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2020 VISION FOR EARTHQUAKE ENGINEERING RESEARCH

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ABSTRACT

This paper provides a brief summary of the discussions that took place during the recent 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 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 debate the emerging principal new directions in earthquake engineering research, practice, education and outreach to be followed by the earthquake engineering community in 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 try to elucidate what new facilities would facilitate rapid progress along these new directions. A total of 83 participants attended, representing a diverse cross section of researchers and practitioners from the earthquake engineering community. This workshop was conducted using Open Space Technology, a radically new approach that enabled participants to self-organize and define the agenda during the meeting. This paper summarizes the main outcomes of the Vision 2020 workshop.

Introduction

Earthquake engineering has matured over the past decades. This maturation process has taken this engineering discipline from its structural engineering roots in the first lateral load code provisions made in the 1930's through an integration of earth sciences, structural and geotechnical engineering, structural mechanics, architecture, numerical and probabilistic mathematics, education and social sciences into what we today know as earthquake engineering. The focus on performance measured by the consequences of an earthquake on the function of a

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stricken structure and/or a stricken community is a direct result of the work of the three NSF-funded Earthquake Engineering Centers during the past decade. Today, the practicing community is adopting a performance-centric approach to design through the new design code provisions (e.g., ASCE 31 [1] and ASCE 41 [2]) for tall buildings, hospitals and bridge infrastructure.

The George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) is a major national resource meeting the research needs of the earthquake engineering community. This NSF-funded network of structural, geotechnical, tsunami and earth science fixed and mobile laboratories provide the means to conduct complex experimental and numerical simulations of seismic response of structures and infrastructures with capabilities not available previously. The NEES network aims to provide a fertile environment for collaboration of teams capable of tackling major earthquake engineering challenges in a multidisciplinary fashion. Thus, the capabilities and continued operation of the NEES network to best address the needs of the hazards community should be considered in parallel with any discussion of the vision for the future of the earthquake engineering disciplines.

The Vision 2020 workshop was organized with the goal to formulate a vision of where Earthquake Engineering in the US needs to be in 2020 going forward. The outcomes of the Vision 2020 workshop are presented in this paper. A more in-depth report will be available through the NEES website (nees.org).

Open Space Technology (OST) was used to conduct this workshop. OST is a method to run meetings of groups of any size to address complex, important issues and achieve meaningful results quickly (www.openspaceworld.org/). OST represents a self-organizing process: participants construct the agenda and schedule during the meeting itself. OST is also a method to allow a diverse group of people to jointly address complex and possibly controversial topics. Most important, it provides the space for everyone in this group to express his or her opinion and a way for that opinion to be heard and affect the final outcome. During the workshop a diverse set of 35 topics were generated by participants. During the course of the two-day workshop, these topics were discussed in terms of their potential for having an impact on how our society responds to earthquakes and other hazards.

The participants of the workshop unanimously identified resilient and sustainable communities as the principal goal to achieve in earthquake engineering by 2020. While the goal of resilient and sustainable communities is evolutionary, achieving it requires a revolutionary change in the earthquake engineering processes deployed to generate fundamental knowledge and develop enabling technologies. Working towards this goal will transform the discipline of earthquake engineering into a complex system of interacting disciplines where new knowledge is generated through intellectual efforts at the intersections of the constituent branches of engineering, fundamental sciences and social sciences. Such transformation of earthquake engineering will broadly impact the coming generations of students through new multi-disciplinary research and practice.

Vision 2020 Outcomes

While the overarching theme was consistent with the goal of the new National Earthquake Hazards Reduction Program (NEHRP) plan for achieving resilient and sustainable communities, the participants recognized that work on achieving this goal could take the research community beyond 2020 and proceeded to develop a vision for how to achieve this goal. Seven required elements and characteristics of engineered systems were identified. These are: metrics to quantify resilience; the means for hazard prediction and risk assessment; continued challenge posed by existing structures and infrastructure and the orderly renewal of the same; opportunity to use new materials, components and systems; methods and tools to develop inventories of sufficient fidelity for monitoring and assessment for resilience; means to simulate resilience of systems at regional scale; and methods for implementation and technology transfer. These goals are defined below.

Metrics to Quantify Resilience

The term “resilient” is defined as “(1) springing back; rebounding; (2) returning to original form or position after being bent, compressed, or stretched”. A definition for resilient communities is needed within the context of our engineering profession, as well as the associated performance metrics. The earthquake engineering community should be able to identify how a structure will respond to a given load intensity (e.g. earthquake size), and this should be communicated in simple, concise terminology to the public. To this end, we need to be able to identify expected performance levels (within the context of resiliency) and be able to evaluate resiliency so that we can identify the expected performance.

However, our goal is a resilient community, not just a resilient building. While a building is a part of the community, our vision and goals are broader than that. In addition, the building is not functional if lifelines (water, electric, sewer, etc) are not functioning. Furthermore, resiliency applies to the entire lifetime of a structure, not just a single event like an earthquake. Therefore designs for resilient performance must be considered for multiple hazards such as earthquake, fire following earthquake, hurricane, impact, blast, or whatever is appropriate for the given structure.

Hazard Prediction and Risk Assessment

In 2020 and beyond, engineers will have developed enabling technologies to provide tools to enhance the situational awareness of first responders (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 in a systematic manner. 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 timescales during, immediately after, and long after the occurrence of the event.

The availability of advanced models for the various systems involved is crucial to the development of this capability. Prediction of tsunami after an earthquake event using an analytical model (e.g. planar fault) involves obtaining measurements related to the earthquake such as focal depth, strike angle, dip angle, rake angle, slip length and width of the fault area. Prediction of structural damage, injury and loss of life is a continuous process and involves models capable of considering multiple length and time scales. Furthermore, advanced nonlinear structural analysis tools would be needed to assimilate real-time measurements with measured data. Thus, this goal requires development of new sensor technologies and data collection and processing systems.

Renewal and Existing Systems

Existing vulnerable physical assets are the number one seismic safety problem in the world today. In the U.S. alone, the 2006 National Research Council Report [3] 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. Based on current rates of replacement for buildings and existing infrastructures, today's built environment, a significant percentage of which does not conform to modern seismic design standards, will continue in use well into the 21st century. The challenges presented by the uncertainties regarding the actual 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 renewal strategies one of the grand challenges for the 21st Century.

This research theme tackles an important and challenging problem that will advance discovery and understanding in earthquake engineering and serve as a model for other hazards, providing a comprehensive and sustainable solution to the problem of our aging built environment. To address the renewal of the built environment, engineers and scientists need new and improved tools to accurately assess the hazard, including the possibility of early warning of impending earthquake. To assess the exposure, improved inventory techniques for management of large databases and technologies to sample and assess the condition of these large inventories need to be developed. Advanced computational models, using the latest cyberinfrastructure and data from tests of large systems both from laboratories and the field, are needed to identify physical systems that represent the largest level of exposure, so communities can prioritize mitigation expenses and conduct an informed renewal of the built environment.

New Materials and Structural Systems

The 2020 vision of resilient and sustainable communities, structures and civil infrastructure can be achieved by harnessing the developments of new materials, new components, connections and modules to engineer new or re-engineer old structural systems with a goal to improve their performance, increase their life and reduce their demand on Earth's resources. New materials, components and systems are those that have not been commonly used in modern earthquake engineering, or such combinations of common materials, components and systems that have not been attempted to date. It is essential to recognize that new materials or improvements of existing materials, or components, or systems cannot be successfully deployed alone; instead, a new material may necessitate a re-design of the components and the system. Similarly, a new system may benefit greatly from the superior properties of a new material or from purposefully designed structural components.

New fundamental knowledge needed to fuel the development of new materials, components and systems including the characterization of material properties and physics-based modeling of materials. New structural components and connections, including innovative strategies of deploying new materials and cyber-physical components to make auto-adaptive, "smart", structural systems and new, modular-construction structural systems are the technologies that will enable new resilient and sustainable communities. Resilient and sustainable structures made using new materials, components and systems must be able to compete in the market place. To win, the benefits of their resilience, improved performance, reduced risk, accelerated construction and deconstruction, and reduced environmental footprint must be quantified and compared to other solutions. Engineering design and evaluation procedures of new resilient structural systems, components and materials are key for adoption of these systems by 2020.

Monitoring and Assessment

Improvements in the resilience of our communities will also be achieved by 2020 through innovative use of data acquired through instrumentation 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 condition, 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 may be collected before, during or after an event. Thus, appropriate algorithms to reduce, digest and aggregate such data are crucial to their use. 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.

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. Simulation can refer to numerical simulation, but more broadly in the earthquake engineering community it encompasses both physical and numerical simulations, as well as hybrid simulations involving both.

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 also be a 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 models and multi-physics models, 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.

Technology Transfer

To have a measurable impact on resilience, the research proposed within the previously discussed Vision 2020 themes must be implemented, and the technologies developed must be transferred. More specifically, this requirement encompasses: i) implementation of earthquake engineering research (e.g., the other 2020 Visions themes) in practice; ii) implementation of earthquake engineering research and practice in public policy and decision making; and iii) the 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.

Unlike other 2020 Vision themes discussed previously, the research required to improve technology transfer is not so much earthquake engineering research as it is research on topics such as diffusion of innovations, early adopters, encouraging change, effective communication (including social media), education (including curriculum development), and collaboration. However the direct impact on the engineering field is clear. This research would lead to: building codes that better take advantage of recent earthquake engineering research, as is done in implementing earthquake science research through the USGS National Seismic Hazard Maps; and building rating systems that, in effect, transfer the technology of risk modeling, once in adequately robust and objective forms, to the public.

Role of NEES in the 2020 Vision

With current NEES facilities, researchers have the capability to conduct a variety of large-scale physical simulations and relatively simple hybrid simulations. Cyberinfrastructure of the NEES collaboratory also allows the research and education communities to ingest, store and access data that is useful for researchers and practitioners. These facilities are making it possible for researchers to perform a new generation of experiments and do so in a collaborative environment.

However, to meet the Vision 2020 goals, the technologies discussed previously will need to be validated through existing and possibly new NEES facilities. Several opportunities for the NEES collaboratory that are related to the Vision 2020 goals discussed previously include:

- Improved NEES capabilities to allow researchers to consider community impact. Developments are needed to better integrate social, physical and numerical components into simulations;
- Enhanced capabilities for the simulation of complex systems that require multi-scale and multi-physics modeling;
- NEES facilities to validate techniques involving the use of new materials, and the new components and connections developed specifically for their use. The behavior of systems constructed using modules made of these components and connections must be determined;
- Verified real-time structural assessment and data assimilation methods using large-scale structural and centrifuge facilities and shake tables;
- State-of-art capabilities of the NEES collaboratory to support the data archiving, testing, computational simulation and collaboration infrastructure;
- Experimental data should also be reported within the context of quantitative resilience metrics at the community level and to measure resilience quantitatively;
- New types of field testing equipment to enable verification and validation of models and methods at full scale;
- Cyberinfrastructure resources to develop the data structures and visualization methods needed to enable effective simulation of new resilient communities;
- Access to national high-performance computing resources to facilitate numerical simulations; and
- Improved data collection and information management capabilities, so that measured data can be used to update simulations in real-time.

The goals should be to make NEES a global resource for a community focused on the mitigation of hazard risk and to fulfill the NEES vision – a laboratory without walls. Earthquakes cannot yet be prevented, but their global impacts on life property and the economy must be managed. The dissemination of knowledge by sharing data, research and learning tools through the NEES cyberinfrastructure resources; and by involving earthquake professionals, social scientists, educators and urban planners should contribute to reduce the risks of life and property from future earthquakes and likely other hazards.

Summary

The Vision 2020 workshop was held to formulate a vision of where earthquake engineering in the US needs to be in 2020. Eighty-three participants in attendance, representing a diverse cross section of researchers and practitioners from the earthquake engineering community, identified resilient and sustainable communities as the overarching goal to achieve by 2020. Seven principal elements and characteristics of engineered systems were identified. These were: metrics to quantify resilience; the means for hazard prediction and risk assessment; continued challenge posed by existing structures and infrastructure; opportunity to use new materials, components and systems; methods for monitoring and assessment of resilience; means to simulate resilience of systems; and methods for implementation and technology transfer.

Achieving the Vision 2020 goals will require a revolutionary change in the earthquake engineering processes deployed to generate fundamental knowledge and develop enabling technologies. The various disciplines within earthquake engineering will need to work together to make progress toward these highly multidisciplinary questions. Furthermore, new and existing NEES facilities and cyberinfrastructure capabilities will play a significant role in performing the research and validation. NEES will also facilitate an impact on practitioners, emergency responders and the education of our youth through related activities. Such a transformation of earthquake engineering will broadly impact the coming generations of students through transformative research followed by application of these innovations in practice.

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