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National Earthquake Hazards Reduction Program
Fact Sheet

Indian Ocean Earthquake/Tsunami of December 26, 2004

The December 26, 2004 event in the Indian Ocean was a rare magnitude 9.0 earthquake with an undersea source that triggered a massive tsunami. The effects of the earthquake-induced tsunami were felt throughout the Indian Ocean rim countries, resulting in estimates of more than 155,000 fatalities, 500,000 injured, and damages well in excess of $10 billion.

The fact sheet was developed by the National Institute of Standards and Technology (NIST), which serves as the NEHRP lead agency, and reflects inputs from the other NEHRP agencies: the Federal Emergency Management Agency (FEMA), the National Science Foundation (NSF), and the U.S. Geological Survey (USGS).

U.S. Tsunami Preparedness. Ninety percent of all tsunamis are generated by earthquakes, and most tsunamis that have caused significant loss of life and property damage have been earthquake generated. Because the vast majority of tsunamis occur in the Pacific Ocean, the U.S. West Coast, Alaska, and Hawaii all are at risk. Hawaii has been struck repeatedly, and coastal communities in Alaska experienced severe damage from tsunamis generated by the 1964 magnitude 9.2 subduction-zone earthquake. Tsunamis have also been generated in the Caribbean Sea, posing a hazard to Puerto Rico and the U.S. Virgin Islands, and earthquake-triggered subsea landslides have generated local tsunamis along the Atlantic coast of North America.

The greatest tsunami risk to the United States is posed by the 680-mile undersea fault known as the Cascadia subduction zone off the coast of Washington, Oregon, and northern California, which generated a magnitude 9 earthquake in 1700. Such an earthquake could generate a tsunami similar to the one that struck the northern coast of Sumatra, giving only about 10-20 minute warning time to the residents in communities along the Pacific Northwest coastline.

NEHRP is contributing in significant ways to U.S. preparedness in response to tsunami threats:

- Providing alerts for global earthquakes via the the National Earthquake Information Center.

- Supporting research to develop models, tsunami wave basin measurements, and risk assessment tools to predict the location and extent of inundation caused when a tsunami hits land, including study of run up effects, forces on structures, and sediment transport.

- Developing tsunami hazard maps to provide risk assessment information to States and local communities and in order to properly rate flood insurance policies, where tsunamis pose a significant probable flood threat. In addition to modeling and observational data, paleotsunami research is conducted to determine the magnitude and frequency of past tsunamis in high-hazard zones.

- Supporting and promoting the NOAA *TsunamiReady* Program that recognizes local communities with adequate hazard awareness, planning, and preparedness to respond to potential tsunami events.

- Developing and implementing use of tsunami design criteria that enable coastal community shelters or critical facilities to be built to withstand both the severe earthquake and a pre-specified level of tsunami forces without collapse and allowing vertical evacuation of occupants.

- Actively cooperating with Japan through the work of the Tsunami Task Committee of the Panel on Wind and Seismic Effects which was established in 1969 under the auspices of the U.S.-Japan Program on Natural Resources (UJNR).

U.S. Earthquake Preparedness. NEHRP believes that the devastating earthquake that struck off the coast of Sumatra underscores the importance of strengthening U.S. preparedness for earthquakes as much as the resulting tsunami has underscored the importance of strengthening U.S. preparedness for tsunamis. Even coastal regions of the U.S. remain far more likely to experience an on-land earthquake than be hit by a tsunami. And based on population demographics and development patterns, on-land earthquakes could cause far greater devastation to the U.S. population and economic infrastructure than earthquake-induced tsunamis.

Potential loss estimates of a large earthquake in a major U.S. urban area now approach $200 billion. Based on historical data, average financial loss associated with U.S. earthquakes in recent decades is $10 billion per year for buildings, transportation networks, and other lifelines systems, and business disruption. Direct economic losses are about 45 percent of this total.

Congress—in its most comprehensive reauthorization of NEHRP completed in October 2004—recognized that slow implementation of new mitigation technologies, combined with continued widespread development in areas of high seismic risk, has resulted in a rapid and steady increase in societal vulnerability to a major earthquake. It strongly endorsed the priorities identified in the recent NEHRP Strategic Plan and authorized significant increases for key initiatives that address national needs. These include:

- Completing the Advanced National Seismic System (ANSS).

- Developing, operating, and maintaining the Network for Earthquake Engineering Simulation (NEES).

- Implementing an R&D roadmap to close the “research-to-practice” gap and accelerate the use of new earthquake risk mitigation technologies.

- Operating and maintaining the Global Seismographic Network (GSN).

In addition, Congress recognized that the National Institute of Standards and Technology (NIST) had a critical role to play in providing leadership for the planning, management, and coordination of NEHRP and designated NIST as the NEHRP lead agency.

Technical Assistance Capabilities. NEHRP has existing capabilities that can be used to support the establishment of an effective earthquake and tsunami preparedness system, including detection, assessment, prediction, warning, evacuation, response, and recovery. NEHRP support capabilities include:

- Leading and/or participating in reconnaissance teams to collect valuable scientific, engineering, social and behavioral data, including the use of remote sensing technologies to quantify damage to large geographic areas and provide reconnaissance information where access to affected areas is difficult.

- Making data from all Global Seismographic Network (GSN) stations available in real time via satellite telemetry. The need for additional stations must be considered in the context of international partnerships and cooperation.

- Enhancing regional cooperation and multi-lateral information sharing agreements, including communications between seismologists, engineers, and emergency responders in regions exposed to the threats.

- Calibrating and validating tsunami propagation and inundation modeling tools, modeling inundation patterns to understand where the threat is most significant, developing tsunami hazard maps, and developing design criteria for coastal community shelters and other critical facilities.

- Training technical personnel and emergency responders to operate and maintain a system for earthquake and tsunami detection, assessment, prediction, warning, and evacuation, including emergency response and recovery networks.

- Conducting social and behavioral studies to ensure the effectiveness of the earthquake and tsunami preparedness system, considering unique aspects of the population demographics and the diversity of cultures and political structures, including a education to ensure that population will respond to warnings.

Background

Congress established the National Earthquake Hazards Reduction Program (NEHRP) in 1977 to address the threat posed by earthquakes to the American public and the U.S. economy. The primary NEHRP program agencies are the United States Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), the National Science Foundation (NSF), and the National Institute of Standards and Technology (NIST).[1]

In its most recent reauthorization which was signed into law on October 25, 2004 (P.L. 108-360), Congress assigned NIST the lead agency responsibility for NEHRP. The NIST Director chairs the NEHRP Interagency Coordinating Committee which comprises the directors of the primary program agencies, the White House Office of Science and Technology Policy (OSTP), and the Office of Management and Budget (OMB).

The law also requires NIST to facilitate coordination with other earthquake-related U.S. federal efforts—for example those of the National Oceanic and Atmospheric Administration (NOAA) on tsunamis, the Federal Highway Administration (FHWA) on highways and bridges, and the U.S. Army Corps of Engineers (USACE) on dams and waterways.

U.S. Tsunami Preparedness

Tsunamis may be initiated by earthquakes, collapse of a major ice shelf, major subsea land slides, and other events. Ninety percent of all tsunamis, however, are generated by earthquakes, and most tsunamis that have caused significant loss of life and property damage have been earthquake generated.

Because the vast majority of tsunamis occur in the Pacific Ocean, the U.S. West Coast, Alaska, and Hawaii all are at risk. Hawaii has been struck repeatedly, and coastal communities in Alaska experienced severe damage from tsunamis generated by the 1964 magnitude 9.2 subduction-zone earthquake. Tsunamis have also been generated in the Caribbean Sea, posing a hazard to Puerto Rico and the U.S. Virgin Islands, and earthquake-triggered subsea landslides have generated local tsunamis along the Atlantic coast of North America.

The greatest tsunami risk to the United States is posed by the 680-mile undersea fault known as the Cascadia subduction zone off the coast of Washington, Oregon, and northern California, which generated an estimated magnitude 9.0 – 9.5 earthquake in 1700. Such an earthquake could generate a tsunami similar to the one that struck the northern coast of Sumatra, giving only

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[1] USGS operates the seismic networks, develops seismic hazard maps, coordinates post-earthquake investigations, and conducts applied earth sciences research (which includes tsunami research and risk assessment). FEMA is responsible for emergency response and management, estimation of loss potential, and implementation of mitigation actions. NSF conducts basic research in seismology, earthquake engineering, and social, behavioral, and economic sciences, and operates the Network for Earthquake Engineering Simulation (which includes the tsunami wave basin research facility and supporting tsunami research). NSF and USGS jointly support the Global Seismographic Network (GSN)—the main facility for pinpointing earthquakes in real time. NIST conducts applied earthquake engineering research to provide the technical basis for building codes, standards, and practices and provides the NEHRP lead agency function.

about 10-20 minute warning time to the residents in communities along the Pacific Northwest coast.

The main focus of NEHRP is on earthquake-induced tsunamis—that have caused widespread devastation in prior disasters—though much of the inundation modeling and prediction work is relevant to other types of tsunamis as well. Examples of specific U.S. capabilities are summarized below.

As lead agency for NEHRP, NIST has the responsibility to support coordination across federal agencies to address the President's question in cooperation with the OSTP and NOAA. While NIST does not carry out tsunami work in-house, it has long established relationships with the agencies conducting tsunami-related work (e.g., NOAA, USGS, and NSF).

NIST also has long established relationships with Japanese government agencies involved in tsunami and earthquake work in its role as the US-side chair of the US-Japan Panel on Wind and Seismic Effects. The panel was formed in 1969 under the US-Japan Natural Resources (UJNR) program and works through a number of active bi-lateral task committees including one on tsunamis. The U.S.-side co-chairs of the Tsunami Task Committee are Dr. Eddie Bernard, Director of NOAA's Pacific Marine Environmental Laboratory (PMEL) and Professor Solomon Yim, Director of the NEES Tsunami Wave Basin Research Facility at Oregon State University. NOAA also operates the Pacific Tsunami Warning Center (PTWC) and the Alaska Tsunami Warning Center (ATWC). The UJNR Task Committee is holding a workshop/symposium on Tsunami Disaster Mitigation—in conjunction with the United Nations World Conference on Disaster Reduction—in Kobe, Japan, January 17-18, 2005.

A key NEHRP role in a tsunami warning system are the alerts for global earthquakes provided by the USGS at the National Earthquake Information Center (NEIC) in Golden, CO. Because NEIC does not have that capability currently, NOAA's Pacific and Alaska Tsunami Warning Centers also calculate earthquake locations and magnitudes based on data coming in from the Global Seismographic Network (GSN)[2] in addition to getting NEIC calculations.

Existing warning systems for the U.S. do not provide adequate service to Micronesia and American possessions in the eastern Pacific Ocean and do not provide service to the North Atlantic Ocean and the Caribbean. The nature of the tsunami problem is not adequately known in these regions, including definition of threats that have already been recognized (such as, for the North Atlantic, tsunami resulting from underwater landslides and failure of volcanic edifices). Further communication has not been established between seismologists, engineers, and emergency responders in regions that are exposed to the threat; effort have not been made to model and predict inundation patterns to understand where the threat is most significant; and nor has a major education effort been undertaken, so that population will respond to warnings.

Further, while there are adequate existing models for predicting the propagation of tsunamis, adequate inundation models do not exist to predict what happens when a tsunami hits land. These include models, measurements, and tools to predict tsunami run up effects, forces on

[2] Jointly funded by USGS and NSF through the Incorporated Research Institutions for Seismology (IRIS) and the University of California at San Diego.

structures, and sediment transport. Basic understanding of the connection between the ground motion and the resulting tsunami do not exist for the tsunami propagation models to take the source into account Such an understanding may not be necessary if there exist a sufficient number of sensors (or remote sensing capability) to detect tsunamis in the open ocean. Both NSF and USGS support considerable research on tsunami risk assessment, paleotsunami characterization, modeling, and measurements.

NSF has established a tsunami wave basin research facility at the Oregon State University through its Network for Earthquake Engineering Simulation (NEES) to support the study of the above issues. Large-scale, realistic models of infrastructure – such as shorelines, underwater pipelines, port facilities, and coastal communities – can be constructed in the NEES tsunami wave basin and instrumented with a network of sensors to measure water height, speed, pressure, and other forces. Computer-controlled waveboards then create waves, in patterns simulating virtually any coastal condition. Tsunamis are the most difficult to simulate, since an extremely powerful thrust is needed to create a large, single wave. The same wave basin can also be used to study the forces (typically deep-sea landslides or earthquakes) that create tsunamis.

The NEES tsunami wave basin supports improved tsunami hazard mitigation as follows:

- Conducting fundamental research into the genesis of tsunamis, to understand when they are likely to occur and the force that will be created.
- Developing numerical models to predict when and where tsunamis will strike land and how extensive the inundation will be.
- Developing new methods, such as the use of remote-sensing (satellite) imagery, for monitoring the occurrence and behavior of tsunamis.
- Conducting fundamental research on the effects when turbulent water impacts built structures, such as bridges, piers, and buildings.
- Developing methods for assessing the effectiveness of coastal infrastructure (such as breakwaters) and resilient construction techniques in protecting shorelines and communities.

The use of remotely sensed information in the context of model validation and calibration, and also of support for emergency response and management decisions is limited. This use keys into the Interagency Working Group on Earth Observations (IWGEO) of the National Science and Technology Council (NSTC) which is charged with developing the strategic plan for the U.S. Integrated Earth Observations System (IEOS). This effort has been of ministerial-level interest and is led by NOAA for the United States and with involvement of NSF. A network of subsurface sensors would support the predictions, since there is a general trend now toward the development of The Global Earth Observation System of Systems (GEOSS).

FEMA has been involved in addressing the tsunami risk for several years. It is one of the federal agency partners in the National Tsunami Hazard Mitigation Program (NTHMP), which is a federal/state program formed to address the tsunami hazard, improve tsunami warning, develop tsunami inundation mapping, and mitigate its effects. The program is led by NOAA[3] and includes FEMA, the USGS and NSF. The NTHMP also includes state emergency management and geoscience agencies from five states; Alaska, California, Hawaii, Oregon, and Washington.

Under the NTHMP, FEMA and the states are primarily involved in the emergency management and hazard mapping issues, NOAA with tsunami modeling and warning system issues, and USGS with seismic system issues. Together, the agencies have developed many products and activities for west coast communities that have increased their readiness for both long distance and local tsunamis.

The NTHMP's and FEMA's focus has been in the Pacific Northwest, Alaska and Hawaii since this has been where the largest number of tsunami and associated fatalities have occurred. Probably the greatest risk to the U.S. is believed to be a tsunami that would be generated by an earthquake along the 680-mile undersea fault known as the Cascadia subduction zone off the coast of Washington, Oregon, and northern California. Similar to the northern coast of Sumatra, a Cascadia subduction earthquake would be very large, would result in a tsunami, and would only give 10-20 minutes of warning time to the residents along the Pacific Northwest coastline. In many cases, this would not be enough time to allow for evacuation, especially during vacation season. This fault last generated an estimated magnitude 9.0 – 9.5 earthquake and tsunami on January 26, 1700. While there is Native American folklore and geologic evidence, such as sand deposits, to prove the impact of the tsunami, the actual date has been confirmed from Japanese tsunami records. While tsunamis have also occurred in the Atlantic Ocean and the Caribbean Sea, and such an event would certainly cause tremendous amounts of damage, the probability of such an event is smaller than that of a Pacific event.

With partial NEHRP support, FEMA has been working in partnership with the State emergency management and science agencies within the NTHMP to improve the level of tsunami hazard awareness, planning, and preparedness. There are several examples of these activities.

- A pilot project to develop risk identification products that will help communities understand their actual level of risk from tsunami in a way that could be conveyed on existing flood maps. FEMA's National Flood Insurance Program (NFIP) is involved because FEMA is responsible for mapping areas subject to flooding in order to properly rate flood insurance policies and provide risk assessment information to States and local communities. In addition, the FEMA NFIP considered tsunami wave heights during the development of its Flood Insurance Rate Maps in areas of Hawaii and the West Coast where tsunami was considered a significantly probable flood threat. These tsunami hazard maps will be used by state and local governments for zoning, code enforcement, and emergency planning.

- FEMA supports and promotes the NOAA *TsunamiReady* Program. Currently, there are 11 *TsunamiReady* communities located in the Pacific Northwest. The criteria for being recognized as a *TsunamiReady* Community includes establishing an Emergency Operations Center, warning systems, a community preparedness program, identifying their hazard zone,

[3] Managed by NOAA's Pacific Marine Environmental Laboratory (PMEL), which is part of the National Weather Service (NWS).

and establishing evacuation routes and safe areas. Also required is the establishment of plans and drills for schools in the hazard zone.

- FEMA is currently examining if it is possible to build a structure that would be capable of resisting the extreme forces of a tsunami. This question takes on a greater significance because there are several coastal communities along the west coast that are vulnerable to tsunami triggered by an earthquake on the Cascadia Subduction Zone. Given that many of these coastal communities are located in areas that would be impossible to evacuate in time, and could result in a significant loss of life, FEMA and its mitigation partners at the Federal, State and local levels are looking for alternatives. The only feasible alternative would be vertical evacuation, providing such a structure could be constructed to resist tsunami loads. It would generally not be economically feasible to build a typical structure to withstand the extreme loads of a tsunami. However, FEMA believes that a specially designed structure could be built to withstand at least some specific level of tsunami loads without collapse for the purposes of providing community shelter for vertical evacuation.

- There is a joint FEMA/NOAA-funded effort underway to develop tsunami design criteria for shelters or critical facilities. In the first phase of this effort, data regarding tsunamis and their potential forces on structures was collected. The second phase will determine whether it is possible to design and build a structure to withstand specific tsunami loads and, if so, to develop a technical design and construction guidance document for special facilities that would allow for vertical evacuation from tsunami conditions. This work will research and produce guidance for a tsunami shelter structure capable of withstanding both the severe ground shaking expected during a design earthquake and specific velocities and water pressure from a tsunami that would impact structures. The project will work with the NEES tsunami wave basin research facility at the Oregon State University. In a planned third phase, information will be developed for States and local communities on how tsunami design guidance can be utilized.

U.S. Earthquake Preparedness

The devastating earthquake that struck off the coast of Sumatra underscores the importance of U.S. preparedness for earthquakes as much as the resulting tsunami has underscored the importance of U.S. preparedness for tsunamis. Even coastal regions of the U.S. remain far more likely to experience an on-land earthquake than be hit by a tsunami. And based on population demographics and development patterns, on-land earthquakes could cause far greater devastation to the U.S. population and economic infrastructure than earthquake-induced tsunamis.

Potential loss estimates of a large earthquake in a major U.S. urban area now approach $200 billion. Based on historical data, average financial loss associated with U.S. earthquakes in recent decades is $10 billion per year for buildings, transportation networks, and other lifelines systems, and business disruption. Direct economic losses are about 45 percent of this total.

The NEHRP Strategic Plan and recent Congressional re-authorization addressed on-land earthquake risks. Recognizing these risks and the agency plans to address them, Congress identified specific initiative areas that address several key national needs. These include:

- Completing the Advanced National Seismic System (ANSS).

- Developing, operating, and maintaining the Network for Earthquake Engineering Simulation (NEES).

- Implementing an R&D roadmap to close the "research-to-practice" gap and accelerate the use of new earthquake risk mitigation technologies.

- Operating and maintaining the Global Seismographic Network (GSN).

Further, the December 26, 2004 event will provide a tremendous amount of data for models of megathrust quakes around the Pacific Rim, especially to assess what could be expected from an earthquake with magnitude 9.0 on the Cascadia subduction zone.

Congress also recognized that NIST had a critical role to play and was best suited to provide leadership and coordination for NEHRP. It transferred NEHRP leadership to NIST from FEMA, which had provided the lead agency function from the program's inception over 25 years ago, and authorized $10 million in FY 2005 for NIST to support these activities (the authorization increased to $11 million in FY 2006 and additional increases were authorized for out years).

Technical Assistance Capabilities

NEHRP agencies are working with NOAA and international multi-lateral organizations to send teams of experts to collect valuable scientific, engineering, social and behavioral data from the December 26, 2004 event. Under the NEHRP post-earthquake investigations plan (USGS Circular 1242; http://geopubs.wr.usgs.gov/circular/c1242/), the principal NEHRP activity for foreign earthquakes is the Learning From Earthquakes (LFE) program funded by NSF through the Earthquake Engineering Research Institute (EERI). EERI has already begun to send teams to the region. The teams include tsunami researchers, civil engineers and social scientists to do initial reconnaissance investigations. Efforts to describe features resulting from the tsunami, and relating them to known characteristics of the tsunami, will enhance the ability to reconstruct the frequency and magnitude of past tsunami preserved in the geologic record. This will improve assessment of the hazard potential of such rare events throughout the Pacific and the Caribbean as well as in the Indian Ocean.

One of NSF's earthquake engineering research centers is participating in a joint effort with Japan's Earthquake Disaster Mitigation Research Center (EDM) and two Asian universities. This group is studying the use of remote sensing technologies to (1) quantify damage to large geographic areas (in the case of this event, over 12,000 miles of coastline), and (2) provide reconnaissance information where access to impacted areas is difficult. For the first time, high-resolutions sensors (Quickbird and Ikonos), moderate-resolution sensors (SPOT, LandSat and IRS), and low-resolution sensors (MODIS, Aster) are all recording the event, almost in real-time.

NEHRP has existing capabilities that can be used to support the establishment of an earthquake and tsunami detection, assessment, prediction, warning, evacuation, response, and recovery system. Such a system would include the installation of detection, assessment and warning systems, calibration and validation of tsunami propagation and inundation modeling tools, regional cooperation and multi-lateral information sharing agreements, training of personnel for operating and maintaining the system, emergency response networks, social and behavioral studies, and training of emergency responders in decision-making relative to preparedness, issuance of warnings, evacuation, and response.

USGS and IRIS (supported by NSF), in collaboration with NOAA, have the capability to provide timely alerts by ensuring that GSN can provide data in real-time through satellite telemetry. Ocean-bottom broad-band seismometers would be any tsunameter buoys. Current GSN station coverage is inadequate in the region. The availability of seismic data in this region is limited since India does not allow sharing of its data, and China requires a 30-minute delay in the transmission of their seismic data to the international seismological community.

Adequate communication has not been established between seismologists, engineers, and emergency responders in regions exposed to the threat; modeling of inundation patterns has not been undertaken to understand where the threat is most significant; and a education efforts have not been implemented so that population will respond to warnings.

NEHRP has the ability to conduct social and behavioral studies to study the effectiveness of various warning and evacuation protocols considering unique aspects of regional population demographics. Examples of such studies include:

- Epidemiological factors associated with the deaths and injuries caused by the earthquake/tsunami event. These include such factors as vulnerable locations (and in what types of structures), demographics of affected groups, and behaviors associated with mortality and morbidity.

- Cross-cultural studies on the impact of cultural values, beliefs, and norms on individual, group and community response. Examination of the diversity of cultures and political structures to assess the impact of these social forces on such issues as risk perception, preparation and communication, volunteerism, search and rescue activity, emergency medical care and the handling of the dead, and the distribution of aid.

- Identification and integration of technological and behavioral elements (public education and preparedness, monitoring/detection systems, warning dissemination strategies, etc.) to ensure warning systems do save lives and protect property.

- Rapid assessment of damage and social impacts to identify and prioritize targets for emergency assistance in the aftermath of extreme events.

- Studying mitigation approaches to ensure equitable and effective assistance for response and recovery, support social and economic recovery and sustainable development, and reduce losses from future disasters.

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