THE DEVELOPMENT OF MOBILE FIELD LABORATORY AND HYBRID TESTING FACILITY AT NZNEES@AUCKLAND

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ABSTRACT :

Since the establishment of the NZNEES@Auckland node in 2006, developments have transformed the Auckland node from an end user portal to a research contributing facility. The New Zealand Network for Earthquake Engineering Simulations (NZNEES) was formed with the intention to act as a vehicle to interface with other similar networks overseas and allow New Zealand researchers to participate equally in the new global forum. NZNEES aims to facilitate collaborations with likeminded experts worldwide and access of state-of-the-art experimental and computational resources. This paper reviews two of the Auckland node's highlights, the capabilities of the Mobile Field Laboratory (MFL) and the distributed hybrid testing setup. The MFL take advantage of Auckland's access to buildings earmarked for destruction to conduct nonlinear tests on in-situ structural and geotechnical systems. A high speed satellite connection provides real time teleparticipation and teleoperation access of the MFL for remote researchers worldwide. Moreover, the NZNEES@Auckland node is equipped with a distributed hybrid testing setup that is compatible with setups found in United States and United Kingdom. NZNEES is already actively participating in coordinated studies with NEES@UCDAVIS, UK-NEES and NCREE. Examples of recent projects are presented to illustrate the current capabilities.

KEYWORDS: International Collaboration, NEES, Distributed Hybrid Testing

1. INTRODUCTION

Earthquakes and earthquake related disasters are amongst the most destructive phenomena in nature. They result in significant direct and indirect economic losses, damage to physical and social infrastructure and loss of lives. Between 1970 and 2005, earthquakes accounted for 8 of the 10 worst natural catastrophes in terms of number of victims (Swiss Reinsurance Company 2006). In the past 100 years, there have been significant advances in the understanding of the nature and the effects of earthquakes. Significant advances in structural analysis have delivered scientific tools to analyse and predict the behaviour of buildings during seismic events. The development and enforcement of building codes has enabled the dissemination and application of knowledge and enhanced the life safety of occupants of modern buildings. Despite these advances, challenges and uncertainties still exist in the seismic response of many commonly seen structures. In addition, engineers face challenges in the design of architecturally extravagant structures on the one hand and highly optimised structures on the other, increasing the demand to better understand earthquakes. Opportunities exist to accelerate the learning process through accurate simulations.

In the United States, the National Science Foundation, recognising the U.S. vulnerability to earthquake disasters, launched a major research initiative in 1999 and established the George E. Brown, Jr. Network for Earthquake Engineering Simulations (NEES). The objectives of the U.S. NEES network were to provide central, unparalleled experimental facilities, accessible to researchers, local or remote, through the use of a grid-based IT infrastructure, and to establish a platform which allows for collaboration and discovery through advanced research based on integrated experimentation and computational simulations, to further the understanding of earthquakes and their effects (Pauschke and Mujumdar 2004).

Alongside the creation of 15 state-of-the-art University based equipment sites, the U.S. NEES created high tech collaborative tools, a centralised public data repository and earthquake simulation software, all freely available to researchers around the world. The U.S. NEES programme has since revolutionised the earthquake engineering research environment in the U.S. and has sparked the inception of similar networks worldwide. For example, the U.K. Network for Earthquake Engineering Simulations (UK-NEES) in the United Kingdom and the Korea Construction Engineering Development Collaboratory Program (KOCED) in Korea (Kim 2006; UK-NEES n.d.).

The arrival of the New Zealand Government funded Kiwi Advanced Research and Education Network (KAREN) (KAREN n.d.), created an opportunity for New Zealand to join the new international collaborative effort. Such an international collaboration allow New Zealand researchers to have access to advanced equipment normally not available to their host institutions and permit participation in large scale experiments with leading experts worldwide.

With the vision of making a unique contribution to existing world earthquake engineering networks in mind, in June 2006 the University of Auckland unveiled the first node of the New Zealand Network for Earthquake Engineering Simulations (NZNEES), NZNEES@Auckland.

2. VISION OF THE NZNEES NETWORK

The underlying objectives behind the NZNEES network coincide with those of the U.S. NEES programme. The vision is that NZNEES will become the primary vehicle for collaborative earthquake engineering research within and beyond New Zealand, with active contribution from universities, crown research institutes and the broader engineering community. NZNEES will:

1. reduce the replication in both human and experimental resources by fostering open exchange of ideas and the shared use of equipment,
2. facilitate access to the world's most advanced experimental and computation facilities,
3. establish a public data repository which will maximise the use of experimental data sets and catalogue fundamental knowledge,
4. provide intuitive and immersive tools to facilitate real-time remote participation,
5. act as a forum for promoting seismic awareness to the public and a forum to represent the New Zealand earthquake engineering community internationally.

Each NZNEES node will have open access to national resources supported by NZNEES. These national resources currently include a failsafe data repository system, an inexhaustive data storage facility and an easy to operate video conferencing system. Many aspects of these are enhanced by the introduction of KAREN. NZNEES is also supported by the Tertiary Education Commission (TEC) funded project BeSTGRID, which aims to create a fully-functional e-research ecosystem for New Zealand (BeSTGRID n.d.). A simple schematic of the proposed NZNEES organisation structure is as shown in Fig. 1 overpage.

3. NZNEES@AUCKLAND OVERVIEW

One of the highlight of the NZNEES@Auckland *equipment site* is its Mobile Field Laboratory (MFL). This facility distinguishes NZNEES@Auckland's contribution to world earthquake engineering networks with its facilities for forced vibration testing and monitoring of in-situ structural and geotechnical systems. The anticipated usage of the facility will revolve around four typical usage scenarios:

1. monitoring in-situ static and dynamic structural response with the aim of providing experimental data to correlate simulation and laboratory testing with real world applications;
2. destructive static and dynamic testing of full scale, in situ structures and geotechnical systems, capturing their performance in the nonlinear range;
3. in-situ geotechnical experiments, facilitating verification of geotechnical simulations that cannot be easily replicated in laboratories;

4. recording structural response to aftershocks, made possible by rapid post-earthquake deployment of the MFL.

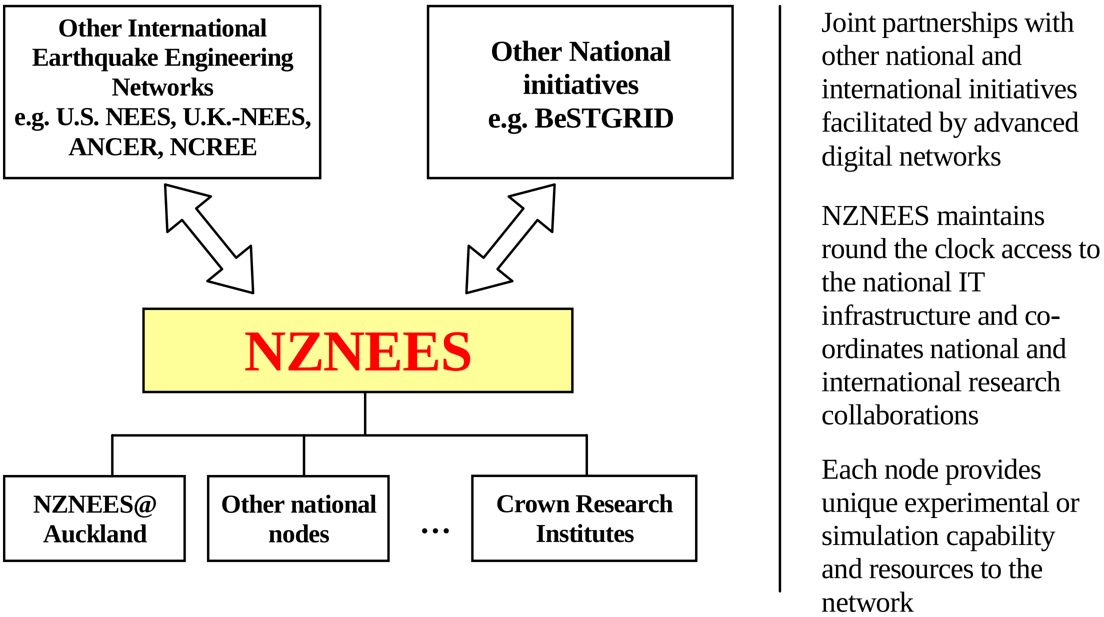

Figure 1 – Schematic of NZNEES organisational structure

3.1. Experimental hardware available for shared use

The NZNEES@Auckland *equipment site* is continuously subjected to ongoing development. Below is a list of the major experimental equipment available at the mobile site. This list is comprised of currently available and soon to be available equipment.

A. Eccentric Mass Shakers: 2 – ANCO MK-140 Eccentric Mass Shakers apply large unidirectional harmonic excitations to structures in the field. These synchronisable shakers operate in a wide frequency range (0-30 Hz) and produce a peak force of 100 kN each. One of these Eccentric Mass shakers is as depicted in Fig. 2a.

B. Electrodynamic Linear Shakers: 2 – APS Dynamics Inc. ELECTRO-SEIS® 400 linear shakers apply low level broadband excitations in the vertical or horizontal directions. These shakers can deliver random as well as sinusoidal forces. In addition, these electro-magnetic devices are not restricted by the physics of the eccentric mass shakers and can produce their peak force of 0.5 kN even at very low frequencies. A photo of the electrodynamic linear shaker is presented in Fig. 2b.

C. Wireless data network and wireless data acquisition system: An outdoor wireless ethernet based data acquisition system permits numeric and video data from a large number of channels to be recorded simultaneously and transmitted wirelessly to a time-critical experimental data recording and streaming server in the mobile command centre. In this system, analogue signals from the sensors are digitised into data packets, then time stamped and transmitted via a 802.11g wireless backbone.

D. Mobile Command Centre (MCC): A custom fitted vehicle designed as a mobile base for remote experiments. This MCC provide transport for equipment to remote sites, a workspace for researchers and storage for the necessary IT infrastructure. A two-way satellite connection links the mobile command centre to the NEES@Auckland main server at the University of Auckland. The data is then broadcast nationally and internationally via KAREN.

An up to date list of equipment is available on the NZNEES@Auckland homepage, http://www.nznees.auckland.ac.nz.

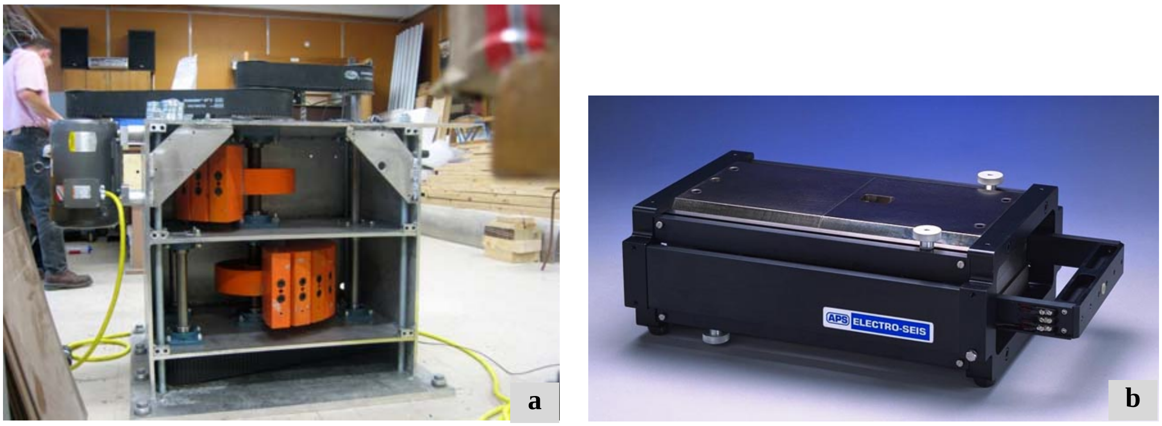

Figure 2 - a) ANCO MK140 eccentric mass shaker b) APS ELECTRO-SEIS® linear shaker

3.2. Distributed Hybrid Testing Equipment

In parallel with the development of the MFL, NZNEES@Auckland node also aims to develop Distributed Hybrid Testing (DHT) capability for earthquake and structural engineering research. DHT, a variant of Hybrid testing is a testing technique which integrates computer models of well understood components with the physical testing of less understood components. Hybrid testing permits cost effective testing as only critical components are experimentally tested. Also, as inertial and dynamic effects may be simulated in a computer model rather than physically replicated, the onerous requirements associated with traditional dynamic testing can be avoided. Furthermore, hybrid testing allows multiple computer and physical models to be separated geographically from each other as the linkages is facilitated through data transfer on a digital network. This capability, better known as DHT, is particularly advantageous for earthquake and structural engineering researchers, as an accurate simulation of many lifeline systems requires a combination of distinct testing capabilities typically not all available to a particular institution or even country. Furthermore physically large specimen can be broken down and physically tested concurrently at separated sites to simulate the behaviour of the full structure. The NZNEES@Auckland node currently has the following actuators capable of conducting hybrid tests,

1. 1 x Shore Western single ended dynamic hydraulic actuator (-300/+500 kN, 300 mm stroke)
2. 1 x Shore Western double ended dynamic hydraulic actuator (+/- 330 kN, 300 mm stroke)
3. 1 x MTS double ended dynamic hydraulic actuator (+/- 340 kN, 200 mm stroke).

These actuators are controlled by a Shore Western's SC 6000 servo control system and a dSPACE DS1103 Real time controller. The control system was tested to interface with established hybrid testing software UI-SIMCOR and OpenFresco (Kwon et al. 2005; Takahashi and Fenves 2006).

3.3. The NZNEES@Auckland IT infrastructure

The aim of the NZNEES@Auckland IT infrastructure is to enable seamless real-time remote participation by remote researchers to support the vision of NZNEES. As such, NZNEES end users employ a set of open source research software, many of which are made available freely by NEES IT, the cyberinfrastructure arm of U.S. NEES. These include:

1. Real-time Data Viewer (RDV)
2. Flexible Telepresence system (flexTPS)
3. NEESDaq
4. Evo
5. NZNEES collaborative space

Screenshots of the aforementioned tools are presented in Fig. 3, 4 and 5 below. More information on the software can be found at NEES IT's and BeSTGRID's website (BeSTGRID n.d.; NEESit n.d.). These softwares are supported by a collection of IT hardware as shown in a schematic in Fig. 6.

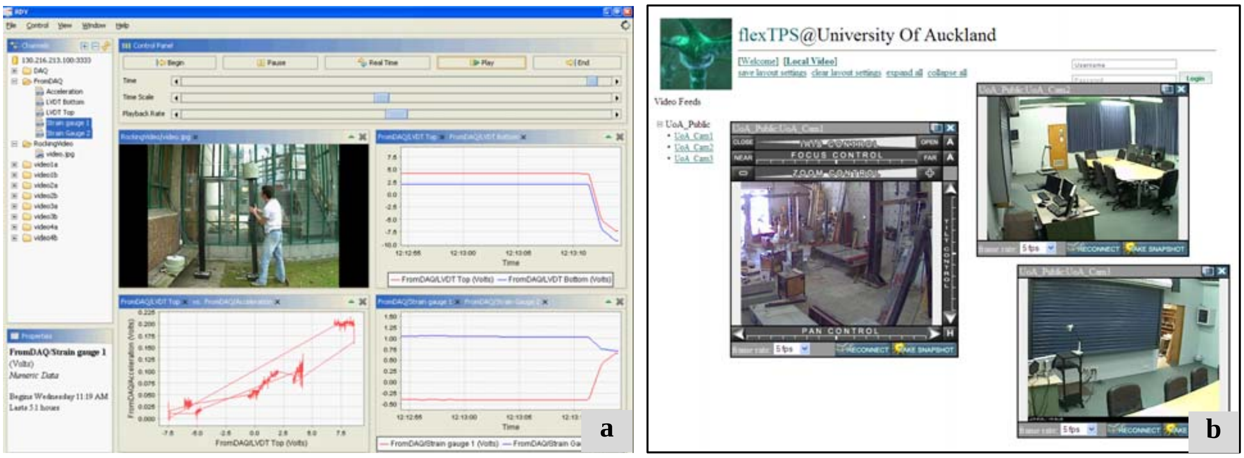

Figure 3 - Screenshots of a) RDV, b) FlexTPS

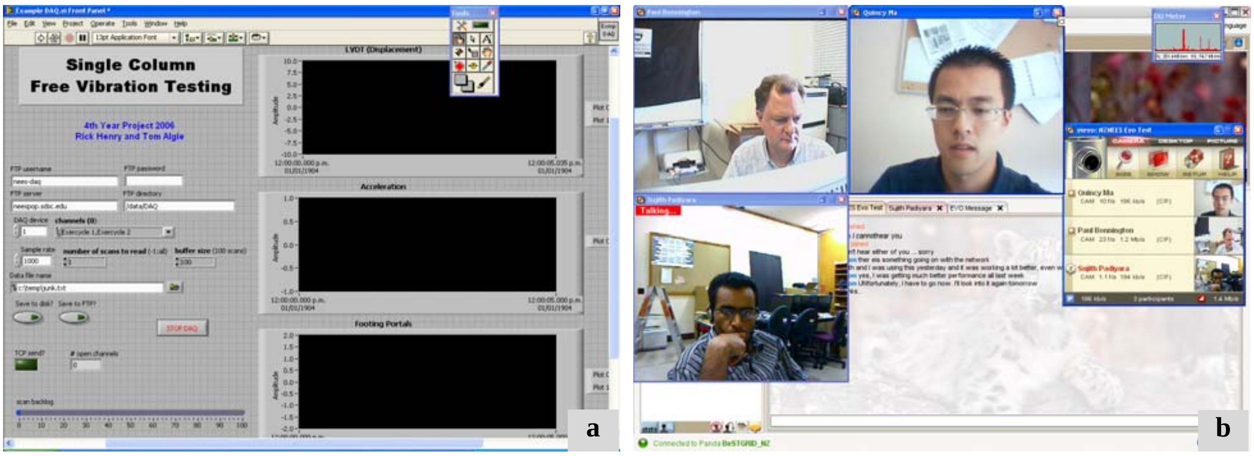

Figure 4 - Screenshots of a) NEESDaq and b) Evo

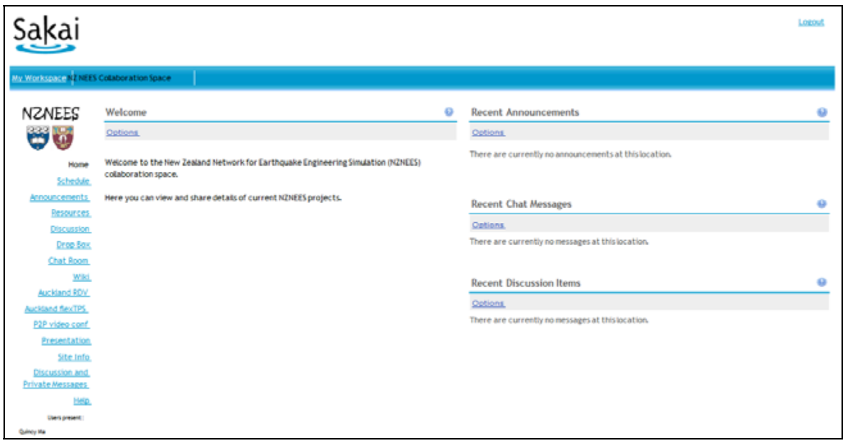

Figure 5 - Screenshot of the NZNEES collaborative space based on Sakai

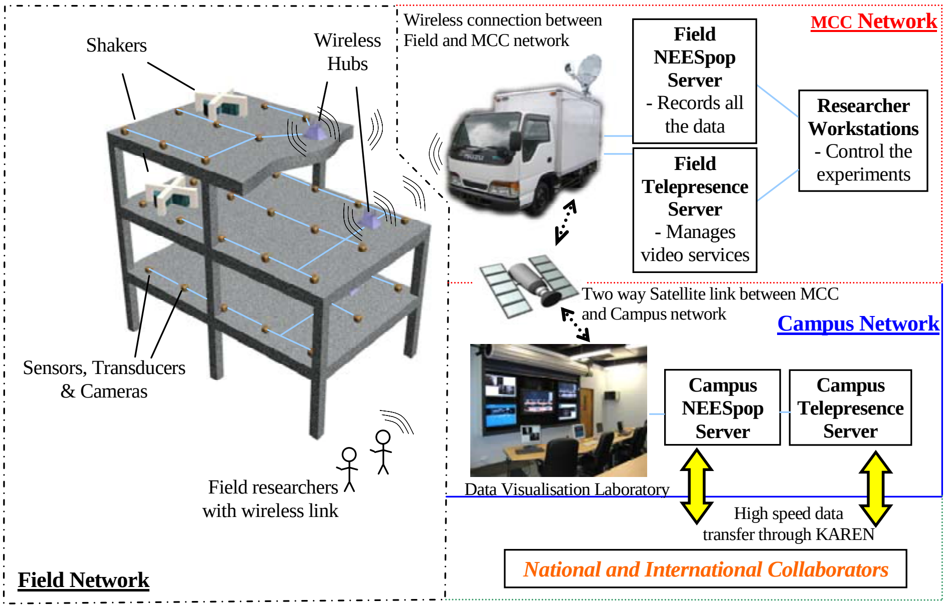

Figure 6 - Illustration of the NZNEES@Auckland mobile field laboratory deployment

4. RECENT NZNEES@AUCKLAND RESEARCH PROJECTS

Auckland researchers have participated in experiments on the U.S. NEES network, experiments conducted in Asia and have also invited U.S. researchers to participate in experiments conducted in New Zealand.

In one of the projects, co-principal investigator of a NEES research project, Dr. S. Sritharan, Iowa State University (ISU), utilised the DVL in Auckland and coordinated remote experiments at the Multi-Axial Subassemblage Testing (MAST) facility, University of Minnesota. The MAST facility represents a large scale three-dimensional, quasi-static, cyclic testing actuator system. The aim of this project was to investigate the seismic performance of non-rectangular structural walls subjected to multidirectional, non-orthogonal loads. The research team constructed ¼ to ½ scaled wall specimens up to six storeys high and subjected them to cyclic loading. RDV was used to connect to the NEESpop at the MAST facility, and the test data and videos were streamed live to the DVL in Auckland using the NEES@Auckland IT infrastructure. By monitoring the test in real time, Dr. Sritharan interacted and instructed the team at Minnesota as obstacles and incidents occurred. Also, the direct controlling of the MAST system from NEES@Auckland was trialled using the HCC software developed by NEES@Minnesota. Further information of the project is available at http://nees.umn.edu/projects/twall/index.php. Photos and screenshots of the test are as shown in Fig. 7.

In another project, Auckland researchers led a modal testing experiment of the Wellesley Street East Footbridge. The experiment utilised NZNEES@Auckland's wireless data transfer ability, structural monitoring capability and electrodynamic linear shakers, to excite the bridge structure and to transfer the sensor data back into the DVL in real-time. Photos and screenshots of the test are presented in Fig. 8.

Finally in 2008, NZNEES@Auckland researchers participated in a major international collaborative project on the large scale validation of an innovative seismic resistant wall system. The participants included researchers from ISU, U.S.A, National Center for Research on Earthquake Engineering (NCREE), Taiwan and NZNEES@Auckland. In one of the large scale test, a 7 m high wall specimen was designed following procedures developed by ISU and UoA, then assembled and tested in the NCREE laboratory in Taiwan. During the testing, live numeric and video data were streamed online using web based interfaces developed at NCREE. Up to 25 channels of the experimental data as well as two live video streams were broadcasted in real-time throughout the 3 day experiment, screenshot of these are as shown in Fig. 9. Additionally, researchers at

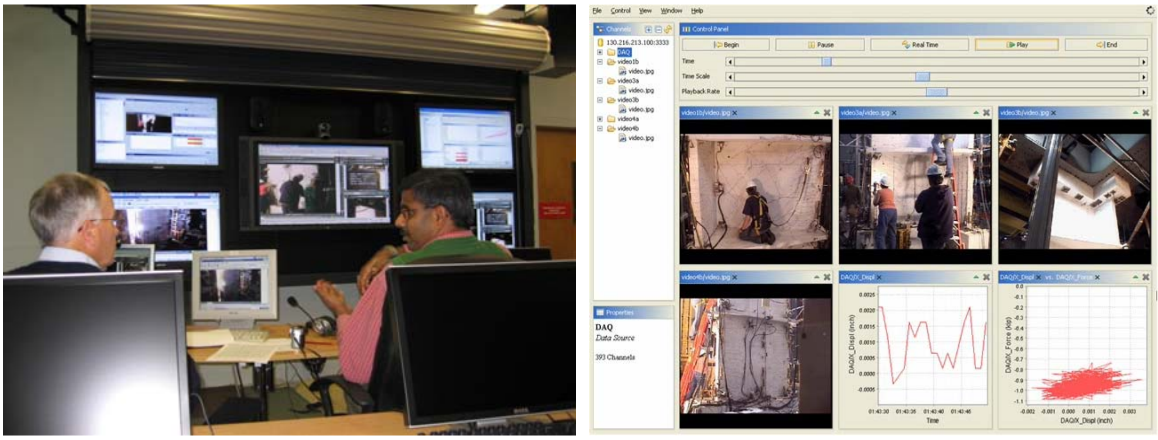

Figure 7- Photo and screenshot of RDV captured during a collaborative experiment between ISU and UoA

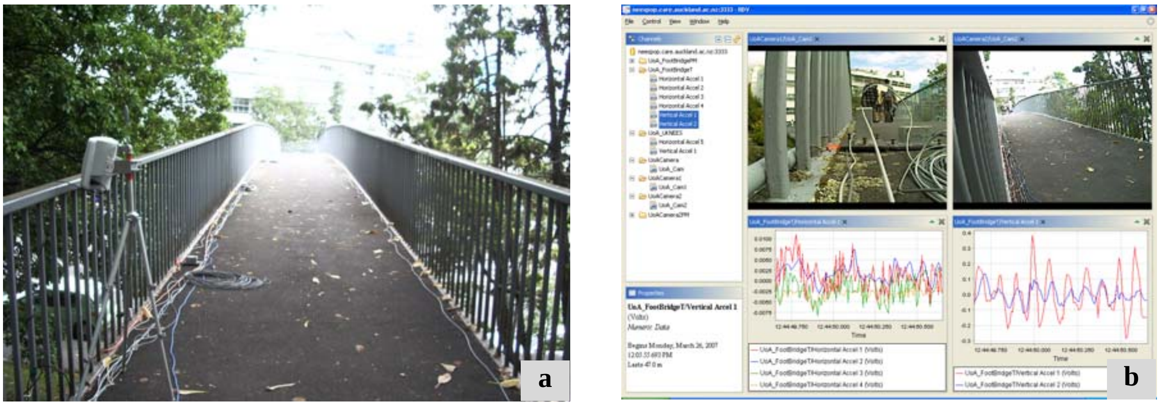

Figure 8 – a) Accelerometers setup and wireless microwave connection; b) Screenshot of RDV

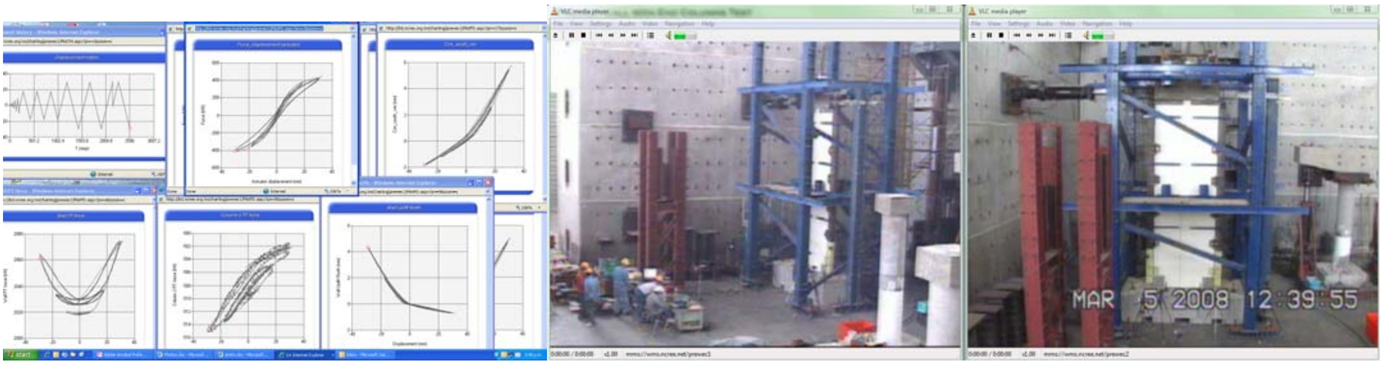

Figure 9 - Streaming data plots and video during the test

NCREE including representative from ISU and UoA hosted a 1.5 hour online webinar on the final day of the testing. The webinar introduced the proposed wall systems to viewers from the U.S.A, Taiwan and New Zealand over the respective international advanced networks. Furthermore the webinar showed the final cycles of the large scale test in real time. Colleagues back in Auckland observed the testing and the webinar using the DVL facilities. The multiple screens setup conveniently showed the graphical data and video simultaneously as it is shown in Fig. 10. This remote viewing capability permitted researchers in NZ and the US that otherwise cannot travel to the test site to participate in the experiment. In additional to the viewing of the test, this project made extensive use of video conferencing throughout all stages of the project and clearly demonstrated that high quality international collaborations can be facilitated using telepresences tools.

Figure 10 - Photos of the webinar as observed in Auckland and Taiwan

5. CONCLUSION

The NZNEES@Auckland equipment site represents the first active New Zealand node in the New Zealand Network for Earthquake Engineering Simulation (NZNEES). The NZNEES initiative integrates with the global initiative in forming networks for earthquake engineering research. It encourages a collaborative research environment that shares resources, knowledge, ideas and experimental data. NZNEES allows New Zealand researchers to participate equally in the new global forum in earthquake engineering research. NZNEES@Auckland node aims to contribute to the global networks as a leader in forced vibration testing and monitoring of in-situ structural and geotechnical systems. The Auckland node is also equipped with equipment compatible with established distributed hybrid testing software packages. Brief examples of recent research, tools, IT infrastructure and current collaborations are presented to illustrate the current capability of the NZNEES@Auckland node. A committed effort is continuing to further develop the node and network, to ensure NZNEES continues to benefit earthquake engineering researchers in their quest to mitigate the devastating effect of earthquakes on the community at large.

6. ACKNOWLEDGEMENT

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