Community Workshop: 2020 Vision for Earthquake Engineering Research in the USA

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SUMMARY:
A brief summary is provided herein of the outcomes of the recent workshop, *Vision 2020: An Open Space Technology (OST) Workshop on the Future of Earthquake Engineering*. Vision 2020 was held to formulate a vision of where Earthquake Engineering in the US needs to be in 2020 to vigorously address the grand challenge of mitigating earthquake and tsunami risk going forward. The objectives of the workshop were: 1) to chart the principal new directions in earthquake engineering research, practice, education and outreach for the earthquake engineering community over the next 10 years, and to postulate the needs beyond 2020; and 2) to reflect on the role of the current NSF NEES facilities in meeting the research needs of the earthquake community and to elucidate what new facilities would facilitate rapid progress along these new directions. Eighty-three participants attended, representing a diverse cross-section of researchers and practitioners from the earthquake engineering community.

Keywords: Resilience, Monitoring, Data, Cyberinfrastructure, NEES

1. OVERVIEW

Earthquake engineering has matured over the past decades. This process has been reactive, driven, to a large extent, by needs to mitigate damage that occurred in recent earthquakes. Today, a decade after the last significant U.S. earthquake, in an economic recession, with the public focus on climate change and energy issues, earthquake engineering faces a challenge to re-new itself.

This report provides a brief summary of the discussions that took place during the January 25-26, 2010 workshop, Vision 2020: An Open Space Technology (OST) Workshop on the Future of Earthquake Engineering. Vision 2020 was established to formulate a vision of where earthquake engineering in the U.S. needs to be in 2020 to vigorously address the grand challenge of mitigating earthquake and tsunami risk going forward. The full text of the report (Figure 1) is available at: http://nees.org/resources/1636

The participants of the workshop unanimously identified resilient and sustainable communities as the over-arching long-term goal to achieve in earthquake engineering. The term "resilient" is defined as (1) capable of resisting a shock without permanent deformation or rupture (2) tending to recover from or adjust easily to misfortune or change" (http://www.merriam-webster.com/netdict/resilience). Seven principal directions were identified in earthquake engineering research where significant progress needs to be made by 2020 to attain the resilient and sustainable community goal.

2. OUTCOMES OF THE WORKSHOP

The seven principal research directions identified where significant progress needs to be made by 2020 are: 1) metrics to quantify resilience; 2) tools for hazard awareness and risk communication; 3) reducing the risk posed by existing structures and infrastructure; 4) developing and implementing new materials, elements and systems; 5) monitoring and assessing resilience; 6) means to simulate resilience of systems; and 7) implementation and technology transfer. Each topic is summarized herein.

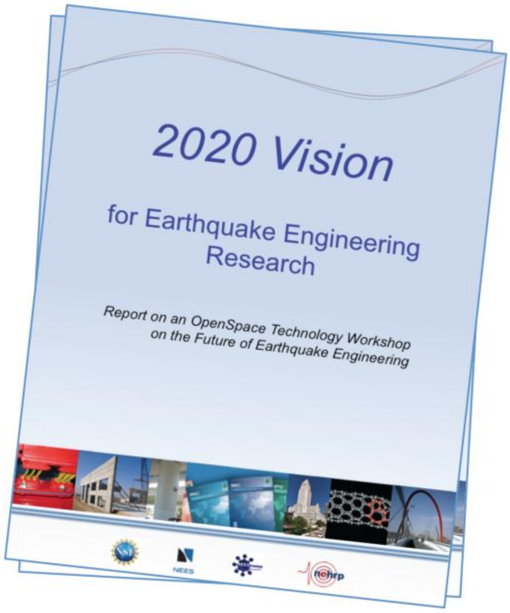

Figure 1. 2020 Vision Report.

2.1. Metrics to Quantify Resilience

Our futuristic vision for resilient communities is one that has transparent expectations of community performance before, during and after an earthquake. In other words, a community should be able to identify how to prepare for an earthquake, how it will respond during an earthquake, and how it will function and recover after an earthquake. Such expectations of community performance should be defined in terms of both functionality and time after an event. They also need to be communicated in simple, concise terminology to the public. To this end, earthquake engineers need to be able to interpret the expected community performance descriptions in terms of engineering performance objectives (within the context of resiliency) and be able to measure resiliency to evaluate the expected performance.

Metrics for resilience can be categorized in the following three ways:
• Performance goals: based on a qualitative definition (e.g., robust, redundant, rapid, etc., based on Bruneau and Reinhorn (2006) and Bruneau et al. (2003)). Once the qualitative definition is given, performance objective levels can be identified based on level of damage and length of time to recovery.
• Response parameters: need to evaluate the response of the infrastructure to the event (e.g. earthquake); and to evaluate the response, we need to know what to measure. For example, within the context of structural performance we may want to measure drift and inelastic material response among other things.
• Quantitative measures: uses numbers. There is a need to quantify the micro- and macro-level resiliency. Then, these values must be related back to the performance objectives so that we can identify the category.

In developing these measures, we need to consider not only the interdependencies among the different infrastructure systems, but also between these systems and the community. Each community should define an overarching goal (e.g., number of days to recovery) and that goal should be more than just safety. The community should also prioritize the required functionality following a large event. For example, safety should be the first priority to minimize casualties. Following that, the goal should be functioning shelter, which means that the building is safe to occupy and the water, sewer, and electric are working. Finally, the community should resume normal work functions, which means being able to use transportation to arrive at their place of work, communication lines are functioning, as is the economy.

The enabling technology needed to develop measures of resilience is high performance computing and computer tools suitable for such computing platforms. Advances in computing technologies will permit fast and advanced analyses so that the measurements can be made within a risk and reliability framework (which considers the uncertainties in the parameters). The measurements should be validated with NEES data that can be used to develop fragility curves, which in turn can be used to measure resilience quantitatively using loss estimation tools.

2.2. Hazard Awareness and Risk Communication

Our vision for 2020 and beyond includes the development of enabling technologies and tools to enhance the situational awareness of first responders (e.g., police, fire fighters, civil authorities, FEMA personnel) through real-time risk assessment. The tools will include new technologies to: assess the real-time structural integrity and predict the immediate post-hazard event environmental risks; communicate optimal rescue and mitigation actions; and assess the subsequent results. A fundamental requirement for these tools will be the development and implementation of smart sensors in structures and the environment, and real-time data collection and assimilation during and after the hazard events. These tools will span multiple time-scales during, immediately after, and long after the occurrence of the event.

These capabilities will require the development of advanced nonlinear structural analysis tools that assimilate measured data in real-time, and the establishment of new sensor technologies and data collection and processing systems. The sensors, which are often inaccessible after installation, would best be self-powered, deriving their energy from the ambient environment. Achieving this vision also requires the adaptation of decision support tools for application to structural damage assessment and mitigation strategies. The tools will enable engineers to provide short-term instantaneous predictions with continuously updated forecast based on real-time data monitoring and assimilation, as well as long-term post-earthquake risk predictions based on response simulation. These predictions will be used for post-hazard event search and rescue and accommodation of people affected by the hazard events.

2.3. Renewal of Existing Structures

Existing vulnerable buildings and infrastructure assets are the number one seismic safety problem in the world today. In the U.S. alone, the 2006 National Research Council Report (2006) notes that 42 states have some degree of earthquake risk, with over 75 million Americans living in urban areas with moderate to high earthquake risk. In addition to unquantifiable potential impact from casualties and injuries, the Earthquake Engineering Research Institute (EERI) concluded in a 2003 report that the direct cost of losses in the built environment and the indirect economic cost (business losses) of a major earthquake that strikes a major urban area could easily exceed 100 billion dollars. This is of the same scale as the losses suffered in hurricane Katrina in 2005 (EERI, 2003).

Urban regions are diverse, complex and interdependent networks of physical systems (education, economic, health, buildings, highways, power and water grids, subways and others) and social and human systems (including schools, agencies, and social networks). In the US, even on the West Coast, urban infrastructure systems are often more than a century old. Thus, many existing buildings and infrastructure assets do not conform to modern seismic design standards. Based on current rates of replacement or repair, today’s built environment will continue in use well into the 21st century. The challenges to community resiliency presented by the uncertainties regarding the actual building and infrastructure inventory and its condition, the costs of current mitigation techniques, and the limitations of existing tools for making decisions about renewal strategies, make the implementation of large-scale structural and geotechnical engineering projects aimed at revitalization to increase resilience one of the grand engineering challenges for the 21st Century (NAE, http://www.engineeringchallenges.org/).

To energetically attack the significant challenge posed by the aging built environment, a number of tools, some existing and some that will have to be developed, systems for renewal, and partnerships between scientists, engineers, and social scientists are needed. The tools cover a broad range, spanning from modeling, physical simulation, computational simulation, to design, repair and revitalization, and to real-time monitoring, behavior data archival, education and information dissemination.

2.4. New Materials and Structural Systems

For the 2020 Vision of resilient and sustainable communities, structures and civil infrastructure will benefit greatly from developments of new materials and new technologies to engineer new or re-engineer old structural systems to improve their performance, increase their lifetime and reduce their load on the Earth's resources. New materials, components and structural systems are those that have not been commonly used in modern earthquake engineering, or such combinations of common materials, components, systems and technologies that have not been attempted to date. It is essential to recognize that new materials and technologies cannot be successfully deployed alone: instead, a new material necessitates a re-design of the components and the system; similarly, a new system may benefit greatly from the superior performance of a new material or a new technology.

Common structural materials: steel, wood, masonry, concrete (a cement-stone composite) and soil are plentiful (thus, inexpensive), and relatively light, strong and stiff. Two research directions are identified: 1) improvement of existing materials; and 2) development of new materials. The first research direction involves starting with the existing, well-known materials, and pushing their properties in desirable directions. The second research direction aimed at developing new materials starts with a description of desirable properties, most likely in terms of mechanical characteristics and durability, followed by a targeted development of new synthetic materials that meet or exceed the stated design requirements. Such new materials may be passive, or may be conceived with sensing and actuation capabilities giving them an auto-adaptive property (Frosh and Sozen, 1999). A newly developed material should be characterized to enable the use of physics-based models to evaluate mechanical response, durability and sustainability of the structures built using it.

Development of new structural technologies is seen as moving on a research track paralleling that of new materials. In fact, significant cross-links between new materials and new technologies are identified. Today, resilent structures are benefiting from material developments that enabled reliable and durable elastomeric and friction-sliding seismic isolators. Tomorrow, new ways to modify the response of structures, through rocking, or through the use of active or semi-active response modification devices, will make use of new materials. An increasing role of cyber-physical systems in new resilient structures is anticiapted: research efforts to understand the dynamics of controlled structural systems, to develop and validate cyber-physical response modification technologies, to introduce them into design practice are needed.

New, resilient, structural components and systems involve strategic deployment of new materials and technologies. Modular structures, engineering structural systems that are built using pre-fabricated components or structural response fuses, and assembled in an accelerated manner, are identified as a paradigm for future resilient structures. Modeling of such structures requires multi-scale and multi-physics modeling and high-performance computing, visualization and data processing capabilities. These models and tools enable simulation of the entire life-cycle of a structure, from the material and component production stages, through construction, service life, including renewal cycles, extreme events and its final de-construction. Validation and verification of such integrated simulation models is necessary, but challenging because of the diversity in length and time scale of the processes involved in the simulation.

Development of resilient and sustainable structures using new materials and structural systems involves a diverse and wide array of engineering disciplines and requires fundamental science. It is clear that structural engineers will have to cooperate closely with materials scientists and mechanical engineers, with computer scientists and experts in cyber-physical systems, as well as architects and community planners to achieve the research goals identified above. It is likely that new alliance, between NEES and similar collaboratories in other engineering and fundamental science areas (e.g. NSF-supported Materials Science Engineering Research Centers) needs to be established to enable cross-disciplinary collaboration to develop new materials and technologies for new resilient structural systems.

2.5. Monitoring and Assessment

Significant improvements in the resilience of our communities will also be achieved by 2020 through innovative use of data acquired through real-time monitoring of the built and natural environments. Ongoing developments in sensor technologies are leading to the possibility of introducing ubiquitous, low-cost, low-energy sensors for monitoring and assessment purposes. Components (buildings, bridges, lifelines, utilities) and systems (communities, regions, oceans, interacting networks) will be instrumented for multiple purposes. Networks of sensors may be used to appropriately measure and monitor event initiation, human responses, ocean conditions, infrastructure conditions, etc., and data acquired from the large number of sensors will offer new opportunities to obtain useful information for decision making. Data acquired may be suitable for a variety of uses such as post-event response planning, model validation, event detection, model updating, real-time diagnostic systems, etc. Vast amounts of data would be collected before, during or after an event and appropriate algorithms to reduce, digest and aggregate such data are crucial to their use.

Furthermore, methods that integrate the latest real-time data to update simulation models and make informed decisions are likely to provide the most useful information during an event. However, techniques to identify suspicious results and verify current conditions are clearly needed. Furthermore, a monitoring and assessment system will often have a need for an information management framework designed specifically to meet the needs of that system.

2.6. Simulation of Systems

Simulation is a central component to improving the resiliency of the built and natural environments to hazards such as earthquakes and tsunamis. The term natural and built environments refers to the natural and human-made surroundings that provide the setting for human activity, ranging in scale from personal shelter and buildings to neighborhoods and cities, and can often include their supporting infrastructure, such as water supply, transportation, or energy networks. From a system of systems perspective, the natural and built environments represent a set of interdependent infrastructure systems that involve some form of dynamic behavior, where parts of the complete system have state conditions that vary independently over time. There has been extensive work in the modeling of some of these systems. However, its application to evaluate their resiliency to earthquake and tsunami hazards has been limited due to the intrinsic complexities and interdependencies involved.

Accurate numerical simulation of individual components (buildings, bridge, traffic, humans, etc) has been a focus of the research for several decades. However, simulations that consider “simulation of systems” should be the focus of future research efforts. Simulation of systems includes developing and utilizing interacting models for the study of interacting elements of the built and natural environments. These include the development of appropriate multi-scale and multi-physics models (and associated software tools), as well as hybrid experiments using current and future NEES facilities and tools. The inter-relations between the built and natural environments include manifestations of the physical and social infrastructures and their connection to the environment. The need for the capability to run such hybrid simulations is clear.

Cyberinfrastructure that will facilitate data collection and management to enable rapid and efficient access and distribution of experimental and simulated data will be essential. High performance computing (HPC) capabilities will also be needed for the analysis of complex systems including interacting systems from the built and natural environments and the implementation of performance based design methodologies that will require thousands of simulations of a given system.

Research focusing on the simulation of systems requires the integration of the outcomes of all of the previously mentioned research directions, and is critical for the acceptance of newly developed approaches.

2.7. Implementation and Technology Transfer

To have a measurable impact on resilience, the research proposed within the previously discussed 2020 Vision directions must be implemented, and the technologies developed must be transferred. More specifically, this requirement encompasses: i) implementation of earthquake engineering research (e.g., the previously discussed research directions) in engineering practice, as well as public policy and decision making; ii) two-way transfers of technology between earthquake engineering and earthquake science, engineering for other natural and man-made hazards (e.g., hurricanes and carbon emissions), and the public and other stakeholders and decision makers; and iii) understanding the social systems that govern the perception of risk, and that mitigate or exacerbate community risk, and nurturing these systems to transform opportunities provided by engineering research into actual community resilience.

3. ROLE OF NEES IN ACHIEVING THIS VISION

The NEES collaboratory has become a global resource for a community focused on the mitigation of earthquake risk and to fulfill the NEES vision – of a global infrastructure network that improves the resilience of new and existing construction, and supports the education of the next engineers and scientists (Figure 2). With current NEES facilities, researchers have the capability to conduct a variety of large-scale physical simulations and relatively simple hybrid simulations, which were not possible before. Existing cyberinfrastructure of the NEES collaboratory also allows the research, education and practicing communities to ingest, preserve and access data that is useful for researchers, educators and practitioners. These facilities are making it possible for researchers to perform a new generation of experiments and do so in a collaborative environment. Several specific requirements for the NEES collaboratory were identified in the full *Vision 2020 Workshop Report* (http://nees.org) as necessary to achieve the 2020 Vision goals.

4. SUMMARY

Achieving the 2020 Vision will require a revolutionary change in the earthquake engineering processes typically followed to generate fundamental knowledge and develop enabling technologies. Earthquakes cannot be prevented, but their global impacts on life, property and the economy can be managed. Our civil infrastructure is already undergoing substantial changes with the integration of sensor networks, intelligent controls, smart materials and real-time health and condition monitoring. This trend will intensify, resulting in improving the efficiency and performance of these systems for future generations. Additionally, research demonstrating the cost-effectiveness of performance-based design practices, applications of new materials to reduce earthquake impacts, and improved retrofit strategies will facilitate removal of existing barriers to their adoption. Demonstrating that investments in earthquake safety can reduce losses from other hazards and improve whole-life cycle performance and sustainability will also support their widespread implementation. However, the various disciplines within earthquake engineering must work together to accelerate progress toward these highly multidisciplinary questions.

Figure 2. NEES Facilitates innovative research and cyberinfrastructure to realize this Vision.

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