Real-ESSI Simulator
Results Postprocessing and Visualization Manual

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Contents

1 Post Processing for Real-ESSI Simulator ................................. 3
  1.1 Introduction ................................................................. 4
  1.2 Model Results Post-Processing .......................................... 4
  1.3 Time Histories Plotting .................................................... 4
  1.4 Post Processing and Visualization using ParaView ..................... 4
    1.4.1 Visualization in ParaView : Features ............................ 5
        pvESSI Visualization Options ........................................ 6
        Sequential Visualization ............................................. 8
        Remote Visualization ................................................. 9
        Parallel Visualization ............................................... 10
        General Field Visualization ....................................... 10
          Displacement Field : ............................................... 11
          Boundary Conditions: .............................................. 13
          Material Tag Visualization : ..................................... 14
          Node Tag Visualization : .......................................... 15
          Element Tag Visualization : ..................................... 16
          Element Class Tag Visualization : .............................. 17
        Relative Displacement Visualization ................................ 18
        Visualizing Element’s Partition ..................................... 20
        Gauss Mesh Visualization Options .................................. 21
        Gauss To Node Interpolation Mode Visualization .................. 24
        upU Visualization .................................................... 26
        Eigen Mode Visualization .......................................... 28
        Visualizing Physical Node and Element groups .................... 29
        Using Threshold to Visualize Certain Elements .................... 33
Chapter 1

Post Processing for Real-ESSI Simulator
1.1 Introduction

1.2 Model Results Post-Processing

This chapter describes methodology for post processing simulation results from the Real-ESSI Simulator. Two main approaches are used:

- Plotting time histories of scalar results (described in section 1.3 on page 4), using Python and/or Matlab for:
  - components of displacements, velocities, accelerations, pore fluid pressures, for finite element nodes,
  - components of stress and/or strain at integration (Gauss) points within each finite element,
  - components of section forces for structural finite elements
  - energy input and dissipation for parts or whole of the volume/model, in incremental and/or cumulative form

- Visualization of a part or a complete model for displacements, velocities, accelerations, stress and strain components, sectional forces, energy dissipation through visualization system ParaView, as described in section 1.4 on page 4.

1.3 Time Histories Plotting

Time histories of various scalar results (as listed above) can be extracted from output files, saved in HDF5 (Group), in a format described in chapter ??, on page ??.

1.4 Post Processing and Visualization using ParaView

ParaView package http://www.paraview.org/ (Ayachit, 2015) is a powerful multi-platform data analysis and visualization application available as an Open Source.

It can be run on supercomputers to analyze datasets of peta-scale size as well as on laptops for smaller data, has become an integral tool in many national laboratories, universities and industry, and has won several awards related to high performance computation.

pvESSI is a plugin for paraview that integrates Real-ESSI Simulator output to Paraview for visualization. pvESSI reads Real-ESSI output file, in HDF5 format, files with extension .feioutput. The plugin works for sequential, parallel as well as remote visualization mode. It has a number of visualization features to visualize stresses, eigen modes, relative displacement, physical groups, energy dissipation, etc.
The pvESSI plugin was originally developed by students from the Computational Mechanics Group at the University of California Davis, including Mr. Sinha (lead) with contributions by Mr. Yang, Feng, Wang and others.

Both Paraview and pvESSI installation is described in some detail in section ?? on page ?? of the main document (Jeremić et al., 1989-present).

1.4.1 Visualization in ParaView: Features

pvESSI has been consistently developed and added with lot of visualization options which are built on ParaView Visualization Toolkit (VTK) framework. This section shows all the visualization options that pvESSI offers other than what is available in ParaView. The features are illustrated in subsections below with help of examples in *Examples* folder of pvESSI source directory.

Before, looking at the features, it’s important to know how pvESSI works. pvESSI takes Real-ESSI HDF5 output (.feioutput) file format as input and creates a *pvESSI* folder inside the HDF5 file. pvESSI does this to ensure the visualization to be optimized. The contents inside this folder are not important for any regular user. The contents of "pvESSI" folder is shown in Figure 1.1, although it is not important to regular users. User must know that, the plug-ins first creates this folder and then uses the content of this folder for visualization in ParaView. So creation/reading of this folder is the essence to visualization in ParaView.

![Contents of pvESSI folder.](image)

**Figure 1.1:** Contents of pvESSI folder.
pvESSI Visualization Options

By default pvESSI builds a node mesh. Figure 1.2 shows the various visualization options that is available for pvESSI. The Gauss to node interpolation is turned off and other options shown in Figure 1.2 is turned off. As stated in previous Section 1.4.1, the plugin creates the pvESSI folder inside the output HDF5 file only once and uses it for rest of visualization (even after you close and reopen it). The ‘Build pvESSI folder’ button shown in Figure 1.2 on clicking rebuilds the ‘pvESSI folder’. If in case the loading of ‘.feioutput’ file fails in ParaView, the user should clicks the ‘Build pvESSI Folder’ before hitting ‘Apply’ button.

![pvESSI build options](image)

Figure 1.2: pvESSI build options.

Description of various pvESSI visualization options in the order shown in Figure 1.2 is listed below.

- **Build pvESSI Folder** - Rebuild the content of pvESSI folder inside output file
- **Refresh** - It reloads the current visualization view.
- **Enable Gauss to Node Interpolation** - Enables the interpolation from Gauss points to node using shape functions. It works only for 8 node and 27 node brick with 8 and 27 Gauss points respectively. See Section 1.4.1.
- **Enable uPU Visualization** - Enables the visualization of fluid displacements (U) and pore-pressure (P) at nodes. See Section 1.4.1.

- **Enable Relative Displacement** - When this is enabled, the displacement of any time step can be visualized with respect to any other reference time step. See Section 1.4.1.

- **Reference Time Step No** - This option is used to set the reference time step number about which the relative displacements would be visualized. See Section 1.4.1.

- **Show Gauss Mesh** - This option can be enabled to visualize the Gauss points (mesh) of the entire model. See Section 1.4.1.

- **Enable Displacement Probing** - This option only works if Gauss mesh option is enabled. With this option, displacements are calculated at Gauss points using ParaView interpolation functions for each elements containing those Gauss points. See Section 1.4.1.

- **Physical Groups** - This option is enabled to visualize pre-defined physical groups in Real-ESSI input or manually defined selected nodes or elements. See Section 1.4.1.

- **Enable Actual Time Step Values** - By default instead of actual simulation time (in seconds), time step number of analysis is provided to ParaView VCR. Figure 1.3 shows the result of enable/disable of this option.

![Time Step Number
Actual Analysis Time in Seconds](image)

(a) Actual Time Step Values Disabled  
(b) Actual Time Step Values Enabled

Figure 1.3: Illustration of difference between enable and disable of actual time step values.

In the Figure 1.3, the enabled option gives the exact simulation time of 3.895s. Whereas, disabling the option shows time step number of 200.

The visualization gets automatically updated on enable/disable of options. When one hit’s apply, the corresponding changed result gets updated i.e. the mesh would get real time updated with enable/disable of these options.
Sequential Visualization

Sequential visualization means visualizing the Real-ESSI output on a single core of laptop/desktop. This is used for single output files that Real-ESSI produces for sequential runs. Figure 1.4 shows the visualization of output file produced by sequential Real-ESSI simulation.

1. `cd pvESSI/Examples`
2. `ParaView ShearBox_Sequential.h5.feiooutput`

The parallel output files of ESSI can also be visualized sequentially. Each individual (core) file can be sequentially visualized showing only a part of the model results. Also all the parallel files at once can be opened as well in ParaView as shown in Figure 1.5. All pvESSI examples can be obtained at [http://sokocalo.engr.ucdavis.edu/~jeremic/lecture_notes_online_material/Real-ESSI_pvESSI/Examples](http://sokocalo.engr.ucdavis.edu/~jeremic/lecture_notes_online_material/Real-ESSI_pvESSI/Examples).

1. To open one core output in sequential

1. `cd pvESSI/Examples`
2. `ParaView ShearBox_Parallel.h5.1.feiooutput`

2. To open all cores output in sequential

1. `cd pvESSI/Examples`
2. `ParaView ShearBox_Parallel.h5.feiooutput`

Figure 1.4: Sequential Visualization of output produced by sequential Real-ESSI simulation.
Remote Visualization

Remote visualization is an important feature that ParaView offers. This is an important feature in need, when simulations are run on super computers with thousands of cores. The steps for remote visualization are shown below with an example on local desktop.

1. Run `pvserver` on server

```
$ pvserver
2 Waiting for client...
3 Connection URL: cs://sumeet:11111
4 Accepting connection(s): sumeet:11111
```

2. Open ParaView on client side and click on `connect` button located on top left window.

   ![Connect Server](image)

   Figure 1.6: Connect Server.

3. Select and connect to the server and then load the plugins on both client and server side as shown in Figure 1.7

4. Navigate to `pvESSI/Examples/ShearBox_Parallel.h5.1.feiooutput` and hit apply
Parallel Visualization

Parallel visualization is similar to remote visualization. The only difference is to start the `pvserver` in parallel on multiple cores. It is recommended to have the same number of cores that was used in Real-ESSI parallel simulation. Below shows steps on how to do parallel visualization in ParaView.

```
1 $ mpirun -np $(nop) pvserver
2 # $(nop) is replaced by number of cores on which parallel visualization is to be run.
```

The next following steps are same to that of Remote visualization as shown in Section 1.4.1. Thus, parallel visualization can be performed remotely as well as locally.

General Field Visualization

Below is the list of general visualization variables available for any model in ParaView using pvESSI plugin. The following subsections describes each option through an example. The examples can be found in pvESSI/Examples directory. The example file ‘ShearBox_Sequental.h5.feiooutput’ can be downloaded here.

```
1 cd pvESSI/Examples
```
Displacement Field: The displacement field represents the total displacement from the start of the Real-ESSI simulation. There are two modes of displacement field visualization available in ParaView.

1. Scalar field visualization: The options available are each individual displacement vector components \( u_x, u_y \) and \( u_z \) in \( x,y,z \) directions respectively. It also shows the displacement magnitude \( |u| = \sqrt{u_x^2 + u_y^2 + u_z^2} \). The units of displacements field in \([m]\).

2. Vector Field visualization: This is achieved using 'Wrap by Vector' plugin available in ParaView. Figure 1.10 and Figure 1.11 shows steps to visualize deformed mesh.

(a) Select Displacement Field  
(b) Select scalar field  

Figure 1.9: Displacement Scalar Field Visualization.

(a) Select Displacement Field  
(b) Select plugin  
(c) Plugin properties  

Figure 1.10: Deformation Visualization.
Figure 1.11: Displacement field visualization in ParaView.
**Boundary Conditions:** Again this a vector field which contains information about boundary conditions i.e fixities applied in $u_x$, $u_y$ and $u_z$ directions. A value of 1 means the node is fixed while 0 means it is free. Figure 1.12 shows steps to visualize boundary conditions.

![Boundary Conditions Visualization](image)

(a) Select Boundary Conditions  
(b) Select Fixities Type  
(c) Boundary Conditions in Uz

Figure 1.12: Boundary Conditions Visualization.
Material Tag Visualization: This is a scalar field visualization that shows the material tag associated with the elements in Real-ESSI simulation. Figure 1.13 shows steps to visualize element's material tag.

Figure 1.13: Material Tag Visualization.
Node Tag Visualization: This is a scalar field visualization that shows the node tag associated with the nodes in Real-ESSI simulation. Figure 1.14 shows steps to visualize node's tag.

(a) Select Node Tag
(b) Node Tag Field

Figure 1.14: Node Tag Visualization.
**Element Tag Visualization**: This is a scalar field visualization that shows the element no associated with the elements in Real-ESSI simulation. Figure 1.15 shows steps to visualize element's tag.

![Element Tag Visualization](image)

(a) Select Element Tag   
(b) Element Tag Field

**Figure 1.15**: Element Tag Visualization.
**Element Class Tag Visualization**: This is a scalar field visualization that shows the **Element’s Class Tag** number associated with each element type in Real-ESSI simulation. Figure 1.15 shows steps to visualize element’s tag. Section ?? shows the class tag for various element types available in Real-ESSI.

![Select Class Tag](image1)

(a) Select Class Tag

![Class Tag Field](image2)

(b) Class Tag Field

**Figure 1.16**: Class Tag Visualization.
Relative Displacement Visualization

When the ‘Enable Relative Displacement’ is checked, the relative displacement visualization option becomes active. By default, the relative displacement time step number is set to ‘0’ as shown in Figure 1.17. Time step number ‘0’ corresponds to initial conditions of the loading stage output file.

Reference Time Step Number - It defines the relative time step index number for relative displacement visualization. By default it is set to 0 i.e. to the initial conditions. It’s very useful, when one wants to visualize deformation coming from the stage itself. For example:- Separating self-weight from Static Pushover Analysis in the Shear Box simulation. The steps to do the same is shown below. The example file ShearBox_PushOver.h5.feioutput can be downloaded here.

1. Open an example in ParaView
   
   ```
   cd pvESSI/Examples
   ParaView ShearBox_PushOver.h5.feioutput
   ```

2. Check on Enable Relative Displacement under visualization options

3. Apply warp by vector plugin and follow the steps as shown in Figure 1.10

Figure 1.18 shows the visualization with and without relative displacement.
Figure 1.18: Pushover analysis of Shear Box after self-weight load application.
**Visualizing Element’s Partition**

If the ESSI simulation was run in parallel mode, it becomes important to visualize the elements distribution between different cores. In ParaView, one can see the element distribution by selecting "Partition Info". Following is shown in Figure 1.19 an example to visualize mesh partitioning. All the example files can be obtained [here](#).

```plaintext
1 cd pvESSI/Examples
2 ParaView ShearBox_Parallel.h5.feoutput
```

and then select **Partition_INFO** as shown below in **Figure 1.19**

![Select Partition Info](image)

![Mesh Partitioning](image)

(a) Select Partition Info  
(b) Mesh Partitioning

Figure 1.19: Visualizing mesh partitioning.
Gauss Mesh Visualization Options

Often, it is required to visualize stress and strain fields. Since stress or strains are evaluated at Gauss points in 3-D elements, Gauss mesh is needed to visualize them. pvESSI offers option to visualize Gauss mesh and its fields.

- **Show Gauss Mesh** - Shows only Gauss mesh with Gauss attributes.
- **Enable Displacement Probing** - When this option is enabled, displacements are probed to the Gauss location. It’s useful in the situation, when one wants to visualize the change in stress with deformation. With this as active, one can apply ‘warp by vector’ filter.

It must be noted that the Enable Displacement Probing options only works when Show Gauss Mesh mode is enabled. Figure 1.20 shows the steps to visualize Gauss mesh.

![Gauss Mesh Options](image1.png)

![Gauss Mesh Fields](image2.png)

Figure 1.20: Visualizing Gauss mesh and its fields.

The various fields that can be visualized in Gauss mesh mode as shown in Figure 1.20 are shown below.

- **Total Strain $\varepsilon$**: It defines the total strain from the start of the simulation. It has six independent component $\varepsilon_{xx}, \varepsilon_{xy}, \varepsilon_{xz}, \varepsilon_{yy}, \varepsilon_{yz}$ and $\varepsilon_{zz}$. The magnitude of the total stress in ParaView is defined as $\sqrt{\varepsilon_{ij} : \varepsilon_{ij}}$.

- **Total Plastic Strain $\varepsilon^{pl}$**: It defines the total plastic strain from the start of the simulation. It has six independent component $\varepsilon_{xx}^{pl}, \varepsilon_{xy}^{pl}, \varepsilon_{xz}^{pl}, \varepsilon_{yy}^{pl}, \varepsilon_{yz}^{pl}$ and $\varepsilon_{zz}^{pl}$. The magnitude of the total plastic strain in ParaView is defined as $\sqrt{\varepsilon_{ij}^{pl} : \varepsilon_{ij}^{pl}}$.

- **Total Effective Stress $\sigma'$**: It defines the total effective stress from the start of the simulation. It has six independent component $\sigma'_{xx}, \sigma'_{xy}, \sigma'_{xz}, \sigma'_{yy}, \sigma'_{yz}$ and $\sigma'_{zz}$. The magnitude of the total effective stress in ParaView is defined as $\sqrt{\sigma'_{ij} : \sigma'_{ij}}$. The unit of visualization is in [Pa].
• **Total Mean Effective Stress** $p$ : It defines the total mean of the effective stress $\sigma'$ from the start of the simulation. It is defined as $p = -\sigma'_{ii}/3$ as described in Equation ???. The unit of Visualization is in [Pa].

• **Total Deviatoric Effective Stress** $q$ : It defines the deviatoric invariant of the total effective stress $\sigma'$ from the start of the simulation. It is defined as $q = \sqrt{3}J_2$ as described in Equation ???. Where, $J_2$ is the second invariant of the deviatoric stress tensor $s_{ij} = \sigma'_{ij} - \sigma'_{kk}/3\delta_{ij}$. The unit of visualization is in [Pa].

• **Total Mean Plastic Strain** $\varepsilon_{pl}^p$ : It defines the mean total plastic strain $\varepsilon_{pl}$ invariant from the start of the simulation. It is defined as $\varepsilon_{pl}^p = -\varepsilon_{pl}^{ii}/3$. This visualization parameter is unit-less.

• **Total Deviatoric Plastic Strain** $\varepsilon_{pl}^p$ : It defines the deviatoric invariant of the total plastic strain $\varepsilon_{pl}$ from the start of the simulation. It is defined as $\varepsilon_{pl}^p = \sqrt{3}J'_2$. Where, $J'_2$ is the second invariant of the deviatoric plastic strain tensor $\varepsilon_{pl}^{ij} = \varepsilon_{pl}^{ij} - \varepsilon_{pl}^{kk}/3\delta_{ij}$. This visualization parameter is unit-less.

1. Open an example in ParaView. All the example files can be obtained at [http://sokocalo.engr.ucdavis.edu/~jeremic/lecture_notes_online_material/Real-ESSI_pvESSI/Examples](http://sokocalo.engr.ucdavis.edu/~jeremic/lecture_notes_online_material/Real-ESSI_pvESSI/Examples).

   ```
   1 cd pVESSI/Examples
   2 ParaView ShearBox_PushOver.h5.feiooutput
   ```

2. Check on **Enable Relative Displacement** under pvESSI build options.

3. Enable Gauss mesh as shown in Figure 1.20(a). Select Mean Effective Stress $p$ [Pa]. The resulting visualization is shown in Figure 1.21(a).

4. Enable displacement probing as shown in Figure 1.20(a). Apply a warp by vector filter and select the vector displacement as shown in Figure 1.10. Now select again the Mean Effective Stress $p$ [Pa] field option to visualize. The resulting visualization is shown in Figure 1.21(b).
Figure 1.21: Visualization of mean effective stress $p$ invariant in Gauss mesh.
Gauss To Node Interpolation Mode Visualization

This visualization mode can be enabled by checking the 'Gauss To Node Interpolation' option as shown in Figure 1.22(a). In this mode, the total effective stress $\sigma_{ij}$, total strain $\epsilon_{ij}$, total plastic strain $\epsilon_{ij}^{pl}$, total mean effective stress $p$, total deviatoric effective stress $q$, total mean plastic strain $\epsilon_{p}^{pl}$, and total deviatoric plastic strain $\epsilon_{q}^{pl}$ are interpolated from the Gauss points to the nodes of individual element. Individual shape functions of the element (with full Gauss integration) are used to obtain the stress or strain field at nodes. To smooth out the jumps in stress or strain field at the node by adjacent elements, unweighted averaging is performed. For the elements (usually structural) with no Gauss points, the stress or strain contribution at nodes are considered as zero. While taking the averaging, their contributions are not taken, as Real-ESSI does not output stress/strain for them.

In this mode, visualization of all the parameters listed and described in Section 1.4.1 is available. Figure 1.22 show the steps to enable and use Gauss to Node Interpolation option.

1. Open an example in ParaView. All the example files can be obtained at http://sokocalo.engr.ucdavis.edu/~jeremic/lecture_notes_online_material/Real-ESSI_pvESSI/Examples.

   ```
   cd pvESSI/Examples
   ParaView ShearBox_Sequential.feivoutput
   ```

2. Follow the steps as shown in Figure 1.22

   **Note:** The option Gauss to node interpolation is provides only an approximate estimate for stress and strains at nodes. The values obtained at nodes is not accurate and thus Gauss Mesh Visualization option described in Section 1.4.1 must be performed to get the accurate stress and strains at Gauss points. Also, it must be noted that this option works only for 8 node brick with 8 Gauss points and 27 node brick with 27 node points. For elements which have less number of nodes that Gauss points, the total number of equations (unknowns) is not equal to constraints (knowns). In this case, only the shape function defined at the nodes are used to get the stress or strain back to the node.
Figure 1.22: Steps to visualize stress and strain interpolated from Gauss points to nodes.
upU Visualization

This mode is to visualize the upU elements used in Real-ESSI simulation. Enabling this mode, produces additional outputs of ‘Pore Pressure $p[Pa]$’ and ‘Fluid Displacement $U_x[m]$, $U_y[m]$ and $U_z[m]$’ at nodes. These additional outputs are described below.

- **Pore Pressure $p[Pa]$**: It defines the pore-fluid pressure in the upU element at the nodes. The magnitude of the pore pressure is $[Pa]$.

- **Fluid Displacement $U[m]$**: It defines the displacement by the fluid particles of upU at nodes. The units is in meters $[m]$. The solid displacement is termed as $u$ and refers to the ‘Displacement $u$’ variable in visualization as described in Section 1.4.1.

Since general dry elements does not have any fluid, enabling this option would produce ‘zero’ pore fluid pressure and fluid displacements at nodes. Below is shown an example that shows how to use the upU visualization feature. Figure 1.23 shows the steps.

1. Open an example in ParaView. All the example files can be obtained at http://sokocalo.engr.ucdavis.edu/~jeremic/lecture_notes_online_material/Real-ESSI_pvESSI/Examples.

   ```bash
   1 cd pvESSI/Examples
   2 ParaView upU_Visualization_Example.feioutput
   ```

2. Follow the steps as shown in Figure 1.23