OPPORTUNITIES FOR INTERNATIONAL COLLABORATION ON EARTHQUAKE ENGINEERING THROUGH THE GEORGE BROWN JR. NETWORK FOR EARTHQUAKE ENGINEERING SIMULATION

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Abstract: In late 1999, the US National Science Foundation (NSF) launched a major new research initiative known as the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). This initiative substantially upgrades resources available in the US for experimental and computational research related to the simulation of earthquake effects on the engineered environment. Importantly, these resources are interconnected and linked to the earthquake engineering community via a state-of-the-art, network-enabled infrastructure for information management and communication. The NEES infrastructure is expected to become fully operational in late 2004, and a ten-year program of collaborative research and education is being planned utilizing these resources. The NEES program raises numerous, important new opportunities for international cooperation and collaboration in the field of earthquake engineering, not only in terms of cooperative activities focused on technical problems of global importance, but also in terms of the prospects at the international level for enhanced communication, archiving of data and exchange of information and personnel.

BACKGROUND

The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) is intended to transform America's ability to carry out earthquake engineering research. This program involves capital outlays from NSF and host institutions in excess of $100 million. Research and operating expenditures are likely to exceed four times this amount over the planned ten-year operation of the facilities. NEES is intended to accelerate substantially progress in earthquake engineering, leading to technically sound and cost-effective guidelines for the design, analysis and evaluation of engineered facilities and systems. Specific goals generally cited for NEES include generating new engineering knowledge vital to reducing the vulnerability of the engineered environment to catastrophic earthquakes, and educating a more diverse and capable workforce.

The NEES initiative is part of the Major Research Equipment and Facilities Construction (MREFC) program at NSF. The intent of this program is to provide the NSF research community with major world-class research tools, on a shared-use basis, that can enable them to address problems of critical importance to the United States and the world. Similar major research facilities programs at NSF include the South Pole Station, Laser Interferometer Gravitational-Wave Observatory (LIGO), National Radio Astronomy Observatory, and the National Center for Atmospheric Research. NEES is the first MREFC initiative to be undertaken by the Engineering Directorate, and as such, incorporates several new and unique features.

When fully operational in October 2004, the NEES program will provide the US earthquake engineering community with an unprecedented infrastructure for research and education. This infrastructure consists of networked and integrated resources for experimentation, computation, model-based simulation, data management, idea generation, and communication. Rather than placing all of these resources at a single location, NSF is leveraging its investment and fostering the integration of research and education by distributing the new shared-use equipment among approximately 15 universities throughout the US. To insure that researchers can effectively use this equipment, the new NSF-funded equipment sites will be operated as shared-use facilities, and NEES will be implemented as a network-enabled collaboratory. As such, members of the broad earthquake engineering community will be able to access unique, next generation instruments and equipment, interact with one another, share data and computational resources, and retrieve information from extensive digital libraries, without regard to geographic location.

In this paper, some of the unique features of NEES are described, focusing on those related to operating NEES as a collaboratory. Opportunities for international collaboration are also highlighted.

CURRENT ACTIVITIES

Currently, four major activities are being undertaken to bring the NEES program on line. These include (1) constructing the shared-use equipment sites, (2) developing standards and advanced networking capabilities to connect experimental, computational and other resources with the earthquake engineering community as well as to the public at large, (3) developing a community-backed research collaboratory and consortium to carryout and help manage NEES activities, and (4) identifying a research agenda that addresses high priority needs. The status of these activities is briefly summarized below.

The portfolio of new shared-use, test equipment being developed within NEES includes major new or upgraded shaking tables, reaction wall facilities, geotechnical centrifuges, tsunami wave tanks, and field test capabilities (a few of the facilities are shown in Figs. 1 through 5). Many next-generation capabilities and features have been incorporated in these facilities, enabling types of experimentation and tests not previously possible in the US. Shared-use sites are currently under construction at:

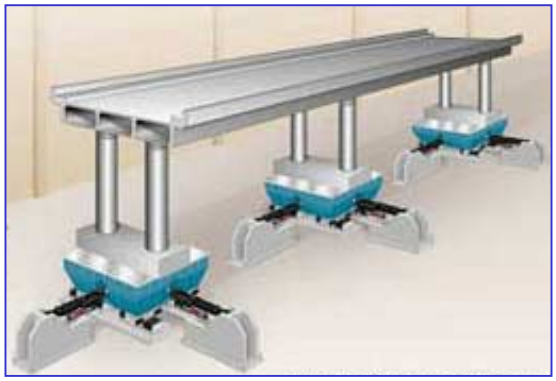
- Actuator-based Hybrid Simulation Facilities: Lehigh University, University of Buffalo, University of California at Berkeley, University of Colorado at Boulder, University of Illinois at Champaign-Urbana, and University of Minnesota at Minneapolis
- Field Test Facilities: Bingham Young University, University of California at Los Angeles, and University of Texas at Austin
- Geotechnical Simulator Facility: Cornell University, Rensselaer Polytechnic Institute, and University of California at Davis

- Shaking Table Simulation Facilities: University of Buffalo, University of California at San Diego, and University of Nevada at Reno
- Tsunami Wave Basin Simulator Facility: Oregon State University

At each site, participation by off-site collaborators is being encouraged through the development and installation of advanced capabilities for tele-observation and tele-operation. Information on the objectives and capabilities at each site may be found at: http://www.nees.org.

To enable broad-based collaboration by the earthquake engineering community, recent advances in information technology and computer science are being adapted and extended as a central feature of the NEES program. The systems being implemented will provide convenient, secure and dependable access to NEES resources and data. Integral to this system is a high-performance (>1Ghz) network with integrated services providing secure access to computational resources, software, databases and communication capabilities. In addition, it is providing a common infrastructure and set of protocols and tools for defining, sharing, analyzing and storing data and metadata, and carrying out hybrid simulations drawing concurrently upon experimental and computational resources at several geographically distributed sites. This system integration effort is led by the National Center for Supercomputer Applications (NCSA) headquartered at the University of Illinois at Urbana-Champaign, in conjunction with a consortium of other universities and national laboratories. In addition, the NEES IT infrastructure will provide a capability for grid-based, high performance computing. This will involve a special implementation of the open source computational framework known as OpenSees (see http://www.opensees.edu) and other similar applications for numerical simulation. Special emphasis will be placed on software for introducing high performance computing within an educational context (see: http://www.ce.berkeley.edu/~filippou/Courses/FEDEASLab.htm). More information on the NEES network and related services may be found at http://www.neesgrid.org.

The overall NEES infrastructure is being administered and managed by a single community-based and community-led not-for-profit entity, known as the NEES Consortium, Inc. (NCI). The NEES program will be operated as a collaboratory serving the needs of the entire earthquake engineering community. As such, NCI will be responsible for the management, operations and maintenance of the various laboratories, computational, network, database, software, and other resources that are part of the overall NEES program, and for facilitating the participation of the earthquake engineering community in NEES related activities. Additional information on the NEES Consortium, including the by-laws and charges to various standing committees, may be found at http://www.nees.org/.



NSF has funded two national projects to help identify and prioritize the long-term uses of NEES resources. The Earthquake Engineering Research Institute (EERI) undertook one of these efforts, which focused on identifying the overall research needs for reducing earthquake losses in the US. The National Research Council, and focuses on the specific uses of NEES carried out the other effort. The results of the EERI effort (EERI, 2003) may be found on line at http://www.eeri.org. The report of the National Research Council (NRC, 2003) is available at http://www.nas.edu/nrc/.

SPECIAL FEATURES OF NEES

While several NSF programs have general goals similar to those articulated for NEES, there are several features that make NEES unique. Clearly, the unprecedented array of new next-generation resources will increase the ability of researchers in the US to carry out cutting-edge research. However, other features are likely to have even more profound long-term impacts. These include the intent of programs organized within NEES to (1) integrate and serve the entire earthquake engineering community and (2) and explicitly incorporate aspects of experimentation, theory formulation and validation, data curation, model-based simulation, high performance computing and education. As such, in solving challenging earthquake engineering problems, NEES programs will employ a comprehensive array of methodologies and tools as well as a diversity of backgrounds, disciplines and expertise.

Another unique feature of NEES is the "shared use" nature of the new experimental facilities being funded by NSF. While a portion of the use of these facilities is reserved for investigators at the host institution, the majority of use is intended for NEES projects by off-site investigators.

An important aspect of the NEES program is that the majority of the efforts and costs associated with managing, operating and maintaining NEES resources are directed by NSF to NCI. NEES research projects using these shared-use facilities are funded directly by NSF, and awards are made on the basis of competitive reviews of proposals received from the entire earthquake engineering community. Thus, NCI has no specific input into the nature of the research programs undertaken. Since NSF will fund (through NCI) the shared-use aspects of operating these new equipment sites, the cost to NEES research projects of conducting tests or other activities at shared use facilities should be substantially reduced. In addition, each shared-use facility will provide on- and off-site researchers with an array of services, including (1) on-site and on-line training on use of the facilities, (2) extensive capabilities for tele-communication, tele-observation and tele-operation; (3) personnel to assist with planning and conduct of tests; (4) help in locating local contractors and support personnel necessary conducting the tests; (5) assistance with documenting and storing data; (6) well-written on-line manuals, help desks and knowledge bases and (7) educational opportunities for participants while on site. NCI will provide a number of critical services, including archiving data and metadata, providing support for the development of shared-risk tools, such as various software applications, and encouraging broad-based collaboration within the earthquake engineering community.

The shared-use aspect of NEES will allow investigators from universities, other research and educational institutions, industry and business to propose (or participate in) research programs even if their home institutions do not have the necessary research resources. Similarly, students interested in conducting experimental research following graduation can join a university or organization that does not have its own laboratory or computational facilities, and be assured of ready access to world-class resources.

One of the major features of NEES is that it is to be implemented as a collaboratory. This strategy is intended to accelerate progress through the integration and synergism associated with collaboration. It also builds upon specific advances in information technology that facilitate the interaction of collaboratory participants with each other, with research equipment and instrumentation, with large and diverse data sets, and with software and other applications. The Collaboratory may well prove to be the primary catalyst within NEES for transformation of the earthquake engineering community.

THE NEES COLLABORATORY

The collaboratory concept utilized in NEES refers in part to the harnessing of information technology to: (1) bring researchers, educators and students together with members of the broad earthquake engineering community and public, (2) provide them ready access to powerful experimental, computational, database, information management and communication tools, and (3) facilitate their collaboration, without regard to geographic location, as if they were "just across the hall." This builds upon the well-known concept initially proposed by William Wulf [NRC, 1993]. To achieve this ideal, collaboratories incorporate a number of specific capabilities to facilitate sharing of data, sharing of software, sharing of research facilities, developing "shared risk" community-based resources, and communicating with remote colleagues. In this context, a collaboratory is not a "research center" per se, but rather, a proactive and supportive virtual environment that facilitates the research activities of its participants.

It is intended that NEES incorporate other facilities for experimentation, computation, data analysis, and visualization beyond the new shared-use sites, both nationally and internationally. Efforts are currently underway by NCI to identify minimum resources, policies and costs associated with a resource provider or group becoming affiliated with NEES.

A World Forum on Collaboration in Earthquake Engineering Research is planned later in 2004to discuss such opportunities amongst the international community. This Forum will focus on large, multidisciplinary programs underway globally related to earthquake engineering research, specific infrastructure requirements for implementing NEES-like networking services among international collaborators, and policies and protocols for carrying out collaborative research within the NEES environment.

An important aspect of the NEES Collaboratory is the integration of experimental and computational forms of simulation, and a shifting of focus in the long-term from the mechanics of simulation, to information and information technology. Thus, one might view NEES and the NEES Collaboratory as a means of "getting information to those who need it in a form most useful to them." Experimentation and computation are powerful means to advancing understanding; stimulating innovation and generating needed information. However, ready access to information and promoting information literacy are high priority goals of the NEES Collaboratory.

The Collaboratory Vision

> OVERARCHING GOAL OF THE NEES COLLABORATORY
>
> Integration of people, ideas, and tools within a collaboratory environment to accelerate progress in earthquake engineering

Much of the background related to the development of the NEES program, and the vision for its implementation may be found in a white paper [Mahin, 2002] entitled "Towards a Vision for the NEES Collaboratory." This document includes an extensive discussion of similar projects at NSF, organizational and practical aspects of operating a network-enabled collaboratory, and metrics often used in assessing the performance of such ventures. In addition, the white paper includes a discussion of the NEES participant community and an assessment of the strengths, weaknesses, opportunities and threats of this community that need to be considered in developing the NEES program. The document also proposes draft mission and vision statements for the NEES collaboratory as well as specific goals. The overarching goal of the NEES Collaboratory is the integration of people, ideas, and tools within a collaboratory environment to accelerate progress in earthquake engineering. To achieve this, the NEES Consortium is being implemented to enable the mission identified for the Collaboratory; this mission includes:

1. facilitate collaboration by the earthquake engineering community in research and education, nationally as well as internationally;
2. enhance the research capabilities of the US earthquake engineering community;
3. foster innovative research leading to technically sound and cost-effective approaches to earthquake loss reduction and otherwise serving the critical needs of society;
4. promote the use of engineering knowledge through curated data repositories and programs of information dissemination; and
5. integrate research and education in support of effective programs of education at all levels.

The vision for the NCI and the NEES Collaboratory is to synergistically blend information technology with earthquake engineering, to promote the widespread acquisition and use of engineering knowledge through curated digital libraries, and proactively facilitate programs of information dissemination. NEES research programs are expected to integrate significant aspects of experimentation, theory formulation and validation, data curation, model-based simulation, high performance computing and education, and involve experts from a diversity of technical disciplines. To realize this vision, it is expected that NCI will partner with government entities, academia, industry and business, nationally and internationally. In addition, outreach and educational activities being formulated by NCI are intended to serve the public in numerous ways, including helping develop improved policies and more effective regulations for earthquake loss reduction, attracting and training a more diverse and capable workforce, and developing effective learning programs across the full educational spectrum.

Collaboratory Services

Collaboratory capabilities are being developed to assist investigators before, during and after projects. At the core, these include services for sharing of information, software, facilities, and communication with remote colleagues. These would support activities related to generating of ideas and support for research projects, developing of proposals, planning of research activities, executing the research plan, analyzing and interpreting the results obtained, and incorporating

findings in various education and outreach efforts. A wide variety of activities are possible, depending on the needs of the participants, and the nature of the project. Various collaboration functions, tools and enabling technologies are needed to offer such services.

NEES PROJECTS

As mentioned previously, NSF will determine the type and nature of projects to be undertaken by NEES through a competitive peer-review process. Specific details of the NEES research solicitation may be found at:
http://www.nsf.gov/pubsys/ods/getpub.cfm?nsf03589.
Projects undertaken will consist of an array of: (1) traditional single investigator grants; (2) grants to small groups of investigators addressing specific problems; and (3) larger multidisciplinary, multiple institution programs involving several investigators.

NEES research projects will differ from current efforts in that investigators will need to utilize at least one of the shared-use experimental facilities and take advantage of the next-generation network infrastructure to interact with (1) other investigators; (2) the shared-use or other resources within the NEES federation of resources; (3) data of various sorts, or (4) NEES software and computer applications. Projects funded through NEES will be required to document and share data obtained from experimental and computational investigations in accordance with community-based policies, procedures and formats. Details are currently being developed by the NEES Site Operations and Shared Use Committee and the Data Sharing Committee regarding the types of data and metadata to be archived, and time frame for the release of information to the public.

It is anticipated that the NEES program will more than double funding for earthquake engineering research in the US during the 2004-2015 time frame. As such, there are tremendous opportunities to solve major technical and social problems associated with earthquake engineering.

Single Investigator Grants

Single investigator grants provide the backbone of NSF's research program. By employing competitive peer review, NSF is able to identify the most promising, innovative and technically sound ideas for research. They would be expected to remain an important and vital component of the NEES program.

Such projects may be particularly useful to explore and develop new concepts and methodologies, identify and fill gaps in existing knowledge. Significantly, such grants may be particularly useful in gathering existing experimental and analytical data/metadata and processing it into the format required by the NEES data repository. Like all NEES projects, single investigator grants must utilize one of the NEES shared-use experimental facilities. It is likely, given the nature of NEES, that there will be, even with single investigator type projects, a high level of collaboration with other investigators.

Group investigations

The telecommunication and other collaboration features of the NEES Collaboratory are particularly well suited to assist small groups of investigators wishing to collaborate on a particular problem. Often, these may involve geographically separated investigators having different expertise and backgrounds. For example, experimentalists, theorists and analysts might unite to advance a particular aspect of model-based analysis. Other projects may integrate individual investigations across scales (for example, investigations characterizing behavior at the material, component and subassemblage level) and disciplines (e.g., involving tsunami- and geo-engineers in the investigation of coastal structures). Similarly, groups of investigators might band together to devise testbeds for comparing different approaches to the solution of a common problem (e.g., devising a benchmark structural test platform to assess different active control algorithms, sensors, actuators, etc.).

A special type of group collaboration may involve "mission payload" type investigations, where investigators leverage the efforts of others to conduct research of their own. For instance, investigators working on health monitoring systems and damage assessment algorithms (or investigators focusing on the response of non-structural systems and contents, approaches for improving the performance of vulnerable structures, methods for post-earthquake repair, and so on) may simply want to install special instrumentation on another investigators test specimen, access another investigators analytical model, or to use these models following the studies undertaken by the primary investigator. The NEES Collaboratory will focus on maximizing opportunities for leveraging the impact of individual investigations through such symbiotic and potentially synergistic activities.

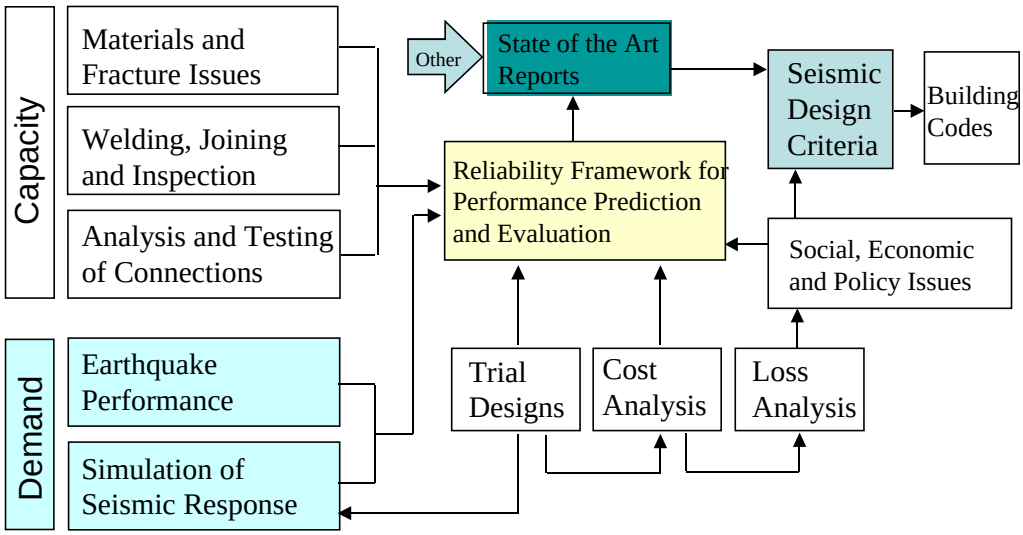
Group collaborations involving expertise from information technology and earthquake engineering may also be appealing. For example, groups may unite to develop community-backed resources, such computational environments and applications for high performance computing and visualization. Other multidisciplinary groups may form to advance experimental methodologies or to enhance data management and mining capabilities.

Grand Challenge Multi-investigator Programs

As important as individual and group investigations are expected to be, it is anticipated that NEES resources will have the largest impact when directed towards "Grand Challenge" projects that address issues of national and international importance. Such projects are ones of substantial scope, and that require, by necessity, large numbers of investigators, consultants, and participants from a variety of disciplines.

A recent example in the US of such a project is the Program to Reduce Earthquake Hazards in Steel Moment Frame Structures [FEMA, 2000]. This project was funded by the US Federal Emergency Management Agency (FEMA), with additional support from other federal and state agencies, industry and a variety of professional and trade associations. This program was initiated in response to the 1994 Northridge earthquake, which caused brittle fractures in the critical beam to column connections of many welded steel moment frame buildings. The types of fractures observed where unexpected, and counter to highly ductile behavior anticipated by building codes. This six year, $12.5 million program involved more than 100 individual research projects, testing at eleven different institutions, and more than 250 individual participants. Using a performance-base reliability framework, it integrated wide-ranging activities, including research, economic, social

and political studies, and guideline development, and training (see Fig. 6). The resources being developed within NEES for analytical and experimental analysis, communication and education would have substantially benefited this program.



Similar grand challenge efforts could be developed to address and extend performance-based criteria for design, evaluation, retrofit and repair other types of new and existing systems. For example, studies could focus on

1. General and regional applications of braced steel frames; composite, reinforced concrete and timber structures; systems incorporating various protective systems, such as seismic isolation and supplemental energy dissipation devices; special occupancy structures employing unusual performance criteria; etc.
2. Various types of nonstructural systems and components as well as critical contents and equipment housed in structures
3. Infrastructure components and systems, including various transportation and utility systems,
4. Geo-structures of various types;
5. Soil-foundation-structure interaction, including the impact of soils and foundations on seismic response and the development and evaluation of various design methodologies,
6. Coastal structures of various types to earthquake ground shaking and the effects of tsunami,
7. Development and evaluation of new and innovative technologies and methodologies (active control, optimum design, high performance materials, hybrid and other special structural systems, etc.)
8. Improved methods for post-disaster condition assessment, safety assessment, loss estimation, repair, including response to unanticipated and undesirable modes of behaviors.

It is clear that the facilities and collaboratory concepts embedded in NEES are applicable to many other forms of natural and man-made hazards, including homeland security. The precise nature and scope of the grand challenge projects undertaken within the NEES program will be developed by NSF on the basis of recommendations contained in the research agenda developed for

NEES and earthquake engineering by EERI and the National Research Council, as well as through various workshops involving various segments of the overall community. Based on anticipated funding levels, between one- and two-dozen grand challenges might be undertaken during 2004-2015.

OPPORTUNITIES FOR INTERNATIONAL COLLABORATION

Tremendous opportunities will arise due to the research infrastructure and programs to be incorporated within NEES. Because earthquake engineering is a worldwide problem, NEES provides special opportunities for international cooperation. This is associated with a number of possible activities, including conduct of international cooperative and collaborative research programs, development of international standards and capabilities for documenting, archiving and sharing information, and exchange of personnel.

While there are regional differences in construction, seismic hazard, performance criteria, building technology and materials, and economic circumstances, many issues are fundamental to all nations. Where major issues of mutual interest can be identified, it is possible that special cooperative or collaborative projects can be facilitated by the technology incorporated within the NEES Collaboratory. Numerous examples of bi-lateral and tri-lateral cooperative programs exist where an international perspective has substantially helped advance achievement of the goals of the program. Importantly, significant opportunities exist to use on an international cooperative basis some of the unique experimental and computational facilities coming on line in the US through NEES, as well as in Asia, Europe and elsewhere in the Americas.

To maximize potential benefits, considerable effort is needed to develop international agreements regarding the basic network services and protocols for sharing information, applications, and implementing tele-presence, tele-observation and tele-operation capabilities. This would include identification of computer and network equipment requirements, resources for data storage and computation, basic user requirements for services, security standards, various definitions, formats and protocols for data and metadata, and so on.

With the acceleration of activities expected in the US related to earthquake engineering research, substantial opportunities should be anticipated related to the exchange of students, faculty, and others in the earthquake engineering community at an international level.

CONCLUDING REMARKS

By bringing researchers, educators and students together with members of the broad earthquake engineering and information technology communities, providing them ready access to powerful experimental, computational, information management and communication tools, and facilitating their interaction as if they were " just across the hall," the NEES and the NEES Collaboratory will be a powerful catalyst for transforming the face of earthquake engineering, nationally and international. The diversity of talents, backgrounds, experience and disciplinary concerns to be represented within the NEES Collaboratory will provide an unparalleled stimulus to intellectual inquiry and education. The NEES Collaboratory will transform the processes by which earthquake engineering research is initiated and performed, accelerate the generation and dissemination of basic knowledge, facilitate the development of effective educational programs, minimize the lag

between knowledge development and its application, and hasten the attainment of universal goals for earthquake loss reduction.

Substantial opportunities exist for cooperation and collaboration at the international level. To this end, it appears desirable to convene a series of international meetings or workshops to begin to lay the foundations for these activities. In addition to experts in earthquake engineering, information technology, and computer science, it is necessary to involve individuals from funding agencies interesting in reducing the threat posed by earthquakes.

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