Lab Manual

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Version 2.5
05/2018
Western Michigan University’s Laboratory of Earthquake and Structural Simulation (LESS) is located at C-113 in the College of Engineering and Applied Sciences (CEAS) building in Kalamazoo, Michigan. It is a state-of-the-art facility for simulating earthquakes and the effects on small scale structures. The major equipment in the LESS includes a uniaxial seismic simulator (commonly called a shake table), two 3 kips hydraulic actuators with the supporting hydraulic power supply and advanced real time controller. Instrumentation available in the lab consists of accelerometers, a linear variable displacement transducer (LVDT), and a wireless sensor network set. Through this equipment, various seismic experiments can be performed, including shake table test, effective force test, and pseudodynamic test in real time and with substructuring.

Version 2.5:

- Section 5.7 distributed real-time hybrid simulation (dRTHS) was added (created by Mohamed and improved by Mehmet)
- Section 5.3.1 software overview was added by Mehmet

Version 2.4:

- Sections 5.3, 5.4 and 5.6 were updated with the new versions of software being installed on the Hybrid Testing Controller.
  - Section 5.3 was added to discuss software installation procedure associated with NI VeriStand 2015
  - Section 5.4 was updated to provide the procedure of creating project in NI VeriStand 2015
  - Section 5.6 was updated to present the hybrid testing procedure using the 2015 version of NI VeriStand

Version 2.3:

- Improved Shake table testing procedure, added steps to load 10 ground motions with the ground motion information provided (Section 4.4).
- Added Section 4.5 Shake table motion generation using Seismosignal.
- Improved Section 5.3 Real-time Controller Formatting and Software Installation using NI Measurement and Automation Explorer (MAX). Specifically, steps on how to choose the Chassis in the MAX and the images of the real-time controller after important steps are provided.
- Improved Section 5.5 Hybrid Testing Procedure with the steps to input calibration equation of the structural actuator (1) external command; (2) LVDT and (3) Load cell in the workscope of the NI Veristand.
- Modified method of calibration structure LVDTs using MAX are provided in Section 6.4.

Version 2.2:

- Added command calibration section (3.2.6)
Version 2.1:

- Added instrumentation frame section (section 3.4.3)
- Updated substructure specimen information (section 3.5.2)
- Updated logging in hybrid testing procedure (section 5.5)
- Added section on UI-SimCor and NICON (section 5.6)
- Updated LVDT installation procedure (section 6.1)
- Added referenced single-ended (RSE) note to system explorer (section 6.4)

Version 2.0:

- Added actuator tuning procedure (section 3.2.5)
- Updated hybrid testing procedure (section 5.5)
  - More information on system mappings
  - Revised primary control loop rate step
  - More information on deployment procedure
  - More information on graph setup
  - Added instrumentation offset procedure
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1 Overview

Western Michigan University’s Laboratory of Earthquake and Structural Simulation (LESS) is located at C-113 in the College of Engineering and Applied Sciences (CEAS) building in Kalamazoo, Michigan. It is a state-of-the-art facility for simulating earthquakes and the effects on small scale structures. The major equipment in the LESS includes a uniaxial seismic simulator (commonly called a shake table), two 3 kips hydraulic actuators with the supporting hydraulic power supply and advanced real time controller. The shake table has a dimension of 3 ft x 3 ft and can subject a specimen with maximum weight of 500 lb to an earthquake time history with peak acceleration up to 4g. Structural dynamic properties and structural response due to seismic attack can be obtained through such a shake table test. Instrumentation available in the lab consists of accelerometers, a linear variable displacement transducer (LVDT), and a wireless sensor network set. Through this equipment, various seismic experiments can be performed, including shake table test, effective force test, and pseudodynamic test in real time and with substructuring.

Firstly, several common test methods in earthquake engineering are presented. Next, the LESS equipment is introduced. The function of each component is briefly described followed by basic specifications. Subsequently, open loop testing as well as hybrid testing is explained with specific pictorial instructions. Lastly the instrumentation available in the lab as well as the calibration procedure of these instruments are discussed.
2 Test Methods in Earthquake Engineering

There are several common testing methods including quasi-static loading testing (QST), shake table testing (STT), effective force testing (EFT), pseudodynamic (PSD) testing, and real time dynamic hybrid testing (RTDHT). When these experiments are conducted only on the physical substructure and combined with numerical simulation of the remaining numerical substructure, they are defined as hybrid testing, during which the seismic response of the entire system is obtained.

2.1 Quasi-Static Testing

The QST method involves slowly applying predefined cyclic displacement or force history to a test structure using hydraulic actuators. QST is generally used for single structural elements or simple subassemblies to obtain their hysteretic responses that can be used to predict the seismic performance in some cases. However, QST does not capture the specimen inertia effects that are associated with the dynamic nature of seismic loadings.

2.2 Shake Table Testing

The STT is a dynamic testing method during which a structural specimen is mounted on a shake table that will simulate an earthquake ground motion. The effect of inertia force on the structure is naturally developed and can be directly observed and measured. STT allows realistic representation of earthquake effects on the structure under investigation; however, the size of the structure being tested is limited to the size of the shake table. It can be difficult for a small scale specimen to accurately represent a complex full size structural system. In addition to scaling, shake table requires an advanced control system that can reduce actuator lag and compensate for the reaction forces between the structural specimen and the table, which is usually expensive and requires further research to improve.

2.3 Effective Force Testing

During EFT the base of a structure is fixed to a strong floor. Dynamic force is applied to the structure representing the real inertia force the structure will experience during an earthquake. This dynamic force is the product of the acceleration of the selected ground motion and the structural mass, and is usually applied utilizing an actuator/reaction loading system. This method removes the dependency on a shake table and allows a full-scale structure to be tested. However, the reliability of EFT is highly dependent on the accuracy of the force control in the actuators. Since force measurements are usually sensitive to the noise, actuator force control remains to be a challenge which needs to be conquered to further advance EFT.

2.4 Pseudodynamic Testing

PSD test is a hybrid test in essence since it uses numerical simulation during the physical experiment to study the structural dynamic behavior subject to seismic attack. The test structure is usually loaded quasi-statically with the simulated displacement response obtained from a computer model, while the corresponding resisting force is fed back to the model to calculate the next step’s displacement command. The real time PSD test was developed to examine the dynamic response of velocity-dependent devices which cannot be accurately captured during quasi-static loading. The advantage of PSD testing is that it allows experimentation on any size of structures, as compared to the general STT that is limited to be performed
on reduced size structures. Therefore, PSD testing has been used in numerous earthquake engineering research projects. However, the real time testing still poses a challenge to this method especially when a large scale complex specimen is being tested.

2.5 Real Time Dynamic Hybrid Testing

The real time dynamic hybrid testing (RTDHT) method was proposed as a seismic response simulation method that combines numerical computation and physical specimens excited by both shake tables and auxiliary actuators. The loadings generated by the seismic excitations at the interfaces between the physical and numerical substructures, in terms of accelerations and forces, are imposed by shake tables and actuators in a step-by-step manner at a real time rate. The unique aspect of the RTDHT method is the versatile implementation of inertia forces and a force based substructuring. However, RTDHT has not been adopted by a research project as a testing method due to some difficulties in numerical simulation and coordinated real time control of both actuators and shake tables. Therefore, more research is necessary to implement this advanced versatile testing method in real research projects.
3 Equipment

3.1 Uniaxial Shake Table

3.1.1 Base Frame

The dimensions of the base frame are 8 ft x 3 ft x 4 in. Its weight is 1400 lb. The base frame exists solely for the purpose of supporting the shake table and reaction frame.

Figure 3-1: Base Frame and Sliding Table

3.1.2 Sliding Table

The uniaxial shake table is designed to impose base ground motion to a test specimen. It does this by moving along two 36 in steel guide rails. It can be utilized alone in a shake table test or shake table substructure test, or it can be combined with the actuator/reaction frame to conduct a real time dynamic hybrid test. When only the actuator/reaction frame is used in a hybrid test, the shake table can be used as a strong floor to hold the test specimen with the 2 in (5.08 cm) space bolt hole pattern for easy and flexible installation.

Table 3-1: Sliding Table Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>3 ft x 3 ft x 2 in aluminum plate</td>
</tr>
<tr>
<td>Weight</td>
<td>310 lb</td>
</tr>
<tr>
<td>Maximum specimen mass</td>
<td>500 lb (228 kg)</td>
</tr>
<tr>
<td>Frequency of operation</td>
<td>0 - 20 Hz</td>
</tr>
<tr>
<td>Maximum specimen acceleration</td>
<td>4 g (with 500 lb specimen)</td>
</tr>
<tr>
<td>Displacement</td>
<td>± 3 in</td>
</tr>
</tbody>
</table>

3.1.3 Material Strength

Table 3-2: Capacities of Materials used in Shake Table
<table>
<thead>
<tr>
<th>Material</th>
<th>Tensile Yield Strength (ksi)</th>
<th>Ultimate Tensile Strength (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum 6061-T6 • Sliding Table</td>
<td>37</td>
<td>42</td>
</tr>
<tr>
<td>• End Support Blocks • Pillow Blocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM A500 Grade B Steel • Base Frame</td>
<td>45.7</td>
<td>58</td>
</tr>
<tr>
<td>• Reaction Frame</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A36 Steel • Base Plates</td>
<td>36.3</td>
<td>58</td>
</tr>
</tbody>
</table>

3.2 Hydraulic System

3.2.1 Hydraulic Power Supply

The hydraulic power supply (HPS) used in the testing system is a Servo Quality 10 gpm Model No. 110.11S. It sends hydraulic fluid to both actuators with a 20 horsepower electric motor to pump up to 10 gpm at 3000 psi. The hydraulic oil passes through a 3 micron high pressure filter. The HPS contains control buttons to switch between high and low pressure as well as an on/off button. It also has an emergency stop button which allows the immediate shut down of the pump and keeps the pump from turning on until the problem is corrected.

![Figure 3-2: Hydraulic Power Supply](image)

3.2.2 Hydraulic Controller SC6000

The manufacturer’s generic hydraulic controller adopted herein is a 2 channel (one for each actuator) desk top controller called Shore Western SC6000. It uses Windows XP operating system and commands the entire hydraulic system including the on/off switch, the pressure of the HPS, and the two actuators’ motions. The controller connects the hydraulic system via input/output connectors which are attached
to the load cells, LVDTs, servo-valves, service manifolds, and the HPS. It uses a proportional–integral–
derivative controller for displacement control of the actuators. Having a user graphical interface the
controller can be easily operated to adjust control parameters, run tests, record feedback, and tune the
system to reach its optimum performance. See the SC6000 Manual for detailed operation instructions.

The hydraulic controller is also capable of tracking external command for real time operation. This
feature is essential for this system to conduct hybrid testing. External command of the actuators (i.e.
simulated interface motion between the physical and numerical substructures determined from the
numerical simulation running in a real-time controller) can therefore be transferred to the hydraulic
controller to drive the actuators applying the desired dynamic loading to the structural specimen.

![Hydraulic Controller SC6000](image)

**Figure 3-3: Hydraulic Controller SC6000**

### 3.2.3 Hydraulic Linear Actuators

The hybrid testing system includes two hydraulic linear actuators (Shore Western Model 910D-1.08-
6(0)-4-1348). Each actuator contains a 2.5 gpm servo-valve and a hydraulic service manifold rated at 15
gpm. The actuators are installed with linear variable differential transducers (LVDT) and load cell sensors,
which provide position and loading feedback for both displacement and force control of the actuators.
One actuator is used to drive the shake table and is named the table actuator. The other actuator is
mounted against the reaction frame to form an actuator/reaction setup and is called the structure
actuator. The hybrid testing system developed therefore consists of both shake table and
actuator/reaction setup allowing hybrid tests to be conducted using individual loading equipment or both
of them simultaneously. This loading capability along with numerical simulation, results in various testing
configurations necessary to perform different hybrid testing methods.
Table 3-3: Actuator Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td>± 3240 lb at 3000 psi</td>
</tr>
<tr>
<td>Stroke</td>
<td>6 inch, ± 2.5 inch, plus ± 0.5 inch cushions</td>
</tr>
<tr>
<td>Swivel Base and End Rod</td>
<td>± 90° swivel, ± 7° tilt</td>
</tr>
<tr>
<td>Servo-valve</td>
<td>2.5 gpm at 1000 psi</td>
</tr>
<tr>
<td>Load Cell</td>
<td>2.5 kip fatigue rated 300% overload capacity</td>
</tr>
<tr>
<td>Hydraulic Service Manifolds</td>
<td>15 gpm at 3000 psi oil service</td>
</tr>
</tbody>
</table>

Figure 3-4: Actuators

3.2.4 Hydraulic System Maintenance

- Always warm up the HPS before performing a dynamic type test. The controller also needs to warm up for calibration (for about 2 hours running).
- For safety, put the green cable (ground cable) under the LVDT connection or servo valve or ground base plate.
- When actuators are not being used or are being stored for a relatively long time, fully retract the stroke to avoid dust. If dust is visible on the actuators, wipe it off.
- Clean oil, clean oil, and clean oil!!! Never open to atmosphere and always put the caps on.
- Loose cable of the instrument for possible movement of the actuators.
- Straighten hoses while running HPS. Never step on hoses. Do not put hoses across sharp edge. Check hose once a month for rubber break.
- No oil on the floor.
- Never plug/unplug cables when HPS is running.
- Always make a copy of the folder C:/Programs/ShoreWesternMfg/swcs/. Play with software/setting using copies instead of original one.
- Change filters every 6 months or 1000 hours of use. First time change shall be around a couple hundred hours of running HPS.
- Regularly check hoses and connections for leakage. If a leakage is detected: 1) Tighten the fittings, 2) Change fittings, GIC standard off the shelf product.
- For calibration, follow ASTM E09. Calibrate once a year.
3.2.5 Actuator Tuning Procedure

1. Startup the hydraulic equipment (see Section 4.1).
2. Type 0 into the table actuator displacement command in SC6000. Press enter. If the position is not exactly 0 inches, the valve balance must be adjusted.

![Figure 3-5](image1)

3. To adjust the valve balance, first click the blue triangle in the Valve Driver 1 box in the lower right panel.

![Figure 3-6](image2)


![Figure 3-7](image3)

5. Adjust the slider until the position reading is 0 inches.

![Figure 3-8](image4)
6. Right click Waveform in the upper left panel of the screen. Click Change selected cards. Click Card 1, click ADD, and then click OK.

7. In the upper left panel, right click Card 1 and select table actuator.

8. Right click actuator and click Add Segment. Then click Square Wave.
9. Use an amplitude of 0.25 inches, a duty cycle of 50%, a frequency of 0.2 Hz, and a large number of cycles. Click OK.

10. Click the blue triangle in the Servo Amplifier 1 box in the lower right panel.
11. Click Monitor A next to the Internal Command box. Also click the Proportional gain and the Rate gain. The sliders shown below will appear. There is no need to adjust the Integrator gain, so do not click on it.

![Figure 3-15](image)

![Figure 3-16](image)

![Figure 3-17](image)

12. Click Select Channels in the upper right panel of the screen and click OK on the dialogue box that appears. The channel colors should change. Make sure only the boxes next to MON A and TABLE POSITION are checked.
13. Click Run in the upper left panel and Start in the upper right panel. Adjust the y-axis and x-axis ranges so that the entire signals can be seen in the plot.
14. The plot consists of two signals: the command being sent to the actuator and the actual displacement of the actuator recorded by the LVDT. The objective is to get these to match.

15. Adjusting the proportional gain will have the greatest effect and is the most important. If the actuator is too slow to reach its command displacement, the proportional gain must be increased. If the actuator is overshooting the command, causing vibrations, the proportional gain must be decreased.

16. The rate gain can also be adjusted, but will have less of an effect. Once again, the integrator gain does not need to be adjusted at all.

The same steps can be followed to tune the structure actuator.

**EXAMPLES**

If the plot looks like this, the proportional gain is too low and needs to be increased.

If the plot looks like this, the proportional gain is too high and needs to be decreased.
The following plot depicts a well-tuned actuator.
3.2.6 Command Calibration

The command calibration equations of both actuators may need to be updated periodically. If the LVDT readings are not matching with the displacement commands, performing command calibration will correct this. The command calibration procedure can be found in the SC6000 Software Operating Guide on pages 75-84.

3.2.7 Hydraulic Actuator Command Calibration for external command

To perform hybrid testing using external command from the hybrid testing model (i.e. Simulink model), the actuators’ command needs to be calibrated so the structure actuator and the table actuator will receive the correct command to move to the desired position under external command.

A calibration of the table actuator was performed in February 2015 when performing shake table testing, which is presented below. Similar procedure can be followed if the structural actuator’s external command needs to be recalibrated.

1. Prepare three shake table tests (same or different ground motions) without any calibration equation applied in the workspace in the NI VeriStand and collect command and measured displacement data of the table actuator. Follow procedure in Section 5.5.2 to conduct shake table test.
2. Run the workspace and make sure to include LVDT1 and EXT1 in data-log recording. Those two channels are critical in obtaining calibration equation. Run three tests and collect data.
3. Import the data to MATLAB following the Section 4.3.3. For the first trail, plot LVDT1 & EXT1 vs time. Apply a scaling factor to match the two graphs. Record the scale factor for the first trial. Do the same for the other two trials and average all three scaling factors to obtain a1 coefficient. Input a1 value into the calibration equation for EXT1.

Through this procedure, a scaling factor of 2.53 was found for the shake table external command that was applied to the NI VeriStand/Workspace/Tools/Channels scaling and Calibration as the “a1” (slope) coefficient. This scaling factor was included in the Appendix II. The structure actuator’s external command was calibrated earlier by Adam which is shown in the Appendix II as well.
3.3 NI-Controller and Data Acquisition

The real-time controller consists of a real-time processor and the general purpose data acquisition (DAQ) cards. Both processor and DAQ cards are contained within a single chassis enabling real time data transfer between these two components without any delay. The real-time controller adopted herein is a National Instruments (NI) PXI system that has two DAQ cards, possessing a total of 48 analog input channels, 6 analog output channels, and 72 digital input/output channels. These channels receive the signals from the instrumentations that are attached to the test specimen and send external command to the hydraulic controller through the connections devised. The real-time processor processes the signal being sent and received through the DAQ cards and runs the hybrid testing model developed specifically for each test.

<table>
<thead>
<tr>
<th>Table 3-4: NI-Controller Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PXI 1050 Chassis</strong></td>
</tr>
<tr>
<td>8-slot 3U PXI Chassis</td>
</tr>
<tr>
<td>Integrated SCXI Chassis: 4 Signal Conditioning Module Slots</td>
</tr>
<tr>
<td><strong>PXI 8108 Controller</strong></td>
</tr>
<tr>
<td>2.53 GHz Dual Core Embedded Controller</td>
</tr>
<tr>
<td><strong>PXI Modules</strong></td>
</tr>
<tr>
<td>PXI-6229: 16-bit, 32 AI, 48 DIO, Multifunction M Series DAQ</td>
</tr>
<tr>
<td>PXI-6221: 16-bit, 16 AI, 24 DIO, Multifunction M Series DAQ</td>
</tr>
<tr>
<td><strong>SCB-68</strong></td>
</tr>
<tr>
<td>68-pin Shielded Desktop Connector Block</td>
</tr>
<tr>
<td>All communication to the DAQs travels through connector blocks</td>
</tr>
</tbody>
</table>

3.4 Instrumentation

For general earthquake experiments, sensors are crucial to understand the performance of the test specimen under investigation. For hybrid testing, the data fed back from the sensors serve a double purpose. In addition to providing the specimen’s seismic response, some of the feedback data is also used to determine the interface loading and to improve the hydraulic loading performance. The sensors currently available for use include accelerometers and LVDTs. Please refer to Chapter 6 for information on instrument installation and calibration.
3.4.1 Accelerometers

<table>
<thead>
<tr>
<th>Wired Accelerometers (Crossbow Technology CXL04GP3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input Range</strong></td>
</tr>
<tr>
<td><strong>Measurement</strong></td>
</tr>
<tr>
<td><strong>Size</strong></td>
</tr>
<tr>
<td><strong>Weight</strong></td>
</tr>
</tbody>
</table>

![Figure 3-26: Wired Accelerometer](image1)

![Figure 3-27: Wireless Accelerometer](image2)

<table>
<thead>
<tr>
<th>Wireless Accelerometer Network Set</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IIB2400 Interface Board</strong></td>
</tr>
<tr>
<td><strong>Size</strong></td>
</tr>
<tr>
<td><strong>IPR2400 Intel Mote 2 (Imote 2) processor/radio board with external antennae</strong></td>
</tr>
<tr>
<td><strong>Size</strong></td>
</tr>
<tr>
<td><strong>Structural Health Monitoring Accelerometer (SHM-A) sensor board</strong></td>
</tr>
<tr>
<td><strong>IBB2400CA battery board with on/off switch</strong></td>
</tr>
<tr>
<td><strong>Input Range</strong></td>
</tr>
<tr>
<td><strong>Measurement</strong></td>
</tr>
</tbody>
</table>

3.4.2 LVDT

<table>
<thead>
<tr>
<th>LVDT Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input Voltage</strong></td>
</tr>
<tr>
<td><strong>Stroke</strong></td>
</tr>
<tr>
<td><strong>Frequency Response</strong></td>
</tr>
<tr>
<td><strong>Power Supply Converter</strong></td>
</tr>
</tbody>
</table>
3.4.3 Instrumentation Frame

The instrumentation frame is a 4’3” tall braced frame with three slots corresponding to story heights of the structure specimen. This allows for adjustment of instrumentation height.

3.5 Specimens

3.5.1 Structure Specimen

The structure specimen is an idealized lumped mass three degree-of-freedom (DOF) structure. Each story contains a mass which is supported by four columns. The columns are removable and replaceable, allowing for the separation of substructures while using the same materials of the full three story structure test. The test specimen is very lightly damped (about 0.5% damping ratio). Therefore, an external damper is available that can be added to the top story to increase the structural damping to a realistic damping level of general civil structural systems.
### Table 3-8: Structure Specimen Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Stories</td>
<td>3</td>
</tr>
<tr>
<td>Story Height</td>
<td>12&quot;</td>
</tr>
<tr>
<td>Structure Height</td>
<td>41 1/2&quot;</td>
</tr>
<tr>
<td>Column Cross Section</td>
<td>1/8&quot; x 1 1/4&quot;</td>
</tr>
<tr>
<td>Story Weight</td>
<td>12.6 lb</td>
</tr>
<tr>
<td>Structure Weight</td>
<td>37.7 lb</td>
</tr>
<tr>
<td>Story Stiffness</td>
<td>0.164 kip/in</td>
</tr>
<tr>
<td>Natural Frequencies</td>
<td>5.04 Hz, 14.10 Hz, 20.30 Hz</td>
</tr>
</tbody>
</table>

The substructure specimen is a cantilever column with an idealized plastic hinge connection at its base. The plastic hinge emulates nonlinear behavior and can be easily replaced after yielding without permanent damage to the specimen. The HSS 3” x 1.5” x 1/8” column is three feet long and is welded all around the base to a 5” x 12” steel plate with a ½” thickness. Two A307 steel bolts that are 4½” long and ¼” in diameter act as coupons on each side. These bolts have a center to center distance of 8”. They are each secured by two nuts that are fastened to the bottom of the upper plate and the top of the lower plate, which is 15” x 15” x ¾”. This lower plate is bolted in the four corners to the shake table in order to provide a fixed support. Two bearings are attached to 5” x 1¾” x ¼” aluminum plates, which are welded to the bottom plate. The two bearings are 4” apart center to center. Finally, a 6” steel rod with a diameter of ½” connects the two new bearings to the hinge.
Figure 3-31: Substructure Specimen Connection

Figure 3-32: Substructure Specimen
Figure 3-33: Typical Hysteretic Response of Substructure Specimen
4  Open Loop Testing Procedure

During an open loop test, a predetermined loading pattern is imposed. Open loop testing does not require force responses to be measured in order to calculate displacement commands. Therefore, no feedback is needed and only a command signal is required. Open loop testing does not involve the use of the real-time controller and is only useful for certain types of tests, such as cyclic testing and shake table testing (STT), which are described in 4.2 and 4.3 respectively.

4.1  Hydraulic Equipment Startup Procedure

1. Make sure the water is turned on with both yellow levers in the up position (If you don’t, the hydraulics could overheat).

![Figure 4-1](image)

2. If it’s not already on, turn on the computer (push both switches).

![Figure 4-2](image)
If the controller is shut down previously due to an emergency stop such as the “Emergency” button shown below is pushed down, you need to first reset the “Emergency” follow the instruction shown.

3. Double click the Shore Western start-up icon.

4. In the lower left panel of the control screen, click the E-STOP RESET button (switching from DISABLED to ENABLED).
5. On the front of the computer (black box) push the lighted red button (not the emergency stop button).

![Image of computer control panel]

**Figure 4-5**

6. In the lower left panel of the control screen, click the AUTOBALANCE button, then click the button labeled LOW under PUMP CONTROL. This will turn on the pump.

![Image of control screen with AUTOBALANCE and LOW buttons highlighted]

**Figure 4-6**

7. Check hoses and fixtures for leaks.
8. To turn on the actuator, click the button labeled DISABLED for the appropriate actuator (this switches it to ENABLED).
9. To turn on high pressure, click the button labeled HIGH.

10. To control the actuator, you can either use the slider in the lower left panel, enter the distance into the box next to the slider, or create a waveform in the upper left panel.

4.2 Hydraulic shut-down procedure

When the test is done, **fully retract actuator** when there’s no specimen attached limiting actuator being fully retracted. This is beneficial to actuator when its stroke is not exposed to dust when not being utilized.

To shut down the hydraulic, one may basically follow the inverse steps as done for the startup procedure, which is summarized below:
- Disable the actuator being used
- Click “low” to low pressure
- Click

### 4.3 Cyclic Testing

A cyclic test can be performed using a sine wave sweep, but it is preferable to use a triangle wave increasing in amplitude over time. SC6000 has a built-in sine sweep, but does not have a built-in triangle wave. Therefore, a triangle wave must be created. This can be done in Microsoft Excel. When finished, save it as a .txt file.

#### 4.3.1 ASSIGN LOAD

1. Right click Waveform in the upper left panel of the screen. Click Change selected cards. Click Card 1, click ADD, and then click OK.

![Select Cards](image)

**Figure 4-9**

2. In the upper left panel, right click Card 1 and select structure actuator.

![Waveform](image)

**Figure 4-10**

3. Right click actuator and click Add Segment.
4. Click Arbitrary Wave, click Load, select the waveform you created in Excel, and then click OK.

5. Setup necessary plots. In a scope plot, the x-axis is time. In an x vs. y plot, both axes are customizable.

### 4.3.2 SETUP DATA LOGGING AND RUN TEST

1. Click Setup DAS and choose a name for your data file.
2. Click Start DAS and Enable Logging.

3. Click Run in the upper left panel.
4.3.3 **PLOT DATA**

1. After the test is complete, open MATLAB and click the Import Data button under the Workspace panel. The `.txt` data file will be in the SC6000_DATA folder on the Desktop.

![Figure 4-17](image)

2. The Import Wizard will appear. Use 12 lines for the header and click Next.

![Figure 4-18](image)

3. In the next window, check “data” only. Click Finish.
4. Type in the following commands into the command window in order to convert the data from metric units to English units and plot the data.

```
>> disp=data(:,1)*39.37;
>> force=data(:,2)/4.48;
>> plot(disp,force);
```

Figure 4-20

5. The slope of the linear section on the plot is the stiffness (k) of the specimen.
4.4 Shake Table Testing with Earthquake Record

NOTE:
- The earthquake data must be saved in two columns, where the first column is time, and the second is displacement commands. The data has to be only in .txt file format, which can be created using Excel spreadsheet.
- The Units must only be in SI system as the SC6000 reads only SI units. Units are seconds for Time and meters for Displacement.

Location of the EQ data files on SC6000 controller PC:
All the EQ .txt files are saved under a folder by name EQ data which can be reached by the following link
C:\Program Files\Shore Western Mfg\SWCS\WAVEFORMS\EQ\EQ data
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NORTHR/MUL009 (Northridge)</td>
<td>A1</td>
<td>6.7</td>
<td>0.57</td>
<td>0.28</td>
<td>8.04</td>
<td>13.23</td>
<td>8.77</td>
<td>2.95</td>
<td>8.45</td>
</tr>
<tr>
<td>2</td>
<td>NORTHR/MUL279 (Northridge)</td>
<td>A2</td>
<td>6.7</td>
<td>0.68</td>
<td>0.35</td>
<td>4.52</td>
<td>16.81</td>
<td>8.96</td>
<td>2.96</td>
<td>9.23</td>
</tr>
<tr>
<td>3</td>
<td>NORTHR/LOS000 (Northridge)</td>
<td>B1</td>
<td>6.7</td>
<td>0.65</td>
<td>0.27</td>
<td>4.67</td>
<td>11.01</td>
<td>6.38</td>
<td>3.00</td>
<td>4.68</td>
</tr>
<tr>
<td>4</td>
<td>NORTHR/LOS270 (Northridge)</td>
<td>B2</td>
<td>6.7</td>
<td>0.60</td>
<td>0.29</td>
<td>5.02</td>
<td>10.66</td>
<td>4.94</td>
<td>2.95</td>
<td>7.90</td>
</tr>
<tr>
<td>5</td>
<td>DUZCE/BOL000 (Duzce, Turkey)</td>
<td>C1</td>
<td>7.1</td>
<td>0.33</td>
<td>0.24</td>
<td>10.75</td>
<td>7.34</td>
<td>11.25</td>
<td>3.00</td>
<td>15.96</td>
</tr>
<tr>
<td>6</td>
<td>DUZCE/BOL090 (Duzce, Turkey)</td>
<td>C2</td>
<td>7.1</td>
<td>0.56</td>
<td>0.46</td>
<td>10.79</td>
<td>13.69</td>
<td>11.08</td>
<td>2.99</td>
<td>11.28</td>
</tr>
<tr>
<td>7</td>
<td>HECTOR/HEC000 (Hector Mine)</td>
<td>D1</td>
<td>7.1</td>
<td>0.33</td>
<td>0.09</td>
<td>5.98</td>
<td>3.71</td>
<td>11.28</td>
<td>2.93</td>
<td>9.41</td>
</tr>
<tr>
<td>8</td>
<td>HECTOR/HEC090 (Hector Mine)</td>
<td>D2</td>
<td>7.1</td>
<td>0.54</td>
<td>0.18</td>
<td>8.42</td>
<td>8.88</td>
<td>6.10</td>
<td>2.97</td>
<td>6.46</td>
</tr>
<tr>
<td>9</td>
<td>IMPVALL/H-DLT262 (Imperial Valley)</td>
<td>E1</td>
<td>6.5</td>
<td>0.63</td>
<td>0.15</td>
<td>8.80</td>
<td>6.45</td>
<td>54.22</td>
<td>2.97</td>
<td>54.82</td>
</tr>
<tr>
<td>10</td>
<td>IMPVALL/H-DLT352 (Imperial Valley)</td>
<td>E2</td>
<td>6.5</td>
<td>0.39</td>
<td>0.14</td>
<td>9.21</td>
<td>5.07</td>
<td>30.03</td>
<td>2.99</td>
<td>69.90</td>
</tr>
</tbody>
</table>

1. Right click “Waveform” in the upper left panel of the screen. Click “Change selected cards” and then click “Card”
2. Click “ADD” and select “Card1”, then click “OK”.

3. **Card 1** will be added under the wave form in the upper left corner. Right click “**Card 1**” and select table actuator.
4. **Actuator** will be added under the card 1. Right click **actuator** and click “**Add Segment**”.

5. **Select “Arbitrary Wave”** to open the arbitrary wave load window a. Click “**Load**” to open the folder that contains the earthquake data files. If not, choose the folder through explorer as indicated in the beginning of this section.
6. Select the earthquake (c1.txt as shown below as an example) and click “open” the earthquake will be loaded as shown in the “Arbitrary Wave” window. Click “OK”
7. Show in the scope the selected earthquake input history. Select "X Vs Y" plot. Customize the x-axis as time and y-axis as the displacement history of the earthquake. The earthquake input history is now shown in the scope.

Figure 4-28

8. In order to log and/or plot data, follow the same steps in section 4.2 "Cyclic Testing".

Figure 4-29
4.5 Shake table motion generation using SeismoSignal

SeismoSignal is one of the Seismosoft’s software which processes strong-motion data. It is a simple yet efficient software that performs the derivation of elastic and constant ductility inelastic response spectra, calculation of Fourier amplitude spectra, filtering and scaling high and low frequency records, and expecting other seismological parameters such as the Arian intensity and significant and effective duration. SeismoSignal can be downloaded easily from www.seismosoft.com and it is free for academic purposes. Researchers can obtain academic license within two days after installing software and requesting academic license.

The following steps illustrates how to generate a earthquake time-history to be used in the LESS. Please note that the LESS shake table has a peak of +/- 3 inch displacement.

1. Open SeismoSignal then open file to select a time-history that needs to be modified as shown in the figure.

![Figure 4-30](image)

2. After choosing time-history the following window will appear and perform the following changes to the appeared window.
   a. Enter last line number of the time column in the last line cell as highlighted in the following figure.
b. Enter time step value in the Time Step dt cell. Time step value must be same time-history time step value, otherwise, software gives unexpected displacement value as shown in the following figure.
c. Change scale factor to reduce the intensity of the time-history in order to obtain +/- 3 inches displacement. +/- 3 inches displacement can be obtained by trial and error, in other word, entering different scale factor until the displacement become +/- inches as shown in the following factor.

![Input File Parameters](image)

**Figure 4-32**

To change acceleration and displacement values

**Figure 4-33**

d. Units should be changed because program default is gravity acceleration (g), centimeter per second (cm/sec), and centimeter (cm) for acceleration, velocity, and displacement respectively as shown in the following figure.

![Acceleration File](image)
3. When step 2 has been done click on OK. Three time-histories will be presented (acceleration, velocity, and displacement). Check the displacement time-history must be within +/- inches range and check maximum displacement value by choosing Ground Motion Parameters window as shown in the following figure.
4. Copy acceleration, velocity, or displacement time-history values then paste it in the Microsoft Excel or any notepad++ as shown in the following figure.

**Figure 4-35**

**Figure 4-36**

**Hint:** some displacement time histories value will not return to zero. SeismoSignal solve this problem by making base line correction. To return displacement value to zero click on Baseline Correction and Filtering and select Apply Baseline Correction then click Refresh icon to show new displacement time-history as shown in the following two figures.
5 Hybrid Testing Controller Systems and Operation

5.1 LESS Hybrid Testing Overview

Over the years, LESS has developed several hybrid simulation capabilities, including slow or real-time hybrid simulation (RTHS), slow distributed hybrid testing and real-time distributed hybrid simulation (dRTHS). The hardware and software integration will be first presented including the software used in each of the type of hybrid simulations. Then a detailed step-by-step procedure to be used in these testing is presented.

5.2 Hardware Integration

5.2.1 Internal Hydraulic Control Connection

The connections between the hydraulic controller, the two actuators, and the HPS are provided by the manufacturer of the equipment as shown in red arrows. The hydraulic controller sends command signals to the servo-valve and the service manifold on the actuators and receives feedback from the embedded LVDTs and load cells. The HPS can be turned on/off by the hydraulic controller through the cable connection. With these connections, the three hardware components form an internal loop hydraulic control that is conventionally utilized in structural experiments to apply a predefined displacement/force history to the structural specimen, during which no feedback from the test specimen is necessary to determine the actuators’ commands (Section 4).

5.2.2 General DAQ Connection

On the other hand, during hybrid testing, an online numerical computation is necessary to generate the loading commands of the actuators based on the feedback from the test specimen and/or the actuators. The numerical computation is conducted in the real-time controller and the feedback is collected using both the general DAQ cards and the DAQ embedded in the hydraulic controller. Therefore, a general DAQ connection (green arrow) and an external hybrid testing connection (blue arrows) were created for the hybrid testing purposes. The general DAQ connection is a standard one way connection that transfers measured structural response from the sensors (i.e. LVDTs and accelerometers) to the general DAQ cards. Utilizing combined chassis housing for both the real-time processor and the general DAQ cards for the real-time controller, the structural response data is immediately available for the hybrid testing controller once they are collected from the sensors.

5.2.3 External Hybrid Testing Connection

The external hybrid testing connection connects the hydraulic controller, the real-time controller, and the hybrid testing controller as shown in Figure 5-1. The two actuators’ positions and forces are fed back to the general DAQ cards located in the real-time controller through the standard Bayonet Neill–Concelman (BNC) connectors (see Figure 5-2). In addition to the four actuators’ feedback signals, two monitor signals (Monitor A and B) are available for the parallel real time simulation that can be used to check any critical point within the hydraulic control loop. In the opposite direction, two external command signals can be sent to the hydraulic controller from the real-time processor. These two external commands are used to control the table actuator and the structure actuator respectively during hybrid testing. The BNC connections shown in Figure 5-2 are essential for hybrid testing purposes by enabling data transfer between physical experiments conducted using hydraulic equipment and numerical
simulation running in the real-time processor. The connection between the real-time controller and the hybrid testing controller is realized through an internet (Ethernet) cable (blue dashed arrow). A hybrid testing model defining a numerical simulation, and/or a control algorithm developed in MATLAB/Simulink, is deployed (downloaded) through this connection to the real-time controller prior to testing, using a software named NI-VeriStand.
5.3 Software Integration

To perform various hybrid tests, the hybrid testing system was designed to connect the numerical simulation in the hybrid testing controller and the physical test by sending interface loading commands to the hydraulic controller which further drives both actuators to apply desired dynamic loadings. Meanwhile desired sensor data is fed back to the hybrid testing model to calculate the next step’s structural response and/or actuator’s command.

The hybrid testing controller runs two software programs. MATLAB/Simulink is used to develop the hybrid testing model. The hybrid testing model can be a numerical substructure simulation utilizing specimen’s response and defining the interface loadings, or it can be an advanced control compensation algorithm that uses the actuator’s feedback and generates compensated driving commands. This hybrid testing model is then deployed using NI-VeriStand to the real-time controller that will be running the model in real time during the test. NI-VeriStand is a testing software, that allows developing control systems and performing real-time testing using hardware input/output and simulation models. The user interface of SC6000 has a function to receive external command from the real-time controller while setting the internal command to zero. This function is activated during a hybrid test that naturally integrates the numerical simulation and the physical testing.

To facilitate fast model development in Simulink, a software platform was created (see Figure 5-3) which integrates all the currently available input and output. The input to the hybrid testing model consists of two sources: the structural response data (i.e. displacement and/or acceleration responses) collected by the general DAQ system and the actuators’ response data obtained from the embedded actuators’ sensors. These feedback data can be processed in Simulink with the available or the specially programmed functions before being utilized in the numerical substructure simulation or the control compensation algorithms. The box labeled Hybrid Testing Model contains the main program that may consist of the available Simulink blocks or a function written in MATLAB script. A C/C++ code can also be integrated here if necessary. The output on the right has two parts. Besides the command signals that are sent to the actuators to apply the desired loadings, general output from the numerical model can be
recorded and output as data files that will be combined with the physical testing results for complete structural response analysis after each test.

5.3.1 **Software overview**

Create table to show all the software, their functions in each HS (3)

5.3.2 **NI VeriStand 2015 Installation**

NI VeriStand 2015 was acquired by LESS in the Fall 2015 semester. A new PC was also obtained to replace the existing Hybrid Testing Controller (HTC). This section discusses the procedure of all compatible software installation on the HTC and the Real-Time Controller (RTC) that are necessary for running the hybrid testing using the new NI VeriStand software.

5.3.2.1 **Model development and compiling software**

At LESS, hybrid testing models are developed and compiled through MATLAB/Simulink and/or LabVIEW. In addition to these software, a supported compiler must be installed to compile Simulink model into a DLL file that can be used by NI VeriStand. Information on like-version software’s and compiler’s
compatibility with NI VeriStand are found in **NI VeriStand Version Compatibility** and the software being installed in the current LESS HTC are listed below.

1. Log on to HTC as an administrator or as a user with administrator privileges.
   - Admin. user: Mohamed
   - Admin. password: lessatwmu
2. Disable any virus detection programs before installing any program, and enable it after successful installation.
3. Obtain **LabVIEW 2015** from CAES Service area (C225) and install the software.

   LabVIEW 2015: A development environment equipped with graphical programming syntax that make it simple to visualize, create, and code hybrid testing system as it’s implemented in the distributed tests.

4. Obtain **MathWorks, Inc. Matlab/Simulink 2015** from CAES Service area (C225) and install the software.

   MathWorks, Inc. Simulink 2015: Along with MATLAB, the Simulink software interface and Real-Time Workshop plugin allows you to develop and generate dynamic link library (DLL) simulation models that can be deployed on Real-time controller (RTC). MATLAB can also function as data analysis tool. NI VeriStand blocks in the Simulink software are added through the VeriStand installation of Model Interface Toolkit (See section 5.3.3 step 1). The NI VeriStand Model Framework adds blocks into Simulink software that can then be utilized in the model.

5. Install MATLAB|Simulink **compiler: Microsoft Visual Studio C++ 2010**

   Window SDK for Windows 7 and .NET Framework 4: For NI VeriStand 2015, this version is necessary and a requirement in order for MATLAB/Simulink to compile DLL model. Reference to compatible like-version compilers of NI VeriStand and the Model interface Toolkit can be found in **NI VeriStand Version Compatibility**. Complete the following steps to set up MATLAB® software to create an NI VeriStand-compatible DLL.

   **NOTE:** If you have any of the following installed on HTC, uninstall them option/s first
   - **Microsoft Visual Studio C++ 2010 SP1** (version greater than 10.0.30319)
   - **.NET Framework 4.5** (also bundled with Visual Studio 2012 or later)

1. Download and run the [**Window SDK for Windows 7 and .NET Framework 4.0**](#).
2. In “Windows© SDK Setup Wizard”, select **Next**.
3. In the “End-User License Agreement”, highlight **I Agree** and select **Next**.

4. Keep the same folder location “Install Locations” dialogue box. Select **Next**.
5. In “Installation Options”, select the following options then select Next.

- Windows Native Code Development Tools
  - Samples
  - Windows Headers and Libraries
  - Tools
  - Visual C++ Compilers
- .NET Development
  - Intellisense and Reference Assemblies
- Redistributed Packages
  - Microsoft Visual C++ 2010
6. Press **Next** to begin installation in “Begin Installation”.

![Begin Installation](image1)

![Installation Progress](image2)
7. When the “Installation complete”, press Finish.

8. To ensure the correct compiler is chosen, open “MATLAB” and run “mex –setup” syntax in the command window. MATLAB should have used ‘Microsoft Windows SDK 7.1 (C)’ as the C language compiler. If the compiler is not used, select the Window SDK from the options given.
5.3.2.2 NI VeriStand 2015 Software and associated drivers

1. Download NI VeriStand (2015) and run the installer. Select Install NI VeriStand 2015 for installation.

2. On the “User Information” activation Wizard, select Install NI VeriStand 2015 with this serial number. Input the following user name, organization, and serial number, then select Next.
   - Full Name: Your name
   - Organization: Western Michigan University
   - Serial number: Obtained from Dr. Shao
3. Follow instructions until you arrive at “select Feature to install” dialogue box. Select the following features for installation, then press Next.

- LabVIEW 2015
  - LabVIEW 2015 (32-bit) Support
- Model Interface Toolkit 2015
  - LabVIEW 2015 (32-bit) Support
- Model Generation:
  - NI VeriStand 2015 Model Framework
  - NI VeriStand 2015 LabVIEW Model Support
- NI Measurement & Automation Explorer 15.0

NOTE: You may choose to download and install NI Device Drivers separately.
4. Select **Next** in the “Product Notifications” dialogue box. Follow the instruction until completions.

![NI VeriStand 2015](image)

5. **NI Device Drivers installation:**
   - **Option 1:** Download and install the following critical NI Device Drivers.
     - NI-DAQmx 15.1.1: Data Acquisition reader compatible with NI VeriStand 2015
     - NI-VISA 15.0.0: Instrument control configuration compatible with NI VeriStand 2015
   - **Option 2** (preferred): Download device-driver-bundle, which contains all necessary NI Device Drivers. The device-driver-bundle is separated into three helper files that manage the download of the larger driver. It is found in three separate downloadable parts. Download and extract NI Device Drivers (**Part 1, Part 2, Part 3**) in the same order. After part 3 has been extracted, the NI Device Drivers installer will run automatically. Additional information of guidelines are found in the “Installation Instructions” tab.

6. Incase device driver are not present, repeat **Step 1 to 4** after installing the Device Drivers.
5.3.2.3 Real-time Controller (RTC) Formatting and Software Installation using NI Measurement and Automation Explorer (MAX)

MAX is a tool that can be used to manage and configure NI components. Under normal circumstances, settings in MAX do not need to be changed, and MAX does not even need to be open during hybrid testing. However, if problems with deployment are experienced, this can indicate a problem in MAX. The following instructions illustrate how to reformat the real-time controller and reinstall software using MAX. From previous experience, this often fixes deployment problems.

1. When booting the real-time controller, repeatedly press the Delete key on the keyboard until a blue screen appears. Use the left arrow key to navigate to the LabVIEW RT tab, press enter to change the boot configuration, and select LabVIEW RT Safe Mode. Then navigate to Save and Exit and press enter, the controller will reboot into safe mode.
2. Open MAX, expand **Remote Systems**. Right click the real-time controller **NI PXI8108** and select **Format Disk**. In “Format Disk” dialogue box, ensure **Reliance** and **Reset all of the network adapters to their default settings** are highlighted. Select **Format**.

![Format Disk Dialogue Box](image)

3. When the format is done and the RTC begins to reboot, click “**delete**” on the RTC keyboard to switch back to “**Labview RT**” start mode. Make sure the controller is **NOT** in safe mode anymore. The RTC shall show an image as below.

![RTC Image](image)
4. In the MAX, press F5 to refresh. The **NI PXI8108** shall reappear under Remote Systems. The IP address will be in “Network Settings.” Right-click the blank space and select **Change IP address**.

5. Use the following IP address (**141.218.148.2**), then select **OK**.
6. In the MAX, press F5 to refresh. Use the Network Settings tab to manually specify an IP address by selecting **Static** for Configure IPv4 Address tab and typing in the following numbers for the IP address, subnet mask, gateway, and DNS server. Once finished, click **Save** in the menu above.

<table>
<thead>
<tr>
<th>Configure Address</th>
<th>IPv4 Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configure IPv4 Address</td>
<td>Static</td>
</tr>
<tr>
<td>IPv4 Address</td>
<td>141.218.148.2</td>
</tr>
<tr>
<td>Subnet Mask</td>
<td>255.255.255.0</td>
</tr>
<tr>
<td>Gateway</td>
<td>141.218.148.1</td>
</tr>
<tr>
<td>DNS Server</td>
<td>141.218.140.6</td>
</tr>
</tbody>
</table>
7. MAX will ask to reboot the real-time controller, click yes and the RTC will be reboot and the screen shown below.

8. In the left pane of MAX, expand the **Remote System**, right click **Software**, and select **Add/Remove Software**.
9. In the “LabVIEW Real-Time Software Wizard” popped up window, left click “NI VeriStand Engine 2015.0.0” and select all for install. NI VeriStand Engine 2015 is dependent on certain software to enable it. Each of the software dependencies must be manually selected for installation. Referring to the list below, select each software to be installed with NI VeriStand Engine in the RTC, then select Next.

Cannot continue because of the following unresolved dependencies:

- RT Console Viewer 3.0 requires Microsoft Visual Studio 2008 Runtime Support 1.0
- RT Console Viewer 3.0 requires LabVIEW Real-Time 8.6.0
- NI VeriStand GE Fanuc Component 1.0 requires NI-VISA 4.4
- NI VeriStand Engine 2015.0.0 requires Microsoft Visual Studio 2010 Runtime Support 1.0
- NI VeriStand Engine 2015.0.0 requires NI-VISA PXI Passport 15.0.0
- NI VeriStand Engine 2015.0.0 requires WebDAV Server 15.0.0
- NI VeriStand Engine 2015.0.0 requires Microsoft Visual Studio 2008 Runtime Support 1.0
- NI VeriStand Engine 2015.0.0 requires LabVIEW Real-Time 15.0.0
- NI VeriStand Engine 2015.0.0 requires Multifunction DAQ 15.0.0
- NI VeriStand Engine 2015.0.0 requires Analog Output Series 15.0.0
- NI VeriStand Engine 2015.0.0 requires NI System Configuration 15.0.0
10. Following installation wizard by selecting **Next** until the software installation begins.
11. As software has finished installing on RTC, press F5 to refresh MAX. Expand **Software** to view the installed software in the RTC.

12. Identifying PXI chassis can be done manually. Right click on **Chassis (Unidentified)** and highlight **Identify As** and then select **PXI-1050**.
13. Under **Tools**, select **NI-DAQmx Configuration** and then select **Reassign Device Names to Default Values**.

![Network Devices - Measurement & Automation Explorer](image)

14. In “Reassign Device Names” pop up window, select **Remote** under **DAQmx Configuration File**. Type in the **IP address (141.218.148.2)** and click **OK**.

![Reassign Device Names](image)
15. All hardware devices should now read as their default name.
5.4 Creating New NI-VeriStand Project

1. Launch VeriStand by clicking the icon 🖥️ and select New NI VeriStand Project to create a new project.

![NI VeriStand 2015](image1)

2. Choose the Project Name under “Project” tab. In this demo, ExampleProject is used.

![Create New Project](image2)
3. In the “System Definition” tab, highlight **Create a new NI VeriStand System Definition File**. Make sure **Use project name** is also highlighted. Then select **OK**.

4. The “Project Explorer” window should now appear. Expand the **System Definition File** and right click on the project created “**ExampleProject.nivsproj**” and select **Launch System Explorer** to launch the “system explorer.”
5. **PXI Real-Time Target:**
Configure the PXI target by highlighting **Controller** in the tree. Select **PharLap** for the RTC “Operating System”. Type the same PXI system “IP Address” (141.218.148.2) displayed in MAX. Rename the controller to a unique name. Type **RT Controller** for the “Name”. The “Target Rate” specifies the primary control loop rate frequency [Hz] of the added simulation model (see Step 9 of Section 5.6.2). For example, if the model’s time step is 0.00025 seconds, the loop frequency (cycle/time) is 1/0.00025=4000 Hz. Type 4000 [Hz] in “Target Rate.”
6. **Add DAQ**: Expand Hardware>>Chassis. This is where you can add the NI-DAQ.

7. There are two methods in adding a hardware; either by using **Hardware Discovery Wizard** or by Add DAQ Device manually. Select [Hardware Discovery Wizard] to enable a hardware search of installed devices on the RTC.
8. The wizard should discover **2 DAQ**. Select Next (x3) to arrive to Step 4 of 4 and then Finish.

![Image of Hardware Discovery Wizard](image1.png)

9. Under **Chassiss>>DAQ**, there should be **PXI1SLOT2** and **PXI1Slot8**.

![Image of System Explorer](image2.png)
10. **Add Channels**: The PXI1Slot2 has channels corresponding to the structure and table actuator, while the PXI1Slot8 has channels corresponding the external sLVDT and Accelerometers (Refer to Appendix 1 section 8 for the channels table). In this experiment, we are only using the structural actuator. Right click on PXI1SLOT2 and select **Add Channels**. In the “Add DAQ Channels” dialog box, specify either analogues input **AI** (or **AO**) in the “Select channel type to add.” “Sample mode” should be configured to **Single-Point**. The “Measurement type” is **Voltage**. Select **Next**.
11. Select all of the analogue input needed for the test. Select channels corresponding to the structural actuator; namely AI14, AI12, and AO0 (if the table actuator is used, add AI11, AI15, and AO1). After selecting AI channels, select Finish and follow procedure 10 to 11 to add the structure actuator analogue output AO channels. To make them easier to identify, you may change the channels’ “Name.” For the structure actuator, change AI12, AI14, and AO0 to LVDT2, LC2, and EXT2 respectively. For the table actuator, change AI11, AI15, and AO1 to LC1, LVDT2, and EXT1 respectively. The Load Cell and LVDT channels measure the response of the structure and are used for feedback channels to the model. EXT channel send the model command to the corresponding actuator. The connector block has each channel labeled for your reference.

NOTE: Refer to Appendix 1 section 8 for table of all the channels.
5.5 RTHS Procedure

5.3.1 BUILD MODEL

1. Turn on real-time controller.

2. Open MATLAB and set the “Current Folder” to the folder that contains the Simulink model that you wish to test. Click the “Current Folder” tab on the left side of the screen, and select the Simulink model (.mdl file).

3. Click on Simulation, Configuration Parameters...
4. Under Real-Time Workshop, make sure the system target file is **NIVeriStand.tlc**. If it is not, click **Browse** and find it under “System Target File Browser,” then select **OK**. If you cannot find it, restart MATLAB and try again. Once the system target file is **NIVeriStand.tlc**, click **Build**.
5.3.2 **DEPLOY MODEL**

1. After the model is built, open VeriStand and select the project you wish to use, or create a new one (see Section 5.4). If project is already created, select the project and click **Configure Project**.

2. Launch “System Explorer” (see Section 5.4 Step 4).

3. Click on **Simulation Models** on the left expandable pane, and click **Add a Simulation Model**.
**NOTE:** Before adding a new model delete already deployed model by selecting the model and clicking on delete.

4. Click the open folder icon. Find the folder that your Simulink model is located and select the **DLL file**.
5. Under the “Settings” tab, highlight **Initial state paused**. The model is now paused until triggered. Select **OK** once finished.
6. Click on **Mappings** icon on the top pane. **Disconnect** all previous mappings.
7. To send commands to the actuators, **connect** External Output "EXT" under the appropriate simulation model to **EXT2** under Analog Output. Remember, 1 corresponds to the table actuator and 2 corresponds to the structure actuator.

8. To receive feedback from the actuators, connect either the **LC** or **LVDT** under the Analog Input to the appropriate **inports** in the simulation model.
9. The primary control loop rate depends on the fixed step size of the test (sdt in the Simulink model). To specify the loop rate, click on the Controller and type in sdt at the bottom of the window. Note that sdt needs to be converted to Hz. For example, if your sdt is 0.00025 seconds, type in 4000 in the “Target Rate.” If your sdt is 0.001 seconds, type in 400.

10. Click **Save**. Then Exit the System Explorer.

11. There are two options for running NI VeriStand projects. **Deploy**: Pressing the **Deploy** button deploys the system definition to the target that you specified in the System Explorer or you can press F6. **Run**: Launches the Workspace window. If you choose to deploy first, the workspace can opened by expandin User Interface, Right-click the .nivsscreen file, and then Launch Workspace window.
5.3.3 SETUP WORKSPACE

1. In the “Project Explorer”, expand User Interface and Right click the project ExampleProject.nivsscreen file to Launch Workspace Window.

2. In the “Workspace”, click Screen>>Edit Mode to enter edit mode.
3. Click on the **Workspace Controls** at the left side of the screen. Expand **Model**, and then drag a **Model Control** into the workspace.

4. In the **Model Control** “Item Properties box”, select the appropriate model (**CL_MFF_FBDK**) and click **OK**.
5. Several graphs may exist in the workspace, but if not, you can drag graphs from **Workspace Controls** if desired. Click on the **Workspace Controls** at the left side of the screen. Expand **Graph**, and then drag a **Simple graph** into the workspace.

6. To configure the graph to display a specific channel, click **Setup**. In “General” tab, select the desired channels and add them to the graph by clicking the arrow.
7. In the “Format & Precision” tab, adjust the maximum and minimum values for the graph’s display.
5.3.4 Input Calibration Equation

1. It is important to input the calibration for those channels that are mapped between the hybrid simulation model and the hydraulic controllers, including the external commands, LVDTs and LCs of both actuators. To input the calibration equations, Click **Tools>>Channel Calibration**.

2. Select a channel for calibration. Select **Next**.
3. Keep selecting **NEXT** until the screen below appears. Enter the calibration values from the list of calibration equations, where $a_0$ is the intercept and $a_1$ is the slope.

**NOTE:** Other calibration equations are found in Appendix II of Section 9 and 10.
4. Repeat **Step 2 to 4** to input all other channels’ calibration equations.
5.3.5 ENABLE EXTERNAL CONTROL

1. To enable external control on SC6000, first set the actuator to 0 inches. Then, in the lower right panel of the control screen, click the **blue arrow** on the Servo Amplifier block for the appropriate actuator.

2. In the lower left panel, click the button of the appropriate actuator under EXT INPUTS.

3. In the lower right panel, click the span gain button and set it at 100%.
5.3.6 OFFSET INSTRUMENTATION

1. Click Tools>>Channel Calibration.

2. Select the channel you want to offset and click Next.
3. Continue selecting **Next** until this screen appears. Adjust the intercept accordingly to obtain a zero reading on the graph. Then select **Finish**.
4. Take note of the change in the sensor reading.

5. Repeat steps 2 and 3, but this time, estimate the offset required to set the sensor reading to zero.
6. If a more accurate offset is desired, click Setup on the graph, click the “Format & Precision” tab, and then adjust the y-axis scale.

7. This will give you a closer look at the graph and enable you to refine your offset.
5.3.7 RECORD DATA

1. Click **Workspace Controls** on the left side of the screen, expand **Logging**, and drag **Logging Control** to the workspace.

2. In **Data Logging Control**, select the **Setting** icon.
3. In “General” tab, make sure Show History Dialog on stop and Stop logging on data loss are selected. This feature enables data logging control to automatically display the File History dialog box once session has been stopped.

4. In “File Settings”, select TXT as the Log file type. The File conflict operation should be set to Create Unique.
5. Under “Channels” tab, select **Add Channels** to be logged. The “Select Channels” dialogue box will prompt to specify the channels. Select and add all channels required for analysis and press **OK**.
6. Under “Rate” tab, highlight **Use custom rate** and specify your primary control loop rate [Hz] (see Step 9 of Section 5.6.2).

7. Under “Start Trigger” tab, pull down the “Trigger condition” and select **Start when condition is true**. This control initiates data logging by setting a conditional function, variable, and Channel.

8. In “Condition formula”, type in **Time>0** (the logger will initiate when the **Time** variable is greater than 0; e.i., start of the test). Highlight **Time** variable and select **Edit Mapping**.
9. Select the appropriate Model Time channel to map into the Time variable. Then select Ok.
10. Under “Stop Trigger”, select **Log indefinitely** as the Trigger condition. Select **OK** to exit setting.

![Setting Screenshot](image)

### 5.3.8 RUN TEST

1. In the “Workspace”, select **Tools>>Edit Mode** (or type **Ctrl+M**) to exit Edit Mode. Press the **record** icon under the **logging control** to begin the data logger.

2. The logging control’s “State” should read as **waiting on Trigger** before starting the test in the **Model Control**, and it should read **Triggered** once the test starts.
3. Click the Run icon on the Model Control box to run the test.

4. When the test has finished, click the Stop icon on the Model Control first, then on the logging control. The “File History” dialogue box should appear with the data Log File.
5.3.9 **DISABLE EXTERNAL CONTROL**

1. To disable external control on SC6000, first set the actuator to 0 inches. Then set the span gain to 0%.

2. Click the OFF button in the lower left panel under EXT INPUTS.

5.3.10 **VIEW DATA**

To view data, go to the following path and select the appropriate **Project**:

C:\Users\Public\Documents\National Instruments\NI VeriStand 2015\Projects

You can also import this data into MATLAB for analysis.
5.6 Distributed Hybrid Testing (DHT) with UI-SimCor and NICON

The Multi-Site Substructure Pseudodynamic Simulation Coordinator (UI-SimCor) is a platform used to conduct geographically distributed pseudodynamic (PSD) hybrid simulation. By combining UI-SimCor with the Network Interface for Controllers (NICON), slow PSD testing can be performed using the equipment at LESS. In addition, UI-SimCor and NICON allow LESS to participate in geographically distributed PSD tests and/or be controlled from a remote location. For specific details and instructions on how to use UI-SimCor, visit the user’s manual at http://nees.uiuc.edu/software/docs/UI-SimCor%20v2.6%20Manual.pdf.

UI-SimCor and NICON operate under MATLAB and LabVIEW, respectively. In addition, the Network Interface for Console Application (NICA), numerical simulation, runs SimCor as a child process and exchange data with it through inter-process communication. The software must be configured first accordingly to the apparent test. It is worth noting that LabVIEW and MATLAB must retain like version compatibility before configuration. In this demonstration, LabVIEW (32-bit) 2015 and MATLAB 2015 versions are implemented. In the subsequent sections, software configuration to communicate using UI-SimCor and NICON followed by test procedures are compiled in a list below:

1. MATLAB 2015 enabled UI-SimCor
2. UI-SimCor coordinator file configuration
3. NICON middleware interface file configuration
4. NICA application setup
5. Single-Site DHT
6. Multi-Site DHT

Shown in comment created in 2016, saying that this part need to be updated!

5.6.1 UI-SIMCOR setup in MATLAB 2015

1. Download UI-SimCor and extract the files into “C:\HSF” folder location. The distributed software is composed of the following files:
   a. Examples
   b. NetworkCom
   c. NICA
   d. SIMCOR
   e. Solvers
2. Open MATLAB and select “Set Path” icon.
3. In the “Set Path” dialog box, select **Add with Subfolders** to add a path.

4. Locate “C:\HSF\SIMCOR” folder, and **Select Folder**.
5. Save the new path and Exit.

5.6.2 UI-SimCor Configuration

In the SimConfig.m file that defines the hybrid simulation, the module which represents the physical substructure must be named STATIC. The command should look like this:

\[ \text{MDL}(i).\text{name} = \text{\textquoteleft} \text{STATIC}\text{\textquoteright}; \]

where \( i \) is the module number.

The URL of the physical module must be the IP address of the real-time controller followed by a port number. The command should look like this:

\[ \text{MDL}(i).\text{URL} = \text{\textquoteleft}141.218.148.2:11997\text{\textquoteright}; \]

where \( i \) is the module number, 141.218.148.2 is the IP address of the real-time controller, and 11997 is the port number.

5.6.3 NICON Configuration

1. The NICON_Config.xml file must be customized for LESS. The port number used in the SimConfig.m file must be specified as follows:
2. The force offset should be zero, but the displacement offset may change from setup to setup and will be described in section 5.6.3.

3. The parameters a0, b0, and c0 represent the calibration offsets of the displacement command, LVDT, and load cell, respectively. The parameters a1, b1, and c1 represent the calibration slopes of the displacement command, LVDT, and load cell, respectively. For units of kips and inches, these parameters should be as follows (see Error! Reference source not found.):

4. Displacement and force limits as well as increment limits are defined here too. These should be selected based on the maximum displacement and force expected to be observed during the test (see figure above on the right).
5. The output channel corresponds to the displacement command, input channel 1 corresponds to the LVDT, and input channel 2 corresponds to the load cell. They should be defined as follows:

```xml
<DAQChannel>
  <Name>OutputCh</Name>
  <Val>PXI1Slot2/ao0</Val>
</DAQChannel>
<DAQChannel>
  <Name>InputCh1</Name>
  <Val>PXI1Slot2/ai12</Val>
</DAQChannel>
<DAQChannel>
  <Name>InputCh2</Name>
  <Val>PXI1Slot2/ai14</Val>
</DAQChannel>
```

**Even though output channel 2 is not used, it still must be specified.** Since the only remaining output channel is AO1, we use it here:

```xml
<DAQChannel>
  <Name>OutputCh 2</Name>
  <Val>PXI1Slot2/ao1</Val>
</DAQChannel>
```

The rest of the parameters that are not mentioned in this section can remain at their default values.

### 5.6.4 NICA Setup

1. Download **ActiveStateTcl8.5** (x86) (Active Tcl is a scripting language commonly used for rapid prototyping scripted applications necessary to execute numerical modules in OpenSEES)
2. Locate the “ActiveTcl8.5.exe” version file and run as administrator. Select **Next** and follow through the installation process. Select **Finish** when installation is done.
5.6.5 **Single-site PSD hybrid simulation**

5.6.5.1 **Start NICON and SC6000 Procedure**

1. In SC6000, zero out the force in order to determine the corresponding displacement offset. Then type this value into the displacement offset in the NICON_Config.xml file. Then zero out the displacement of the actuator.

   ```xml
   <DBL>
   <Name>DisplacementOffset</Name>
   <Val>-0.07</Val>
   </DBL>
   ```

2. Open MAX, expand Remote Systems, right click the real-time controller, and select File Transfer.

3. Locate [ftp://141.218.148.2/ni-rt/startup/] folder, then drag and drop the modified “NICON_Config.xml” file and close the dialogue box.
4. In **MAX**, press **F5** to refresh.
5. Open the NICON_PXI LabVIEW project with **LabVIEW (32-bit)**. Expand the real-time controller (i.e. NI- PXI8108), and open the NICON_ver2.1 LabVIEW.vi

6. Click the **run** button in the upper left corner of the screen.

7. If you see a Conflict Resolution box, click **Save**. This will override real-time VIs that are necessary to use VeriStand. Close the dialogue when finished. If you wish to use VeriStand after using NICON, you will need to reinstall the software following procedure described in Section 5.3.3.
8. Click the **Control** button in the upper right panel.

![](image.png)

9. In the “User Input” tab in the upper left panel, and type zero into the Actuator Stroke box.

![](image.png)

10. Click **Execute Target CMD** in the upper right panel.

![](image.png)
11. Enable External Control in SC6000 by following the same procedure described in Section 5.3.5. Make sure to increase the span gain slowly. Once it is at 100%, the force reading should be zero in both SC6000 and NICON. The displacement reading should also be zero in NICON.

12. Go back to the Network (PSD Test) tab in the upper left panel, and click **Start Server**.

**5.6.5.2 Start Numerical Simulation**

13. Open the numerical simulation module/s “NICA.bat” file. Press the **Enter** key twice to initiate connection. “Waiting for connection appears” should be displayed.
5.6.5.3 **UI-SIMCOR connection**

14. Open MATLAB, start UI-SimCor by running “SimCor” syntax. Click Establish Connection.

![Figure 5-4](image-url)
15. Click Start Communication in the upper left panel of NICON.

16. Click the switch in the upper right panel to switch from Manual to Auto. The test will now run automatically.

5.6.6 Geographically Distributed Procedure

If you are running UI-SimCor on a computer outside the WMU network and need to communicate with the controller at LESS, an extra step is needed before the steps listed in section 5.6.3. The WMU network
blocks all incoming connections from outside the network, so a VPN is required on the computer which is running UI-SimCor. First, download and install Java from http://www.java.com. Then log onto https://vpn.wmich.edu, type in your Bronco NetID and password, and then click Start next to Network Connect.

![VPN Connect](image)

Figure 5-7

Click Always or Yes on the popup box. If the VPN software has already been installed, this will execute it. If it has not been installed, this will download, install, and execute it.

![Software Download Window](image)

Figure 5-8

5.7  Distributed Real-Time Hybrid Simulation (dRTHS) with VeriStand

5.7.1  Real-time System Evaluator

In order to use a desktop as real-time target, verification of the hardware capabilities must be checked moving forward. National Instrument provides a utility that can be run through the computer BIOS to verify its LabVIEW Real-Time fitting. The following steps depict the procedure and it is also found [here](link).

**Part 1:** Setting up the Utility USB Drive

1. Insert a FAT formatted empty USB disk into your host computer.

2. Open Measurement and Automation Explorer (MAX) and select **Tools**»**Real-Time Disk Utilities**»**Create Desktop PC Utility USB Drive**.
3. Click Yes when asked to accept to reformat the USB drive.

4. Select the Real-Time Operating System Version you want to install onto your computer and it must match the version that you are using for the project configuration (VeriStand 2015).

5. Select the USB drive. Make sure the USB drive is already FAT formatted, because the utility simply zeroes out the partition table of the drive.
6. Click **Yes** when asked to confirm the creation of the utility.

7. After getting a successfully created PC Utility USB Drive confirmation message, click **OK** to finish

**Part 2:** Booting the USB Drive from BIOS

1. Insert the newly formatted USB Drive into your PC.

2. Change BIOS settings on the Desktop system to boot from the USB Drive. As the Desktop is booting up, repeatedly press the **Delete** key on the keyboard until a BIOS screen appear. Use the left arrow key to locate the startup disk configuration and prioritize the **USB Drive** to boot up first. Then navigate to **Save and Exit** and press enter, the Desktop will reboot into safe mode.

**Part 3:** Evaluate/Reformatting the desktop system
1. The Desktop should boot from the Utility USB Drive and the following menu should appear. Navigate to and select **7. Evaluate system**.

![Menu Image]

2. The utility then begins testing your system. If you pass the test successfully, then you should see a similar result as shown in Figure 1. If the PC cannot be converted to a real-time system, you will see an incompatibility result. An example is shown in Figure 2.

![Figure 1 Image]
3. For Navigate to and select 6. Format hard disk.

4. You will be presented with a set of options on how to proceed with the format. You can choose to format ONLY the RT partition, erase all partitions and create a single new partition, or cancel the format.

5. Next, you will be prompted to select what file system to format as. It's recommended that you choose 2 (Reliance).
6. You will then need to type \texttt{yes} to confirm the reformat.

7. The desktop system will then go through the reformat, and will provide the following message to indicate that the controller has been successfully formatted:
8. Press any key, and the computer will begin to reboot. As the computer is restarting, press **Delete** several time and open up BIOS. Navigate through BIOS and reconfigure the system to run the hard disk. You can remove the Utility USB Drive from the desktop system.

9. The computer will reboot, and will be running the LabVIEW Real-Time Operating System now. You should be able to access the Real-Time PC through **MAX**, and add necessary software. You can view the IP address of the newly formatted computer on the console output.

### 5.7.2 Real-time Operating System (Pharlab) Installation

Follow Section 5.3.3 (Step 1 to 11) for a remote PC with IP address 141.218.148.3.

### 5.7.3 Custom Devices Setup

The instructions below describe the steps for adding a custom device to be used in your NI VeriStand project.

1. Download and move the following Custom Devices before opening NI VeriStand:
   - Embedded Data Logger (Readily available in NI VeriStand 2015): Logs dynamic data in each target.
   - DVel (Reflective Ethernet): Handles asynchronous data communication between targets through TCP connection. Overview of the device is displayed in Figure_x.

2. Move the Source Files to any location on your computer.

3. Move the Source Distribution Files from the Custom Device llbs folder to
Windows Vista/7: C:\Users\Public\Documents\National Instruments\NI VeriStand\Custom Devices
5.7.4 Single-site dRTHS with VeriStand

Setup Targets:
1. Follow Section 5.4 to create a VeriStand project and configure PXI target.

2. Add a new target by right-click on Targets and selecting Add Target. Name the newly created target “PC Target” by highlighting Controller in the tree. Select PharLap in Operating System drop down menu. Type the same PC IP Address (141.218.148.3) configured in MAX. The Target Rate specifies the primary control loop rate frequency [Hz] of the VeriStand engine, which should coincide with Simulation Model (see Step 9 of Section 5.6.2). For example, if the model’s time step is 0.00025 seconds, the loop frequency (cycle/time) is 1/0.00025=4000 Hz. Type 4000 [Hz] in “Target Rate.”

Build Models:
3. Follow Section 5.3.1 to build each sub-models that can later be uploaded to each PXI and PC target.

Upload Models:
4. Follow Section 5.3.2 (steps 1-5 & 9) to upload sub-models for each PXI and PC target. Do not deploy the system definition yet.

**Target-to-Target Communication:**

The communication between numerical models located in geographically separated targets is done through the Reflective Ethernet custom device. In addition, data is logged through the Embedded Data Logger custom device.

**Reflective Ethernet**

5. Expand the PXI Target section. Add the Reflective Ethernet custom device by right-clicking Custom Devices » DVel » Reflective Ethernet.

6. Expand the PC Target section. Add the Reflective Ethernet custom device by right-clicking Custom Devices » DVel » Reflective Ethernet.

7. The input of the device on one target (PXI-RT) is the output of the device on the other target (PC-RT). Their names must be identical for the custom device to recognize the link. Also note that the Output target names must be the IP address of the remote target to communicate with.

8. On PXI Target, add input channel (ex. Model Execution Command) by right-click on Input » Add Channel. Give an appropriate input channel name, because an output channel name on another target should have the same name.

9. On PC Target, add Output Target by right-click on the Output » Add Target. Named the target with the IP address (141.218.148.2) to reflect that data is coming from the other remote target (PXI-RT).

10. On PC Target, add output channel (ex. Model Execution Command) by expanding Output and right-click on the target (with IP 141.218.148.2), then Add Channel. Name the channel with same name used for the input channel on sending target (PXI-RT).

11. Repeat steps 11 to 13 for adding input channels with their corresponding output channels. Although, at one channel should be created; a Model Execution channel connecting the triggered PXI-RT Model Execution Command channel through the workspace into the remote target(s) Model Execution Command channels.
12. Note that the 'Inputs' and 'Outputs' are named from the Reflective Ethernet point of view. An 'Input' is data flowing from the VeriStand Engine into the Custom Device and an 'Output' is data flowing from the Custom Device into the VeriStand engine. This should be considered in the following mapping section.
13. Expand the **PXI Target** section, add the **Embedded Data Logger** custom device by right-clicking **Custom Devices»National Instrument»Embedded Data Logger**.

14. To add a log file, right-click the **Embedded Data Logger** node you created in previous step and select **Add Log File**.

15. Select the newly created log file and edit the settings of the log file on its configuration page.

16. Under the log file, select **Channel Groups**, and on its configuration page click the **Add Channel Group** button.

17. Select the newly created channel group, and then click the **Add Channels** button.

18. In the **Select Channels** dialog box, specify the channel(s) you want to log in the channel group and click **OK**.

19. Select **Log Trigger** by expanding **Command** and depress the Boolean control to initialize logging data to a file.

20. Repeat steps 8 to 14 for **PC Target**.

**Mapping:**
21. **Click on Mappings** icon on the top pane. **Disconnect** all previous mappings.
22. To send commands to the actuators, **connect** External Output "EXT" under the appropriate simulation model to **EXT2** under Analog Output. Remember, 1 corresponds to the table actuator and 2 corresponds to the structure actuator.

23. To receive feedback from the actuators, connect either the **LC** or **LVDT** under the Analog Input to the appropriate **inports** in the simulation model.
24. **To send** commands from a target (PXI-RT) to a target (PC-RT), **connect** Output Channel (Model Execution Command) under the appropriate simulation model in a target (PXI-RT) to **Inport Channel** (Model Execution) under Reflective Ethernet of the target. Refer to step 7 to 12 for help mapping routed channels.

25. **To receive** commands from a target (PXI-RT) into target (PC-RT), **connect** the routed signal **Outport Channel** (Model Execution) under Reflective Ethernet of a target (PC-RT) into the Inport Channel (Model Execution Command) under the appropriate simulation model in the target.

26. Repeat the steps 16 to 17 for each created inport/outport channel in the custom device per target.

27. In order to open the configured Embedded Data Logger log file in each model, connect each target’s **Model Execution Command** channel found under the appropriate simulation model with the **Log Command** channel found under Embedded Data Logger Custom Device.

28. **Save** the system definition.

29. There are two options for running NI VeriStand projects. **Deploy**: Pressing the button deploys the system definition to the target that you specified in the System Explorer or you can press F6. **Run**: Launches the Workspace window. If you choose to deploy first, the workspace can opened by expanding User Interface, Right-click .nivsscreen file, and then Launch Workspace window.
**Setup Workspace:**
30. Setup the workspace following Section 5.3.3 procedure.

**Run dRTHS:**
31. Click the Run icon on the Model Control box to run the test.

5. When the test has finished, click the Stop icon on the Model Control.

**5.7.5 Geographically Distributed Procedure**

If you are running NI VeriStand on a computer outside the WMU network and need to communicate with the controller at LESS, an extra step is needed before the steps listed in section 5.7.5. The WMU network blocks all incoming connections from outside the network, so a VPN is required on the computer which is running NI VeriStand. First, download and install Java from [http://www.java.com](http://www.java.com). Then log onto [https://vpn.wmich.edu](https://vpn.wmich.edu), type in your Bronco NetID and password, and then click Start next to Network Connect.
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Figure 5-9

Click Always or Yes on the popup box. If the VPN software has already been installed, this will execute it. If it has not been installed, this will download, install, and execute it.

Figure 5-10

6 Instrumentation Installation and Calibration

6.1 LVDT Installation

There are currently three LVDTs used for the position measurement of the test specimen, referred to as structure LVDTs (sLVDTs) as compared to those embedded LVDTs in the two actuators. All three sLVDTs needs to be a connected to a DC power supply (i.e. Schaevitz DC LVDT power supply used at LESS) for proper measurement.

1. First connect the sLVDTs to the power supply. For sLVDT 1 (purchased in 2009), the first wire adjacent to the red-strip wire goes into the positive power source and the red-strip wire into the negative power source. For sLVDT 2 & 3 (purchased in 2014), the brown wires are connected to negative power (-15v) source and the orange wires connected to the positive power (+15v) source. A screwdriver shall be used to tighten these wires to their respective outlet.
2. Then connect the sLVDT to the NI data acquisition box, the SCT-68 68-Pin Shielded Connector Block. The third and fourth wire of sLVDT1 (counted from the red-strip wire) and the yellow/ blue of the sLVDT 2 and 3 are connected to the analog input of the NI SCB-68 as shown in Figure 6-2. The fifth wire of sLVDT1 was not used for the installation purposes and therefore it was cut short. Table 6-1 listed channel number and wire information of the three sLVDTs.

<table>
<thead>
<tr>
<th>Devise</th>
<th>Pin #</th>
<th>Signal</th>
<th>Actual LVDT Device Cable</th>
<th>When Linked to John’s Cable (i.e. sLVDT 2 &amp; 3)</th>
<th>When Linked to the our Cable (i.e. sLVDT 1)</th>
<th>Represent</th>
</tr>
</thead>
<tbody>
<tr>
<td>sLVDT1:</td>
<td>57</td>
<td>AI 7</td>
<td>1st</td>
<td>Red</td>
<td>Orange</td>
<td>Red Stripe</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>AI GND</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sLVDT2:</td>
<td>32</td>
<td>AI 9</td>
<td>2nd</td>
<td>Black</td>
<td>Brown</td>
<td>Second One Next to Red St.</td>
</tr>
<tr>
<td></td>
<td>66</td>
<td>AI GND</td>
<td></td>
<td></td>
<td></td>
<td>Third One Counting from Red Str.</td>
</tr>
<tr>
<td>sLVDT3:</td>
<td>64</td>
<td>AI 10</td>
<td>4th</td>
<td>White</td>
<td>Blue</td>
<td>Fourth One Counting from Red Str.</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>AI 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Plug in the wires using the same screwdriver method described in step 1. The finished view on the SCB-68 box and closed-up view of sLVDT1 connection are shown in Figure 6-3.
4. To use the structure sLVDTs in an experiment, plug the power supply of the Schaevitz DC supply into an outlet.
5. Install sLVDTs using the instrumentation frame and the bolts as shown in the figures below with a closed-up view on both ends of the sLVDT. Note that two square bolts are used to tightly hold the rod to the structure and make sure the rods touch the test structure.

![Figure 6-4](image)

6.2 Accelerometer Installation

1. Attach each accelerometer to its corresponding number as shown. Make sure the numbers are facing up on both connections. Each accelerometer has five wires: one for voltage (V), one for ground (G), and one for each axis (X, Y, Z). The labels indicate the order of these wires. Note that the voltage wires are lightly colored red.

![Figure 6-5](image)
2. The label on the connector block indicates the accelerometer number of each set of wires. From here, each voltage wire must be connected to a voltage source (+5 V). Each ground wire must be connected to an analog input ground (AI GND). Each axis wire must be connected to an analog input (AI). Use the chart on the back of the block to determine corresponding pin numbers. Make note of the AI number (channel) used for each axis.

![Image of connector block](image)

Figure 6-6

6.3 Adding Instrumentation in System Explorer

1. In the System Explorer in VeriStand, add a new DAQ device (see step 3 of section 5.4). Make sure that the device type is MIO and the input configuration type is referenced single-ended (RSE). Type in the name “PXI1Slot8”. This name must be the same as it is in MAX. Click OK.
2. To make them easier to identify, you can change the names of the channels that you will be using.

![Image](image.png)

2. On the right side of the MAX window, a corresponding window will then show for you to operate the PXI1Slot8 as selected. Click on the tab “Test Panels” as shown on the right of Figure 6-9.

6.4 LVDT Calibration

6.4.1 Operation in the Measurement & Automation Explorer (MAX)

1. After adding the LVDT in the system explorer (section 6.3), open the MAX. Under the Remote Systems click on the tab **NI-PXI8108-2F119B78/Devices and Interfaces/PXI-1050 “Chassis 1”/ 8: NI PXI-6221 “PXI1Slot8”**. See Figure 6-9 left for the path.

2. On the right side of the MAX window, a corresponding window will then show for you to operate the PXI1Slot8 as selected. Click on the tab “Test Panels” as shown on the right of Figure 6-9.
3. Find the associated channel number from the “SCB-68 Quick Reference label” box and state it under the Channel Name table. For Mode, choose Continuous. The Input Configuration should be RSE, short for Reference Single Ended Run Workspace. See Figure 6-9 right.

4. Press start to read the voltage reading of the selected channel.

6.4.2 Setting up the sLVDTs for calibration

1. Set the desired LVDT that needs calibration on the table
2. Put a paper on top of the table, beneath the LVDT and the caliper to mark your startup point
3. Move the caliper and the LVDT to close to a zero voltage. You can check the Test Panel in the NI-MAX for a voltage value.

   Now, tape the one end of the caliper on the table and the other end to the rod of the sLVDT, see

4. Make sure to use duct tape to fix the sLVDT to prevent it from moving.

5. **Zero** out the caliper by clicking the red button on the caliper as shown in Figure 6-13.

   ![Figure 6-12](image)

**6.4.3 sLVDT calibration**

1. Write the voltage value in an Excel sheet with “0” as the current position.
2. Move the stroke (rod) of the sLVDT 5 inches to the right with one inch as a time. Write down the voltage reading associated with each one inch position of the sLVDT. Note you don’t need to be exactly
at a one inch position, slightly off the inch position is acceptable during sLVDT calibration as long as you write the caliper reading and the corresponding voltage reading in the Excel file.

3. Move the sLVDT rod back to zero point with the help of the voltage reading from the MAX.

4. Then repeat the same steps when moving the sLVDT 5 inches to the left.

5. Once all the caliper and voltage readings are entered in the Excel sheet through the previous steps, one may plot the voltage an X-Y graph using Excel function, where the voltage reading is plotted along the x-axis and the displacement reading from the caliper is plotted on the y-axis.

6. Right click on the data in the X-Y graph and add a trendline to show the line of best fit. The slope of the lines is the slope of the LVDT within the calibration equation. The following three figures shows the calibration equations of the three sLVDTs that were obtained in November 2014.

![Figure 6-13](image-url)
6.4.4 APPLY CALIBRATION

1. Click Tools and select Channel Scaling & Calibration.
Figure 6-16
2. Select the LVDT.

![Figure 6-17](image)

3. Click Next until this screen appears. Type the sensitivity that Excel calculated into the box for a1. The offset (a0) is not as important because an arbitrary zero displacement point will likely be chosen when using the LVDT. Therefore, the offset can be handled on a case-by-case basis. Click Next then Finish.
6.5 Accelerometer Calibration

6.5.1 SETUP WORKSPACE

1. This procedure assumes that only accelerometer 1 needs to be calibrated. The procedure for the other two is exactly the same.
2. Follow the same steps as the LVDT calibration, but in step 4, select the accelerometer channels (1x, 1y, 1z). Steps 7 and 8 need to be repeated a total of three times, one for each channel. There should be one numeric indicator for each channel, as shown below.
6.5.2 CALIBRATE ACCELEROMETER

1. To calibrate the x-axis, first expose it to -1g by placing the x-axis vertical to the ground with the arrow pointing down. Then expose it to +1g by doing the same thing with the arrow pointing up. Record the voltage from the numeric indicator both times. To get the x-axis exactly vertical, it helps to align it to a vertical object, such as a desktop tower.

![Image of accelerometer with -1g and +1g readings](image)

Figure 6-20

2. Follow the same procedure for the y-axis and z-axis.

3. Solve for the sensitivity and offset. This can be done the same way as the LVDT in Excel, but since there are only two points (-1g and +1g), a quick hand calculation may be easier.

6.5.3 APPLY CALIBRATION

1. Follow the same steps as the LVDT calibration, but select the accelerometer channels. Unlike the LVDT, for accelerometers the offset (a0) is necessary and must be entered.

7 Contact Information

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Email: xiaoyun.shao@wmich.edu
Website: http://homepages.wmich.edu/~dpb8848/
Appendix 1: Data Acquisition Channels of SCB-68

<table>
<thead>
<tr>
<th>Pin #</th>
<th>Signal</th>
<th>Pin #</th>
<th>Signal</th>
<th>Pin #</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>ACH6</td>
<td>12</td>
<td>DGND</td>
<td>1</td>
<td>FREQ_OUT</td>
</tr>
<tr>
<td>18</td>
<td>ACH12</td>
<td>2</td>
<td>GPCTRL_OUT</td>
<td>3</td>
<td>DGND</td>
</tr>
<tr>
<td>26</td>
<td>ACH13</td>
<td>3</td>
<td>DGND</td>
<td>4</td>
<td>DGND</td>
</tr>
<tr>
<td>34</td>
<td>ACH8</td>
<td>4</td>
<td>DGND</td>
<td>5</td>
<td>PF1/GPCTRL1_GATE</td>
</tr>
<tr>
<td>50</td>
<td>DGND</td>
<td>6</td>
<td>PF6/UPDATE*</td>
<td>7</td>
<td>DGND</td>
</tr>
<tr>
<td>58</td>
<td>ACH14</td>
<td>8</td>
<td>+5V, FUSED</td>
<td>8</td>
<td>DGND</td>
</tr>
<tr>
<td>59</td>
<td>ACH15</td>
<td>9</td>
<td>PF1/TRIG2</td>
<td>10</td>
<td>DGND</td>
</tr>
<tr>
<td>67</td>
<td>ACH9</td>
<td>10</td>
<td>DGND</td>
<td>11</td>
<td>PF10/TRIG1</td>
</tr>
<tr>
<td>74</td>
<td>ACH11</td>
<td>11</td>
<td>DGND</td>
<td>12</td>
<td>EXSTROBE*</td>
</tr>
<tr>
<td>13</td>
<td>DGND</td>
<td>12</td>
<td>DGND</td>
<td>13</td>
<td>DGND</td>
</tr>
</tbody>
</table>

Figure 8-1 Image of the Channel Labels of the NI SCB-68 SCB-68 Pin Shielded Connector Block- E Series
### 8.1 PXI1Slot2

<table>
<thead>
<tr>
<th>Device</th>
<th>Pin #</th>
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<tbody>
<tr>
<td>LC 1</td>
<td>63</td>
<td>AI 11</td>
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<tr>
<td></td>
<td>29</td>
<td>GND</td>
</tr>
<tr>
<td>LVDT1</td>
<td>61</td>
<td>AI 15</td>
</tr>
<tr>
<td></td>
<td>56</td>
<td>GND</td>
</tr>
<tr>
<td>EXT 1</td>
<td>21</td>
<td>AO 1</td>
</tr>
<tr>
<td></td>
<td>54</td>
<td>GND</td>
</tr>
<tr>
<td>Monitor A</td>
<td>31</td>
<td>AI 10</td>
</tr>
<tr>
<td></td>
<td>64</td>
<td>GND</td>
</tr>
<tr>
<td>Monitor B</td>
<td>26</td>
<td>AI 13</td>
</tr>
<tr>
<td></td>
<td>59</td>
<td>GND</td>
</tr>
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### 8.2 PXI1Slot8

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<th>Device</th>
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<th>Pin #</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>8</td>
<td>5V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GND</td>
<td>59</td>
<td>AI</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>GND</td>
</tr>
<tr>
<td>ACCEL 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>28</td>
<td>AI 4</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>60</td>
<td>AI 5</td>
</tr>
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<table>
<thead>
<tr>
<th>Device</th>
<th>Type</th>
<th>Pin #</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>8</td>
<td>5V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GND</td>
<td>27</td>
<td>AI</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>GND</td>
</tr>
<tr>
<td>ACCEL 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>63</td>
<td>AI 11</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>61</td>
<td>AI 12</td>
</tr>
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<table>
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<th>Device</th>
<th>Type</th>
<th>Pin #</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>14</td>
<td>5V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GND</td>
<td>27</td>
<td>AI</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>GND</td>
</tr>
<tr>
<td>ACCEL 3</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>X</td>
<td>33</td>
<td>AI 1</td>
</tr>
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<td>Y</td>
<td>65</td>
<td>AI 2</td>
</tr>
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</table>
### Device Details

<table>
<thead>
<tr>
<th>Device</th>
<th>Pin #</th>
<th>Signal</th>
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</thead>
<tbody>
<tr>
<td>sLVDT1</td>
<td>57</td>
<td>AI 7</td>
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<td></td>
<td>24</td>
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<td>sLVDT2</td>
<td>66</td>
<td>AI 9</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>GND</td>
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<tr>
<td>sLVDT3</td>
<td>31</td>
<td>AI 10</td>
</tr>
<tr>
<td></td>
<td>64</td>
<td>GND</td>
</tr>
</tbody>
</table>

### sLVDT 2 and 3 Cable Designation

<table>
<thead>
<tr>
<th></th>
<th>Actual LVDT Device Cable</th>
<th>When Linked to John's Cable (i.e. sLVDT 2 &amp; 3)</th>
<th>When Linked to the our Cable (i.e. sLVDT 1)</th>
<th>Represent’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Cable</td>
<td>Red</td>
<td>Orange</td>
<td>Red Stripe</td>
<td>Positive</td>
</tr>
<tr>
<td>2nd Cable</td>
<td>Black</td>
<td>Brown</td>
<td>Second One Next to Red Str.</td>
<td>Negative</td>
</tr>
<tr>
<td>3rd Cable</td>
<td>Green</td>
<td>Green</td>
<td>Third One Counting from Red Str.</td>
<td>Ground</td>
</tr>
<tr>
<td>4th Cable</td>
<td>White</td>
<td>Blue</td>
<td>Fourth One Counting from Red Str.</td>
<td>Channel</td>
</tr>
<tr>
<td>5th Cable</td>
<td></td>
<td></td>
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### Appendix II: Calibration Equations of all the instruments

The following calibration equations were prepared by Adam Mueller in June 2014.
### TABLE ACTUATOR

<table>
<thead>
<tr>
<th>ACTUATOR</th>
<th>LVDT1 (in)</th>
<th>LC1 (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXT1 (V)</td>
<td>-0.0038+0.3946X</td>
<td>-0.02+313.32X</td>
</tr>
<tr>
<td>Needs recalibration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### STRUCTURE ACTUATOR

<table>
<thead>
<tr>
<th>ACTUATOR</th>
<th>LVDT2 (in)</th>
<th>LC2 (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXT2 (V)</td>
<td>0.0063+0.4076X</td>
<td>2.80+32.513X</td>
</tr>
</tbody>
</table>

### Note: Table and Structure actuators’s

### EXTERNAL LVDTs (in)

<table>
<thead>
<tr>
<th>LVDT1</th>
<th>LVDT2</th>
<th>LVDT3</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXT_LVDT1: 2.0298X</td>
<td>EXT_LVDT2: TBD</td>
<td>EXT_LVDT3: TBD</td>
</tr>
</tbody>
</table>

### ACCELEROMETER 1 (g)

<table>
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<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x</td>
<td>-4.739+1.992X</td>
</tr>
<tr>
<td>1y</td>
<td>-4.706+1.970X</td>
</tr>
<tr>
<td>1z</td>
<td>-4.697+1.982X</td>
</tr>
</tbody>
</table>

### ACCELEROMETER 2 (g)

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x</td>
<td>-4.694+1.972X</td>
</tr>
<tr>
<td>2y</td>
<td>-4.689+1.978X</td>
</tr>
<tr>
<td>2z</td>
<td>-4.609+1.994X</td>
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### ACCELEROMETER 3 (g)

<table>
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<th>Value</th>
</tr>
</thead>
<tbody>
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<tr>
<td>3y</td>
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<tr>
<td>3z</td>
<td>-4.761+1.990X</td>
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