Utilizing Telepresence Tools to Remotely Participate in Wall Tests Conducted at the NEES@Minnesota Facility and their Current Developments

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ABSTRACT:

Researchers from the University of Minnesota (UMN), Iowa State University and the University of Puerto Rico at Mayagüez and a consulting engineer from the Nakaki Bashaw Group, Inc. in California have undertaken a collaborative Pre-NEESR research project since 2004 to investigate the behavior of nonrectangular structural walls subjected to the effects of multi-directional loading. The experimental component of the study utilized the Network for Earthquake Engineering Simulation (NEES) Multi-Axial Subassemblage Testing (MAST) system at the University of Minnesota (NEES@Minnesota) to conduct large-scale seismic testing of a T-shaped concrete wall and several rectangular walls. In each test, a variety of telepresence tools developed by the research team and the NEES Cyberinfrastructure Center (NEESit), were used to enable effective real-time collaboration between the researchers at the test site and those at the three remote locations. These tests were the first NEES experiments to extensively utilize the available telepresence tools and not only provided a proof of concept but were instrumental in identifying deficiencies and guiding future enhancements to the NEESit capabilities. This paper describes features of the NEESit telepresence tools, provides an end-to-end case study demonstrating the ability for remote researchers to actively participate in a seismic experiment, and describes the benefits of using various IT capabilities during large-scale physical testing including the ability to interact with people and equipment at the remote facility and manipulate test data in real-time. Also discussed are current developments of these telepresence tools to make them more suitable for real-time dynamic tests.

KEYWORDS: Telepresence, information technology, data, large-scale testing, remote testing

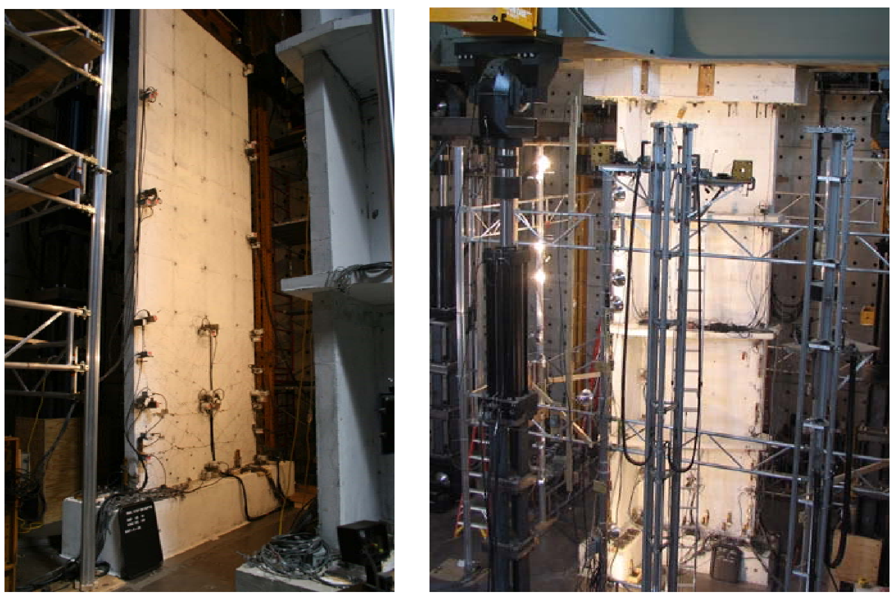
1. INTRODUCTION

Researchers from the University of Minnesota (UMN), Iowa State University and the University of Puerto Rico at Mayagüez and a consulting engineer from the Nakaki Bashaw Group, Inc. in California have undertaken a collaborative PreNEESR project since 2004 (http://nees.umn.edu/projects/twall/). This project focuses on analytical and experimental efforts to investigate the behavior of nonrectangular structural walls subjected to multi-directional loading. The experimental component of the study utilized the NEES Multi-Axial Subassemblage Testing (MAST) system at Minnesota (NEES@Minnesota). To date, large-scale testing of two T-shaped concrete walls and three rectangular walls has been completed. In each test, a variety of telepresence tools, including those developed and supported by the NEES Cyberinfrastructure Center [1] were used to enable effective collaboration between the researchers at the test site at NEES@Minnesota (http://nees.umn.edu/) and those at the remote locations. The principal author of this paper was on sabbatical leave at the University of Auckland in New Zealand during testing of two rectangular walls. Consequently, the telepresence capabilities of NZNEES@Auckland (http://www.nznees.auckland.ac.nz/) together with the NEESit tools were used to continue the research project without compromising the real-time collaboration between researchers during the tests.

The wall tests conducted at NEES@Minnesota were the first NEES experiments to extensively use the telepresence tools and experience the benefits of real time capabilities to advance the simulation models. Consequently, these tests served as a testbed for various telepresence tools. While the benefits of real-time collaboration were realized satisfactorily in the experiments, improvements to the capabilities of telepresence tools were identified and recommended to NEESit. This paper largely focuses on a researcher's experience in remotely participating in seismic tests, including the ability to interact with both people and equipment and manipulate test data in real-time, and describes how different telepresence technologies were used in the project as well as some recommendations made towards improving capabilities of telepresence tools to enhance real-time research collaboration.

2. TESTING OF WALLS

The overall scope of the project described in this paper is to investigate the behavior of nonrectangular concrete walls subjected to multi-directional loads. The project utilized both rectangular and T-shaped concrete walls to examine the adequacy of reinforcement details prescribed in the design codes, validate and improve the existing analysis capabilities to predict the lateral load behavior of walls, understand the interaction between shear and flexural behavior of walls, and examine the influence of using splices and the couplers in the plastic hinge region of concrete walls. The experimental part of the study included testing of three rectangular walls and two T-walls. Hundreds of sensors, 10 video cameras and eight still cameras were used in each of these wall tests.



(A) Rectangular Wall Test (B) T-WALL TEST
Figure 1: Testing of Walls at NEES@Minnesota

3. TELEPRESENCE TOOLS AND CAPABILITIES

A variety of telepresence tools were utilized during testing of the walls. A brief description of these tools and how they were used during testing to enhance effective participation of researchers, especially those who were at remote locations, are summarized in the following sections.

3.1 WebEx

WebEx is a commercial software that enables internet teleconferencing by connecting regular phones and computers, providing capabilities necessary to support real-time meetings on the Web. Two sessions of WebEx were initiated and maintained during the entire test by the NEES@Minnesota IT team. The first session shared the critical data collected by the data acquisition system (DAQ) in tabular and graphical forms (see Figure 2). The second WebEx session shared a basic session of RDV that displayed critical data streaming through a DataTurbine server at Minnesota (see Section 3.2). One of these WebEx sessions was also used to enable audio communication between researchers at different locations, which included researchers at the test floor who were equipped with wireless headsets that were linked to a phone connected to the WebEx session. These two WebEx sessions provided common ground for researchers to communicate effectively and make critical decisions.

Figure 2: Webex Session that Displayed the Data Gathered by the Data Acquisition System

3.2 RDV (Real-Time Data Viewer) and DataTurbine

RDV enables viewing of video data and visualization of streaming instrumentation data in real-time. In addition to the RDV session shared through WebEx, several RDV sessions were administered at remote locations depending on the researchers' interest in the project. These sessions included data in tabular form, graphs of data channels as a function of time as well as X-Y plots, and limited video streams (see an example in Figure 3). The various data sources (data acquired from sensors and videos) were synchronized using DataTurbine [6], which provides the high performance, time-synchronized data streaming services that feed data into RDV. The project researchers were able to access the data in real-time from the DataTurbine server at NEES@Minnesota. To improve efficiency of RDV, mirroring the DataTurbine server at Minnesota to a local server at Iowa in real-time, and accessing the data from the local server was explored.

DataTurbine is an open-source streaming data system that lets researchers quickly stream live data from experiments, labs, webcams and even Java enabled cell phones [6]. Data can consist of numeric sensor results, video, still images, sound or text. DataTurbine provides the middleware for data streaming (in real-time), sharing, browsing, processing, and archiving for future playback. NEESit develops DataTurbine Utilities that provide an interface between a DataTurbine server and connected data sources such as cameras and data acquisition systems [7].

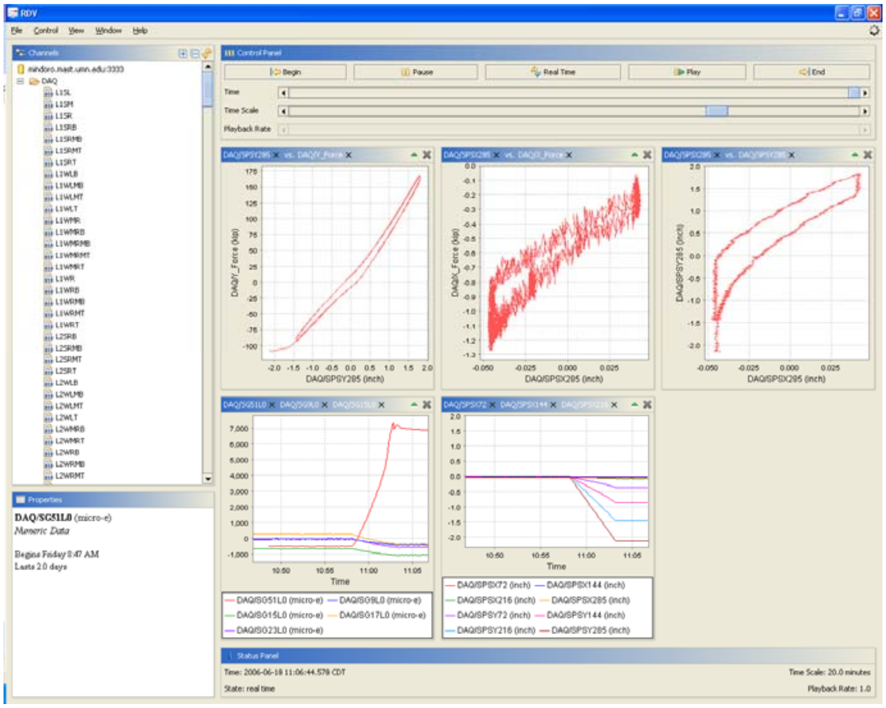


Figure 3: RDV Session on a Remote Computer

3.3 flexTPS (flexible TelePresence System)

flexTPS is open source software designed to enable remote viewing of live video and remote control operation of video and still cameras over the internet using a web browser on the user's computer. flexTPS was primarily used during the tests to view live videos from multiple cameras at a higher refresh rate than that used in RDV (see Figure 4).

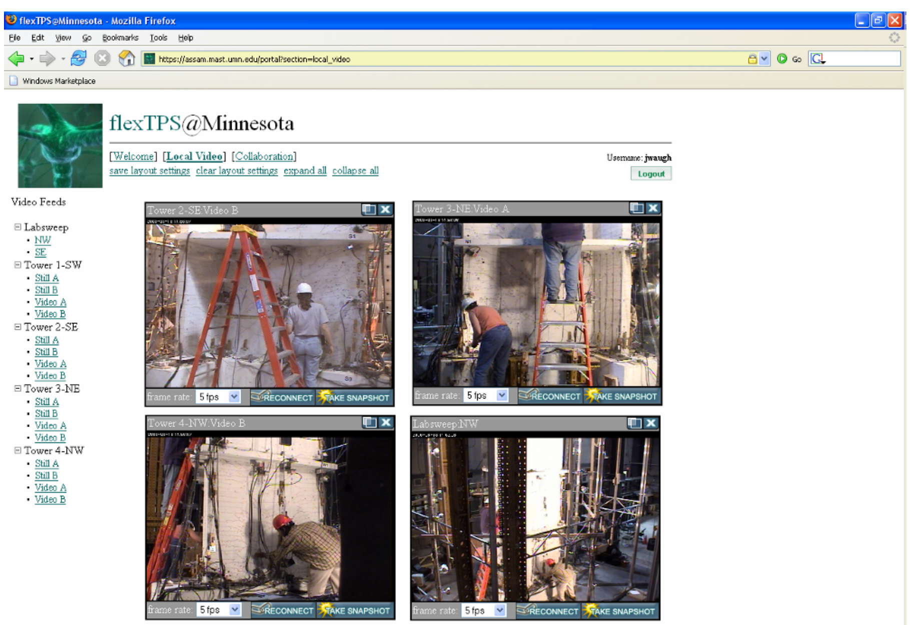


Figure 4: flexTPS Session on a Remote Computer

3.4 Still Images

At the time of testing, no special software was available to archive high-resolution still images. Hence, the still images were taken, time stamped and made available to the researchers through a web server by NEES@Minnesota. By automating operation of most still cameras, the images were made available almost instantaneously. Figure 5 shows images appearing as thumbnails on the web, which were linked to large high-resolution images to visually inspect the extent of local damage that occurred to the test walls. Note: this feature is now available through RDV as described in Section 4.

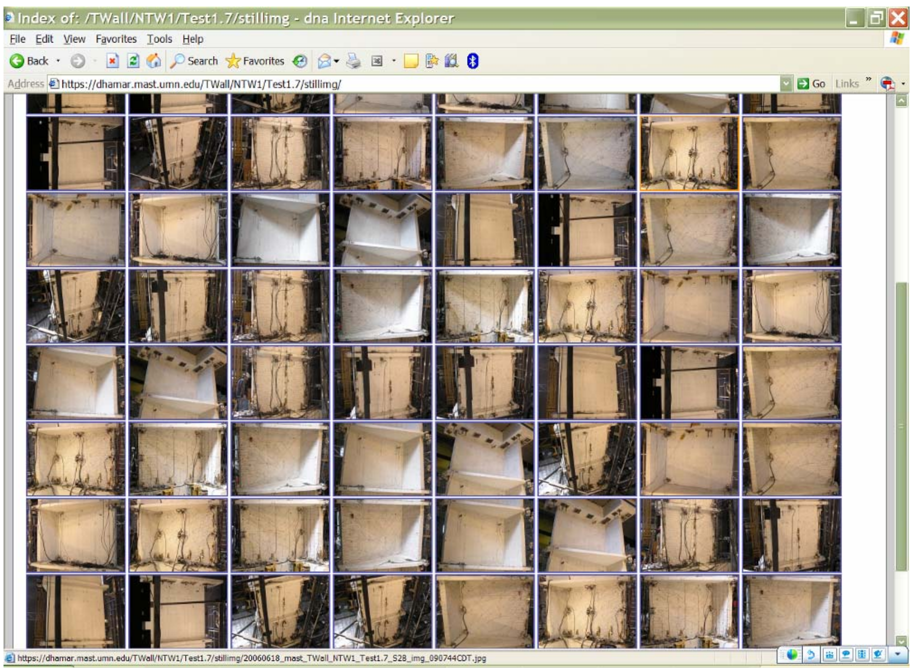


Figure 5: Webpage Showing Thumbnails of High-Resolution Still Images

3.5 HCC (Hydraulic Control System Software)

HCC is a command entry and monitoring layer that provides a direct user interface to the MTS Controller of MAST at NEES@Minnesota [2]. HCC polls for and displays status information of MAST and enables precise control of it by allowing a remote user to specify the next target point through defining six degrees of freedom (DOF) for the control point. HCC was used during some segments of the tests to verify its capabilities and successfully operate MAST in Minnesota from a remote site in Iowa. Capabilities of HCC were also verified by operating MAST remotely from Auckland, New Zealand. In both cases, the features of HCC were found to be sufficient and accurate.

3.6 MAST-RSVtool

In light of the limitations existed with the collaborative tools described above, the MAST Real-time System Visualization Tool (RSVtool) was developed locally at Iowa State University to enhance research collaboration in real-time [3]. The MAST-RSVtool enables a remote researcher to 1) monitor the condition of the MAST hydraulic system (i.e., force and displacement of all MAST actuators) through progress bars and data viewer; 2) set soft limits (i.e., limits used by a user for research purposes and not for actuator control) for the MAST actuators; 3) monitor the load path effects on the test specimen, which was necessary to determine the critical paths for the next load cycles; and 4) compare the predicted force-displacement responses with measured responses, all in real-time.

3.7 NZNEES@Auckland:

NZNEES@Auckland provides a unique contribution to the capabilities that exist currently in earthquake engineering networks, and foster collaborative research in New Zealand and internationally. Included in NZNEES@Auckland is a Data Visualization Laboratory (DVL), connected to the New Zealand Kiwi Advanced Research and Education Network (KAREN). Using advance telepresence technologies, the DVL was designed to enable New Zealand researchers to effectively participate in experimental research. Using the above described IT tools, the principal author participated in two wall tests in real-time from NZNEES@Auckland (see Figure 6).

Figure 6: Real-time Participation in a Rectangular Wall Test at MAST from NZNEES@Auckland

4. RECOMMENDATIONS FOR TECHNOLOGY ENHANCEMENTS

Various telepresence tools and their capabilities described above made researchers at remote locations to effectively participate during testing of walls at the NEES site in Minnesota. The principal author participated in all tests from either Iowa or Auckland, New Zealand. Although critical decisions during testing of walls were made collectively by researchers at the test and remote sites, the author had sole responsibility to make some of the decisions from a remote location for portions of the tests. Under no circumstances did the principal author feel that the information made available in real time was inadequate and that making a decision or contributing effectively for decision making during quasi-static wall tests was difficult. However, some limitations and possible improvements to the capabilities of the telepresence tools were identified and communicated to the NEESit team for their consideration. These requirements included: 1) incorporating discontinuous timelines into RDV; 2) enabling RDV to manipulate data and compare them with simulated results in real-time; 3) establishing robustness of the data turbine and RDV system as a whole; 4) providing specifications to guide remote researchers to realize the limitations of RDV based on the bandwidth and latency of the available network; 5) improving playback capabilities of RDV possibly by enabling history data to be uploaded individually in each window chosen within an RDV session; 6) adding audio capability to flexTPS; 7) integrating still images into the NEES telepresence portal; 8) promote mirroring of the data turbine server to a local server at a remote site in real time; 9) integration of a wireless video camera at the NEES equipment site that can be viewed through flexTPS; and 10) improving reliability of audio connections between wireless headsets and WebEx.

To date, recommended improvements 1, some aspects of 3, 7 and 8 have been accommodated into the NEESit tools, making the capabilities of the current NEES telepresence tools far superior than those available to the PreNEESR research team especially at the beginning of the project in 2004. Additionally, RDV version 1.9, released in July 2008, contains significant new features for viewing images and video, a new dial visualization, and support for exporting MATLAB files. A number of smaller improvements for plotting digital data have been added in addition to fixing a few bugs reported by the users for the previous version of this tool.

Notable new RDV features include:

- Support for zooming and panning of an image. A clickable navigation image can be used to move around parts of an image when zoomed in;
- Filmstrip interface to view images sequentially;
- Support for viewing a thumbnail of an image to conserve bandwidth;
- DialViz, a visualization extension to view a numeric data channel on a dial;
- Ability to export data to the MATLAB MAT-file format; and
- Support for port knocking authentication.

The support for still images (e.g., zooming, panning, filmstrip interface, etc.) allows remote researchers to closely assess the performance and damage states of test units in critical regions. Such assessments include estimating width of crack, observing crack propagation and/or failure of connections, and determining the extent of concrete spalling or local buckling of steel members.

Furthermore, NEESit has begun to extend the telepresence capabilities to be more practical for dynamic testing. Because the duration of shake table and centrifuge tests is extremely short in comparison with quasi-static testing, the need for real-time data streaming is not as significant as the capability to replay the experiment and analyze the data immediately following a loading event. Therefore, current and future development is focused on providing better analysis tools in RDV. One example is the ability to create virtual channels representing the arithmetic output of two or more data channels (e.g., calculating curvature in a column from two displacement transducers). This "calculator" will allow for basic operations such as addition, subtraction, multiplication, division, power, log, ln, with future extensions to support more complex operations over two or more channels, including data filtering.

Additionally, NEESit is developing a Frequency Spectrum Analyzer which will plot the power vs. frequency of a time domain signal. The processing steps would include filtering data, selecting portion of data set, performing FFT and calculating the power of the amplitudes. Other processing steps could include resampling of the data, performing FFT averaging, and calculating cross, transfer and coherence functions. This would facilitate the viewing of data required to support frequency based testing.

Furthermore, NEESit is working towards further integration of RDV into the NEEScentral Data Repository, where NEES research data is organized, archived, and made available to the broader earthquake engineering community. Currently, users can access numerical data, video files and still images that are archived in the NEEScentral Data Repository and replay them in a synchronized manner within RDV. Further integration would include the ability for researchers to launch RDV directly within the NEEScentral application and replay their data with a click of a button. This interoperability of the various NEESit and community developed cyberinfrastructure tools will facilitate efficient knowledge extraction, ultimately allowing researchers to gain important new insights into earthquake engineering problems that will contribute towards improving our understanding of today's build environment.

4. CONCLUSIONS

Overall, the capabilities of the telepresence tools available to the researchers, especially those at remote locations in Iowa, Puerto Rico, California, and New Zealand, were sufficient. However, some difficulties and limitations were encountered with these tools. Recommendations to eliminate these limitations, along with potential new features for the telepresence technologies, were communicated to the NEESit team, some of which have been already implemented.

With the added capabilities, the NEES telepresence tools described herein are sufficiently adequate or effective real-time collaboration during slower quasi-static testing where sufficient time is available for remote researchers to assess performance and damage states, compare experimental results with analyses, replay certain parts of the test, and ultimately inform the equipment sites of any changes to the loading protocol. However, this type of methodical evaluation has not been completed during dynamic testing such as a shake table or centrifuge test. It is anticipated the use of the telepresence tools in dynamic tests will be used in near real time, which is appropriate as these tests are most carefully evaluated at the conclusion of a test to a selected input record. Nonetheless other challenges such as performing evaluation of the test in the frequency domain and acquiring data with sufficient sampling rates need to be examined and appropriate improvements should be made for the NEES telepresence tools. A key element for the rapid advancement of the NEES telepresence tools suitable for quasi-static testing was the feedback that the NEESit team received from the NEES researchers. Through similar interaction between the NEES researchers and NEESit, it is hoped that the capabilities of the telepresence tools can be sufficiently advanced to enable remote researchers to effectively collaborate during dynamic tests.

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