\mathbf{u}_{el}(t),\dot{\mathbf{u}}_{el}(t)\right)$$

$$\mathbf{P}_{\mathbf{0}}=\mathop{\mathbf{A}}_{el}\mathbf{p}_{\mathbf{0},el}(t)$$

$$\mathbf{m}_{el}=\int_{V_{el}}\mathbf{N}^{T}\rho\mathbf{N}\,dV$$

$$\mathbf{p}_{\mathbf{r},el}=\int_{V_{el}}\mathbf{B}^{T}\boldsymbol{\sigma}(\boldsymbol{\varepsilon})\,dV$$

$$\mathbf{p}_{\mathbf{0},el}=-\int_{V_{el}}\mathbf{N}^{T}\mathbf{b}\,dV-\int_{\partial V_{t,el}}\mathbf{N}^{T}\mathbf{t}\,dS-\int_{V_{el}}\mathbf{B}^{T}\mathbf{D}\boldsymbol{\varepsilon}_{\mathbf{0}}\,dV+\int_{V_{el}}\mathbf{B}^{T}\boldsymbol{\sigma}_{\mathbf{0}}\,dV$$

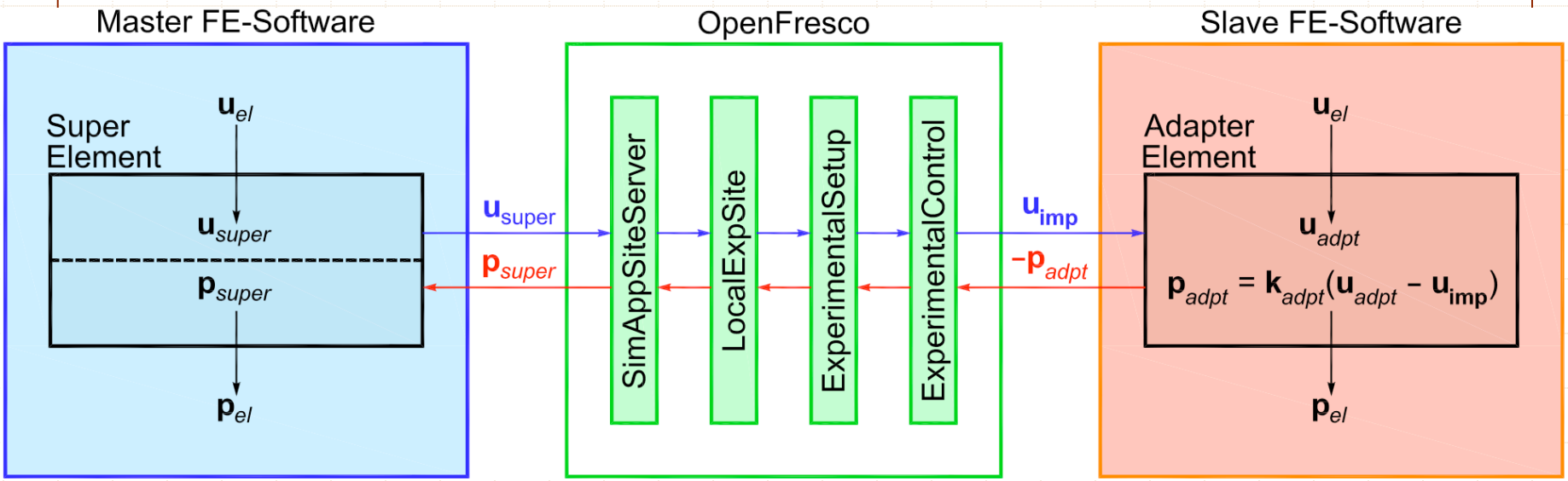
for AdpaterElement

$$\mathbf{p}_{\mathbf{0},adpt}=-\mathbf{k}_{adpt}\,\mathbf{u}_{\mathbf{imp}}(t)$$

Nodal force vector of AdapterElement:

$$\mathbf{p}_{adpt}=\mathbf{p}_{\mathbf{r},adpt}+\mathbf{p}_{\mathbf{0},adpt}=\mathbf{k}_{adpt}\left(\mathbf{u}_{adpt}(t)-\mathbf{u}_{\mathbf{imp}}(t)\right)$$

Implementation Details

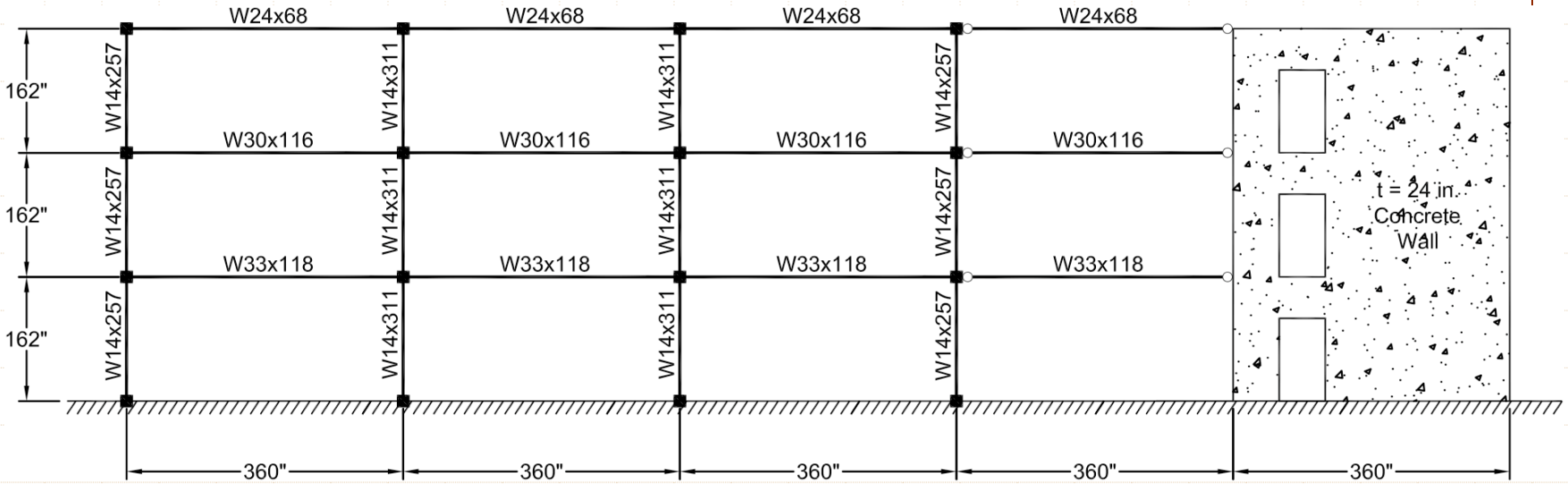


Both, the super-element in the master FE-software and the adapter element in the slave FE-software need to be once implemented as user-defined elements using the software packages' published programming interfaces

Implementation Details Cont.

- Integration methods in the master and slave programs need to be compatible
- If the behavior of the subassembly in the slave program is time-dependent:
  - Time in master and slave programs need to advance at the same rate
  - Thus, use special integration methods in master program
  - Utilize any integration method in slave program, as long as time step size is compatible with master program

3-Story 5-Bay Frame Example

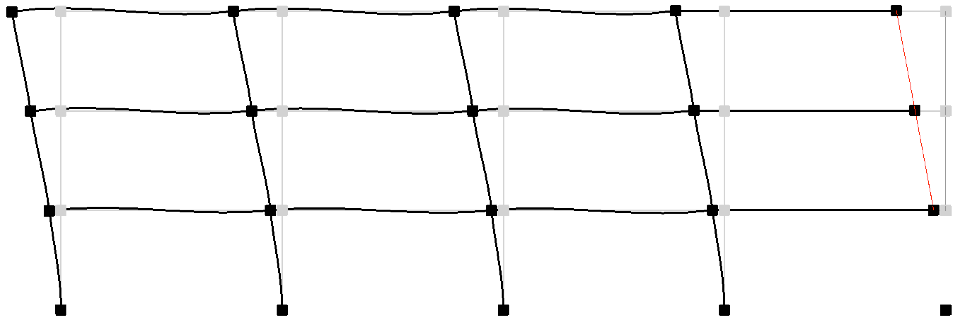


Properties of Model:

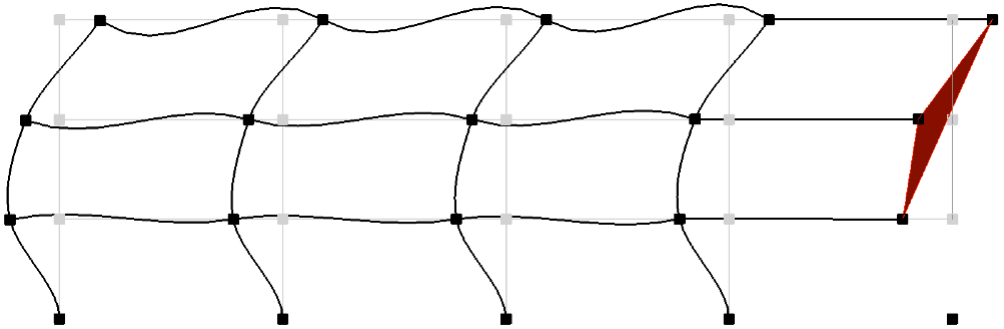
- NDOF = 27+414
- Damping: $\zeta_1 = 0.05$
- SACNF01: pga = 0.755g
- $k_{ii,adpt}$ = 1E12 kips/in.

$$\mathbf{k}_{super} = \begin{bmatrix} 93204.7 & -51063.1 & 10190.1 \\ -51063.1 & 82381.2 & -36235.3 \\ 10190.1 & -36235.3 & 23304.8 \end{bmatrix}$$

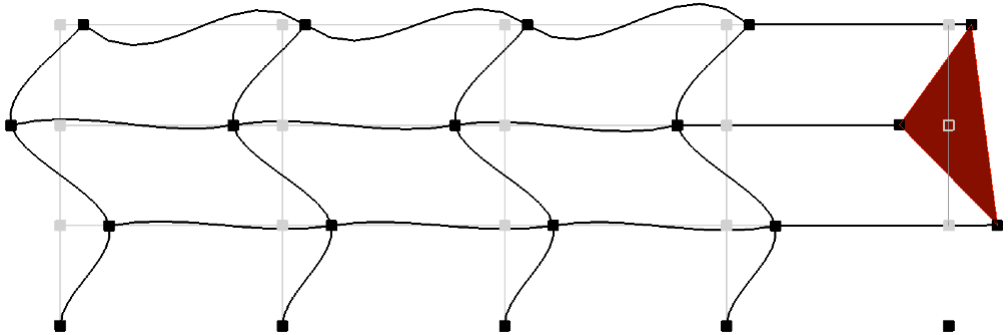
Mode Shapes



1st Mode:
T_1 = 0.312 sec

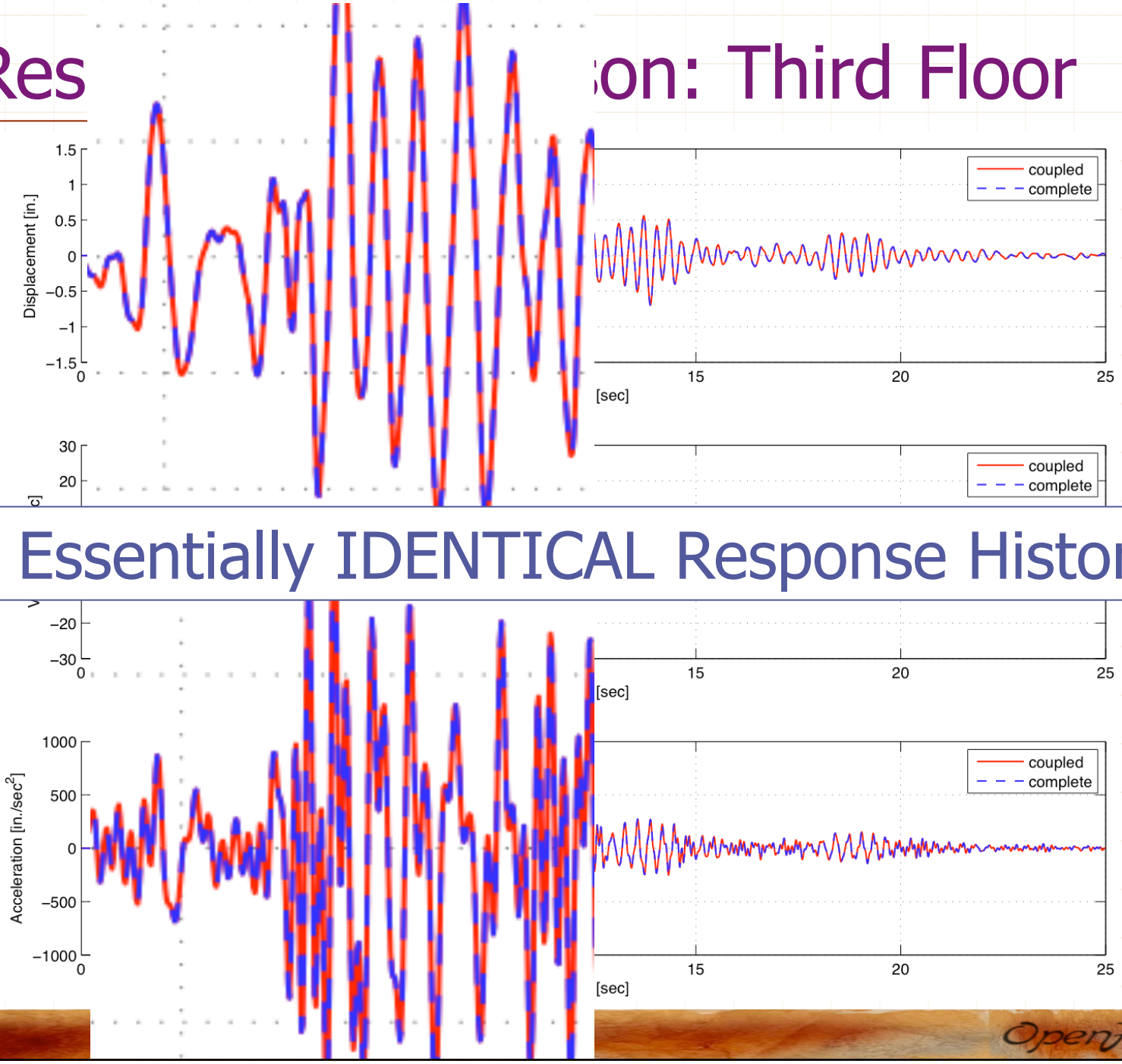


2nd Mode:
T_2 = 0.089 sec



3rd Mode:
T_3 = 0.051 sec

Res son: Third Floor

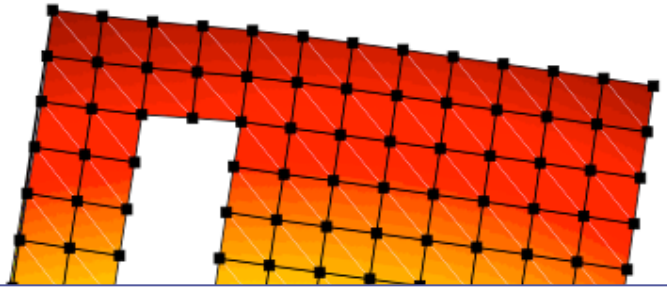


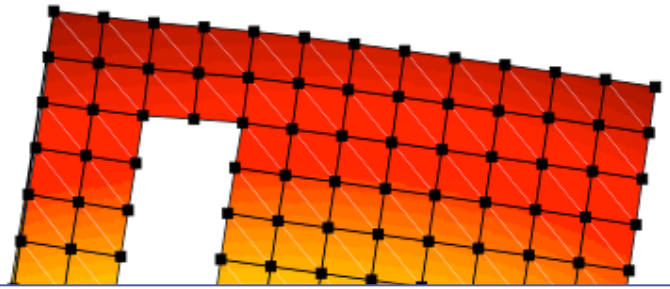
Essentially IDENTICAL Response Histories

Response Comparison: Wall Defo.

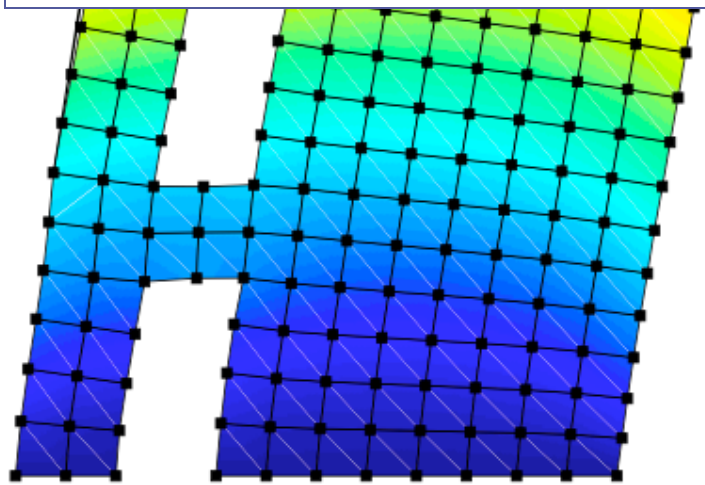
Coupled (at 6.33 sec)

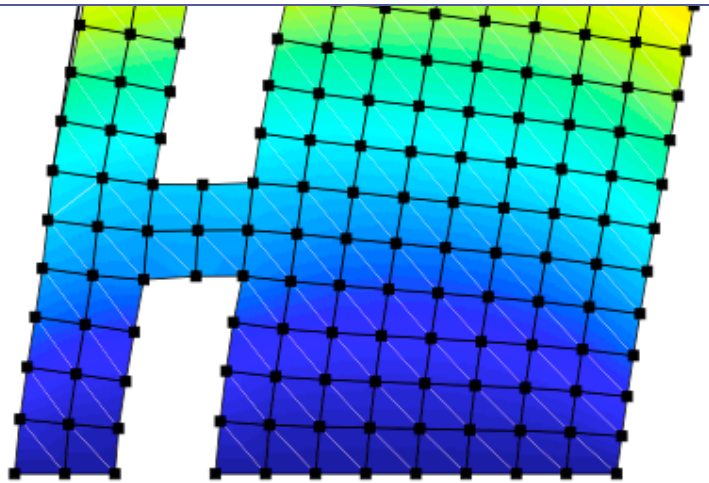
Complete (at 6.33 sec)





Essentially IDENTICAL Wall Deformations





50x magnified

50x magnified

Analysis Time Consumption

- Measure elapsed times for 2500-step-long transient analyses
- For coupled analysis this corresponded to 9990 network transactions across the TCP/IP connection
- Coupled simulation ~3-times slower

	complete simulation	coupled simulation
elapsed time	28.7 sec	84.4 sec
number of analysis steps	2500	2500/4995 (master/slave)

Conclusions

- Software coupling is important for large structural systems that require unique modeling capabilities of diff. programs
- The adapter element approach and the OpenFresco middleware provide a useful and effective set of modules for coupling structural analysis software
- The novel approach avoids the need to repetitively shutdown/restart programs and read/write data files

Questions?
Thank you!

http://openfresco.neesforge.nees.org

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OpenFresco