UK Network for Earthquake Engineering Simulation (UK-NEES)

Introduction

This project will develop a UK Network for Earthquake Engineering Simulation (UK-NEES), initially comprising the research laboratories at Bristol, Oxford and Cambridge, but with the potential for expansion to other laboratories. UK-NEES will build on and take advantage of the much larger US network, and will:

- allow teleparticipation by remote users in tests performed in any of the three laboratories,
- provide open access to consistently formatted data from tests in the three laboratories,
- enable synchronous distributed tests between the three laboratories, maximising the size of structure that can be tested, and
- allow the laboratories to link into the US NEES network, giving access to advanced facilities and systems that are the result of US government investment totalling over $200M.

The project will involve close interaction with the US NEES consortium, and particularly with three specific NEES sites: the University of California at Berkeley, the University of California at Davis and the State University of New York at Buffalo. It is also intended that the proposed network will represent the first step towards the development of a European network, bringing in major facilities such as the large reaction wall at the Joint Research Centre at Ispra, and large shaking tables at Saclay (Fr), Athens (Gr), Bergamo (It) and Lisbon (Pt).

Participants

This is a collaborative project between three research groups:

- Dr Martin Williams and Dr Tony Blakeborough, Oxford University, Department of Engineering Science. Pioneers of real-time hybrid (or substructure) testing, in which a test of a physical substructure is coupled in real-time to a numerical model of the surrounding structure. This approach is fundamental to the NEES concept of performing synchronous, linked tests in geographically distributed laboratories. See refs 1-6 and [http://www-civil.eng.ox.ac.uk/research/structdyn](http://www-civil.eng.ox.ac.uk/research/structdyn) for more details of the group’s research.


- Prof. Colin Taylor, Dr Adam Crewe and Prof David Stoten, Bristol University, Faculty of Engineering. Leaders in shaking table testing of structures, location of the new, £18.5m JIF-funded Bristol Laboratory for Advanced Dynamics Engineering (BLADE), which is integrating the dynamics and materials engineering research
across the Faculty of Engineering at Bristol. See refs 14-20 and http://www.blade.bris.ac.uk/ for details.

**Background**

The US National Science Foundation (NSF) has invested $80m in creating the George E. Brown Network for Earthquake Engineering Simulation (NEES) (http://www.nees.org), a Grid-based network of advanced laboratories, which NSF will support by a further $205m over the next 10 years. $10m was spent on developing the open source software system at the heart of NEES. The network became operational in October 2004 and, at the behest of NSF, the NEES Consortium is now encouraging international collaboration and participation. NEES nodes are now being established in Japan, Taiwan and Mexico. The goal of NEES is to foster collaboration and integration of earthquake engineering research and, ultimately, practice, both within the US and across the world wide earthquake engineering research community.

The network is intended to enable participation of remote researchers in experiments (teleparticipation), remote operation of certain facilities (teleoperation), synchronous operation of distributed experimental facilities in a common experiment (distributed hybrid testing), and the archiving and sharing of data via a curated data repository. These capabilities have many generic features relevant beyond NEES’s earthquake engineering context.

Distributed testing is one of the most exciting and technically challenging aspects of NEES. This aims to use the network to conduct an integrated experiment where components of a larger assembly are tested synchronously at geographically distributed laboratories, with interactions being fed back electronically between the laboratories. A practical example might be the seismic loading of a large scale multi-span bridge. There are few laboratories in the world that could house a complete specimen of this kind. However, by using the distributed control technology, several laboratories can each test a single component (e.g. a pier or a deck section) at the same time, with interface forces and displacements being fed back between the laboratories. The result is that existing laboratory facilities can meet the demand for large scale testing, which is essential for the development of the new generation of performance based seismic engineering techniques. Hybrid testing is closely related to distributed testing in that it integrates testing of a physical sub-structure with a synchronous numerical sub-structure (e.g. a physical model of a beam column joint with a numerical model of the remainder of the building). The advantage of hybrid testing is that large scale components can be subjected to more realistic loading patterns without having to test the complete structure.

The purpose of this project is to provide the main UK earthquake engineering experimental laboratories at Bristol, Oxford and Cambridge with the necessary equipment to become nodes of the NEES network. The smaller UK centres, most of which lack experimental facilities, stand to benefit significantly from the data-sharing and teleparticipation aspects of the NEES system, including the opportunity to strengthen collaborative links both within the UK and world wide. The UK practitioner community will also have better access to UK and world wide research.
Equipment and methodology

NEES comprises 15 advanced earthquake engineering test facilities (known as the NEES Equipment Sites) across the USA. The network is overseen by a non-profit organisation, the NEES Consortium Inc. (NEESinc). Interaction between the sites and remote users is achieved via the NEESgrid computer network and supporting software, administered by NEESit.

Figure 1 shows a typical NEES node configuration for an experiment, including remote users and live monitoring of data and video. The key components of the NEESgrid system are as follows; further details can be found at http://it.nees.org/.

- The NEES Point-of-Presence server (NEESpop) is the main point of entry for NEESgrid services. This standardised server hosts the NEESpop software, which provides a variety of tools for collaboration, telepresence, simulation, and local data management, for example the Teleoperations Control Protocol, which allows remote users to control aspects of a physical experiment or simulation, and the Streaming Data Service (NSDS).
- The Telepresence Management Server hosts the flexTPS software system, designed to enable the remote viewing and robotic control of live video over the internet using a standard web browser.
- The Distributed Data Repository allows users to manage data and metadata about NEES experiments and other activities. This component consists of local repositories, a central repository and archiving service, and a set of service protocols to link the repositories together and connect them with NEESgrid users, applications, and portal components.
- NEESdaq provides example programs for data acquisition, file formatting and NTCP-based control, implemented in LabView 6.1.
- The NEESgrid software distribution includes a number of other open source software packages such as the Apache web server, Grid programming libraries, security tools and finite element simulation software (OpenSees and FedeasLab).
The UK-NEES system will be implemented over a two-year timespan. Broadly speaking, the work can be divided into four tasks, some of which can be carried out in parallel.

**Task 1: Procurement and commissioning of the basic NEES and AGN equipment**

The equipment required is constrained by the need for the UK-NEES system to integrate as closely as possible with the US system, allowing us to take advantage of the substantial development effort that has already taken place in the USA. This will also enable tele-participation and data exchange between the USA and UK, in both directions, in addition to the within-UK networking capabilities.

We will use identical equipment at each site in order to minimise set up costs, maintain compatibility and facilitate long term mutual support. Given Bristol’s prior Grid-related experience, the first facilities will be set up in the BLADE laboratories, following which the Bristol staff will assist Oxford and Cambridge colleagues in the deployment of their systems.

Each of the three UK-NEES sites will have a common base configuration as per the standard NEES specification, augmented to suit site-specific requirements. The base configuration will comprise three dual processor Red Hat Linux based servers, each with 2GB RAM, 250GB hard disk, twin 1Gbs Ethernet ports, and a common tape backup. These servers will support the NEESpop, NSDS and flexTPS services described above. Up to five pan-tilt-zoom (PTZ) AXIS 213 PTZ network cameras will be deployed at the sites. These will be located around laboratories and specimens on wall mounts or tripods, as appropriate, to provide streaming video of ongoing experiments. Each camera will be addressable over the Internet and provide remote PTZ control for authorised users.
In conjunction with the NEES servers, each site will have Access Grid Node (AGN) capabilities. The AGN will provide high performance Grid-based teleconferencing and data visualisation in order to facilitate interaction with remote researchers during experimental planning, execution and data processing. At Bristol and Cambridge, the AGN facilities will be in two parts; a two-camera facility in the shaking table or centrifuge control rooms respectively, to enable effective operator interaction, and a larger three camera facility in an adjacent meeting room to support interactions of larger groups of researchers and data processing. The Oxford laboratory is of a different character, comprising a strong floor on which actuators are deployed in bespoke test rigs. For this, only a relocatable three camera AGN is needed. A separate video-conferencing suite is available for out-of-lab interactions. We intend to use AGN equipment supplied by InSors. Bristol University already has excellent experience of an InSors AGN as the basis of its EPSRC funded Regional e-Science Centre, located in the Dept of Physics. We will therefore be able to take advantage of this experience and minimise the project risks associated with the AGN. Suitable rooms for the AGNs already exist at Bristol and Cambridge. These will need minimal adaptation, but additional high speed network switches will be needed in all cases to augment the existing networking infrastructure.

At the end of Task 1, the three labs will have achieved a basic functionality in terms of teleconferencing and access to the wider NEESgrid facilities.

**Task 2: Integration of control and data acquisition systems**

While the main software required for the UK-NEES is available free of charge from NEESinc, importing this into the three UK laboratories will inevitably result in some compatibility problems which will have to be addressed through local modification and augmentation of the software. The main systems integration effort will be associated with the interfaces with existing data acquisition and control systems at the three sites. While NEES has established a basic framework for such integration, the NEES-developed software has for pragmatic and cost reasons been based on a single data acquisition software platform (LabView), which is not currently used at the three UK laboratories. We will therefore have to adapt the NEES framework and LabView platform to our existing systems.

At the conclusion of Task 2, all sites will have full functionality – they will have the capability to observe remote experiments, to be observed, and to perform distributed hybrid tests. For example remote researchers from other centres in the UK will be able to teleparticipate at virtually no cost using their normal desktop PC with a standard cheap web camera and free, open source Grid-access software, or alternatively using any large scale AGN to which they may have access. The proposed UK-NEES website will provide a help service in this respect.

**Task 3: Evaluation and demonstrator tests**

This task will comprise two types of test of the system capabilities – teleparticipation, and distributed hybrid testing.

Teleparticipation tests will aim to evaluate the ability of a remote user to observe and interact with a laboratory experiment. At the simplest level, the remote user would merely be able to observe a fixed view of a test in progress. Higher levels of sophistication would involve remote control of the cameras, simultaneous monitoring of video and test data, and visual and
verbal interaction with the local test personnel. A series of such tests is envisaged, first between the three UK-NEES laboratories, then involving a non-NEES user, for example an academic at Bath or Newcastle University. Lastly, trans-Atlantic interaction between each of the three UK-NEES sites and their US partners would be investigated. This last case would involve teleparticipation in both directions, i.e. a UK lab (e.g. Oxford) acting as remote participant in a test at a US lab (e.g. Berkeley), and also the reverse set-up.

The second and more ambitious test element will be the performance of a series of distributed hybrid tests between the three laboratories. Since these will aim to test out the capabilities of a highly complex distributed system, the test structure itself will be deliberately simplified. Testing will take place out of real time, but with forces and displacements passed between the sub-structures at each timestep. A key issue to be addressed in this task is ensuring continuity and stability of a test in the event that a required item of data fails to arrive within the expected timescale. Various strategies to address this issue will be investigated, for example, running extrapolation algorithms at each site, which can provide estimates of displacement increments in the absence of better data, or controlling each physical test via a local numerical model which is regularly updated by data from the other sites.

Initially, two-site tests would be performed, and then finally a three-site test. Figure 2 shows a schematic set-up for the three-site hybrid test of an idealised bridge structure subjected to an earthquake ground motion. Physical testing will be performed on a reduced-scale piled foundation model (Cambridge), a large-scale model of a support pier (Bristol) and a full-scale bearing (Oxford). The deck and the remaining pier will be modelled numerically. The numerical models will output interface displacements, which will be applied to the test specimens by actuators. Measured forces will be fed back as part of the inputs to the next analysis step of the numerical models. This approach minimises the potential for stability problems by enabling each physical test to run under displacement control. A wide variety of tests can be obtained by simple alterations to this set-up. For example, it would be possible for the two numerical models to run at different sites. Additionally, two-site tests can be achieved by replacing any one of the three physical tests by a simple numerical model.

![Figure 2 Schematic of three-site distributed testing of an idealised bridge structure](image)
**Task 4: Dissemination**

The work programme will be completed by focusing on dissemination to the UK and European research communities, to the UK practitioner community, and to schools and the general public. This will involve developing web based information and training materials etc., to encourage and simplify remote participation, holding demonstrator on-line experiments, and running a workshop and presentations.

**References**


