United States Government Accountability Office

Report to Congressional Requesters

August 2016

EARTHQUAKES

Additional Actions Needed to Identify and Mitigate Risks to Federal Buildings and Implement an Early Warning System

GAO-16-680

GAO Highlights

Highlights of GAO-16-680, a report to congressional requesters

August 2016

EARTHQUAKES

Additional Actions Needed to Identify and Mitigate Risks to Federal Buildings and Implement an Early Warning System

Why GAO Did This Study

Earthquakes pose a significant threat to people and infrastructure because of their capacity to cause catastrophic casualties, property damage, and economic disruption. According to the USGS, 16 states have a relatively high likelihood of experiencing damaging ground shaking in the next 50 years, and nearly half of all Americans are exposed to potentially damaging earthquakes.

GAO was asked to review efforts to mitigate against earthquakes impacts in the United States. Specifically, this report address (1) actions select cities have taken to mitigate seismic risks, (2) the distribution of federal buildings relative to earthquake prone areas and actions to identify and mitigate seismic risks to these buildings, and (3) what is known about the benefits of USGS's earthquake early warning system, ShakeAlert, and the extent to which implementation challenges are being addressed. GAO reviewed key documents and federal authorities; collected federal building inventory information; conducted site visits to selected cities—Seattle, San Francisco, Los Angeles, Memphis; and interviewed, among others, federal, state, and local officials.

What GAO Recommends

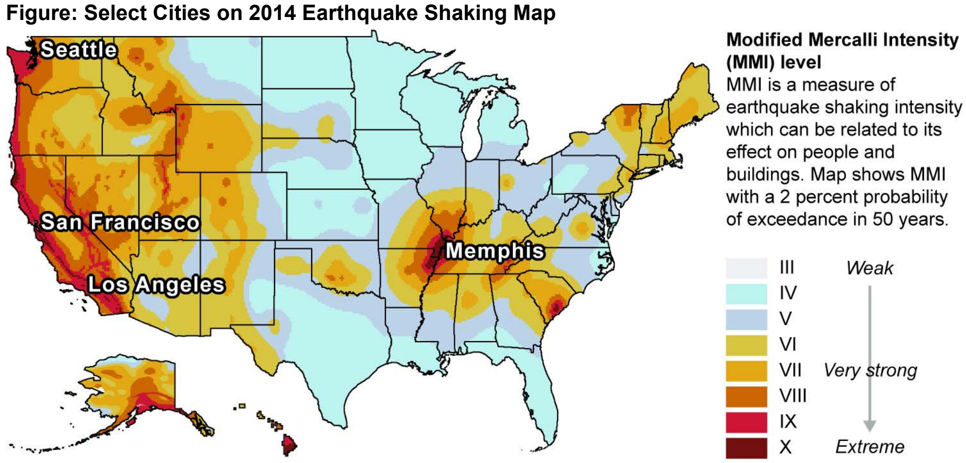
GAO recommends that DOD and GSA (1) fully identify their exceptionally high risk buildings; (2) prioritize and implement comprehensive seismic safety measures to mitigate earthquake risks; and (3) that USGS develop a program management plan to address, among other things, ShakeAlert implementation challenges. DOD, GSA, and USGS agreed with the recommendations.

View GAO-16-680. For more information, contact Chris Currie at (404) 679-1875 or curriec@gao.gov or David Wise at (202) 512-5731 or wised@gao.gov

What GAO Found

The four cities GAO visited (see figure) have taken various actions to assess and mitigate seismic risks, including identifying and assessing their high risk buildings, structurally retrofitting buildings, and requiring that furnishings and nonstructural components be secured, among other things.

Figure: Select Cities on 2014 Earthquake Shaking Map



Source: GAO presentation of U.S. Geological Survey mapping; MapInfo (map). | GAO-16-680

Note: A 2 percent in 50 years probability equates to an earthquake recurring and exceeding a given MMI level about every 2,475 years.

About 40 percent of federally-owned and -leased buildings in the United States are located in areas where very strong to extreme shaking from earthquakes could occur. The Department of Defense (DOD) and General Services Administration (GSA), which are responsible for the majority of these buildings, have not fully identified their exceptionally high risk (EHR) buildings or prioritized and implemented comprehensive seismic safety measures. Federal agencies identified their EHR buildings as part of a government-wide effort in the 1990's, and GSA has begun taking initial steps to identify its current EHR buildings. In addition, while DOD and GSA have taken some steps to reduce the seismic risk of their buildings through seismic retrofits, disposals, and low-cost mitigation alternatives, GAO observed gaps in the extent to which these agencies have comprehensively implemented these mitigation measures, such as securing furniture. Until they fully identify their EHR buildings and prioritize and implement comprehensive safety measures, DOD and GSA will be unable to fully understand and address the vulnerabilities of their buildings.

U.S. Geological Survey's (USGS) early warning system—ShakeAlert—is capable of broadcasting early warnings, and stakeholders, including state agencies and universities, have identified multiple benefits, such as enhanced public safety. However, implementation challenges exist that could inhibit efforts to expand the system throughout the western United States. For example, decisions on funding, public education, and user certification are needed to enable implementation of an integrated system across jurisdictions. Developing a program management plan, which helps establish management controls, could help address ShakeAlert implementation challenges.

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Abbreviations

AEL	Annualized Earthquake Loss
AELR	Annualized Earthquake Loss Ratio
ANSS	Advanced National Seismic System
ATC	Applied Technology Council
BART	Bay Area Rapid Transit
CAL OES	California Office of Emergency Services
CISN	California Integrated Seismic Network
CFO	Chief Financial Officers
CGS	California Geological Survey
Corps	U.S. Army Corps of Engineers
DBI	San Francisco Department of Building Inspection

DOD	Department of Defense
EEW	Earthquake Early Warning
EHR	Exceptionally High Risk
EHRA	Earthquake Hazards Reduction Act of 1977
EHRI	Enterprise Human Resources Integration
FEMA	Federal Emergency Management Agency
FRPP	Federal Real Property Profile
GSA	General Services Administration
IBC	International Building Code
ICC	International Code Council
ICSSC	Interagency Committee on Seismic Safety in Construction
IEBC	International Existing Building Code
IPAWS	Integrated Public Alert and Warnings System
JMA	Japanese Meteorological Agency
LADBS	Los Angeles Department of Building & Safety
LAUSD	Los Angeles Unified School District
MMI	Modified Mercalli Intensity
NEHRP	National Earthquake Hazards Reduction Program
NIST	National Institute of Standards and Technology
NMSZ	New Madrid Seismic Zone
NSF	National Science Foundation
PMI	Project Management Institute
RP5	ICSSC Recommended Practice 5
RP8	ICSSC Recommended Practice 8
Seattle OEM	City of Seattle Office of Emergency Management
URM	unreinforced masonry
USGS	United States Geological Survey
WGCEP	Working Group on California Earthquake Probabilities

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August 31, 2016

Congressional Requesters:

In the United States each year, natural disasters cause hundreds of deaths and cost billions of dollars in disaster aid, disruption of commerce, and destruction of homes and critical infrastructure. According to the Department of the Interior United States Geological Survey (USGS), within the United States, hurricanes account for about two-thirds of the insured property losses, and over 75 percent of declared federal disasters are related to floods; however, earthquakes, while less frequent, have the highest potential for causing catastrophic casualties, property damage, and economic disruption.[1] Earthquakes pose a significant threat to people and infrastructure by producing damaging ground shaking, tsunamis, and fires, among other hazards. According to the USGS, 16 states have a relatively high likelihood of experiencing damaging ground shaking in the next 50 years, and nearly half of all Americans are exposed to potentially dangerous damaging earthquakes. For example, according to USGS, there is a 99 percent chance that California will experience a magnitude 6.7 or greater earthquake in the next 30 years.[2]

Preparing for and reducing risk of damage from earthquakes is largely the responsibility of state and local government agencies; however, the federal government provides support through coordinated activities of key agencies in response to legal requirements and policy directives. For example, the Earthquake Hazards Reduction Act (EHRA) of 1977, *as amended,* seeks to reduce the risks of life and property from future earthquakes through the establishment and maintenance of an effective

[1]According to USGS, larger fatality events (1,000 fatalities per event) such as earthquakes produce about 100 times more fatalities than small fatality events (10 fatalities per event) such as floods and tornadoes.

[2]Magnitude is a number that characterizes the relative size of an earthquake and is a measurement of the maximum motion recorded by a seismograph. The severity of an earthquake can be expressed in terms of both intensity (the Modified Mercalli Intensity (MMI) scale is described later in this report) and magnitude. However, the two terms are quite different. Intensity is based on the observed effects of ground shaking on people, buildings, and natural features and varies from place to place within the disturbed region. Magnitude is related to the amount of seismic energy released at the center of the earthquake.

earthquake hazards reduction program.[3] EHRA established the National Earthquake Hazards Reduction Program (NEHRP), which, among other things, promotes the adoption of earthquake hazards reduction measures by the federal government and others with a role in planning and constructing buildings, structures, and lifelines through the development of standards, guidelines, and voluntary consensus codes aimed at reducing the damaging effects of earthquakes. NEHRP promotes improved design and construction methods, coordinated emergency preparedness plans, and public education and involvement programs.

The four agencies that work together in coordination through the NEHRP partnership are the Department of Homeland Security's Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and USGS. FEMA is the federal agency responsible for improving the nation's capacity to prepare for, protect against, respond to, and recover from and mitigate all hazards. As part of these responsibilities, FEMA is charged by NEHRP with, among other things, promoting better building practices and providing assistance to enable states to improve earthquake preparedness. NIST is the lead NEHRP agency and has the primary responsibility for NEHRP planning and coordination. NIST conducts earthquake engineering research to provide the technical basis for building codes, standards, and practices, and is responsible for working with FEMA and others to implement improved earthquake-resistant design guidance for building codes and standards for new and existing buildings. NSF supports research in seismology, fault physics, and rock and mineral physics; structural and geotechnical earthquake engineering; and social, behavioral, and economic sciences pertinent to the preparation for, mitigation of, response to, and recovery from earthquakes and tsunamis. USGS provides the nation with earthquake monitoring and notification, delivers regional and national seismic hazard assessments, and coordinates post-earthquake investigations, among other responsibilities. In addition, USGS is the lead federal agency responsible for developing and implementing an Earthquake Early

[3]Pub. L. No. 95-124, 91 Stat. 1098 (1978) (codified as amended at 42 U.S.C. §§ 7701-7709).

Warning (EEW) system—known as ShakeAlert—which is intended to warn people prior to earthquake shaking.

In addition to the four agencies responsible for managing earthquake preparedness, all federal agencies manage their own building inventories, the majority of which are owned or leased by the Department of Defense (DOD) and the General Services Administration (GSA). Specifically, as of September 2014, DOD owns or leases 50 percent and GSA owns or leases 3 percent of the approximately 252,000 federally-owned or -leased buildings in the 50 states and the District of Columbia. In addition, DOD (56 percent) and GSA (16 percent) owned or leased buildings account for about 72 percent of total federal building space in the United States.

Understanding the concerns that seismically deficient buildings located in earthquake hazard areas pose a public safety threat, you requested that we review federal earthquake mitigation efforts. Specifically, this report addresses the following questions:

1. What actions have select city governments taken to assess and mitigate seismic risks that could affect buildings in their jurisdictions?
2. What is the distribution of federal buildings with regard to seismic hazard areas, and to what extent have select federal agencies identified and mitigated seismic risks to their buildings?
3. What are the potential benefits of ShakeAlert, and to what extent are USGS and stakeholders addressing technical and implementation challenges, if any, to implementing the system?

To address the first objective, we conducted site visits to four U.S. cities—Seattle, Washington; Memphis, Tennessee; San Francisco, California; and Los Angeles, California—selected from among those with the highest earthquake loss estimates to buildings and seismic hazard level (probabilities of ground shaking), as identified by FEMA, and to reflect geographic diversity. For each of these cities, we met with officials from FEMA regional offices, state and local government, and regional nonprofit consortia with familiarity of the four cities to discuss mitigation activities that had been undertaken or are planned. We also toured new and existing buildings in San Francisco and Los Angeles selected by local officials to observe examples of the physical mitigation measures implemented to avoid or reduce damage to structures and related injuries resulting from earthquake disasters. In addition, for each of the four cities, we reviewed the relevant state and local policies, hazard mitigation plans, practices, and other process activities used to reduce risk. Additionally, we reviewed FEMA's guidelines about seismic building practices, efforts to support earthquake mitigation implementation activities at the state and local level, and education and outreach and promotion of earthquake preparedness, and prior GAO reports. The findings, while providing important perspectives that could be beneficial to federal, state, and local government efforts to mitigate earthquake risks to buildings, are not generalizable to all U.S. cities.

To address the second objective, we performed a geographic analysis of the number of leased and owned federal buildings in use or which will be needed in the future, total building square footage of both leased and owned federal buildings in use or which will be needed in the future, and the number of federal employees assigned to work in each area of earthquake shaking intensity based on the Modified Mercalli Intensity (MMI) scale.[4] To perform this analysis, we obtained fiscal year 2014 Federal Real Property Profile (FRPP) building data from GSA and DOD, including building size, location, ownership, legal status (which indicates if the building is owned or leased); status of use (which indicates if the building is currently being used, will be needed in the future, or has been or is in the process of being disposed of, or is considered as excess or surplus); and the date of disposal for buildings that have been disposed of. We also obtained Office of Personnel Management's Enterprise Human Resources Integration (EHRI) database as of September 2014 with federal employee official worksite data and 2014 earthquake shaking intensity maps from USGS. To assess the reliability of the FRPP data, we reviewed previous GAO and GSA Office of Inspector General work on FRPP data reliability and limitations, reviewed FRPP system controls in place, interviewed GSA and DOD officials regarding data checks, and conducted electronic testing to determine completeness and that data element values are consistent with expected values. To assess the reliability of the EHRI data, we examined existing information about the overall reliability and system controls, and performed electronic testing. We found the data elements of interest to this engagement were sufficiently reliable for the purpose of our reporting objectives.

[4]MMI—the intensity scale used in the United States—is composed of increasing levels of intensity that range from unnoticeable shaking to buildings being destroyed. See Figure 1 later in this report for additional information.

We focused on DOD and GSA efforts to identify and mitigate seismic risk within their buildings because together they own and lease about 53 percent of all federal buildings by number, about 72 percent of the federal owned and leased buildings in square feet, and, as of 2013, accounted for about 68 percent of the annual operating costs for owned and leased federal buildings.[5] We interviewed DOD (Air Force, Army, and Navy) and GSA headquarters officials and solicited written responses to questions regarding the extent to which they identify and mitigate seismic risks to their federal buildings agency wide. We also visited three DOD installations—one for each service Air Force, Army, and Navy—which had a large number of buildings and were located near the above cities selected because of their high seismic hazard levels. At these installations, we interviewed facility officials and visited buildings which had been constructed to modern seismic building codes, seismically retrofitted, or have not been retrofitted to observe DOD's seismic risk mitigation efforts. Furthermore we interviewed GSA facility officials and seismic engineers in the three GSA regions that cover the above selected cities and visited GSA buildings which had been seismically retrofitted and buildings which have not been retrofitted to observe GSA's seismic risk mitigation efforts. We also reviewed executive orders, federal law, and federal standards regarding the requirements for federal agencies to mitigate seismic risk. Additionally, we interviewed officials and reviewed seismic mitigation documents from FEMA and USGS who play roles in federal earthquake risk mitigation efforts and earthquake hazard identification. Based on our review of the *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings: ICSSC Recommended Practice 8 (RP 8)* and FEMA guidance on earthquake risk mitigation, we developed questions to determine the extent to which each DOD component and GSA had implemented key mitigation strategies identified in those documents. Specifically we asked questions regarding their compliance with the RP 8 requirement for seismically retrofitting buildings, including when buildings are being rehabilitated or when a building is considered exceptionally high risk. We also asked questions to determine the extent to which they implement less expensive mitigation strategies identified by FEMA, such as non-structural retrofits, building contents

[5]Based on the 2013 Federal Real Property Profile summary data from GSA, the most recent federal building data available at the time the selection was made.

mitigation, and earthquake drills.[6] We then summarized their responses in this report.

To address the third objective, we reviewed relevant ShakeAlert documentation, including policies, plans, and legislation. We also conducted interviews with USGS officials and other stakeholders of the ShakeAlert system, including the California Integrated Seismic Network, Pacific Northwest Seismic Network, and academia, using a standard set of questions to discuss what, if any, potential benefits, limitations, and implementation challenges exist. We also visited Japan, which has an operational earthquake early warning system, to interview officials from the Japanese government, private sector, and transportation sector to discuss the implementation challenges they overcame to deploy a national earthquake early warning system. We also interviewed beta testers from the companies, government entities, and others that were participating in ShakeAlert's beta testing effort to collect their perspectives on the benefits, limitations, and potential challenges to developing and implementing ShakeAlert. We selected beta testers from the three western states—California, Oregon, and Washington—that have entities involved in the beta testing effort and chose officials from each region to represent utility companies, emergency management offices, and the private sector. We then performed a content analysis to identify common themes related to the limitations and implementation challenges of the ShakeAlert system. We assessed the results of this analysis against the Project Management Institute's *The Standard For Program Management,* Third Edition, to determine the extent to which a program management plan should be established to address key elements, such as those

[6]We used information from our review of FEMA E-74: *Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide*, December 2012; FEMA 395: *Incremental Seismic Rehabilitation of School Buildings (K-12)*, June 2003; and FEMA 397: *Incremental Seismic Rehabilitation of office Buildings*, December 2003, to identify earthquake risk mitigation strategies beyond those required by RP 8, which FEMA has developed for inclusion in a comprehensive earthquake program such as non-structural mitigation, building contents mitigation, and earthquake drills.

identified by ShakeAlert stakeholders.[7] Additional details on our scope and methodology are contained in appendix I.

We conducted this performance audit from January 2015 to August 2016 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Earthquake Shaking Hazards

According to the USGS, a large portion of the United States' population lives in areas vulnerable to earthquake shaking hazards that are sources of potential harm or loss during earthquakes.[8] The effect of an earthquake can be described by its intensity. The intensity scale used in the United States is the Modified Mercalli Intensity (MMI) Scale composed of increasing levels of intensity that range from unnoticeable shaking to buildings being destroyed (see fig. 1).[9]

[7] The Project Management Institute is a not-for-profit association founded in 1969 that aims to improve organizational success and further mature the profession of project management through its globally recognized standards, certifications, academic research, publications, and professional development courses.

[8] USGS is responsible for reporting the occurrence of earthquakes in the United States. It also develops various mapping products showing the potential earthquake shaking in the United States which are used for various purposes such as implementing building code and standards.

[9] The lower Roman numerals of the intensity scale generally deal with the manner in which the earthquake is felt by people. The higher Roman numerals of the scale are based on observed structural damage.

Figure 1: Modified Mercalli Intensity Scale Used to Describe Earthquakes

Intensity		Shaking	Description/damage
	I	Not felt	Not felt except by a very few.
	II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
	III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck.
	IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
	V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
	VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
	VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
	VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
	IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
	X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations.

Source: U.S. Geological Survey. | GAO-16-680

Note: The Modified Mercalli Intensity (MMI) scale is a 12 point scale; however the U.S. Geological Survey (USGS) only uses the first 10 points of the scale as estimated MMI does not exceed a level of MMI X in the United States, and the USGS has never observed damage in the United States at MMI XI or XII level.

Maps showing the probability of earthquake shaking exceeding certain MMI levels over a specified time period can be used to better understand the extent to which earthquake shaking can affect people and buildings. Figure 2 shows a USGS-developed map of the United States which depicts MMI levels based on a 2 percent probability of an earthquake exceeding the MMI level in 50 years.[10] The 2 percent in 50 years

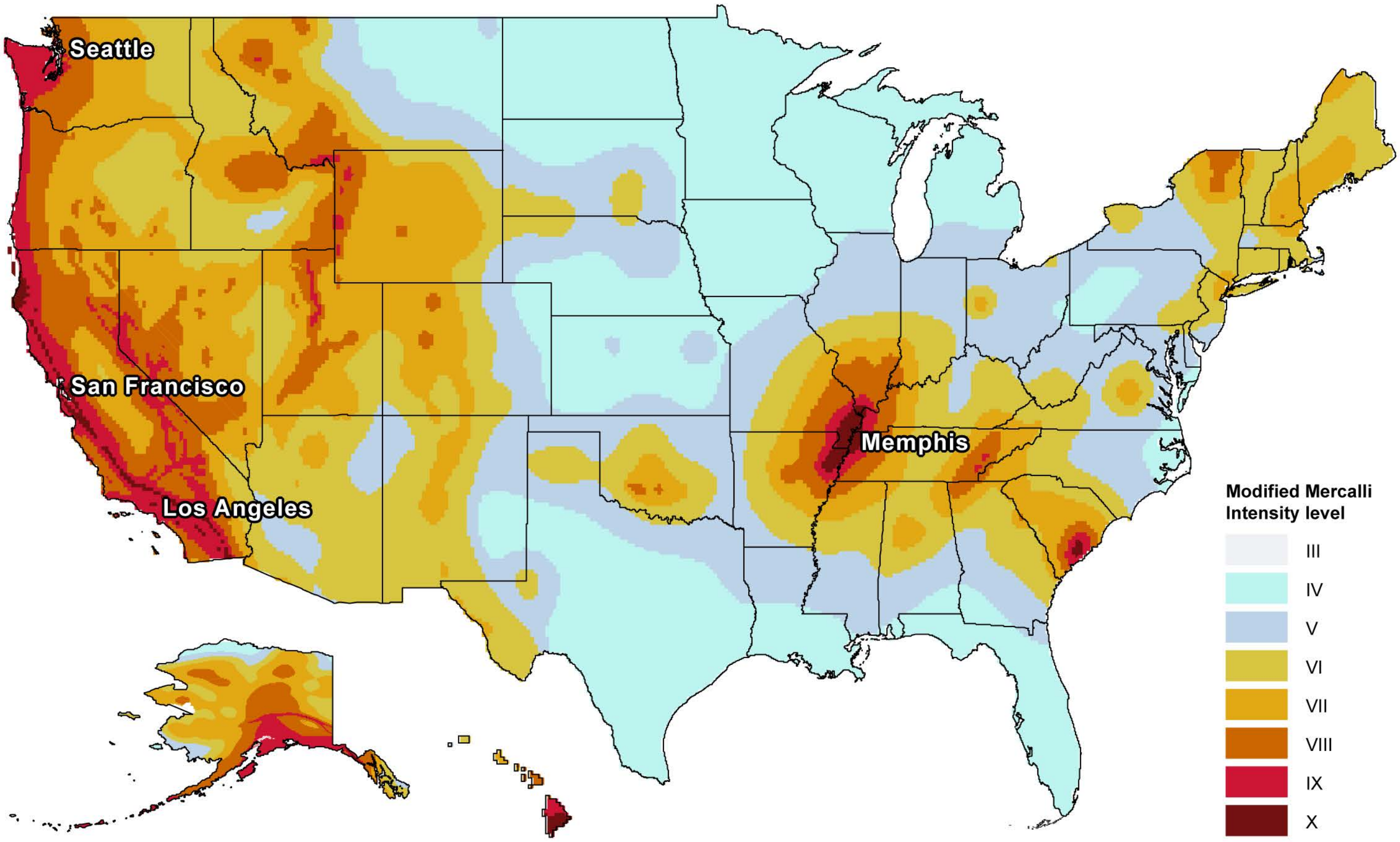
[10]A 2 percent in 50 years probability equates to an earthquake recurring and exceeding a given MMI level about every 2,475 years.

probability is the same probability level that the International Code Council uses to establish seismic provisions within building codes.[11] Figure 2 also shows the four cities located in high MMI areas we visited as part of our review. These cities have experienced strong earthquakes in the past and could potentially sustain substantial damage and casualties in the future as a result of earthquakes. According to USGS, over 240 million people in the 48 contiguous states are located in areas exposed to moderate or greater earthquake shaking.[12] For additional information on the shaking intensities projected with higher probabilities of occurring see appendix II.

[11]The International Code Council (ICC) produces the International Building Code (IBC), which has been adopted by federal, state, and local governments to help establish minimum safety standards for new buildings. The ICC uses 2 percent in 50 year ground acceleration mapping, with some adjustments to account for geographic differences in how shaking affects buildings in different parts of the United States, to determine the Maximum Considered Earthquake (MCE_R) based on risk of collapse.

[12]Estimate is based on the 2 percent probability of exceedance in 50 years map for the 48 contiguous states. See Kishor S. Jaiswal, Mark D. Petersen, Ken Rukstales, and William S. Leith (2015). “Earthquake Shaking Hazard Estimates and Exposure Changes in the Conterminous United States,” *Earthquake Spectra*: *December 2015*, Vol. 31, No. S1, pp. S201-S220.

Figure 2: Selected City Information on a Nationwide 2014 Modified Mercalli Intensity (MMI) Earthquake Shaking Map With a 2 Percent Probability of Exceedance in 50 Years



Seattle

Earthquakes larger than magnitude 6.0 occurred in 1909, 1939, 1946, 1949, 1965 and 2001. According to the U.S. Geological Survey, Seattle has a 5% chance of experiencing strong ground shaking levels within the next 50 years. A magnitude 7.2 Seattle fault earthquake scenario might result in structural collapses, landslides, fires and a tsunami which, when combined, cause 1200 deaths and 15,000 severe to critical injuries.

San Francisco

San Francisco has experienced 69 recorded magnitude 5.0 or greater earthquakes since 1800, including three at a magnitude 6.8 or greater. According to the Working Group on California Earthquake Probabilities (WGCEP), there is a 72 percent chance that a magnitude 6.7 or greater earthquake will strike the San Francisco region within 30 years. Depending on the magnitude, location and time of day of an earthquake, deaths could range from 70 to nearly 1,000, and injuries could number from 1,900 to more than 14,000.

Los Angeles

Approximately 20 earthquakes of magnitude 6.0 or higher have occurred in southern California since 1912. According to the WGCEP, there is a 60 percent chance that a magnitude 6.7 or greater earthquake will occur in the Los Angeles region within 30 years. A magnitude 7.1 earthquake could cause between 500 to 2,000 deaths and result in moderate damage to over 470,000 buildings in southern California.

Memphis

Western Tennessee, which includes Memphis, experienced earthquakes in 1811, 1812, 1843, and 1895. According to the USGS, within 50 years, there is a 25 to 40 percent chance that a magnitude 6.0 or greater earthquake, and approximately a 10 percent chance that a magnitude 7.0 or greater earthquake will occur in Memphis. A magnitude 7.7 earthquake could result in an estimated 21,500 casualties and completely damage 53,500 buildings, in Shelby County, where Memphis is located.

Source: U.S. Geological Survey (MMI map); GAO analysis; MapInfo (map). | GAO-16-680

Earthquake Risks

Risks to the population located in areas vulnerable to earthquake shaking hazards include the harm or losses that are likely to result from an earthquake. These risks are usually measured in terms of expected casualties (fatalities and injuries), direct economic losses (repair and replacement costs), and indirect economic losses (income lost during downtime resulting from damage to private property or public infrastructure). In any geographic area, three main factors determine earthquake risks: (1) the level of earthquake hazard, (2) the number of people and amount of property that are exposed to earthquake hazards, and (3) how vulnerable these people and property are to the hazards.

The vulnerability of buildings to earthquake hazards is determined by the prevalence of earthquake-resistant construction, which may vary significantly from building to building. Buildings that have been constructed in compliance with the latest seismic building codes and standards should be more resistant to earthquake damage. Older structures that were built under earlier, less-effective codes and have not been retrofitted to meet later standards are likely to sustain more damage from an earthquake. The extent to which the contents of the buildings are braced, anchored, or otherwise restrained from falling or moving in an earthquake can also affect the extent of damages and casualties, thereby impacting the level of risk.

Standards for Mitigation of Seismic Risks to Federally-Owned Buildings

Federal law generally requires that all federal buildings newly constructed or altered with funds appropriated for a fiscal year after September 30, 1989, be constructed—to the maximum extent feasible as determined by the agency administrator or head—in compliance with the latest edition of a nationally recognized model building code.[13] Nationally recognized codes such as the International Building Code include provisions to ensure that buildings can adequately resist seismic forces during earthquakes.

[13] 40 U.S.C. § 3312.

In addition, *Executive Order 13717 Establishing a Federal Earthquake Risk Management Standard* (February 2016)[14] requires each agency that owns or leases an existing federal building to adopt the *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings*, which are developed, issued, and maintained by the Interagency Committee on Seismic Safety in Construction (ICSSC), as the minimum level acceptable for managing the earthquake risks in that building.[15] The ICSSC standards identify the common minimum evaluation and mitigation measures for all federal departments and agencies to ensure that all federal entities have a balanced agency-conceived and -controlled seismic safety program for their existing owned or leased buildings. The current version of these standards was issued as ICSSC Recommended Practice 8 (RP 8) in December 2011. In particular, these standards establish building design and construction performance objectives for the seismic safety of federal buildings, including (1) Life Safety, (2) Occupancy, and (3) Mission Critical designations as described in table 1. Executive Order 13717 also provides that new federal buildings must be constructed using the 2015 edition of the International Building Code (IBC). It further states that new and existing federal buildings may need to exceed the minimum life safety codes and standards to ensure that the buildings can continue to perform their essential functions following earthquakes and encourages federal agencies to consider going beyond the codes and standards set out in the order.[16]

[14]Exec. Order No. 13,717, 81 Fed. Reg. 6407 (Feb. 5, 2016). Prior executive orders which set out the federal policy for earthquake risk mitigation, Executive Order 12699, Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction (January 5, 1990) and Executive Order 12941, Seismic Safety of Existing Federally Owned or Leased Buildings (December 1, 1994) were repealed by this order.

[15]The ICSSC standards serve as the federal standards developed and issued by ICSSC and published by NIST in support of NEHRP.

[16]Tools such as FEMA P-58 *Seismic Performance Assessment of Buildings* are available to help agencies in this regard.

Table 1: Seismic Performance Objectives for Existing Federal Buildings

Recommended Practice 8 performance objective[a]	Description of intended building performance during and after an earthquake
Life safety	Unless an agency decides a building shall be designed to a higher performance objective, federal buildings are to meet a life safety objective where the building is designed such that significant structural damage may occur, but a partial or total structural collapse does not occur. Damage is non-life-threatening, but there could be injuries. Buildings designed under this objective should be able to be repaired, but might incur structural damage that would not allow the building to be immediately useable after an earthquake or might not be repairable for economic reasons.
Occupancy-based	For buildings where it is necessary to control damage or maintain function in the post-earthquake period, federal agencies may–but are not required–to pursue performance objectives more stringent than life safety. These are known as “essential facilities” in building codes. The definition of what is essential is determined by each individual agency. Buildings designed to this objective are not expected to incur life-threatening damage or suffer structural damage to the extent that it would prohibit immediate occupancy after an earthquake.
Mission critical	Federal buildings that must remain fully operational during and after an earthquake are subject to the mission-critical performance objective. Assignment of a mission-critical objective and specification of the corresponding evaluation, rehabilitation, and mitigation measures are left to the discretion of each agency and are not specifically addressed in the *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings: ICSSC Recommended Practice 8*.

Source: GAO presentation of Interagency Committee on Seismic Safety in Construction standards. | GAO-16-680

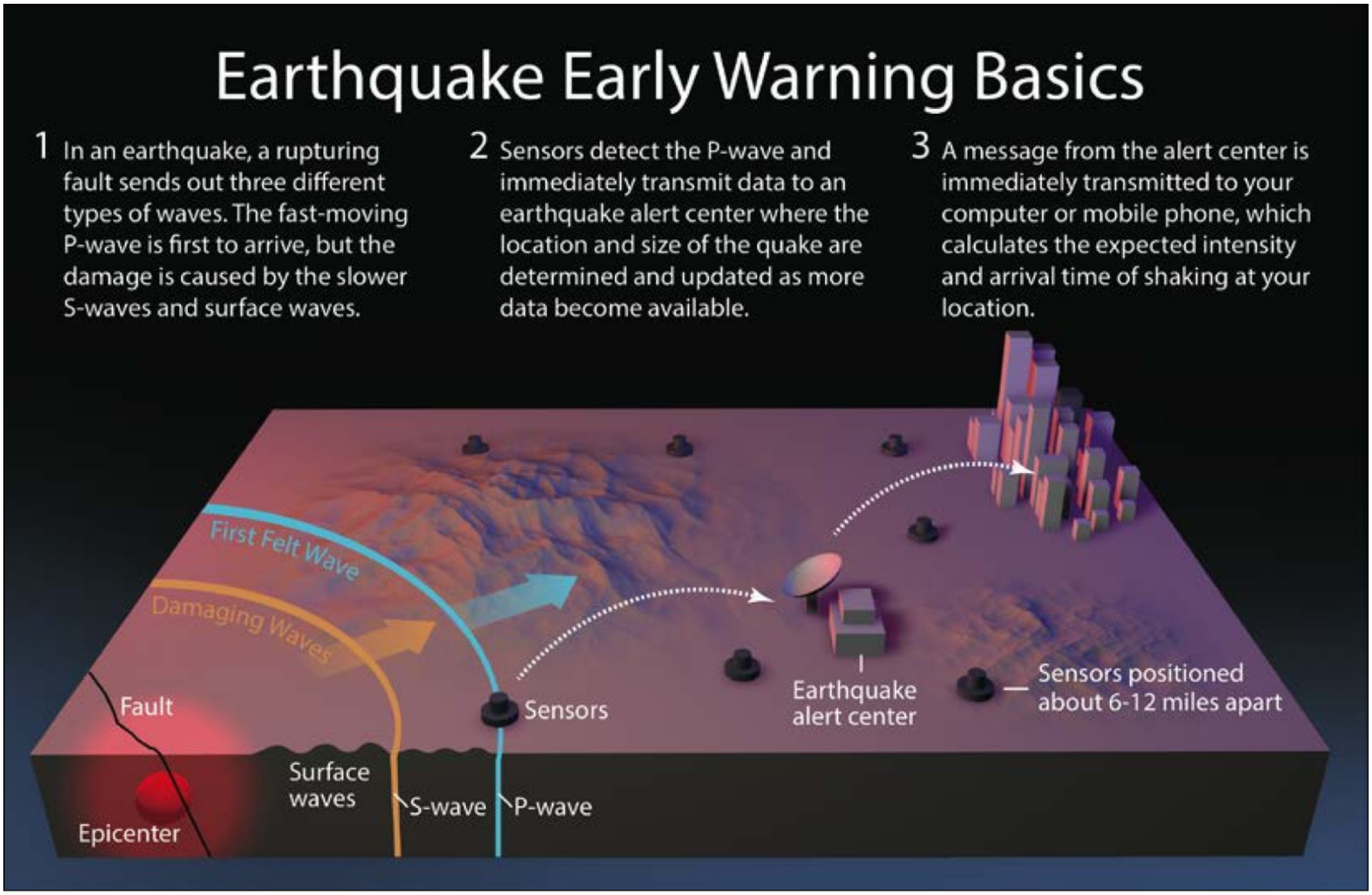
[a]National Institute of Standards and Technology (NIST), *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings: Interagency Committee on Seismic Safety in Construction Recommended Practice 8*, NIST GCR 11-917-12 (December 2011).

RP 8 also identifies FEMA E-74, *Reducing the Risks of Nonstructural Earthquake Damage*, as an additional reference that may be useful for scoping and prioritizing the protection of nonstructural components and contents because the guidance provides information on the relative risks posed by nonstructural elements, as well as appropriate mitigation techniques. In addition, RP 8 cites several FEMA guidance documents for incrementally retrofitting buildings including FEMA 397, *Incremental Seismic Rehabilitation of Office Buildings*. FEMA 397 provides office building owners who have budgetary constraints and cannot afford expensive and disruptive seismic rehabilitation projects an affordable strategy for responsible mitigation measures that can be integrated into ongoing facility maintenance and capital improvement operations. RP 8 also references FEMA 547, *Techniques for the Seismic Rehabilitation of Existing Buildings* as additional guidance on strategies for retrofitting which are practical and effective.

Earthquake Early Warning

The technology exists today to detect earthquakes so quickly that an alert can reach some areas before strong shaking—generated from the earthquake—arrives. The purpose of an EEW system is to identify and characterize an earthquake a few seconds after it begins, calculate the likely intensity of ground shaking that will result, and deliver warnings to people and infrastructure in harm's way. USGS is the lead federal agency responsible for developing and implementing ShakeAlert—the United States' EEW system. USGS has been working with western state governments, academic institutions, and various seismic networks to leverage existing infrastructure while developing the ShakeAlert system. USGS's fiscal year 2017 budget requested $8.2 million, which according to USGS, will be used to, in part, expand the system. Multiple sources—from academia, a philanthropy foundation, and federal, state, and local governments—have contributed funding or resources to the development of ShakeAlert through the purchase and installation of seismometers, research and development of detection algorithms, and the storage and maintenance of servers needed to host the system. ShakeAlert is currently in the beta testing stages in the western United States. Figure 3 illustrates how EEW systems provide advanced warnings.

Figure 3: Earthquake Early Warning: How It Works



Source: U.S. Geological Survey. | GAO-16-680

Selected Cities Are Taking Actions to Assess and Mitigate Seismic Risks of Their Buildings

Methods to Assess Seismic Risks

Local governments have taken actions to protect the health, safety, and welfare of their citizens against potentially damaging earthquakes. Proactive efforts to assess and understand seismic risks can help reduce these risks and create safer, more disaster resilient communities. The risk assessment process focuses attention on areas most at risk by evaluating where populations, infrastructure, and critical facilities are vulnerable to hazards, and to what extent injuries or damage may occur, according to FEMA. In the four cities we studied—Los Angeles, California; Memphis, Tennessee; San Francisco, California; and Seattle, Washington—officials told us about efforts to assess and understand seismic risks. These efforts fell into several categories including: hazard mitigation planning, seismic hazard mapping, loss estimating, and identifying vulnerable and mission critical buildings.

Hazard Mitigation Planning: According to FEMA, mitigation is most effective when it is based on a comprehensive, long-term plan that is developed before a disaster occurs.[17] The purpose of mitigation planning is to identify local policies and actions that can be implemented over the long term to reduce risk and future losses from hazards. These policies and actions are identified based on an assessment of hazards, vulnerabilities, and risks and the participation of a wide range of stakeholders in the planning process. The assessment can include gathering information on the types, locations, and potential extent of natural or man-made hazards and the types and numbers of buildings, infrastructure, and critical facilities located in hazard areas. The cities that we studied have conducted hazard mitigation planning and identified policies and actions to mitigate risk of damage and losses likely to occur as a result of an earthquake. For example, Memphis is located within Shelby County and participated in the development of Shelby County's 2010 multi-jurisdictional hazard mitigation plan, which found that Memphis is greatly vulnerable to earthquake threats because of the city's large clusters of dilapidated buildings and infrastructure. In addition, Seattle, using a grant funded through FEMA's Pre-Disaster Mitigation Grant Program, recently completed a seismic risk assessment for a representative set of city-owned buildings as a demonstration project. This study helped the city develop a methodology to evaluate seismic risks, prioritize mitigation actions, and reduce seismic risk over time.

[17]According to FEMA, all states have FEMA-approved hazard mitigation plans and approximately 60 percent of the U.S population lives in communities having local mitigation plans. Federal law requires the development of a hazard mitigation plan that identifies a jurisdiction's natural hazards, risks, vulnerabilities, and mitigation strategies prior to receiving hazard mitigation funding from FEMA. 42 U.S.C. § 5165.

Seismic Hazard Mapping: Seismic hazard maps show the distribution of earthquake shaking levels that have a certain probability of occurring. Applications of seismic hazard maps include helping to determine seismic risks and inform policies and actions intended to mitigate those risks. These policies and actions may relate to areas such as building code development, land-use planning, establishing retrofit priorities, and planning allocation of assistance funds for education and preparedness. In the cities we studied, we examined how seismic hazard mapping is being used to support development of policies and actions to mitigate seismic risks. For example, Seattle has used seismic hazard maps developed by the USGS that provide the probability of the maximum ground motion Seattle neighborhoods could face in the next 50 years to inform its mitigation policy and actions.[18] In addition, Los Angeles and San Francisco are bound by the State of California's Alquist-Priolo Earthquake Fault Zoning Act of 1972 and the Seismic Hazards Mapping Act of 1990 which requires California's State Geologist (California's chief of the Division of Mines and Geology) to map areas subject to ground shaking, liquefaction, and landslide hazards.[19],[20],[21] Local California

[18]Ground motion is mapped in terms of acceleration. Acceleration is the rate of change of velocity at which a reference point moves during ground motion and is expressed as a fraction of gravity—typically the higher the acceleration, the more stress on a building. Seismic acceleration is divided into horizontal (east-west and north-south) and vertical components. The distinction can be critical as buildings may have been constructed to withstand motion in some directions better than others. Acceleration varies with distance from the epicenter and local conditions like soil type.

[19]Cal. Pub. Resources Code § 2622. The Alquist-Priolo Act was established as a direct result of the 1971 San Fernando earthquake. The purpose of this act is to provide policies and criteria to assist cities, counties, and state agencies in the exercise of their responsibility to prohibit the location of developments and structures for human occupancy across the trace of active faults and to provide the citizens of the state with increased safety and to minimize the loss of life during and immediately following earthquakes by facilitating seismic retrofitting to strengthen buildings, including historical buildings, against ground shaking.

[20]Cal. Pub. Resources Code § 2696. California's Seismic Hazard Mapping Act was adopted in 1990 to provide for a statewide seismic hazard mapping and technical advisory program to assist cities and counties in fulfilling their responsibilities for protecting public safety from the effects of strong ground shaking, liquefaction, landslides, or other ground failure caused by earthquakes. The Act requires that the state geologist delineate the various seismic hazard zones. Under the Act and its implementing regulations, cities, counties, or other permitting authorities are required to regulate certain development projects within the zones. They may approve development permits for a site within a zone only when the geologic conditions are investigated and appropriate mitigation measures, if any, are incorporated into the development plans.

jurisdictions are required to conduct additional studies and take appropriate mitigation measures for certain development projects in areas identified as potentially hazardous by the maps.

Seismic Loss Estimation: To aid seismic hazard mitigation planning, loss estimating tools such as FEMA's HAZUS program can be used to determine areas of vulnerability and to help prioritize mitigations that address these vulnerabilities.[22] HAZUS estimates losses from potential hazards, including earthquakes, and quantifies these losses in terms of potential fatalities, injuries, direct property loss and damage, and indirect economic loss for a certain event scenario or over time (annualized loss). For example, a 2008 FEMA study based on HAZUS indicates that the Annualized Earthquake Loss (AEL) to the national building stock is $5.3 billion per year.[23] The majority (77 percent) of average annual loss is located on the West Coast (California, Oregon, and Washington) with 66 percent ($3.5 billion per year) concentrated in the state of California (see app. IV for additional information). The cities we studied used HAZUS to support their seismic hazard mitigation planning efforts, according to local planning documents we reviewed. For example, San Francisco used HAZUS in a risk assessment of high-priority city-owned buildings to help identify those buildings expected to perform "better" or "worse" than average, and determine the relative earthquake risk within the city's portfolio. San Francisco used this analysis to prioritize buildings for mitigation action or more detailed engineering evaluations.

Building Inventory: As indicated in the preceding example describing HAZUS, building stock data can be used to assess buildings' exposure to seismic risks and estimate losses likely to result from an earthquake. In addition, information on the type of buildings in the inventory can be used to develop estimates of costs to mitigate risks, such as structural retrofit projects. Together, information on estimated losses and mitigation costs can be used to prioritize efforts to address unacceptable risks. Having an

[21]Liquefaction is a type of ground failure that occurs when shaking during an earthquake causes water-saturated sand, silt, or gravel layers underground to behave like a liquid rather than a solid. Soils that are prone to this are frequently found along natural waterways and in areas where the ground consists of artificial fill.

[22]HAZUS is a standardized methodology to estimate potential losses from earthquakes, floods, and hurricanes.

[23]Federal Emergency Management Agency, *HAZUS® MH Estimated Annualized Earthquake Losses for the United States*, FEMA 366 (Washington, D.C.: April 2008).

inventory of buildings that includes information such as their location, type of occupancy and building construction, age, and mitigation needs is important to determining their exposure to seismic risks and prioritizing mitigations. In the communities we studied, we found some had developed building inventories and were using information in the inventories to prioritize mitigation projects. For example the Los Angeles Unified School District (LAUSD) conducted a risk assessment of its facilities and developed a list of 667 potentially at risk K-12 school buildings, according to LAUSD officials. In addition, Shelby County, Tennessee, as part of its multi-jurisdiction hazard mitigation plan, identified mission critical government buildings, including fire and police service facilities, hospitals, water pumping stations, waste treatment plants, and electrical power plants.

Methods to Mitigate Seismic Risk

Officials from Los Angeles, Memphis, San Francisco, and Seattle told us they have employed a variety of methods that can reduce the risk of losses from earthquake hazards. As discussed below, these actions include conducting earthquake drills that provide building occupants the opportunity to practice how to be safer during earthquakes, utilizing land use planning to determine how best to develop hazard-prone areas, requiring compliance with building codes to make new structures more resistant to earthquakes, and mandating structural and non-structural retrofits for existing vulnerable structures.

Earthquake Drills: Earthquake drills are actions to inform and educate building occupants about earthquake risks and potential ways to mitigate them. For example, according to the State of California's Governor's Office of Emergency Services, most injuries in California earthquakes occur when building occupants attempt to exit buildings or move to a different location in the building. Earthquake drills can improve preparedness and minimize risk of injury during earthquakes. For example, the Great ShakeOut is a national program which annually encourages people in homes, schools, businesses, and other buildings to practice what to do during earthquakes, which is to "drop, cover, and hold on." Among the communities we studied, all have participated in a Great ShakeOut drill.

Land Use Planning: State or local land-use programs can help guide more prudent development in seismic hazard areas. Land-use planning may include limiting growth in hazard-prone areas. At the state level, for example, California law requires the State Geologist to delineate seismic hazard areas. Cities, counties, or other permitting authorities in the state are required to regulate certain development projects according to the hazard level determined for the development site. Regulatory action might include, for example, withholding development permits for a site until the geologic conditions are investigated and appropriate mitigation measures, if required, are incorporated into the development plans. Concerning local programs, we observed land-use planning regulations or guidance being used in the cities we studied. For example, the Los Angeles Department of Building & Safety (LADBS) has established three new "Preliminary Fault Rupture Study Areas" for several fault lines within the city that have not yet been mapped by the California Geological Survey. If a proposed development is found to be in a Preliminary Fault Rupture Study Area, geologic investigations to determine the presence or absence of an active fault will be required before building permits are issued by LADBS.

Building Code Enforcement: According to FEMA, many states and local jurisdictions have adopted the model building codes maintained by the International Code Council (ICC). ICC maintains the International Building Code (IBC).[24] These codes incorporate seismic design standards aimed at preventing loss of life caused by building collapse.[25] Authorities often use these codes to regulate the design and construction of buildings, which helps ensure the structures provide the level of protection for which they were designed. The four cities we studied have adopted these model building codes and have departments responsible for ensuring compliance with the building codes. In addition, some of the jurisdictions we studied have modified or were considering modifying their building codes to reflect local earthquake risks and require more rigorous actions to address these risks.

[24]The ICC's family of International Codes includes the International Building Code (IBC) which applies to almost all types of new buildings and the International Existing Building Code (IEBC), which is intended to regulate the alteration, repair, addition or change in occupancy of existing structures. ICC publishes new editions of the International Codes every 3 years, and many states and localities have adopted them since the first editions were issued in 2000. Adoption of the model codes has been uneven across and within states, even in areas with high levels of seismic hazard, according to FEMA. Some states and local jurisdictions have adopted the codes but have made amendments or exclusions relating to the seismic provisions.

[25]Buildings designed to these standards may be heavily damaged as a result of an earthquake, making them uninhabitable until repaired or even requiring demolition if repairs are uneconomical.

Structural Retrofits: Retrofitting existing structures is an action that can improve their ability to withstand earthquakes.[26] The vast majority of seismic-related fatalities have been caused by failure of structural building components, according to FEMA. Some communities in the United States have taken steps to retrofit their public buildings and have adopted ordinances that require seismic upgrades to privately-owned buildings. While retrofitting may not bring a structure up to code standards for new buildings, it will help existing structures better withstand seismic activity. Among the cities we studied, we identified several examples of retrofitting (see app. III for additional information). For example, since the 1989 Loma Prieta earthquake, San Francisco has completed more than 190 structural retrofit projects to its public buildings, including City Hall, the Main Library, the historic Ferry Building, library and park facilities, and various critical facilities, such as police and fire stations.

Nonstructural Retrofits: According to FEMA, most of the damage caused by several recent U.S. earthquakes has been due to nonstructural failures.[27] Falling nonstructural building components are responsible for far more injuries than structural components are for fatalities according to FEMA officials. Simple mitigation measures can vastly reduce the potential for non-structural failures, according to FEMA. These mitigation measures include low-cost efforts such as relocating and bracing furniture, relocating heavy items to lower shelves, or securing hazardous chemicals in such a way that they remain in place during an earthquake. Nonstructural retrofits are particularly important in facilities such as hospitals where people may be exposed to risk of injury from furniture or medical equipment being displaced during an earthquake. The State of California has recognized this risk and requires hospitals to address hazards from non-structural building components. For example, in all

[26]Structural retrofitting involves strengthening the structural components of existing buildings. Structural building components include columns (posts, pillars); beams (girders, joists); braces; floor or roof sheathing, slabs, or decking; load-bearing walls (i.e., walls designed to support the building weight or provide lateral resistance); and foundations.

[27]Nonstructural components of a building include those components that are not part of the structural system; that is, all of the architectural, mechanical, electrical, and plumbing systems, as well as furniture, fixtures, equipment, and contents. Windows, partitions, granite veneer, piping, ceilings, air conditioning ducts and equipment, elevators, computer and hospital equipment, file cabinets, and retail merchandise are all examples of nonstructural components that are vulnerable to failure during an earthquake and causing injury or damage.

California hospitals, non-structural components such as medical equipment and piping must be secured to the structure (see app. V for examples). In addition, following the 1994 Northridge Earthquake, LAUSD completed non-structural mitigation projects, including seismic anchoring and bracing of conduits and mechanical ducts, and securing overhead lights to prevent them from swinging and falling during future earthquakes.[28] We toured a high school where LAUSD completed non-structural retrofits, including anchoring or bracing of mechanical ducts, as shown in figure 4.

Figure 4: Anchoring and Bracing of Building Components in a Los Angeles Unified School District School Building

Source: GAO. | GAO-16-680

[28]In the Northridge Earthquake, 5,500 buildings owned by LAUSD suffered an estimated $134 million in damages. Under Section 406 of the Stafford Act, FEMA obligated $3.1 million for damaged, unbraced pendant ceiling and lights. In addition, $45 million was obligated under Section 404 of the Stafford Act to mitigate unbraced pendant ceiling and light systems of the same design that were not damaged.

Funding Seismic Risk Mitigation Efforts

Many mitigation measures, such as structural retrofits, can be expensive. Local municipalities can seek financial assistance for making mitigation measures through various means, including federal grants, municipal bonds, and capital improvement program funding. Limited federal assistance is available to states through several FEMA programs, including the Hazard Mitigation Grant Program,[29] Pre-Disaster Mitigation Grant Program,[30] and the NEHRP Earthquake State Assistance Program.[31] Some cities we studied used resources from a combination of sources to fund seismic mitigation measures. For example, since 2008, voters have approved seven General Obligation bonds totaling $2.8 billion that have funded improvements to the San Francisco's hospitals, fire and police stations, and other facilities. These projects were selected, in part, from a HAZUS analysis used to prioritize projects in a 10-year capital plan. For instance, HAZUS identified fire stations that were not previously identified as having seismic hazards, and San Francisco is prioritizing projects to address these hazards.

[29]FEMA's Hazard Mitigation Grant Program assists in implementing long-term hazard mitigation measures following presidential disaster declarations. Funding may be authorized after a declaration to implement projects in accordance with state, tribal, and local priorities.

[30]FEMA's Pre-Disaster Mitigation Grant Program provides funds on an annual basis for hazard mitigation planning and mitigation project implementation prior to a disaster. The goal of the program is to reduce overall risk to the population and structures, while at the same time also reducing reliance on federal funding from actual disaster declarations.

[31]The NEHRP Earthquake State Assistance Program was created to increase and enhance the effective implementation of earthquake risk reduction at the local level. Examples of mitigation activities funded through this program include: developing seismic mitigation plans; conducting seismic safety inspections of critical structures and lifelines; updating building codes, zoning codes, and ordinances to enhance seismic safety; or increasing earthquake awareness and education.

Federal Buildings Are Located in Areas of Varying Seismic Hazard, and DOD and GSA Could Do More to Identify and Mitigate Seismic Risk

Almost 40 Percent of Federally Owned and Leased Buildings Are Located in Very Strong to Extreme Earthquake Hazard Areas

As of September 2014, the federal government owned and leased almost 100,000 buildings (about 40 percent of the total approximate 252,000 federal buildings) within the United States that were located in earthquake hazard areas which could experience very strong (MMI VII) to extreme (MMI X) shaking (see table 2).[32] Almost 405,000 federal civilian personnel are assigned to work in buildings located in these earthquake hazard areas (see table 3). Very strong to severe shaking from earthquakes (MMI VII and VIII) could cause varying levels of damage to buildings depending on how well they were designed and constructed. In addition, earthquakes at this intensity can cause heavy furniture to be overturned and building components such as chimneys and walls to collapse. Violent to extreme shaking (MMI IX and X) could cause considerable damage in most buildings, including the collapse of wood and masonry structures. Actual damage sustained by a building depends on both the intensity of shaking and factors such as soil conditions and the building's structural design and proximity to an earthquake's epicenter. For additional information on the potential exposure of federally-owned and -leased buildings to earthquake shaking and the total number and size of federally-owned and -leased buildings by agency see appendix VI.

[32] MMI shaking hazard level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years.

Table 2: Estimated Intensity of Earthquake Shaking on Federal Buildings by Agency, as of September 30, 2014[a]

			Estimated intensity of earthquake shaking Modified Mercalli Intensity (MMI) Based on 2 percent in 50 year probability of exceedance					
Agency	Number of buildings	Size of buildings in thousand square feet	Moderate to extreme MMI≥V	Very strong to extreme MMI≥VII	Violent to extreme MMI≥IX	Moderate to extreme MMI≥V	Very strong to extreme MMI≥VII	Violent to extreme MMI≥IX
			Percent of agency buildings			Percent of agency square feet		
Department of Defense	125,834	1,497,929	81.3	34.9	12.5	80.5	32.5	12.8
Air Force	33,135	463,138	73.4	32.5	10.3	74.3	32.1	11.4
Army	59,615	596,781	84.1	29	8.1	85.3	25.4	7.4
Navy	31,866	419,591	84.3	49	23.3	80.6	43.2	22.1
Other[b]	1,218	18,420	82.6	23.1	6.3	88.9	15.3	5.9
General Services Administration	8,433	419,968	78.8	28.6	9	86.6	25	8
All other federal agencies	118,140	744,049	84.8	45.1	9.9	83.1	37.8	11.4
All federal agencies	252,407	2,661,945	82.8	39.4	11.2	82.2	32.7	11.6

Source: GAO analysis of Department of Defense data, General Services Administration data, and United States Geological Survey mapping. | GAO-16-680

Note: Includes owned and leased federal buildings reported to the Federal Real Property Profile (FRPP) located in the 50 states and the District of Columbia as active or inactive. The FRPP database includes federal buildings under the custody and control of United States executive branch agencies or components as set out in Executive Order 13327 and certain executive branch agencies which voluntarily report. The data does not include those buildings held by the legislative branch agencies, judicial branch agencies, or other non-executive branch agencies such as the United States Postal Service. MMI shaking hazard level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years.

[a]Approximately 2.0 percent or 5,036 of the 252,407 federal buildings identified as active or inactive (1.8 percent or 48.6 million square feet of the 2,662 million square feet of buildings) in the FRPP building data were not included in our analysis and are not reflected in the above percentages because they either did not have location information included in the FRPP or the location information in the FRPP had inconsistencies in the data which did not allow the building to be accurately located.

[b]Other includes the civil works buildings reported by the United States Army Corps of Engineers and military buildings reported by the Washington Headquarters Services.

Table 3: Federal Civilian Personnel With Official Worksites Located in Areas of Earthquake Shaking, employed as of September 30, 2014

	Estimated Intensity of Earthquake Shaking Modified Mercalli Intensity (MMI) Based on 2 percent in 50 year probability of exceedance		
	Moderate to Extreme (MMI≥V)	Very Strong to Extreme (MMI≥VII)	Violent to Extreme (MMI≥IX)
Number of Federal Employees	1,548,027	404,707	35,619
Percent of Federal Employees	78.1	20.4	1.8

Source: GAO analysis of Office or Personnel Management data and United States Geological Survey mapping. | GAO-16-680

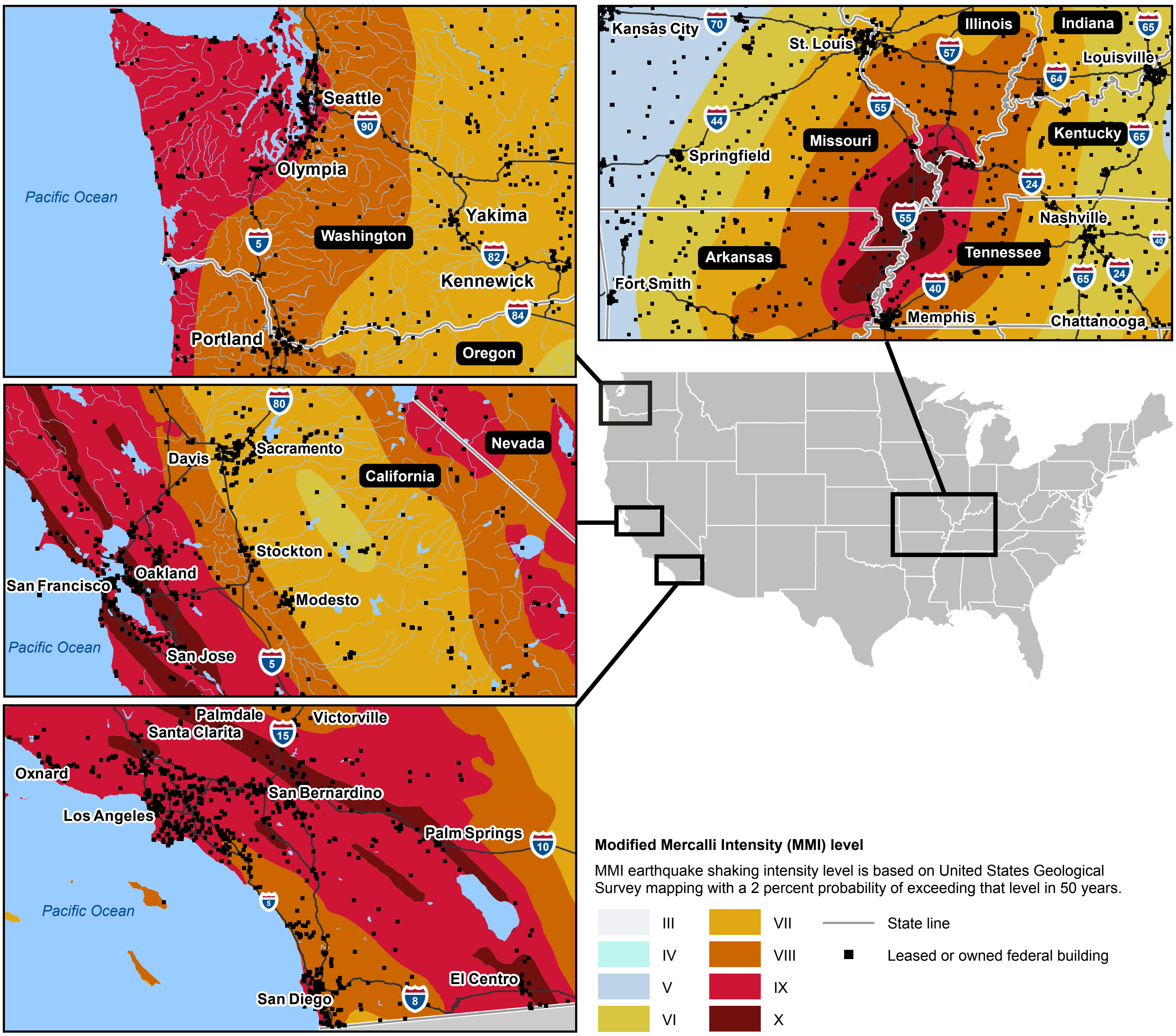
Note: Analysis includes the personnel of the Chief Financial Officers (CFO) Act of 1990 (Pub. L. No. 101-576, 104 Stat. 2838) agencies in the Office of Personnel Management's Enterprise Human Resources Integration (EHRI) database with their official worksite in the 50 states and the District of Columbia. The data includes 1,983,164 persons and does not include military or other non-CFO agency personnel (such as legislative branch, judicial branch, or United States Postal Service) or civilian contractors. MMI shaking hazard level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years. Because the EHRI worksite location data was based on the employee's worksite county and counties can have more than one MMI level within the county, we reported the above data based on the lowest potential MMI shaking identified for the county. As a result, the actual number of personnel in each shaking intensity category would be higher in counties with more than one MMI zone.

Figure 5 shows federally-owned and -leased building locations relative to areas of potential earthquake shaking intensity around the cities we visited and discussed above—Los Angeles, Memphis, San Francisco, and Seattle. See appendix VII for additional information on figure 5.

Interactive graphic

Figure 5: Federal Buildings In Four High Earthquake Shaking Intensity Zones of the United States, as of September 30, 2014

Click on regional maps to see a more detailed view. Click on the ☒ to close. For a noninteractive version see appendix VII.



Source: GAO analysis of Department of Defense data, General Services Administration data, and U.S. Geological Survey mapping; MapInfo (map). | GAO-16-680

Note: Includes leased and owned federal buildings reported to the Federal Real Property Profile (FRPP) as active or inactive. The FRPP database includes federal buildings under the custody and control of United States executive branch agencies as set out in Executive Order 13327 and certain executive branch agencies which voluntarily report. The data does not include those buildings held by the legislative branch agencies, judicial branch agencies, or other non-executive branch agencies such as the United States Postal Service. Modified Mercalli Intensity (MMI) earthquake shaking intensity level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years. Approximately 2.0 percent of the total number of active and inactive buildings (1.8 percent of the square feet of buildings) in the FRPP data were not included in the analysis because they either did not have location information included in the FRPP or the location information in the FRPP had inconsistencies in the data which did not allow the building to be accurately located.

DOD and GSA Have Not Fully Identified Their Exceptionally High Risk Buildings or Developed Comprehensive Seismic Safety Measures

Defining and Identifying Exceptionally High Risk Buildings

DOD components and GSA have made varied efforts to define what constitutes an "exceptionally high risk" building—those that are most susceptible to earthquake damage—and identify these buildings within their portfolios. More specifically, GSA recently defined what constitutes an exceptionally high risk (EHR) building and began evaluating and rating its buildings in high seismic areas to identify EHR buildings within its owned-building portfolio. As for DOD components, the Air Force and Army have defined what constitutes an EHR building, but have not identified these buildings in their portfolios while the Navy does not have a current definition of EHR. Executive Order 13717 states that agencies are to adopt the Standards of Seismic Safety for Existing Federally Owned and Leased Buildings (ICSSC Standards).[33] The latest version of the ICSSC Standards is Recommended Practice 8 (RP 8), which requires agencies to designate buildings that are of exceptionally high seismic risk and develop a plan to reduce the risks. To do so, agencies must first define what constitutes an exceptionally high risk building and identify those buildings. According to RP 8, exceptionally high risk buildings can

[33]Executive Order 12941 (December 1994), revoked in 2016, also adopted the *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings* as the minimum standards for federal departments and agencies to use in assessing and mitigating the seismic risk in their buildings. The current version of these standards is the Interagency Committee on Seismic Safety in Construction, *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings: ICSSC Recommended Practice 8 (RP 8),* NIST GCR 11-917-12 (Gaithersburg, MD.: December 2011).

be identified by agencies based on factors such as a building's age, structure type, location, number of occupants, and importance to mission. Table 4 provides details on the extent to which DOD components and GSA have defined and identified exceptionally high risk buildings.[34]

Table 4: Extent to Which Department of Defense (DOD) Components and General Services Administration (GSA) Have Defined and Identified Exceptionally High Seismic Risk (EHR) Buildings

Component or agency	EHR Currently Defined	Identified and listed current EHR buildings	Knows occupancy of EHR buildings	Component/agency remarks
Air Force	Yes	No	No	The Air Force defined EHR in the late 1990's as part of a government-wide effort to identify EHR buildings and still uses that definition. The resulting 1998 report listed 226 EHR buildings; however, the list is no longer current. Air Force officials said they do not have staff dedicated to managing a program for maintaining a current list of EHR buildings. Further, Air Force officials said the cost to develop the 1998 report which identified the EHR buildings was $5.9 million and would be much higher today when accounting for inflation.
Army	Yes	No	No	The Army uses a definition for EHR from the Interagency Committee on Seismic Safety in Construction (ICSSC) Recommended Practice 5 (RP 5), which was issued in 1995. Army officials had previously identified EHR buildings using the RP 5 definition and listed them as part of the late 1990's government-wide effort; however, they do not have a current list of EHR buildings. Army officials stated there has not been any directive or funding to expand and develop the 1990's list of EHR buildings into an effective tracking and remediation tool.
Navy	No	No	No	The Navy defined EHR in a 2003 guide pertaining to seismic mitigation but never implemented the guidance. In addition, Navy officials said while a list of EHR buildings with the number of occupants was developed circa 2000 as part of the government-wide effort, the list has not been kept current. According to these officials, the Navy would need to start a new effort to generate a valid inventory of exceptionally high risk buildings.

[34]DOD (50 percent) and GSA (3 percent) are responsible for more than half of the approximately 252,000 federally-owned or -leased buildings in the 50 states and the District of Columbia. In addition, those DOD (56 percent) and GSA (16 percent) owned or leased buildings account for about 72 percent of total federal building space in the United States.

Component or agency	EHR Currently Defined	Identified and listed current EHR buildings	Knows occupancy of EHR buildings	Component/agency remarks
GSA	Yes	In progress	No	GSA adopted a definition of EHR based on its engineering consultant's Seismic Rating Report, completed on March 31, 2016.[a] Based on this report, GSA has begun training staff in the process used to calculate a seismic risk rating, which is used to determine if a building is EHR. Of GSA's federally-owned inventory, its consultant's report identified 8 EHR buildings among the 63 buildings for which a seismic risk rating was calculated. GSA is in the process of hiring a contractor to evaluate and develop seismic risk ratings for additional federally-owned buildings located in high-seismic areas to determine which of these are EHR. GSA plans to complete this work by July 2017.

Source: GAO presentation of responses from DOD component and GSA headquarters officials. | GAO-16-680

[a]Rutherford + Chekene, GSA Seismic Rating (final report), a report prepared at the request of the General Services Administration, Mar. 31, 2016. According to GSA, this report developed a methodology that defines EHR for the agency based on a Seismic Risk Rating (SRR), tested the methodology used to calculate SRR, and developed a partial list of prioritized GSA EHR buildings. The SRR methodology takes into account information such as location, type of occupancy, type construction, age, and structural deficiencies of the buildings being evaluated; and uses the Federal Emergency Management Agency's HAZUS modeling to identify and prioritize buildings. The SRR methodology does not take into account deficiencies related to non-structural items such as furniture not being braced, parapet walls falling, brick chimneys falling, ceiling tiles and light fixtures falling, and glass windows cracking.

A government-wide effort in the 1990s led by FEMA identified about 2,900 exceptionally high risk federal buildings and proposed a plan for mitigating the seismic risk of those buildings.[35] However, FEMA's report—which estimated about $22.9 billion[36] (Fiscal Year 1999 dollars) was needed to retrofit these and other seismically at risk federal buildings—was never issued to the Congress, as was required by the Order.[37] In addition, DOD officials told us that they believe the costs of retrofitting the exceptionally high risk buildings—the estimated $22.9 billion—was too expensive to pursue. According to Air Force, Army, and Navy installation officials and GSA regional officials, costs are still a challenge to identifying and retrofitting seismically at-risk buildings. Navy and GSA officials said, for example, that the cost to fully evaluate a building for

[35]This effort was a result of Executive Order 12,941, 59 Fed. Reg. 62,545 (Dec. 5, 1994).

[36]Approximately $31.4 billion in Fiscal Year 2015 dollars.

[37]Executive Order 13717 revoked Executive Order 12941 in February 2016, and as a result this requirement is no longer in place.

seismic risk can be very high, ranging from $5,000 to more than $100,000 depending on the level of evaluation required.[38] However, we found that the U.S. Fish and Wildlife Service uses FEMA's Rapid Visual Screening tool as a less-costly alternative to quickly screen buildings and identify those which may need additional evaluation.[39] According to U.S. Fish and Wildlife Service officials, the cost to complete a rapid visual screening is about $300 to $625 per building.

DOD officials and GSA officials we interviewed support the creation of a uniform definition of exceptionally high risk, but one official noted that agencies might prefer flexibility in the definition and how it is applied. To take steps toward establishing a common definition of exceptionally high risk, GSA officials said they presented a proposal this year to the ICSSC for developing a process to create such a definition that would apply to all federal agencies and are planning to work with ICSSC to pursue this effort in fiscal year 2017. However, it is unclear at this time whether this proposal will be adopted and implemented. The proposal, if implemented, to define what constitutes an exceptionally high risk building could help DOD and GSA to more fully and consistently identify such buildings and evaluate whether there may be unacceptable risks posed by their buildings. In accordance with RP 8, once EHR buildings are identified, agencies should develop a plan to mitigate the associated risks. As such, defining and identifying EHR buildings could afford DOD and GSA opportunities to develop a plan to mitigate potential earthquake damages to their building portfolios and protect building occupants.

[38]This is for an evaluation of seismic risk based on the American Society of Civil Engineers' *Seismic Evaluation and Retrofit of Existing Buildings*, Standards ASCE/SEI 41-13.

[39]The rapid visual screening tool has been developed for a broad audience, including building officials and inspectors, and government agency and private-sector building owners, to identify, inventory, and rank buildings that are potentially seismically hazardous. Its principal purpose is to identify (1) older buildings designed and constructed before the adoption of adequate seismic design and detailing requirements, (2) buildings on soft or poor soils, or (3) buildings having performance characteristics that negatively influence their seismic response. Once a building is identified as potentially hazardous, it should be further evaluated by a design professional experienced in seismic design to determine if, in fact, it is seismically hazardous. See Federal Emergency Management Agency, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*, Third Edition, FEMA P-154 (Washington, D.C.: January 2015) for additional information.

Comprehensive Seismic Safety Measures

DOD components and GSA have taken steps to mitigate risk through disposing of buildings and making seismic retrofits when completing major building renovations at some buildings, as required in RP 8. However, DOD and GSA have not developed and implemented comprehensive seismic safety measures to mitigate the impacts of earthquakes across their building portfolios. Seismic safety measures can be employed across agencies' buildings through various mitigation efforts, including seismically retrofitting and disposing of buildings, as well as lower cost mitigation measures like non-structural retrofits, earthquake drills, and seismic safety inspections.

Seismic Retrofits: According to DOD installation officials and GSA regional officials, due to limited budgets and the lack of dedicated funding for seismic retrofits, they generally do not undertake many projects specifically for the purpose of retrofitting a building to improve seismic safety. Moreover, according to GSA officials, limiting projects to only seismic work is not cost effective when considering other building improvements that are needed and the invasive nature of seismic upgrades. However, in some cases agencies are required to include seismic retrofits when renovations are being made for other reasons.[40] According to the recommended practices in RP 8 that agencies are required to follow, when agencies reconstruct a building and the reconstruction cost reaches a specific threshold, agencies are generally required to include any needed seismic retrofits as part of the reconstruction.[41] For example, as part of a renovation project, GSA also seismically retrofitted the historic James R. Browning U.S. Court of Appeals Building, in San Francisco, California. A GSA agency official told us that the combined renovation and seismic retrofit cost was about $91 million in 1991. Figure 6 below shows a system installed below the

[40]GSA provided two examples of projects undertaken specifically for the purpose of completing seismic retrofits. The Auburn Building 7 in Auburn, Washington, was retrofitted in 2014 (approximately 205,535 square feet) at a cost of about $17 million. In addition, GSA is in the process of having non-structural and structural seismic renovations made to the Robert A. Young Federal Building (approximately 1,131,930 square feet) in St. Louis, Missouri at an estimated cost of about $70 million.

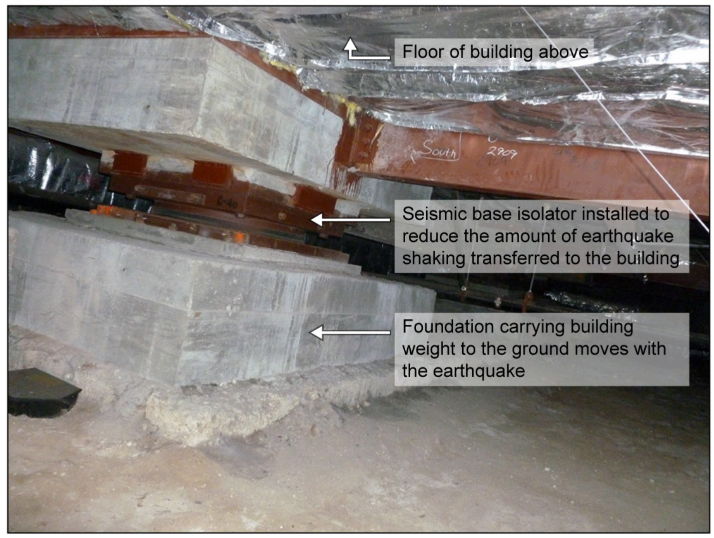
[41]The thresholds are met on projects which significantly extend the building's useful life through alterations or deferred maintenance reductions and whose total cost exceeds either 30 percent or 50 percent of the replacement value of the building. The percentage threshold is determined by the occupancy type of the building, the soils on which it is located, and the type of earthquake shaking expected.

building that is intended to reduce the amount shaking experienced by the building during an earthquake.

Figure 6: Renovated and Seismically Retrofitted GSA James R. Browning U.S. Court of Appeals Building

Renovated interior

Seismic retrofit base isolation



Source: GAO. | GAO-16-680

In another example, we visited a Navy installation in a seismically hazardous section of Tennessee which had renovated a building because it was converting its use from a child development center to a Navy band unit. The project, which was completed in 2010, included seismic retrofits to comply with ICSSC Standards. Installation officials told us that they have not been able to secure funding to address seismic deficiencies at the Security and Fire Department building, which is constructed of unreinforced masonry (see fig. 7). In addition, these officials told us that they have limited funding to replace or retrofit buildings and a large number of unreinforced masonry structures–such as the mission-critical Security and Fire Department Building–remain exposed to risk of damage and casualties from earthquakes.

Figure 7: High Seismic Risk Unreinforced Masonry at Security and Fire Department Building on Navy Installation

Source: GAO. | GAO-16-680

Disposals: In addition to retrofitting buildings, DOD and GSA officials stated that they have mitigated the seismic risk of their building portfolios by disposing of some buildings. For example, GSA officials identified four seismically at-risk buildings in Seattle, Olympia, and Everett, Washington, totaling almost 500,000 square feet that they have disposed of. In addition, GSA is considering for disposal another 11 seismically at-risk buildings in the Seattle area totaling over 2.5 million square feet. Our analysis of all federal buildings in the U.S. indicated that in fiscal year 2014, agencies disposed of about 1 percent or 991 of federally-owned buildings (9.6 million square feet) located in very strong (MMI VII) to extreme (MMI X) shaking intensity zones; however, not all of those 991 buildings may have been at seismic risk because they could have been constructed to meet seismic building codes.[42] DOD and GSA officials stated that they do not track that information.

Non-structural Retrofits: According to FEMA, nonstructural failures have accounted for the majority of earthquake damage in several recent U.S. earthquakes, and it is critical to raise awareness of potential nonstructural risks and strategies to mitigate these risks. Further, RP 8 references FEMA guidance that can be used to obtain information on the relative risks and appropriate mitigation techniques posed by nonstructural building components.[43] For example, according to FEMA guidance, for areas with moderate or high seismicity, the risks associated with many of these components can be reduced by efforts such as securing tall furniture, heavy objects, falling hazards, or hanging objects so that they cannot fall onto a person or block an exit; anchoring pipes, ducts, and equipment to a structural floor, ceiling, or wall; and bracing or anchoring non-structural building components such as chimneys or signs. Based on our interviews with agency officials and observations during site visits, we identified gaps in the extent to which agencies in our review have implemented these non-structural retrofits. For example:

- *Air Force:* At a new fire station on an Air Force installation in California, we observed that while the building's mechanical equipment had been fastened to the structure, furniture such as a tall glass trophy case, bookcases, and wardrobe cabinets were not

[42]Includes owned federal buildings reported to the Federal Real Property Profile (FRPP) as disposed of between October 1, 2013, and September 30, 2014. The FRPP database includes federal buildings under the custody and control of U.S. executive branch agencies or components, as set out in Executive Order 13327 and certain executive branch agencies which voluntarily report. The data does not include those buildings held by the legislative branch agencies, judicial branch agencies, or other non-executive branch agencies such as the United States Postal Service. MMI shaking hazard level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years.

[43]FEMA E-74, *Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide* explains the sources of earthquake damage that can occur in nonstructural components and provides information on effective methods for reducing risk. FEMA 74-FM, *Earthquake Hazard Mitigation for Nonstructural Elements: Field Manual* outlines procedures to identify nonstructural components that may be vulnerable to earthquake damage, prioritize what should be done, and implement a retrofit plan. For a listing of FEMA publications that provide guidance on various earthquake mitigation measures, see Appendix VIII.

secured to the wall or floor. As a result, the wardrobe cabinets which were located in the sleeping rooms are at risk of overturning during an earthquake and preventing fire station personnel from exiting the rooms (see fig. 8). Air Force officials stated that the mechanical equipment, such as the tanks and pipes, were secured because they were installed as a part of the building construction contract, which required compliance with seismic provisions in the building code. However, these officials said that the furniture, such as the wardrobe cabinets, was installed by others after completion of construction, and that there are no requirements or contract provisions to ensure that furniture is properly secured to keep it from being moved during earthquakes.

Figure 8: New Fire Station at Air Force Installation in California with Seismically Secure Equipment and Unsecured Furniture

Source: GAO. | GAO-16-680

- GSA: In a multi-tenant federal building we visited in California, we found filing cabinets and tall furniture were securely fastened in space occupied by GSA staff; however, these types of items were not always adequately secured in offices occupied by staff of tenant agencies in adjacent spaces in the same building. In addition, in a federal building we visited in Tennessee, GSA's building manager was not aware of the results of a seismic assessment prepared for GSA by an engineering firm, which had identified deficiencies in how some mechanical equipment was secured. Upon learning of this assessment at the time of our visit the building manager stated that work to address these deficiencies could likely be done at a low cost and could be addressed within the existing maintenance budget.

Earthquake Drills and Seismic Safety Inspections: Earthquake drills and seismic safety inspections could be beneficial for buildings in all earthquake intensity areas, according to FEMA, because even the newest buildings could suffer damage from a large earthquake such as broken windows, fallen ceilings, and displaced furniture that could cause injury to those who are not taking protective measures. According to FEMA, implementing earthquake drills into emergency management programs is important because knowing what to do and where to go during an earthquake can be critical to life safety.[44] In addition, FEMA guidance states that seismic safety inspections, such as those which could be part of routine housekeeping or maintenance practices, could reduce or eliminate risks from earthquake damage to equipment, furnishings, and unsecured objects in buildings.[45] However, based on our interviews with DOD and GSA officials and observations during site visits, we identified gaps in the extent to which agencies have implemented earthquake drills and seismic safety inspections as part of a comprehensive approach to seismic safety. For example:

- *Air Force:* Officials stated that Air Force instructions provide installations the authority to develop seismic safety measures such as earthquake drills and building content inspections; however, those instructions do not contain specific guidelines concerning measures installations must take. For example, officials stated the instructions do not require furniture to be secured. As a result, personnel in some buildings may be exposed to injuries from furniture overturning during an earthquake. According to these officials, the extent to which seismic safety measures have been developed, if any, varies across installations based on the installations' assessments of their needs. Moreover, these officials also told us that they do not know how many installations have determined that seismic risk is a threat and have included earthquake preparedness in their Installation Emergency Management Plan because they do not collect and summarize that information.

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[44]FEMA 397 Incremental Seismic Rehabilitation of Office Buildings.

[45]Ibid.

- *Army:* Officials told us that earthquake drills are conducted at facilities related to the U.S. Army Corps of Engineers (Corps) Civil Works program but did not know which installations, if any, were conducting earthquake drills at facilities associated with the Army's military operations.[46]
- *Navy:* According to Navy officials, most Navy regions exercise their readiness to respond to an earthquake by holding annual drills—called "Citadel Rumble"—to assess emergency operations staff, training team members, and other emergency response personnel reacting to a strong earthquake. Some of these exercises included "drop, cover, and hold on" drills. Officials also indicated that their safety programs serve to identify housekeeping measures that can mitigate seismic risks. For example, according to these officials, annual "zone inspections" include checking items—such as shelves being attached to walls, heavy objects being placed low on shelves, and overhead lights being braced—associated with mitigating seismic risks. However, information provided by Navy officials from several installations across the United States stated that their "zone inspections" did not include any earthquake related preparedness or earthquake response requirements.
- *GSA:* While GSA conducts earthquake drills and has taken steps to implement non-structural retrofits and housekeeping tasks to mitigate seismic risks in some of its building spaces, it does not have a policy requiring its own agency to conduct routine seismic drills or advise its tenant agencies' of the mitigation measures they could take to reduce seismic risks. For example, we visited the John E. Moss Federal Building and found unsecured bookcases stored near an exit door within tenant office space, but found that GSA had taken steps to secure office furniture within the GSA office space (see fig. 9).

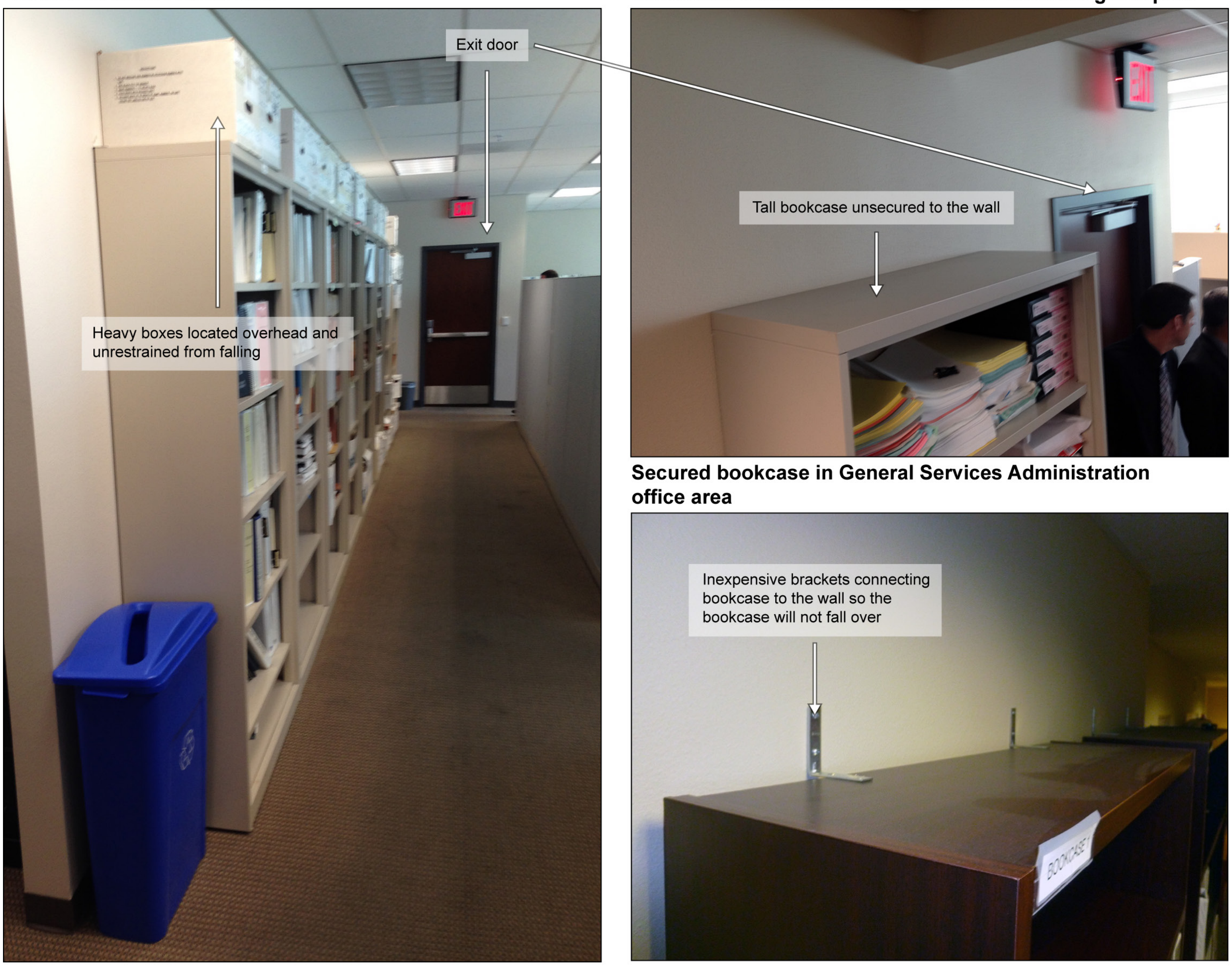
[46]The Corps has both civilian and military responsibilities. Through its Civil Works program, the Corps plans, designs, and operates water resources infrastructure projects. The Corps' military program provides, among other things, engineering and construction services to other U.S. government agencies and foreign governments.

Figure 9: Secured and Unsecured Office Furniture in General Services Administration's John E. Moss Federal Building

Heavy boxes stored overhead along exit path without being secured in tenant office area

Unsecured bookcase in a tenant office area along exit path

Secured bookcase in General Services Administration office area



Source: GAO. | GAO-16-680

Incorporating seismic safety measures—especially lower-cost mitigations such as non-structural retrofits, earthquake drills, and seismic safety inspections—as part of a comprehensive approach could reduce future earthquake damages. The benefits of implementing comprehensive seismic safety measures such as non-structural retrofits, earthquake drills, and seismic safety inspections is documented in ICSSC

Recommended Practice 8 and various FEMA guidance, as discussed above. In addition, DOD and GSA officials agreed that use of lower-cost mitigation measures such as non-structural retrofits to secure building furnishings and mechanical equipment could be incorporated to mitigate risk at relatively low cost. However, DOD and GSA have not consistently implemented comprehensive seismic safety measures throughout their entire building portfolios because, in part, it is not required by DOD and GSA policies. As such, these agencies could benefit by prioritizing and implementing comprehensive seismic safety measures that address the gaps we identified and better enable their facilities to withstand earthquakes and enhance their capacity to save lives, reduce injuries and property damages, and reduce operational impacts when an earthquake does occur.

ShakeAlert Is Capable of Delivering Earthquake Early Warnings, but Cannot Be Fully Implemented until Challenges are Addressed

ShakeAlert System Is Capable of Issuing Early Earthquake Warnings to Enhance Public Safety and Benefit Private Users

Public Safety

According to Shake Alert stakeholders we spoke with, the implementation of an Earthquake Early Warning (EEW) system could have numerous benefits, including providing warnings to the general public prior to shaking and giving more time for individuals to take protective measures such as to “drop, cover, and hold on.” For example, in the western United States where the system is initially being implemented, EEW is capable of providing up to a 90 second warning in California and up to a 5 minute warning in the Pacific Northwest.[47] Stakeholders' expectations of public benefits are based in part on the experience Japan has realized in the operation of its EEW, which has been in place since 2007. For example, Japanese officials told us that during the 2011 Tohoku-oki magnitude 9 earthquake, several million people near the epicenter received a warning approximately 15 to 20 seconds prior to shaking. According to the Japanese Meteorological Agency (JMA), a study intended to assess Japan's EEW system's performance indicated that the vast majority of these people were able to take advance actions prior to shaking arriving.[48] ShakeAlert stakeholders in the United States told us that similar public safety benefits can be achieved through early warnings provided to transportation providers, school systems, hospitals and first responders, among others.

- *Transportation* - According to ShakeAlert stakeholders, the EEW system is capable of providing warnings to the transportation sector, which could enhance safety of various transportation modes. For example, according to Bay Area Rapid Transit (BART) officials, the agency has been operationally testing the system since August 2012 as part of ShakeAlert's beta testing phase. BART officials told us that they use the system to slow down trains when shaking is expected to surpass a certain threshold within a specific area.[49] Slowing the trains down, or stopping them completely, could help prevent additional damages and potentially save lives during an earthquake. In reference to rail transportation, the United States is in position to learn from Japan's experiences. For example, according to officials in Japan, in 2004 a high speed "bullet" train was derailed during an earthquake in Japan, and since that time, the railroad company that operates these trains has implemented an early earthquake warning system, distinct from Japan's national system, to help reduce seismic risks and improve safety. The system is designed to automatically shut off power to the train tracks when shaking exceeds a certain

[47]Differences in regional geography help determine how far in advance an early warning can be distributed.

[48]The Japanese Meteorological Agency is a government agency responsible for implementing and managing Japan's earthquake early warning system, among other things.

[49]BART can reduce train speeds from 80 miles per hour to 25 miles per hour in roughly 18 seconds.

magnitude which causes the trains to slow down and stop. According to Japanese railroad company officials we spoke with, the system has operated successfully in slowing trains during earthquakes and preventing derailments.[50]

- *Schools* - ShakeAlert stakeholders said that the EEW system could be used to provide warnings to school systems, allowing students to take protective measures prior to shaking occurring. In reference to Japan's experience, for example, its national government instituted a nationwide educational program to inform students how to react during an earthquake warning. According to the government officials involved with this program we spoke with, key implementation actions included creating and disseminating leaflets to all public kindergartens, primary schools, and high schools.
- *Hospitals and First Responders* - According to ShakeAlert stakeholders, hospitals and first responders could use the technology to help ensure the safety of patients and enable effective response in the aftermath of a disaster. More specifically, surgeons about to perform elective surgery could halt or delay a surgery if they were aware that shaking from an earthquake was about to occur. In addition, early warnings to first responders would allow them to take steps such as opening firehouse doors so fire trucks are not stuck inside when needed for response efforts. Moreover, pre-notice events would allow additional time for first responders to begin taking steps to identify where their assistance may be most needed.

Commercial and Private Sector Use

In addition to public safety benefits, according to ShakeAlert stakeholders, private companies' use of ShakeAlert could help prevent economic losses. For example, a Boeing company official from Seattle told us that if the federal government commits to funding and implementing the ShakeAlert system, Boeing plans to consider integrating an automated capability into its operations that will help mitigate employee safety concerns and protect against potential losses. In Japan, we observed how a private company—OKI Engineering—has used earthquake early warning information to automatically shut down plant operations, thereby limiting damage from shaking and reducing the time

[50] According to railroad company officials, the early warning system does not provide enough forewarning to stop high speed trains—which typically takes 80 to 90 seconds—before shaking occurs. Rather, the warning is sufficient to reduce train speeds such that they are less likely to derail when shaking begins.

to recover from the earthquakes. Prior to implementing its automated shut-down process in 2003, the company experienced two earthquakes (magnitudes 7.0 and 6.2) that caused $15 million in losses. In addition to losses suffered from fire and equipment damage, OKI Engineering experienced approximately 17 days and 13 days lost productivity following the earthquakes. After it implemented its automated shut-down process, OKI experienced fewer losses and recovered more rapidly from earthquakes. For example, according to company officials, two earthquakes (magnitudes 7.2 and 6.8) in 2008 resulted in the company experiencing approximately $200,000 in damages and 8 total days of lost productivity.

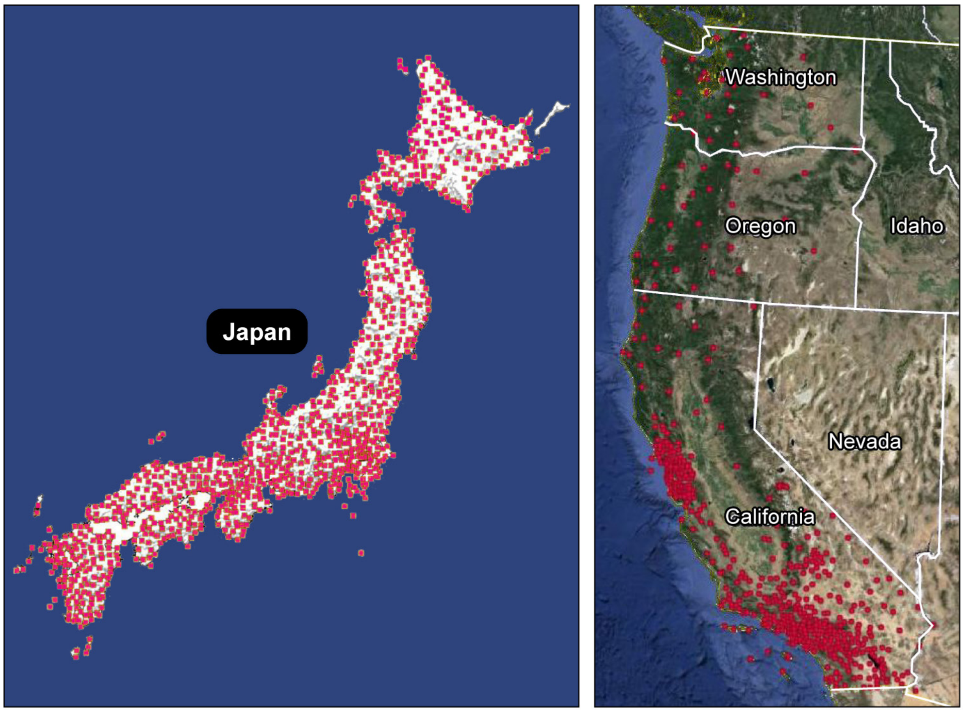
ShakeAlert Stakeholders Identified Implementation Challenges That Have Not Been Addressed

Technical Challenges

Blind Zones: According to stakeholders, people and facilities near the epicenter of an earthquake will not always receive an early warning because the S-waves (i.e., shaking) will arrive at a given point prior to the system having ample time to relay the warning to those in harm's way. More specifically, in "blind zones," shaking will arrive prior to the P-waves reaching distant seismometers, which in turn provide data to ShakeAlert, allowing the system to issue an alert. According to a USGS official, increasing the density of seismometers will allow ShakeAlert to more quickly detect the earthquake and distribute the warning more rapidly, thereby decreasing the size of potential blind zones. USGS has outlined a plan to address this issue in its Technical Implementation Plan for ShakeAlert, which identifies the need for about 440 new and upgraded seismic stations in California and about 280 new and upgraded stations in Washington and Oregon. In addition, the plan anticipates that the life cycle of the stations is approximately 10 years, which means roughly 10 percent of the stations would need to be replaced annually. According to ShakeAlert's Technical Implementation Plan, the goal is to build and operate a network of seismic stations that are no more than 20 kilometers apart and within 5 kilometers of all mapped fault traces. In addition, according to the plan, more densely placed stations—about 10 kilometers apart—would be needed to minimize blind zones in more densely populated areas. For reference, see figure 10 below, which shows the 2007 (when it became operational) seismic station density of Japan's

EEW system and the 2016 seismic station density in the western United States.

Figure 10: Seismic Station Density in Japan (2007) and in Washington, Oregon, and California (2016)



Source: U.S. Geological Survey. | GAO-16-680

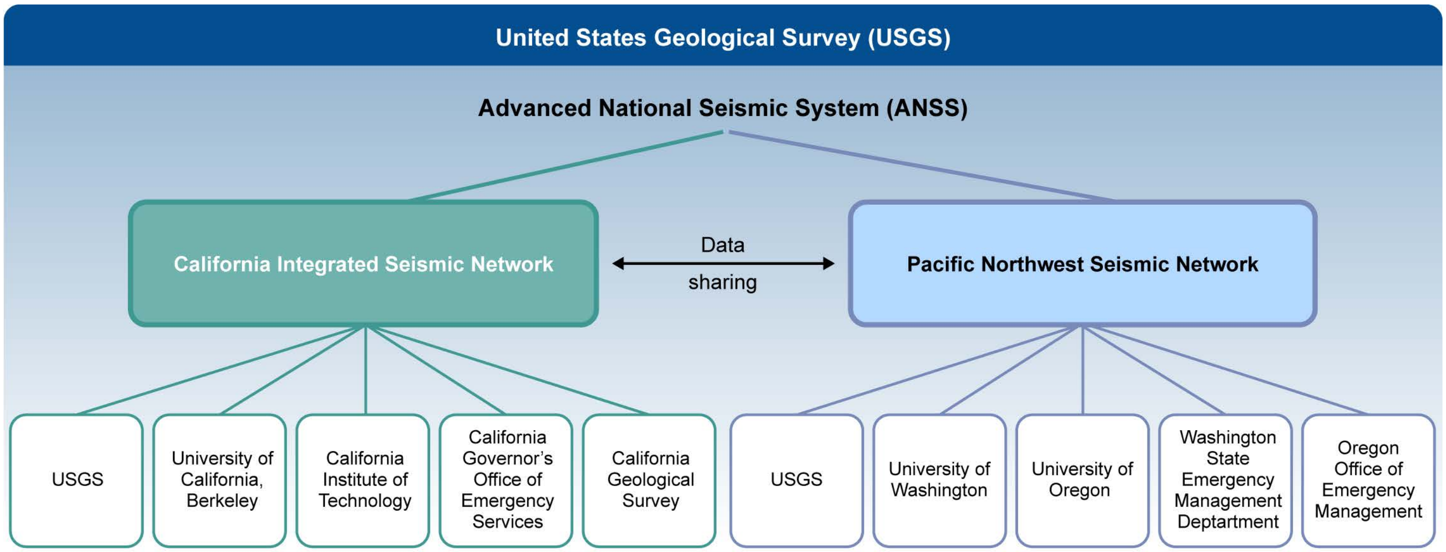
False Positives: False positives—or false alarms—are possible. According to the USGS Earthquake Early Warning Coordinator, the EEW technology has steadily improved its earthquake detection algorithms, mitigating the likelihood of false positives. However, false positives can still occur and their impacts vary across users. For example, a BART official who has been involved in ShakeAlert's beta testing told us they are not overly concerned about false positives disrupting the train schedule. These officials said that false positives happen occasionally and result in the slowing of a train for a few seconds, which is a relatively minor inconvenience. Officials noted that they are tolerant of such inconveniences because missing an event could result in catastrophic damage. However, other potential users may not be as tolerant of false positives. For example, a gas utility company that initiates an emergency shutdown of service to mitigate the chance of fires occurring during an earthquake would likely be less tolerant of a false positive that resulted in a massive shutdown of gas lines.

User Sensitivity: Beta testers currently receiving earthquake early warnings can set their notification thresholds at different levels. For example, some beta testers may want to know every time a small earthquake hits, regardless of whether they will feel shaking or not. Others may only want to know when strong shaking will occur that could potentially result in damage. Understanding that users may desire different notification thresholds and have different tolerances for false positives, the USGS EEW Coordinator told us that, when the system is implemented, they expect that each user will be able to establish its own specific protocols, including at what level of predicted shaking and at what level of certainty (i.e., predicted accuracy of the warning) it will receive the notification and choose to take action. This flexibility, along with the continued scientific research dedicated to improving the accuracy of the detection algorithms to reduce false positives, could help mitigate potential disruptions.

Program Management Challenges

Stakeholder Coordination and Governance: USGS and stakeholders are expanding an existing governance structure to help manage the development and implementation of ShakeAlert. Currently, the development and implementation of ShakeAlert is a shared responsibility between and amongst the federal government, state governments, academic research institutions, and regional seismic networks. This could result in disparate work streams, difficulty in identifying dedicated annual funding, and limit planning efforts that could, for example, help determine how the public will receive warnings and educate them on how to react to such warnings. The development of EEW has been underway for many years within the California Integrated Seismic Network (CISN), which is the California region of the Advanced National Seismic System (ANSS). CISN is a collaborative effort among USGS; the California Institute of Technology; University of California, Berkeley; the California Geological Survey; and the California Office of Emergency Services (CAL OES). More specifically, since 2006, the USGS has supported the EEW system development through partnerships with universities and the State of California, which have leveraged existing expertise and essential equipment to develop and implement system requirements, such as the development of detection algorithms and integration of existing seismometers owned by different entities. Figure 11 shows the multiple stakeholders that participate in ANSS, CISN, and the Pacific Northwest Seismic Network, some of which have already contributed to the development of the ShakeAlert system.

Figure 11: Stakeholders Participating in the Advanced National Seismic System



Source: USGS. | GAO-16-680

USGS officials are currently involved in efforts to refine and formalize these organizational relationships to support implementation of ShakeAlert. According to USGS, the agency recognizes the need for improving coordination with the states as a priority going forward. Specifically, in March 2016, USGS officials told us that they plan to propose a governance structure for ShakeAlert similar to the existing ANSS network, which was originally established to coordinate and establish standards for reporting on earthquake monitoring. USGS officials believe this existing structure, which has been used for 16 years, could be expanded to serve as a starting point in developing the governance structure needed to implement ShakeAlert on a broader scale. In addition, USGS officials told us that the existing ANSS governance structure is already being leveraged to help manage the development of the ShakeAlert system.

USGS's proposed expansion of the governance structure would include a management group as well as two working groups. According to USGS officials, one working group would be constructed to work on technical challenges, such as minimizing false positives and reducing blind zones while the other working group would be focused on program management challenges, such as educating the public on how to react to potential warnings and establishing a certification process for system users (see below). Officials from the States of Oregon and California agreed that the proposed governance structure could be effective in managing the implementation of the ShakeAlert program. In addition to expanding the existing ANSS governance structure, other groups have already been working on select issues to address the known challenges. For example, officials from CAL OES told us that they are currently working with a steering committee, which includes State of California officials and USGS, among others, to determine how they will approach public outreach and education in the State of California, which might lead it to take a different approach than other states.[51] Given that USGS is just beginning to reach out to stakeholders to discuss its proposed governance structure, it is reasonable to expect that stakeholders will need time to work together to assign responsibilities and coordinate on key implementation issues and address associated challenges.

Since USGS is now beginning to expand the existing governance structure for the purpose of managing ShakeAlert, they have not yet developed a program management plan to identify dedicated funding streams in the amounts necessary to develop, implement, and maintain the system; resolved how the public will be alerted to earthquake early warnings or educated the public as to how they should react during a warning; or determined how they will certify users of the system to receive the warning to make sure they are using it in a responsible manner.[52]

Funding: Stakeholders have not been able to identity a dedicated annual funding stream for the purpose of developing, implementing, and maintaining ShakeAlert. Initial USGS estimates indicated that implementation of an earthquake early warning system for the west coast would require a capital investment of $38.3 million in addition to recurring annual outlays of $16.1 million for maintenance and operations. According to the USGS EEW Coordinator, the agency is now requesting recurring annual outlays to fund system development, implementation, and maintenance. However, according to USGS officials, USGS estimates for system implementation have not considered some program

[51]California law requires CAL OES, in collaboration with USGS and other stakeholders, to develop an EEW system. CAL GOV § 8587.8.

[52]According to the Project Management Institute, a program management plan, in part, establishes management controls for integrating and managing the program's individual components.

management costs, such as the cost associated with a public outreach and education campaign, user certification, or other related costs. To help support the estimated implementation costs, the President's fiscal year 2017 budget identifies $8.2 million for USGS's earthquake early warning implementation efforts. In addition, CAL OES officials told us that the State of California is considering the approval of $23 million in a one-time allocation from the general fund to help, in part, educate California citizens about the ShakeAlert system and how to react when receiving an earthquake early warning.

Public Alerting and Education: Stakeholders have not developed a plan as to how ShakeAlert will alert the public to an earthquake early warning or begun to educate the public on how to react to such warnings. According to officials involved with the development and implementation of the ShakeAlert system, a public outreach and education campaign is critical to the success of the program. Officials explained that the public needs to know how to react when provided a ShakeAlert warning; however, ShakeAlert officials have yet to determine how they will begin educating the public and when that process will begin. In discussing their approach to public education, officials from JMA told us that while they had a limited budget, they successfully conducted a public outreach and education campaign in 2007. Among their efforts was creating and distributing many kinds of public relations materials, such as leaflets, posters, and movies. According to JMA, television programs and commercials were the most effective. However, JMA officials noted that the level of education needed in the United States may be different than what was needed in Japan. In addition, the communication methods for distributing ShakeAlert warnings to the public still need to be defined. For example, USGS is considering using FEMA's Integrated Public Alert and Warnings System (IPAWS), which is used to provide public safety officials a way to alert and warn the public about serious emergencies using the Emergency Alert System and Wireless Emergency Alerts, among others. However, according to the EEW Coordinator, there are concerns about using IPAWS because the system does not immediately announce a warning and the resulting delays could render ShakeAlert useless during "short-notice" events where the warning only precedes shaking by a few seconds.

User Certification: According to the USGS EEW Coordinator, they plan to implement a certification process to ensure that users who receive ShakeAlert warnings act responsibly when issuing those warnings; however, stakeholders have not developed a plan for doing so. For example, a radio station receiving the warning for the purpose of broadcasting to its listeners should know how to relay the message accurately and in a manner that prepares people to take appropriate action, but does not incite panic. However, currently, according to USGS officials, USGS and other stakeholders have not defined what the requirements for certification will be, how this process should be executed, and how costs will be covered. USGS has begun identifying potential stakeholders that would form a working group to help determine how this process could be implemented and managed. In addition, as related to costs, ShakeAlert officials had considered the possibility of subscription services to potentially help fund and offset some of the anticipated costs of the program, such as for certification. In Japan, for example, the national agency responsible for distributing EEW system warnings assesses a fee to cover its costs to distribute EEW. In March 2016, a USGS official told us that USGS is not considering the use of subscription fees.

According to the Project Management Institute (PMI), an effective governance structure ensures that strategic alignment is optimized and that the program's targeted value and benefits are delivered as expected. Further, according to PMI, establishing a single program governance board that is accountable for all critical elements of program oversight within an organization is considered to be the most efficient means for providing effective and agile governance oversight. PMI also notes that under certain circumstances, some programs may need to report to multiple governance boards. These may include, for example, programs that are sponsored and overseen jointly by private and governmental organizations, that are managed as collaborations between two private but otherwise competitive organizations, or that exist in exceedingly complex environments whose subject matter experts cannot be effectively assembled into a single program governance board. Under these circumstances, it is critical that the systems and methods for program governance and the authority for program decision making be clearly established.

USGS's plan to extend the existing governance structure to include officials from the States of Washington, Oregon, and California could help provide an effective first step towards overcoming the program management challenges that were identified by ShakeAlert stakeholders. More specifically, once the governance structure is expanded, it could allow USGS and other ShakeAlert stakeholders to begin developing plans to address the program management challenges identified above. However, currently, ShakeAlert stakeholders have not established a program management plan to help manage the development, implementation, and maintenance of the program, in part, because the governance structure has yet to be expanded to include many of the key stakeholders that are needed to help coordinate such issues. USGS has developed a technical implementation plan that identifies and prioritizes the technical needs of the system. However, the technical implementation plan is largely limited to the hardware and software needed to develop and implement the ShakeAlert system and does not address program management issues, such as funding, public alerting and education, and user certification. According to the Project Management Institute, a program management plan, in part, establishes management controls for integrating and managing the program's individual components. Such a plan could include subsidiary plans, such as how the program would manage a public outreach and education campaign and the certification of ShakeAlert users. USGS officials and ShakeAlert stakeholders agreed that stakeholder participation in the development of these plans will be beneficial to development and implementation of ShakeAlert. Further, USGS officials agreed that more detailed plans are needed prior to fully implementing ShakeAlert in the western United States. Without a program management plan that addresses the various challenges identified by stakeholders, ShakeAlert program management officials may not be able to identify and implement solutions to the challenges that have already been identified.

Conclusions

Nearly half of all Americans are exposed to potentially damaging ground shaking from earthquakes, according to USGS, with communities such as Los Angeles, Memphis, San Francisco, and Seattle being particularly vulnerable because of their locations in areas where extreme shaking could occur. These cities have taken actions to assess and mitigate earthquake risks, including mandating structural retrofits of buildings to enable them to better withstand shaking and requiring that building furnishings, equipment, and other nonstructural components be secured to prevent their displacement and causing damage when shaking occurs.

Because many federally-owned and -leased buildings are located in earthquake hazard areas where moderate to extreme shaking is expected, it is important that the federal agencies responsible for these buildings take steps to assess and mitigate earthquake risks to their buildings. These steps can include identifying exceptionally high risk buildings that are most susceptible to damage from earthquakes and developing a plan to address those risks. Further, for all buildings, making risk-informed mitigation decisions ranging from structural retrofits to implementation of lower-cost mitigations such as non-structural retrofits, seismic safety inspections, and earthquake drills as part of a comprehensive seismic safety program could better enable agencies to protect their assets from earthquake damage and reduce injuries to building occupants. Moreover, while DOD components and GSA have implemented mitigation measures to varying degrees intended to reduce earthquake risks, including making structural and non-structural retrofits to some buildings, these efforts are generally not part of a comprehensive approach, which results in buildings, or spaces within buildings, having dissimilar levels of protection against earthquake risks. Until they fully identify their exceptionally high risk buildings, DOD and GSA will be unable to fully understand the most significant earthquake risks affecting buildings for which they are responsible and develop a plan to reduce those risks—in accordance with RP 8—which could inform prioritizing funding requests for mitigations such as retrofits. In addition, as a result of not employing comprehensive seismic safety measures—which include non-structural retrofits, seismic safety inspections, and earthquake drills—to mitigate earthquake risks where applicable, DOD and GSA are also missing low cost opportunities to reduce potential damages, injuries, and casualties from future earthquakes. Limited funding available for earthquake mitigation efforts makes it critical for agencies to effectively prioritize high-cost retrofits and to know and understand where low cost seismic safety measures could be the most effective across their building portfolios.

Earthquake Early Warning (EEW) technology has the potential to enhance public safety and benefit users by providing time for protective measures to be taken before shaking occurs. USGS is currently working with ShakeAlert stakeholders to expand an existing governance structure that could help better define these roles and responsibilities and create the plans needed to fully implement ShakeAlert. To do so, as ShakeAlert's governance structure takes shape, stakeholders will need to coordinate on key program management challenges and make decisions on issues such as (1) identifying sources of funding to further develop and implement ShakeAlert; (2) educating and alerting the public; and (3) determining the extent to which entities need to be certified to use the system and how to provide such certifications. Developing a program management plan that establishes management controls for integrating and managing the program's individual components could help address these challenges. Such a plan could include subsidiary plans, such as how ShakeAlert would manage public outreach, conduct educational campaigns, and potentially identify dedicated funding streams from ShakeAlert stakeholders.

Recommendations for Executive Action

To strengthen efforts to mitigate earthquake risks to federal buildings, we recommend that the Secretary of Defense and the Administrator of GSA take the following actions:

1. Define what constitutes an exceptionally high risk building, identify such buildings, and develop plans to mitigate those risks, including prioritizing associated funding requests as needed.
2. To the extent practicable, prioritize and implement comprehensive seismic safety measures which could include earthquake drills, seismic safety inspections, and non-structural retrofits to decrease risks and reduce damage in federally-owned and -leased buildings in earthquake hazard areas.

Following the expansion of the ShakeAlert governance structure to include key stakeholders, we recommend that the Secretary of the Department of the Interior direct the U.S. Geological Survey, working through the ShakeAlert governance structure, to take the following action:

3. Establish a program management plan that addresses, among other things, the known implementation challenges.

Agency Comments and Our Evaluation

We provided a draft of this report to the Departments of Commerce (NIST), Defense, the Interior (USGS), and Homeland Security (FEMA); GSA; and NSF for review and comment. DOD, GSA, and USGS agreed with our recommendations, as applicable to each agency.

In written comments (see app. IX), DOD said that it is participating in the ICSSC effort described in this report to develop a common definition for EHR buildings and will proceed to assess its inventory once a standard definition is adopted as funding is available. If implemented effectively, this action should begin to address the recommendation. In addition, DOD said that it has implemented comprehensive seismic safety measures on a limited basis and indicated that more comprehensive implementation would need to compete with other departmental priorities. More information will be needed over time about DOD's efforts to implement comprehensive seismic safety measures to determine whether its efforts address the intent of the recommendation.

GSA officials said in their written comments that they agreed with the overall nature of our findings but noted they were concerned about the extent to which we discussed progress GSA had made to identify its EHR buildings and prioritize building seismic risk. We modified the text of the report to provide additional context and information related to the steps

GSA has taken to 1) define what constitutes an exceptionally high risk building and 2) begin identifying its exceptionally high risk buildings. This information can be found in Table 4 of the report and in related text. However, we communicated to the agency our belief that it needed to continue taking actions to fully meet the intent of our recommendations. More specifically, GSA will need to continue identifying its EHR buildings and then develop plans to mitigate the risks that are identified, as well as implement comprehensive seismic safety measures. GSA officials subsequently said that they agreed with our recommendations. GSA's letter, along with our responses to specific points, is reprinted in app. X.

FEMA provided technical comments, which we included, as appropriate. USGS, NIST, and NSF did not provide written comments.

As agreed with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies of this report to the Secretaries of Commerce, Defense, the Interior, and Homeland Security, the Administrator of GSA, and the Director of the National Science Foundation, as well as appropriate congressional committees and other interested parties. In addition, the report is available at no charge on the GAO website at http://www.gao.gov.

If you or your staff have any questions about this report, please contact Chris P. Currie at (404) 679-1875 or curriec@gao.gov, or David J. Wise at (202) 512-5731 or wised@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix XI.

Chris P. Currie
Director, Homeland Security and Justice

David J. Wise
Director, Physical Infrastructure

List of Requesters

The Honorable Thomas R. Carper
Ranking Member
Committee on Homeland Security and Governmental Affairs
United States Senate

The Honorable Dianne Feinstein
United States Senate

The Honorable Peter A. DeFazio
Ranking Member
Committee on Transportation and Infrastructure
House of Representatives

Appendix I: Objectives, Scope, and Methodology

This report examines (1) What actions have select city governments taken to assess and mitigate seismic risks that could affect buildings in their jurisdictions? (2) What is the distribution of federal buildings with regard to seismic hazard areas, and to what extent have select federal agencies identified and mitigated seismic risks to their buildings? (3) What are the potential benefits of ShakeAlert and to what extent are United States Geological Survey (USGS) and stakeholders addressing technical and implementation challenges, if any, to implementing the system?

To address the first objective, we conducted site visits to four U.S. cities—Seattle, Washington; Memphis, Tennessee; San Francisco, California; and Los Angeles, California – selected from among those with the highest earthquake loss estimates to buildings and seismic hazard level (probabilities of ground shaking), as identified by Federal Emergency Management Agency (FEMA), and to reflect geographic diversity. For each of these cities, we met with officials from FEMA regional offices, state and local government, and regional nonprofit consortia with familiarity of the four cities to discuss mitigation activities that had been undertaken or are planned. We also toured new and existing buildings in San Francisco and Los Angeles selected by local officials to observe examples of the physical mitigation measures implemented to avoid or reduce damage to structures and related injuries resulting from earthquake disasters. In addition, for each of the four cities we reviewed the relevant state and local policies, hazard mitigation plans, practices, and other process activities used to reduce risk. Additionally, we reviewed FEMA's guidelines about seismic building practices, efforts to support earthquake mitigation implementation activities at the state and local level, and education and outreach and promotion of earthquake preparedness; prior GAO reports; and numerous other reports, summaries, and studies on earthquake hazard mitigation activities to provide background and context. The findings, while providing important perspectives that could be beneficial to federal, state, and local government efforts to mitigate earthquake risks to buildings, are not generalizable to all U.S. cities.

To address the second objective, we performed a geographic analysis of the number of leased and owned federal buildings in use or which will be needed in the future, total building square footage of both leased and owned federal buildings in use or which will be needed in the future, and the number of federal employees assigned to work in each area of earthquake shaking intensity based on the Modified Mercalli Intensity (MMI) scale. To perform this analysis, we obtained Fiscal Year 2014

Federal Real Property Profile (FRPP) building data including building size, location, ownership, legal status (which indicates if the building is owned or leased), status of use (which indicates if the building is currently being used, will be needed in the future, or has been or is in the process of being disposed of, or is considered as excess or surplus), and the date of disposal for buildings that have been disposed of. We also obtained Office of Personnel Management's Enterprise Human Resources Integration (EHRI) database federal employee official worksite data as of September 2014 and 2014 earthquake shaking intensity maps from USGS. To assess the reliability of the FRPP data we reviewed previous GAO and General Services Administration (GSA) Office of Inspector General work on FRPP data reliability and limitations, reviewed FRPP system controls in place, interviewed GSA and Department of Defense (DOD) officials regarding data checks, and conducted electronic testing to determine completeness and that data element values are consistent with expected values. To assess the reliability of the EHRI data, we examined existing information about the data's overall reliability and system controls; and conducted manual and electronic testing. We found that the FRPP and EHRI data elements of interest to this engagement were sufficiently reliable for the purpose of our reporting objectives.

To conduct our geospatial mapping analysis, we used USGS earthquake shaking mapping with a 2 percent probability of exceeding a given MMI level in 50 years. We used mapping with this probability of exceedance because the International Code Council uses 2 percent in 50 year percent ground acceleration mapping with some adjustments to determine the Maximum Considered Earthquake (MCER) for the International Building Code. This report only includes the effects from natural earthquakes. The effects of induced earthquakes are not incorporated in the MMI maps we used and are not considered for the purposes of this report. To determine the MMI level for each of the buildings we used a SAS analytics software procedure to geocode each building's location from the FRPP data. During our analysis we found that approximately 2 percent or 5,036 of the 252,407 owned and leased federal buildings identified as active or inactive (1.8 percent or 48.6 million square feet of the 2,661 million square feet of buildings) in the FRPP building data either did not have location information included in the FRPP or the location information in the FRPP had inconsistencies in the data which did not allow the building to be accurately located. As a result, the MMI could not be determined for those buildings and they were excluded from the MMI results. We determined that this small percentage of missing data did not materially affect the results of our work and that the data were sufficiently reliable for the purposes of our reporting objectives.

To determine the extent to which selected federal agencies assessed and mitigated the seismic risks of their buildings in objective two, we selected DOD and GSA to review because as of September 2014 they owned and leased about 53 percent of all federal buildings by number, about 72 percent of the federal owned and leased buildings in square feet, and as of 2013 accounted for about 68 percent of the annual operating costs for owned and leased federal buildings.[1] We interviewed DOD (Air Force, Army, and Navy) and GSA headquarters officials and solicited written responses to questions regarding the extent to which they identify and mitigate seismic risks to their federal buildings agency wide. We also selected three DOD installations–one for each service Air Force, Army, and Navy–which had a large number of buildings and were located near the above cities selected because of their high seismic hazard levels. We visited these installations, one in the State of California, one in the State of Tennessee, and one in the State of Washington. At these installations we interviewed facility officials and visited buildings which had been constructed to modern seismic building codes, seismically retrofitted, or have not been retrofitted to observe DOD's seismic risk mitigation efforts. Furthermore, we interviewed GSA facility officials and seismic engineers in the three GSA regions—Regions 4, 9, and 10—that cover the above selected cities and visited GSA buildings which had been seismically retrofitted and buildings which have not been retrofitted to observe GSA's seismic risk mitigation efforts.[2] We also reviewed executive orders, federal law, and federal standards regarding the requirements for federal agencies to mitigate seismic risk. Additionally, we interviewed officials and reviewed seismic mitigation documents from FEMA and USGS who play roles in federal earthquake risk mitigation efforts and earthquake hazard identification. During our document reviews and interviews, we identified and interviewed other federal agencies including the United States Fish and Wildlife Service, associations including the American

[1]Based on the 2013 Federal Real Property Profile summary data from GSA, the most recent federal building data available at the time the selection was made.

[2]GSA Region 4 (Southeast Sunbelt Region) includes the states of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina and Tennessee; Region 9 (Pacific Rim Region) includes the states of Arizona, California, Hawaii, and Nevada, as well as overseas in the U.S. territories of American Samoa, Guam and the Commonwealth of the Northern Mariana Islands, Diego Garcia, mainland Japan and Okinawa, the Republic of Korea, and Singapore; and GSA Region 10 (Northwest/Arctic Region) includes the states of Alaska, Idaho, Oregon, and Washington.

Society of Civil Engineers, and a private industry representative to provide background and additional information on earthquake mitigation practices. We limited our selection to those that have experience relative to earthquake science and its potential impacts on buildings. Based on our review of the Standards of Seismic Safety for Existing Federally Owned and Leased Buildings: ICSSC Recommended Practice 8 (RP 8) and FEMA guidance on earthquake risk mitigation, we developed questions to determine the extent to which each DOD component and GSA had implemented key mitigation strategies identified in those documents. Specifically we asked questions regarding their compliance with the RP 8 requirement for seismically retrofitting buildings, including when buildings are being rehabilitated or when a building is considered exceptionally high risk. We also asked questions to determine the extent to which they implement less expensive mitigation strategies identified by FEMA, such as non-structural retrofits, building contents mitigation, and earthquake drills.[3] We then summarized their responses in this report.

To address the third objective, we reviewed relevant ShakeAlert documentation, including policies, plans, and legislation. Specifically, we reviewed USGS documentation, including the Technical Implementation Plan for the ShakeAlert Production System – An Earthquake Early Warning System for the West Coast of the United States and other documents to gather information on the potential benefits and limitations of the earthquake early warning system, ShakeAlert.[4] We also visited Japan, which has an operational earthquake early warning system, to interview officials from the private sector, transportation sector, and Japanese government to discuss the implementation challenges they overcame to deploy a national earthquake early warning system. We also conducted interviews with USGS officials and other stakeholders of the ShakeAlert system using a standard set of questions to discuss what, if

[3]We used information from our review of FEMA E-74: *Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide*, December 2012; FEMA 395: *Incremental Seismic Rehabilitation of School Buildings (K-12)*, June 2003; and FEMA 397: *Incremental Seismic Rehabilitation of office Buildings*, December 2003 to identify earthquake risk mitigation strategies beyond those required by RP 8 which FEMA has developed for inclusion in a comprehensive earthquake program such as non-structural mitigation, building contents mitigation, and earthquake drills

[4]We did not assess the tsunami warning system or the potential integration of the earthquake early warning system with the tsunami warning system.

any, potential benefits, limitations, and implementation challenges exist. To do so, we interviewed USGS officials; stakeholders from the California Integrated Seismic Network, and Pacific Northwest Seismic Network, and academia.

We then identified ShakeAlert beta testers by requesting information from the three seismology lab coordinators, in partnership with USGS on the companies, government entities, and others that were participating in ShakeAlert's beta testing effort. We then selected beta testers from this list to interview to collect their perspectives on the benefits, limitations, and potential challenges to developing and implementing ShakeAlert. In doing so, we ensured that we selected representatives from each of the three western states—California, Oregon, and Washington—that have entities involved in the beta testing effort. To help ensure balance, we chose officials from utility companies, emergency management offices, and the private sector from throughout the geographic region. Following interviews with the selected beta testers, we performed a content analysis to identify common themes related to the limitations and implementation challenges, of the ShakeAlert system. More specifically, two analysts identified and coded recurring themes and engaged two additional analysts to help resolve any questions or potential discrepancies in determining how the challenges were grouped. We assessed the results of this analysis against the Project Management Institute's The Standard For Program Management – Third Edition to determine the extent to which a program management plan should be established to address key elements, such as those identified by ShakeAlert stakeholders.

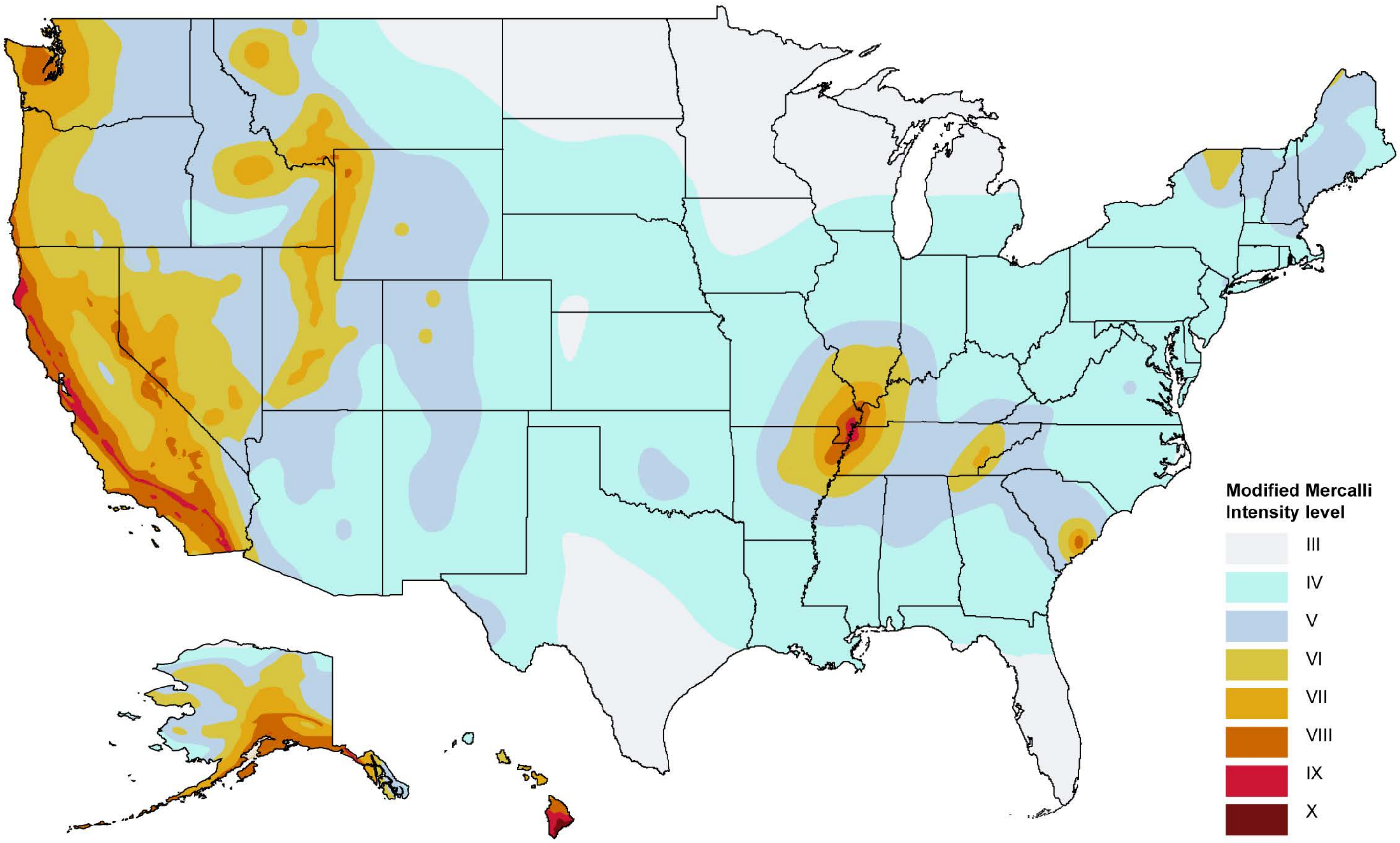
We conducted this performance audit from January 2015 to August 2016 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Modified Mercalli Shaking Intensity Maps

In addition to figure 2 shown above in the report, USGS has also mapped the Modified Mercalli Intensity (MMI) of earthquakes based on a higher probability of exceedance. For example, figure 12 depicts a map showing areas where there is a 10 percent chance of an earthquake exceeding the MMI level in 50 years. A 10 percent in 50 years probability equates to an earthquake recurring and exceeding a given MMI level about every 475 years. Based on this map and probability, USGS staff estimate over 97 million people in the 48 contiguous states are located in areas exposed to moderate (MMI = V) or greater earthquake shaking.[1]

[1] Kishor S. Jaiswal, Mark D. Petersen, Ken Rukstales, and William S. Leith, "Earthquake Shaking Hazard Estimates and Exposure Changes in the Conterminous United States," *Earthquake Spectra*, vol. 31, No. S1, pp. S201-S220 (2015).

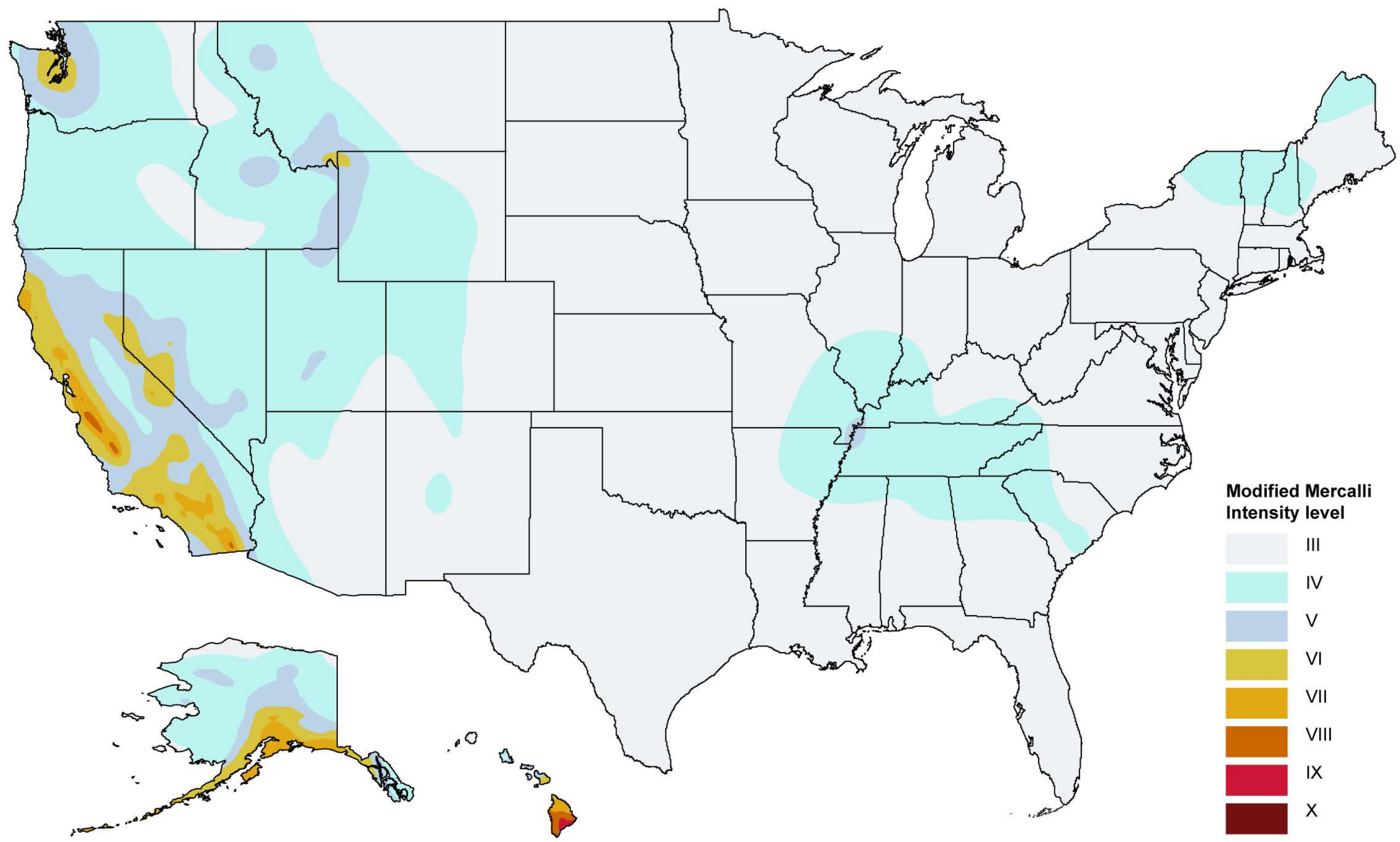
Figure 12: Nationwide 2014 Modified Mercalli Intensity Earthquake Shaking Map With a 10 Percent Probability of Exceedance in 50 Years



Source: GAO presentation of U.S. Geological Survey mapping; MapInfo (map). | GAO-16-680

In figure 13, the mapping shows a 50 percent chance of an earthquake exceeding the MMI level in 50 years, and while the shaking intensities are even less than the 10 percent in 50 year map, this probability equates to an earthquake recurring and exceeding a given MMI level every 72 years. Based on this map and probability, USGS staff estimate about 43 million people in the 48 contiguous states are located in areas exposed to moderate (MMI = V) or greater earthquake shaking.[2]

Figure 13: Nationwide 2014 Modified Mercalli Intensity Earthquake Shaking Map With a 50 Percent Probability of Exceedance in 50 Years



Source: GAO presentation of U.S. Geological Survey mapping; MapInfo (map). | GAO-16-680

[2]Jaiswal, Petersen, Rukstales, and Leith, "Earthquake Shaking Hazard Estimates" S201-S220.

Appendix III: Summary of Seismic Hazard, History, Future Damage Estimates, and Examples of Efforts to Assess and Mitigate Seismic Hazards for Seattle, Memphis, San Francisco, and Los Angeles

Seattle

Seismic hazard. Washington State is vulnerable to a variety of earthquakes because of its location near the collision boundary of two major tectonic plates, according to the Washington State hazard mitigation plan. Washington State ranks second (behind California) among states most susceptible to damaging earthquakes in terms of economic loss, according to FEMA. Seattle is at risk for earthquakes from three sources: (1) deep earthquakes like those that damaged the city in 1949, 1965 and 2001; (2) shallow earthquakes along the Seattle Fault; and (3) huge megathrust earthquakes that could reach magnitude 9.0 but would be centered outside Seattle.

Deep earthquakes with a magnitude of 6.0 or greater occur in Seattle about every 30 to 50 years. Deep earthquakes occur at depths of 30-70 km in oceanic crust as it dives under lighter continental crust. Because of the depth, even buildings located right above them are far enough away that ground motions are weakened, according to the City of Seattle Office of Emergency Management (Seattle OEM). The 2001 Nisqually Earthquake was a deep earthquake, according to Seattle OEM. Shallow earthquakes with a magnitude of 6.0 or greater occur about every 500 years. Shallow earthquakes occur in the North American plate at a depth of 0-30 km near the crust's surface along faults. Intense shaking occurs near the epicenter but usually diminishes quickly with distance relative to the other earthquake types. Shallow earthquakes are the type expected on the Seattle Fault zone, which is the primary but not only source for shallow earthquakes in Seattle, according to Seattle OEM. Megathrust earthquakes occur every 200 to 1,100 years, or average every 500 years. Megathrust earthquakes occur on the interface between the North American plate and the San Juan de Fuca plate, a small plate extending from northern California to British Columbia. These are the largest type of earthquakes in the world, according to Seattle OEM. Recently, geologists found evidence of massive earthquakes off the Washington coast (referred to as the Cascadia Subduction Zone) and along the Seattle Fault. The northernmost strand of the Seattle Fault Zone had long been thought to lie south of the downtown area. Recent research and a compilation of existing geophysical and geologic data, however, suggest that the fault tip may lie directly beneath the downtown area. If the fault lies directly beneath the downtown area, ground motions there during a Seattle Fault earthquake may be significantly larger, according to the 2009 Seattle hazard mitigation plan.

Seismic history. Three major earthquakes have struck Seattle since the beginning of the 20th century (in 1949, 1965 and 2001). The February 28, 2001 magnitude 6.8 Nisqually Earthquake was the last major earthquake that hit the Puget Sound Region. This was a deep earthquake that was centered about 10 miles northeast of Olympia and at a depth of about 30 miles. One person died of a stress induced heart attack, 407 people were injured of which four were considered serious, and estimates place damage at $2 billion.

Probability of seismic occurrence / estimated damages. Downtown Seattle has a 5 percent chance of experiencing violent shaking within the next 50 years, according to the U.S. Geological Survey (USGS). The Seattle Fault is Seattle's most dangerous source, according to Seattle OEM. The Seattle Fault ruptured around 900AD causing a 7.2 magnitude earthquake, massive landslides and a tsunami. The major consequences from a future earthquake include building collapse, landslides, fires, liquefaction (where the ground turns liquid under buildings) and potentially a tsunami. Casualties could exceed 1,000 people and economic damage could easily run into billions of dollars, according to Seattle OEM. Deep earthquakes are the most common large earthquakes that occur in the Puget Sound region, according to Seattle OEM. Earthquakes larger than magnitude 6.0 occurred in 1909, 1939, 1946, 1949, 1965 and 2001. Megathrust earthquakes are the greatest risk to the region as a whole, according to Seattle OEM. A megathrust earthquake could reach magnitude 9.0 or greater and affect an area from Canada to northern California. Shaking in Seattle would be strong to very strong and prolonged, but not as intense as a Seattle Fault earthquake. This area has a megathrust earthquake about every 500 years.

A magnitude 7.2 Seattle Fault earthquake scenario might result in structural collapses, landslides, fires, and a tsunami causing 1,200 deaths and 15,000 severe to critical injuries, according to Seattle OEM. The earthquake might cause an estimated $20 billion in damage and indirect losses, including destroying 6,000 buildings, and leaving 21,000 buildings severely damaged and unsafe to occupy, according to Seattle OEM. A large Seattle Fault earthquake, similar to the 900AD earthquake, could trigger a 16 foot tsunami that would strike the Seattle shoreline within seconds of the earthquake and flood it within 5 minutes. Although megathrust and deep earthquakes will not directly cause tsunamis in Seattle these sources could initiate landslides that result in local tsunamis, according to the City of Seattle. New modeling suggests small tsunamis in Puget Sound and Hood Canal but strong currents are predicted to be a big problem from megathrust tsunamis, according to the

USGS. A magnitude 7 Seattle Fault earthquake could cause dozens of fires. Suppressing the fires would be more difficult because damage to the water system would reduce water pressure in many parts of the city, according to the City of Seattle.

Examples of efforts to assess and mitigate seismic risks. Seattle has a hazard mitigation plan that identifies earthquake risks and the capabilities needed to mitigate those risks. In addition, Seattle is implementing a program to retrofit or replace existing fire stations, police precincts, and community centers to provide seismic upgrades. This effort is being funded by a levy and a capital improvement program intended to make these critical facilities more resilient and better able to support emergency operations in crisis situations.

Seattle obtained funding to upgrade, renovate, or replace 32 neighborhood fire stations using funds from a levy program.[1] Seattle has approximately 1,160 unreinforced masonry (URM) buildings scattered around the city and concentrated in historic districts. Seattle has been working on developing a program whereby URM buildings would be required to be seismically upgraded, or demonstrate they meet a proposed standard for seismic resistance. At the time of our study, Seattle was considering implementing a seismic retrofit policy that would require URM building owners to apply a “Bolts Plus” standard to reinforce URMs. The “Bolts-Plus” standard essentially involves the installation of shear and tension anchors at the roof and floors, and, when required, the bracing of the unreinforced masonry bearing walls. By anchoring these components together, building walls are much less likely to collapse, according to a study prepared for the Seattle Department of Planning and Development.[2]

[1]In November 2003, Seattle approved the Fire Facilities and Emergency Response Levy. The levy provided $167 million to enable the Seattle Fire Department to be more resilient in dealing with crisis situations, especially those that could damage critical department assets and disrupt emergency operations.

[2]Gibson Economics and Collins Woerman, *Seattle Unreinforced Masonry Retrofit Policy: Benefit Cost Analysis*, prepared at the request of the Seattle Department of Planning and Development, Apr. 11, 2014.

Memphis

Seismic hazard. Memphis is located within the New Madrid Seismic Zone (NMSZ) which includes eight states (Illinois, Indiana, Kentucky, Tennessee, Alabama, Mississippi, Arkansas and Missouri). The NMSZ is responsible for three of the largest earthquakes in U.S. history, during 1811-1812. These earthquakes were felt strongly over 50,000 square miles and moderately across 1 million square miles, according to USGS. The affected area was therefore more than twice that of the 1964 Great Alaskan Earthquake, the largest earthquake in U.S. history, and approximately 10 times that of the 1906 San Francisco Earthquake. Earthquakes in the central and eastern United States affect much larger areas than earthquakes of similar magnitude in the western United States. For example, the San Francisco, California earthquake of 1906 (magnitude 7.8) was felt 350 miles away in the middle of Nevada, whereas the New Madrid earthquake of December, 1811 (magnitude ~7.5) was felt in Boston, Massachusetts, 1000 miles away, and caused minor damage in Charleston, South Carolina, and Washington D.C., about 700 miles away, according to USGS.

Differences in geology east and west of the Rocky Mountains cause this strong contrast. At the time of the three earthquakes, the Central United States was sparsely populated, with very few structures. Currently, however, the Central United States is densely populated, with major population centers in the metropolitan areas of Memphis and St. Louis. Both of these regions are likely to sustain damage from a NMSZ event, and Memphis, in particular, could see severe damage, according to a 2014 study.[3] Memphis and the surrounding metropolitan area of more than one million people would be severely impacted. Memphis has an aging infrastructure, and many of its large buildings, including unreinforced masonry schools and fire and police stations, would be particularly vulnerable when subjected to severe ground shaking, according to USGS.

Relatively few buildings were built using building codes that have provisions for seismic-resistant design. Soil liquefaction and related ground failures are likely to occur in downtown Memphis along the Mississippi River and along the Wolf River that passes through Memphis.

[3]Witt O'Brien's, *CAPSTONE-14 Exercise After Action Report*, prepared at the request of the Central United States Earthquake Consortium, July 2014

A major earthquake is expected to result in several thousand of fatalities in Memphis, according to the Tennessee Emergency Management Agency. The risk for loss of human life due to earthquake hazard in the region is high according to a 2013 National Earthquake Hazards Reduction Program (NEHRP) study.[4] Based on risk to life-safety, the hazard is very similar to coastal California, but there have been essentially no damaging earthquakes to remind the populace of the hazard, according to the 2013 NEHRP study.[5]

Seismic history. The western part of Tennessee was shaken strongly by the New Madrid, Missouri, earthquake of 1811-1812 and by earthquakes in 1843 and 1895. During 1811-1812, a series of three earthquakes with magnitudes of approximately 7.5 occurred, according to USGS. On January 4, 1843, a severe earthquake (intensity VIII) affected Memphis/Shelby County and other places in western Tennessee. Walls were cracked, chimneys fell, and windows were broken. Memphis suffered a magnitude 5.0 earthquake in1865, in which chimneys collapsed. The city experienced similar damage from a July 19, 1895, earthquake.

Probability of seismic occurrence / estimated damages. According to the USGS, the chance that Memphis will experience a magnitude 6.0 or greater earthquake within a 50-year window is between 25 percent and 40 percent. For a repeat of an 1811-1812 type event, with a magnitude 7 or greater, there is a 7 percent to 10 percent chance. According to a 2009 Mid-America Earthquake Center study, the number of damaged buildings resulting from a potential 7.7 earthquake in western Tennessee is far greater than all other states located in the NMSZ.[6] An estimated 264,000 buildings would be moderately or more severely damaged and nearly

[4]NEHRP Consultants Joint Venture, *Cost Analyses and Benefit Studies for Earthquake-Resistant Construction in*

Memphis, Tennessee, prepared at the request of the Engineering Laboratory of the National Institute of Standards and Technology (NIST), NIST GCR 14-917-26, December 2013.

[5]NIST GCR 14-917-26.

[6]Mid-America Earthquake Center, University of Illinois, New Madrid Seismic Zone Catastrophic Earthquake Response Planning Project, Impact of New Madrid Seismic Zone, Earthquakes on the Central USA, Volume I, MAE Center Report No. 09-03, 2009.

107,000 of those buildings would be completely damaged, according to the Mid-America Earthquake Center study.[7] Furthermore, Shelby County, Tennessee, which includes Memphis, comprises half of all estimated building damage in the state primarily due to the major metropolitan area in and around Memphis, according to the Mid-America Earthquake Center study.[8] In addition, Shelby County experiences the greatest number of total estimated casualties, nearly 21,500.

Examples of efforts to assess and mitigate seismic risks. Memphis participated in the development of Shelby County's 2010 multi-jurisdictional hazard mitigation plan, which identified actions that can be taken to reduce vulnerabilities against seismic events, including five seismic related projects for the Memphis. Four of the five seismic projects focus on highway bridge and road construction and the fifth project calls for the development of a multi-jurisdictional comprehensive earthquake hazard mitigation plan specifically benefiting Memphis.

San Francisco

Seismic hazard. According to the San Francisco Capital Plan, a number of factors contribute to San Francisco's vulnerability to earthquakes. In addition to being situated between two major earthquake faults (San Andreas to the west and Hayward to the east), San Francisco has some of the most dense wood-structured neighborhoods in the country; the city's windy conditions could contribute to the spread of fire following earthquakes in these neighborhoods. San Francisco is also surrounded by water on three sides which makes it very susceptible to the seismic impacts of sea level rise. Furthermore, some low-lying areas that were filled around1900 are particularly at risk for liquefaction, according to USGS.

Seismic history. The San Andreas and other regional faults, including the Hayward Fault, have generated 69 recorded magnitude 5.0 or greater earthquakes since 1800. Of these recorded earthquakes, three (1838, 1906, and the 1989 Loma Prieta earthquake) registered at a magnitude of 6.8 or greater. Historically, the San Andreas Fault system is the most active fault system in Northern California. This fault system is capable of

[7]Mid-America Earthquake Center, Impact *of New Madrid Seismic Zone*, p. 73.

[8]Mid-America Earthquake Center, Impact *of New Madrid Seismic Zone*, p. 73.

generating very strong earthquakes of magnitude 7.0 or greater, according to the San Francisco hazard mitigation plan. The last major earthquake on the northern portion of the fault occurred in 1906, according to the San Francisco hazard mitigation plan. Known as the Great San Francisco earthquake, this event lasted 45 to 60 seconds and is estimated at magnitude 7.7. It is believed to have caused intensities as high as XI on the MMI Scale, according to the San Francisco hazard mitigation plan.[9] The Great San Francisco earthquake and the subsequent fire resulted in approximately 3,000 deaths and damage estimated over $500 million, according to USGS. Shaking damage was extensive throughout San Francisco, but the 3-day fire that followed the earthquake destroyed the entire downtown area and many of the surrounding residential neighborhoods, according to USGS.

Probability of seismic occurrence / estimated damages. There is a strong likelihood that San Francisco will experience a significant earthquake from one of the known major faults in the next 30 years, according to the San Francisco hazard mitigation plan. In 2015, the Working Group on California Earthquake Probabilities (WGCEP) forecasted that the probability a magnitude 6.7 or greater would strike the San Francisco region was 72 percent over the next 30 years.[10] In addition, a 2010 Applied Technology Council study of four scenario earthquakes found depending on the magnitude, location and time of day of an earthquake, deaths could range from 70 to nearly 1,000, and injuries requiring medical care could number from 1,900 to more than 14,000.[11] Casualties could be much higher than these estimates if even

[9]The Modified Mercalli Intensity (MMI) scale is a 12 point scale; however USGS only uses the first 10 points of the scale as estimated MMI does not exceed a level of MMI X in the United States and the USGS has never observed damage in the United States at MMI XI or XII level.

[10]The Working Group on California Earthquake Probabilities (WGCEP) is a collaboration between the Southern California Earthquake Center, the USGS, and the California Geological Survey aimed at developing official earthquake-rupture forecast models for California. The project is closely coordinated with the USGS National Seismic Hazard Mapping Program, and has received financial support from the California Earthquake Authority.

[11]Applied Technology Council (ATC), Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, A Community Action Plan for Seismic Safety, ATC 52-2, prepared at the request of the Department of Building Inspection of the City and County of San Francisco 2010.

one large, densely occupied office or apartment building collapses. In addition, multistory concrete buildings in the city built before 1980 have the potential to collapse and kill many people.

Examples of efforts to assess and mitigate seismic risks. The City and County of San Francisco (San Francisco) Hazard Mitigation Plan provides seismic hazard profiles for ground shaking and ground failure (including landslide and liquefaction) that could occur during an earthquake. The plan includes a list of essential facilities and infrastructure within San Francisco. In addition, the plan describes current, ongoing, and completed large-scale seismic mitigation projects and programs implemented by San Francisco. For example, the plan includes a project to seismically retrofit fire stations to ensure they are fully functional after a major earthquake. San Francisco has implemented or planned mitigation activities, including structural retrofits, at fire and police stations, animal shelters, courts, and prisons. In addition, pursuant to the California Seismic Hazards Mapping Act, the San Francisco Department of Building Inspection (DBI) requires geotechnical reports prepared by a licensed geologist and geotechnical engineer for projects in areas with susceptibility to ground failure, including liquefaction and landslides. DBI requires that foundations and structural systems be designed to survive these hazards. DBI also has procedures for requesting additional review of proposed projects which the Department believes present difficult or unusual issues in areas with the potential for ground failure. San Francisco policy also requires that equipment such as book shelves and filing cabinets are bolted or adhered to the wall in municipal buildings.

Los Angeles

Seismic hazard. Los Angeles faces one of the greatest risks of catastrophic loss from earthquakes of any city in the world, eclipsed only by Tokyo, Jakarta, and Manila according to a 2013 ranking by Swiss Re, a reinsurance company. There are numerous active and potentially active faults in southern California that have the potential for generating strong ground motions in Los Angeles according to the Los Angeles hazard mitigation plan. The seismic hazards of most concern to Los Angeles include ground shaking, fault rupture and liquefaction. Recent studies have identified various vulnerabilities. For example, pre-1980 soft story (wood frame buildings where the first floor has large openings, such as tuck-under parking, garage doors, and retail display windows) and non-ductile concrete buildings (parts of the building such as columns and frame connectors are too brittle and break in strong shaking) pose a significant risk to life in strong earthquake shaking.

Seismic history. Some 20 earthquakes of magnitude 6.0 or higher have occurred in Southern California since 1912. The most recent of these was the magnitude 6.7, 1994 Northridge Earthquake which was centered in the northwest part of Los Angeles. The earthquake resulted in 57 deaths, 8,000 injuries, and 92,000 plus buildings damaged. The Northridge Earthquake is the most costly seismic event in the United States since the 1906 San Francisco Earthquake. The infrastructure of the metropolitan area was severely disrupted. Freeways collapsed, the power systems for Los Angeles and linked communities as far away as Oregon were temporarily “blacked out,” and communications were disrupted. In addition, the earthquake resulted in non-structural damage that was extensive, and as dangerous as and far more expensive than structural damage, according to the Los Angeles hazard mitigation plan.

Probability of seismic occurrence / estimated damages. According to the WGCEP, within the next 30 years the probability is 60 percent that an earthquake measuring 6.7 or greater will occur in the Los Angeles region. In Southern California, one of the most damaging USGS scenarios is a magnitude 7.1 earthquake on the Puente Hills Fault, with building percent loss of 30% in some census tracts and total predicted building loss of $79 billion ($82.8 billion in total economic loss). It would kill 500 to 2,000 people and displace an estimated 58,000 households. It would cause at least moderate damage to 569 highway bridges, 2 airports, and over 470,000 buildings.

Examples of efforts to assess and mitigate seismic risks. In 1981, Los Angeles passed an ordinance requiring the retrofit of unreinforced masonry buildings given their vulnerability to earthquake damage. This was the first-ever mandatory retrofit ordinance in the State of California. Since the ordinance was passed, more than 99 percent of the city’s unreinforced masonry buildings have been retrofitted or demolished, according to a 2014 Los Angeles study.[12] More recently, in October 2015, Los Angeles passed an ordinance requiring retrofits to strengthen two additional types of buildings that are vulnerable to earthquake damage: brittle concrete buildings and buildings with large first floor openings, such

[12]City of Los Angeles, *Resilience by Design*, (December 2014).

as garages or tuck-under parking.[13] In addition, the Los Angeles Department of Building & Safety (LADBS) has established three new "Preliminary Fault Rupture Study Areas" for several fault lines within the city that have not yet been mapped by the California Geological Survey (CGS). LADBS's Preliminary Fault Rupture Study Areas are areas where active faults may exist and present a potential for ground rupture to occur during a local earthquake. If a proposed development is found to be in a Preliminary Fault Rupture Study Area, geologic investigations to determine the presence or absence of an active fault will be required before building permits are issued by LADBS.

The Los Angeles Unified School District (LAUSD) is actively prioritizing mitigation measures to lower the risks that have been identified and has taken actions to implement mitigation measures at school buildings. According to the 2014 LAUSD Strategic Execution Plan, LAUSD had 26 completed projects. In addition, an evaluation found that 673 sites, which included 4,500 out of 13,500 total school buildings, had possible non-structural hazards – such as hangers and seismic bracing deficiencies, according to LAUSD officials. LAUSD is using the evaluation to prioritize future mitigation projects, according to LAUSD officials. For fiscal years 2011 through 2015, LAUSD received about $5 million from FEMA's Pre-Disaster Mitigation grant program and the Hazard Mitigation Grant Program for LAUSD's seismic-related mitigation measures, according to LAUSD. However, the majority of LAUSD's seismic mitigation funding has come from various state programs, according to LAUSD officials.

[13]Under the law, property owners will have seven years to fix or retrofit buildings with large first floor openings and 25 years to retrofit brittle concrete buildings known as "non-ductile reinforced concrete" buildings. "Non-ductile reinforced concrete" buildings are at higher risk of collapse, because some parts of the building such as columns and frame connectors are too brittle and break in strong shaking. The weight of the concrete makes them particularly hazardous when they fail.

Appendix IV: Annualized Earthquake Loss Estimates for Metropolitan Areas in the United States

The Federal Emergency Management Agency (FEMA) estimates seismic risk in all regions of the United States by using two interrelated risk indicators:

- The Annualized Earthquake Loss (AEL), which is the estimated long-term value of earthquake losses to the general building stock in any single year in a specified geographic area (e.g., state, county, metropolitan area); and
- The Annualized Earthquake Loss Ratio (AELR), which expresses estimated annualized loss as a fraction of the building inventory replacement value.

The AEL addresses two key components of seismic risk: the probability of ground motion occurring in a given study area and the consequences of the ground motion in terms of physical damage and economic loss. It takes into account the regional variations in risk. For example, the level of earthquake risk in the New Madrid Seismic Zone is measurably different from the risk in the Los Angeles Basin with respect to: a) the probability of damaging ground motions, and b) the consequences of the ground motions, which are largely a function of building construction type and quality, as well as ground shaking and failure during earthquakes. Consequences vary regionally, as well. For example, the earthquake hazard is higher in Los Angeles than in Memphis, but the general building stock in Los Angeles is more resistant to the effects of earthquakes.

The AELR is the AEL as a fraction of the replacement value of the building inventory and is useful for comparing the relative risk of events. For example, $10 million in earthquake damages in Evansville, Indiana represents a greater loss than a comparable dollar loss in San Francisco, a much larger city. The annualized loss ratio allows gauging of the relationship between AEL and building replacement value. This ratio can be used as a measure of relative risk between regions and, since it is normalized by replacement value, it can be directly compared across metropolitan areas, counties, or states.

A 2008 FEMA study indicates that the Annualized Earthquake Loss (AEL) to the national building stock is $5.3 billion per year.[1] The majority (77

[1] Federal Emergency Management Agency, *HAZUS® MH Estimated Annualized Earthquake Losses for the United States*, FEMA 366 (Washington, D.C.: April 2008).

percent) of average annual loss is located on the West Coast (California, Oregon, Washington) with 66 percent ($3.5 billion per year) concentrated in the state of California. The high concentration of loss in California is consistent with the state's high seismic hazard and large structural exposure. The remaining 23 percent (1.1 billion per year) of annual loss is distributed throughout the rest of the United States (including Alaska and Hawaii). While the majority of economic loss is concentrated along the West Coast, the distribution of relative earthquake risk, as measured by the AELR, is much broader and reinforces the fact that earthquakes are a national problem. There are relatively high earthquake loss ratios throughout the western and central United States (states within the New Madrid Seismic Zone) and in the Charleston, South Carolina area.

As shown in table 5, forty-three metropolitan areas, led by the Los Angeles and San Francisco Bay areas, account for 82 percent of the total AEL. Los Angeles County alone has about 25 percent of the total AEL, and the Los Angeles and San Francisco Bay areas together account for nearly 40 percent of the total AEL.

Table 5: Annualized Earthquake Loss (AEL) and Annualized Earthquake Loss Ratios (AELR) for 43 Metropolitan Areas with AEL Greater Than $10 Million

Rank	State	AEL ($ Million)	Rank	State	AELR ($/Million $)
1	Los Angeles-Long Beach-Santa Ana, CA	1,312.3	1	San Francisco-Oakland-Fremont, CA	2,049.44
2	San Francisco-Oakland-Fremont, CA	781.0	2	Riverside-San Bernardino-Ontario, CA	2,021.57
3	Riverside-San Bernardino-Ontario, CA	396.5	3	El Centro, CA	1,973.77
4	San Jose-Sunnyvale-Santa Clara, CA	276.7	4	Oxnard-Thousand Oaks-Ventura, CA	1,963.00
5	Seattle-Tacoma-Bellevue, WA	243.9	5	San Jose-Sunnyvale-Santa Clara, CA	1,837.58
6	San Diego-Carlsbad-San Marcos, CA	155.2	6	Santa Rosa-Petaluma, CA	1,662.57
7	Portland-Vancouver-Beaverton, OR-WA	137.1	7	Santa Cruz-Watsonville, CA	1,580.97
8	Oxnard-Thousand Oaks-Ventura, CA	111.0	8	Los Angeles-Long Beach-Santa Ana, CA	1,574.85
9	Santa Rosa-Petaluma, CA	68.6	9	Napa, CA	1,398.18
10	St. Louis, MO-IL	58.5	10	Vallejo-Fairfield, CA	1,375.94
11	Salt Lake City, UT	52.3	11	Anchorage, AK	1,238.56
12	Sacramento-Arden-Arcade—Roseville, CA	52.0	12	Santa Barbara-Santa Maria-Goleta, CA	1,207.93
13	Vallejo-Fairfield, CA	39.8	13	Reno-Sparks, NV	1,150.40
14	Memphis, TN-MS-AR	38.2	14	Bremerton-Silverdale, WA	1,110.13
15	Santa Cruz-Watsonville, CA	36.2	15	Salinas, CA	1,075.54
16	Anchorage, AK	34.8	16	Seattle-Tacoma-Bellevue, WA	1,052.43
17	Santa Barbara-Santa Maria-Goleta, CA	34.4	17	Salt Lake City, UT	984.61

Rank	State	AEL ($ Million)	Rank	State	AELR ($/Million $)
18	Las Vegas-Paradise, NV	33.1	18	Olympia, WA	969.50
19	Honolulu, HI	32.0	19	Portland-Vancouver-Beaverton, OR-WA	942.62
20	Bakersfield, CA	30.3	20	Bakersfield, CA	870.43
21	New York-Northern New Jersey-Long Island, NY-NJ-PA	29.9	21	San Luis Obispo-Paso Robles, CA	848.65
22	Salinas, CA	29.2	22	Ogden-Clearfield, UT	826.52
23	Reno-Sparks, NV	29.0	23	Salem, OR	797.50
24	Charleston-North Charleston, SC	22.3	24	San Diego-Carlsbad-San Marcos, CA	770.20
25	Columbia, SC	21.6	25	Charleston-North Charleston, SC	766.01
26	Stockton, CA	20.9	26	Eugene-Springfield, OR	701.95
27	Atlanta-Sandy Springs-Marietta, GA	19.1	27	Provo-Orem, UT	683.30
28	Bremerton-Silverdale, WA	17.7	28	Stockton, CA	597.79
29	Ogden-Clearfield, UT	17.5	29	Memphis, TN-MS-AR	509.13
30	Salem, OR	17.4	30	Evansville, IN-KY	485.60
31	Eugene-Springfield, OR	16.5	31	Columbia, SC	478.05
32	Napa, CA	15.9	32	Modesto, CA	473.60
33	San Luis Obispo-Paso Robles, CA	15.7	33	Las Vegas-Paradise, NV	390.28
34	Nashville-Davidson—Murfreesboro, TN	15.4	34	Sacramento—Arden-Arcade—Roseville, CA	374.73
35	Albuquerque, NM	14.7	35	St. Louis, MO-IL	337.23
36	Olympia, WA	13.7	36	Albuquerque, NM	322.20
37	Modesto, CA	13.0	37	Honolulu, HI	311.12
38	Fresno, CA	12.6	38	Fresno, CA	283.13
39	Evansville, IN-KY	11.7	39	Little Rock-North Little Rock, AR	248.74
40	Birmingham-Hoover, AL	11.3	40	Nashville-Davidson-Murfreesboro, TN	167.26
41	El Centro, CA	10.7	41	Birmingham-Hoover, AL	115.54
42	Little Rock-North Little Rock, AR	10.5	42	Atlanta-Sandy Springs-Marietta, GA	65.39
43	Provo-Orem, UT	10.4	43	New York-Northern New Jersey-Long Island, NY-NJ-PA	20.90

Source: Federal Emergency Management Agency | GAO-16-680

Appendix V: Examples of Structural and Nonstructural Enhancements to New and Existing Buildings

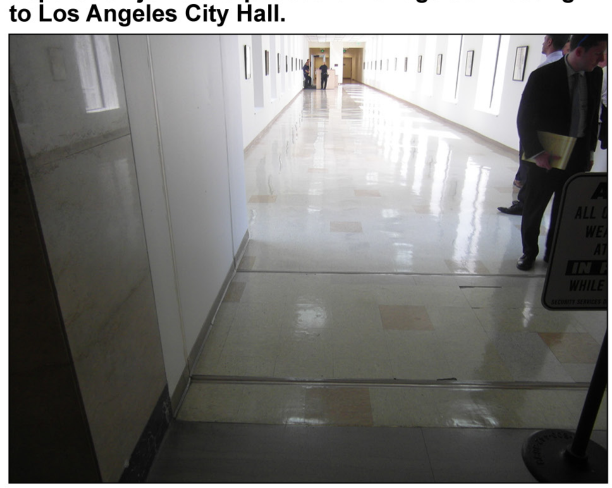
We examined examples of seismic retrofit and non-structural seismic upgrade mitigation projects. For example, the Los Angeles City Hall was built in 1928 and retrofitted in 2001 for $300 million dollars, according to Los Angeles officials. The retrofit included renovation of terra cotta tiles on the dome roof, using concrete to replace unreinforced masonry, and replacing the cracked floor outside the main hallway (see figure 14). In addition, the pedestrian bridge connecting City Hall to an adjacent building was renovated from 1998 to 2001 to include a separation (or sliding) joint. In the case of an earthquake, the two buildings may not sway from side-to-side at the same rate or in the same direction. As such, the separation joint connecting the bridge with City Hall can fall away in the event of an earthquake, allowing for up to 6 inches of separation. This is built to ensure that the two buildings will not collide in an earthquake up to an 8.1 magnitude event. The building is also fitted with base isolators and dampers (see figure 14). The base isolators are designed to move as much as 24 inches. See figure 15 for examples of nonstructural earthquake mitigation enhancements to hospital and school buildings in California.

Figure 14: Earthquake Mitigation Structural Renovations to the Los Angeles City Hall

Renovation of terra cotta tiles on the Los Angeles City Hall dome roof, using concrete to replace unreinforced masonry.

A base isolator located at the City of Los Angeles Emergency Operations Center with reinforced piping surrounding it.

Separation joint of a pedestrian bridge connecting to Los Angeles City Hall.



Source: GAO. | GAO-16-680

See figure 15 for examples of nonstructural earthquake mitigation enhancements to hospital and school buildings in California.

Figure 15: Earthquake Mitigation Nonstructural Enhancements to Hospital and School Buildings in California

Anchorage of medical equipment at a City and County of San Francisco hospital and trauma center.

Los Angeles Unified School District building with wall anchorage to roof diaphragm and seismic bracing.

Source: GAO. | GAO-16-680

Appendix VI: Potential Intensity of Earthquake Shaking on Leased and Owned Federal Buildings by Agency

The following tables provide a detailed overview of the potential MMI shaking intensity for federal leased and owned buildings by agency.

Table 6: Number of Leased Federal Buildings In Modified Mercalli Intensity Earthquake Zones by Federal Agency, as of September 30, 2014

	Number of leased federal buildings									
	Modified Mercalli Intensity (MMI) Based on 2 percent in 50 year probability of exceedance								Undetermined MMI	
Agency	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**Number**	**Percent**
Agriculture	0	965	813	659	418	208	88	16	14	0.4
Air Force[a]	0	156	202	46	47	4	2	2	0	0
Army[a]	0	1,294	1,217	1,261	543	235	277	40	7	0.1
Broadcasting Board of Governors	—	—	—	—	—	—	—	—	—	—
Commerce	1	49	29	32	26	14	26	4	1	0.5
Court Services and Offender Supervision Agency for the District of Columbia	0	0	10	0	0	0	0	0	0	0
Energy	0	4	9	19	8	6	3	0	0	0
Environmental Protection Agency	0	0	1	0	0	0	0	0	0	0
Federal Communications Commission	—	—	—	—	—	—	—	—	—	—
General Services Administration	3	1,498	1,987	1,449	931	387	588	79	5	0.1
Health and Human Services	0	5	50	22	12	0	0	0	0	0
Homeland Security	0	378	209	188	198	54	196	13	9	0.7
Interior	2	46	52	63	96	33	34	4	1	0.3
John F. Kennedy Center for the Performing Arts	—	—	—	—	—	—	—	—	—	—
Justice	0	3	6	5	6	0	2	0	0	0
Labor	0	1	132	34	33	47	29	1	0	0
Merit Systems Protection Board	0	0	1	0	0	0	0	0	0	0
National Aeronautics and Space Administration	0	1	8	1	0	1	3	0	0	0
National Archives and Records Administration	0	1	0	1	2	0	1	0	0	0
National Gallery of Art	0	0	3	0	0	0	0	0	0	0

Number of leased federal buildings										
	Modified Mercalli Intensity (MMI) Based on 2 percent in 50 year probability of exceedance								Undetermined MMI	
Agency	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**Number**	**Percent**
National Science Foundation	0	0	2	6	2	4	0	0	0	0
Navy[a]	0	44	120	15	5	33	81	0	6	2.0
Office of Personnel Management	0	0	2	2	0	0	0	0	0	0
Smithsonian	0	0	16	1	8	0	0	0	1	3.8
State	0	0	0	0	2	0	0	0	0	0
State (United States Agency for International Development)	0	0	1	0	0	0	0	0	0	0
Tennessee Valley Authority	0	0	1	8	5	10	2	0	4	13.3
Transportation	0	247	216	166	212	72	101	13	11	1.1
Treasury	0	19	31	15	15	6	5	1	1	1.1
United States Army Corps of Engineers[a]	0	53	30	30	12	8	11	2	1	0.7
United States Holocaust Memorial Council	—	—	—	—	—	—	—	—	—	—
Veterans Affairs	0	337	283	241	174	78	73	25	356	22.7
Washington Headquarters Services[a]	—	—	—	—	—	—	—	—	—	—
Overall	6	5,101	5,431	4,264	2,755	1,200	1,522	200	417	2.0

Legend: — = agency has no leased buildings.

Source: GAO analysis of Department of Defense data, General Services Administration data, and United States Geological Survey mapping. | GAO-16-680

Note: Building data are all active or inactive buildings located in the 50 states and the District of Columbia from the Federal Real Property Profile (FRPP) database which includes those buildings under the custody and control of executive branch agencies or components as set out in Executive Order 13327 and certain executive branch agencies which voluntarily report. The data does not include those buildings held by the legislative branch agencies, judicial branch agencies, or other non-executive branch agencies such as the United States Postal Service. MMI shaking hazard level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years. Some buildings have an undetermined MMI because they either did not have location information included in the FRPP or the location information in the FRPP had inconsistencies in the data which did not allow the building to be accurately located.

[a]A component of the Department of Defense.

Table 7: Cumulative Size of Leased Federal Buildings In Modified Mercalli Intensity Earthquake Zones by Federal Agency, as of September 30, 2014

	Cumulative size of leased federal buildings, in thousand square feet									
	Modified Mercalli Intensity (MMI) Based on 2 percent in 50 year probability of exceedance								Undetermined	MMI
Agency	III	IV	V	VI	VII	VIII	IX	X	Square feet	Percent
Agriculture	0	4,176	3,385	3,236	2,780	1,161	480	82	87	0.6
Air Force[a]	0	3,867	2,047	535	4,578	32	120	29	0	0
Army[a]	0	4,126	5,401	4,598	1,624	952	869	156	27	0.2
Broadcasting Board of Governors	—	—	—	—	—	—	—	—	—	—
Commerce	2	254	204	176	295	30	130	9	0	0
Court Services and Offender Supervision Agency for the District of Columbia	0	0	237	0	0	0	0	0	0	0
Energy	0	204	105	180	53	70	4	0	0	0
Environmental Protection Agency	0	0	156	0	0	0	0	0	0	0
Federal Communications Commission	—	—	—	—	—	—	—	—	—	—
General Services Administration	16	28,402	94,466	32,888	19,777	5,699	13,613	1,012	30	<0.1
Health and Human Services	0	48	2,216	182	190	0	0	0	0	0
Homeland Security	0	2,413	2,884	969	940	253	970	236	61	0.7
Interior	1	258	562	619	1,330	265	362	65	1	<0.1
John F. Kennedy Center for the Performing Arts	—	—	—	—	—	—	—	—	—	—
Justice	0	31	297	210	177	0	25	0	0	0
Labor	0	18	1,329	687	312	394	434	5	0	0
Merit Systems Protection Board	0	0	2	0	0	0	0	0	0	0
National Aeronautics and Space Administration	0	127	273	122	0	427	126	0	0	0
National Archives and Records Administration	0	208	0	352	474	0	183	0	0	0
National Gallery of Art	0	0	136	0	0	0	0	0	0	0
National Science Foundation	0	0	2	128	73	19	0	0	0	0
Navy[a]	0	1,003	519	140	78	201	1,032	0	257	8

Office of Personnel Management	0	0	41	34	0	0	0	0	0	0
Smithsonian	0	0	1,060	3	534	0	0	0	1	0.1
State	0	0	0	0	117	0	0	0	0	0
State (United States Agency for International Development)	0	0	4	0	0	0	0	0	0	0
Tennessee Valley Authority	0	0	1	95	56	95	9	0	8	2.9
Transportation	0	691	1,230	854	2,750	181	547	33	22	0,4
Treasury	0	191	1,312	206	345	25	96	55	4	0.2
United States Army Corps of Engineers[a]	0	168	47	44	6	34	110	5	0	0
United States Holocaust Memorial Council	—	—	—	—	—	—	—	—	—	—
Veterans Affairs	0	4,190	3,378	2,150	1,619	781	703	273	3.300	20.1
Washington Headquarters Services[a]	—	—	—	—	—	—	—	—	—	—
Overall	19	50,375	121,294	48,407	38,106	10,620	19,814	1,960	3,797	1.3

Legend: — = agency has no leased buildings.

Source: GAO analysis of Department of Defense data, General Services Administration data, and United States Geological Survey mapping. | GAO-16-680

Note: Building data are all active or inactive buildings located in the 50 states and the District of Columbia from the Federal Real Property Profile (FRPP) database which includes those buildings under the custody and control of executive branch agencies or components as set out in Executive Order 13327 and certain executive branch agencies which voluntarily report. The data does not include those buildings held by the legislative branch agencies, judicial branch agencies, or other non-executive branch agencies such as the United States Postal Service. MMI shaking hazard level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years. Some buildings have an undetermined MMI because they either did not have location information included in the FRPP or the location information in the FRPP had inconsistencies in the data which did not allow the building to be accurately located. Square feet of buildings may not add to the total due to rounding.

[a]A component of the Department of Defense.

Table 8: Number of Owned Federal Buildings In Modified Mercalli Intensity Earthquake Zones by Federal Agency, as of September 30, 2014

	Number of owned federal buildings									
	Modified Mercalli Intensity (MMI) Based on 2 percent in 50 year probability of exceedance								Undetermined MMI	
Agency	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**Number**	**Percent**
Agriculture	0	1,817	1,891	5,292	5,634	3,087	1,460	310	403	2
Air Force[a]	0	8,627	6,099	7,187	4,806	2,471	2,631	786	69	0.2
Army[a]	0	7,965	10,446	19,110	7,217	4,129	4,312	106	1,456	2.7
Broadcasting Board of Governors	2	8	0	0	0	0	0	0	0	0

Number of owned federal buildings										
	Modified Mercalli Intensity (MMI) Based on 2 percent in 50 year probability of exceedance								Undetermined MMI	
Agency	III	IV	V	VI	VII	VIII	IX	X	Number	Percent
Commerce	5	91	74	109	62	56	69	2	4	0.8
Court Services and Offender Supervision Agency for the District of Columbia	—	—	—	—	—	—	—	—	—	—
Energy	0	512	1,072	1,420	4,590	1,582	688	320	21	0.2
Environmental Protection Agency	0	26	28	29	53	17	18	0	1	0.6
Federal Communications Commission	0	7	12	13	4	4	5	0	2	4.3
General Services Administration	0	288	459	331	226	103	86	9	4	0.3
Health and Human Services	1	378	1,026	831	213	45	29	0	76	2.9
Homeland Security	34	1,986	1,476	1,717	579	272	2,005	188	33	0.4
Interior	9	5,005	6,924	9,627	10,071	6,485	2,423	820	142	0.3
John F. Kennedy Center for the Performing Arts	0	0	1	0	0	0	0	0	0	0
Justice	0	690	807	998	139	535	82	0	594	15.4
Labor	0	405	357	513	416	163	199	33	0	0
Merit Systems Protection Board	—	—	—	—	—	—	—	—	—	—
National Aeronautics and Space Administration	0	1,026	445	288	0	55	393	8	14	0.6
National Archives and Records Administration	0	9	5	6	0	0	1	0	0	0
National Gallery of Art	—	—	—	—	—	—	—	—	—	—
National Science Foundation	0	1	37	120	24	0	3	0	3	1.6
Navy[a]	4	4,842	8,706	2,164	3,694	4,268	6,754	416	714	2.3
Office of Personnel Management	—	—	—	—	—	—	—	—	—	—
Smithsonian	—	—	—	—	—	—	—	—	—	—
State	0	83	11	31	4	0	6	0	3	2.2
State (United States Agency for International Development)	—	—	—	—	—	—	—	—	—	—
Tennessee Valley Authority	0	0	1	278	689	475	198	1	770	31.9
Transportation	1	2,107	2,233	1,755	1,793	702	766	163	276	2.8
Treasury	0	0	6	4	0	0	1	0	0	0
United States Army Corps of Engineers[a]	0	153	391	183	146	33	49	12	0	0

	Number of owned federal buildings									
	Modified Mercalli Intensity (MMI) Based on 2 percent in 50 year probability of exceedance								Undetermined MMI	
Agency	III	IV	V	VI	VII	VIII	IX	X	Number	Percent
United States Holocaust Memorial Council	0	0	2	0	0	0	0	0	0	0
Veterans Affairs	0	1,266	1,524	1,525	915	159	615	27	0	0
Washington Headquarters Services[a]	0	0	70	0	0	0	0	0	34	32.7
Overall	56	37,292	44,103	53,531	41,275	24,641	22,793	3,201	4,619	2

Legend: — = agency has no owned buildings.

Source: GAO analysis of Department of Defense data, General Services Administration data, and United States Geological Survey mapping. | GAO-16-680

Note: Building data are all active or inactive buildings located in the 50 states and the District of Columbia from the Federal Real Property Profile (FRPP) database which includes those buildings under the custody and control of executive branch agencies or components as set out in Executive Order 13327 and certain executive branch agencies which voluntarily report. The data does not include those buildings held by the legislative branch agencies, judicial branch agencies, or other non-executive branch agencies such as the United States Postal Service. MMI shaking hazard level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years. Some buildings have an undetermined MMI because they either did not have location information included in the FRPP or the location information in the FRPP had inconsistencies in the data which did not allow the building to be accurately located.

[a]A component of the Department of Defense.

Table 9: Cumulative Size of Owned Federal Buildings In Modified Mercalli Intensity Earthquake Zones by Federal Agency, as of September 30, 2014

	Cumulative size of owned federal buildings, in thousand square feet									
	Modified Mercalli Intensity (MMI) Based on 2 percent in 50 year probability of exceedance								Undetermined MMI	
Agency	III	IV	V	VI	VII	VIII	IX	X	Square feet	Percent
Agriculture	0	8,002	6,555	8,114	7,897	4,275	2,782	590	426	1.1
Air Force[a]	0	115,206	88,510	104,028	65,350	26,213	41,164	11,388	70	<0.1
Army[a]	0	81,287	137,621	200,610	61,721	40,708	41,470	324	15,286	2.6
Broadcasting Board of Governors	2	52	0	0	0	0	0	0	0	0
Commerce	10	743	3,741	1,242	257	874	870	10	41	0.5
Court Services and Offender Supervision Agency for the District of Columbia	—	—	—	—	—	—	—	—	—	—
Energy	0	3,107	24,716	11,818	35,679	16,789	15,285	3,287	46	<0.1
Environmental Protection Agency	0	171	2,227	114	1,384	128	114	0	75	1.8

	Cumulative size of owned federal buildings, in thousand square feet									
	Modified Mercalli Intensity (MMI) Based on 2 percent in 50 year probability of exceedance								Undetermined MMI	
Agency	III	IV	V	VI	VII	VIII	IX	X	Square feet	Percent
Federal Communications Commission	0	19	45	19	7	8	8	0	2	1.6
General Services Administration	0	27,814	98,456	32,941	34,580	11,270	18,405	521	79	<0.1
Health and Human Services	100	2,123	19,614	7,453	2,079	408	605	0	349	1.1
Homeland Security	91	8,740	9,452	8,245	2,867	941	9,865	653	217	0.5
Interior	17	12,486	19,686	23,333	22,240	12,835	5,508	1,402	298	0.3
John F. Kennedy Center for the Performing Arts	0	0	1,500	0	0	0	0	0	0	0
Justice	0	10,475	16,058	17,315	3,035	7,265	3,496	0	11,920	17.1
Labor	0	4,512	4,639	4,730	3,445	1,374	2,993	290	0	0
Merit Systems Protection Board	—	—	—	—	—	—	—	—	—	—
National Aeronautics and Space Administration	0	21,338	9,650	5,031	0	834	7,991	23	56	0.1
National Archives and Records Administration	0	213	2,967	359	0	0	147	0	0	0
National Gallery of Art	—	—	—	—	—	—	—	—	—	—
National Science Foundation	0	1	171	589	201	0	34	0	13	1.3
Navy[a]	38	79,541	130,872	23,248	38,882	48,289	86,090	4,656	4,745	1.1
Office of Personnel Management	—	—	—	—	—	—	—	—	—	—
Smithsonian	—	—	—	—	—	—	—	—	—	—
State	0	256	842	43	61	0	312	0	110	6.8
State (United States Agency for International Development)	—	—	—	—	—	—	—	—	—	—
Tennessee Valley Authority	0	0	1	4,412	10,614	8,439	2,017	0	2,582	9.2
Transportation	2	2,557	5,771	2,290	3,832	1,154	1,323	391	1,610	8.5
Treasury	0	0	3,059	942	0	0	123	0	0	0

Cumulative size of owned federal buildings, in thousand square feet										
	Modified Mercalli Intensity (MMI) Based on 2 percent in 50 year probability of exceedance								Undetermined MMI	
Agency	III	IV	V	VI	VII	VIII	IX	X	Square feet	Percent
United States Army Corps of Engineers[a]	0	1,118	6,689	1,070	796	247	543	22	0	0
United States Holocaust Memorial Council	0	0	320	0	0	0	0	0	0	0
Veterans Affairs	0	34,231	36,926	34,541	23,985	2,315	16,442	850	0	0
Washington Headquarters Services[a]	0	0	642	0	0	0	0	0	6,878	91.5
Overall	260	413,994	630,733	492,490	318,913	184,365	257,587	24,407	44,804	1.9

Legend: — = agency has no owned buildings.

Source: GAO analysis of Department of Defense data, General Services Administration data, and United States Geological Survey mapping. | GAO-16-680

Note: Building data are all active or inactive buildings located in the 50 states and the District of Columbia from the Federal Real Property Profile (FRPP) database which includes those buildings under the custody and control of executive branch agencies or components as set out in Executive Order 13327 and certain executive branch agencies which voluntarily report. The data does not include those buildings held by the legislative branch agencies, judicial branch agencies, or other non-executive branch agencies such as the United States Postal Service. MMI shaking hazard level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years. Some buildings have an undetermined MMI because they either did not have location information included in the FRPP or the location information in the FRPP had inconsistencies in the data which did not allow the building to be accurately located. Square feet of buildings may not add to the total due to rounding.

[a]A component of the Department of Defense.

The following table provides a detailed overview of the number and square footage of federally leased and owned buildings by agency.

Table 10: Number and Square Feet of Leased and Owned Federal Buildings by Agency, as of September 30, 2014

	Leased buildings				Owned buildings			
Agency	Number of buildings	Percent of leased buildings	Square feet of buildings (in thousands)	Percent of leased square feet	Number of buildings	Percent of owned buildings	Square feet of buildings (in thousands)	Percent of owned square feet
Agriculture	3,181	15.2	15,387	5.2	19,894	8.6	38,641	1.6
Air Force[a]	459	2.2	11,208	3.8	32,676	14.1	451,929	19.1
Army[a]	4.874	23.3	17,753	6.0	54,741	23.6	579,027	24.5
Broadcasting Board of Governors	—	—	—	—	10	<0.1	54	<0.1
Commerce	182	0.9	1,100	0.4	472	0.2	7,788	0.3

	Leased buildings				Owned buildings			
Agency	Number of buildings	Percent of leased buildings	Square feet of buildings (in thousands)	Percent of leased square feet	Number of buildings	Percent of owned buildings	Square feet of buildings (in thousands)	Percent of owned square feet
Court Services and Offender Supervision Agency for the District of Columbia	10	<0.1	237	0.1	—	—	—	—
Energy	49	0.2	616	0.2	10,205	4.4	110,727	4.7
Environmental Protection Agency	1	<0.1	156	0.1	172	0.1	4,213	0.2
Federal Communications Commission	—	—	—	—	47	<0.1	108	<0.1
General Services Administration	6,927	33.1	195,903	66.5	1,506	0.7	224,066	9.5
Health and Human Services	89	0.4	2,636	0.9	2,599	1.1	32,731	1.4
Homeland Security	1,245	6.0	8,726	3.0	8,290	3.6	41,071	1.7
Interior	331	1.6	3,463	1.2	41,506	17.9	97,805	4.1
John F. Kennedy Center for the Performing Arts	—	—	—	—	1	<0.1	1,500	0.1
Justice	22	0.1	740	0.3	3,845	1.7	69,564	2.9
Labor	277	1.3	3,179	1.1	2,086	0.9	21,983	0.9
Merit Systems Protection Board	1	<0.1	2	<0.1	—	—	—	—
National Aeronautics and Space Administration	14	0.1	1,075	0.4	2,229	1.0	44,923	1.9
National Archives and Records Administration	5	<0.1	1,217	0.4	21	<0.1	3,686	0.2
National Gallery of Art	3	<0.1	136	<0.1	—	—	—	—
National Science Foundation	14	0.1	222	0.1	188	0.1	1,009	<0.1
Navy[a]	304	1.5	3,230	1.1	31,562	13.6	416,361	17.6
Office of Personnel Management	4	<0.1	75	<0.1	—	—	—	—
Smithsonian	26	0.1	1,598	0.5	—	—	—	—
State	2	<0.1	117	<0.1	138	0.1	1,624	0.1

	Leased buildings				Owned buildings			
Agency	Number of buildings	Percent of leased buildings	Square feet of buildings (in thousands)	Percent of leased square feet	Number of buildings	Percent of owned buildings	Square feet of buildings (in thousands)	Percent of owned square feet
State (United States Agency for International Development)	1	<0.1	4	<0.1	—	—	—	—
Tennessee Valley Authority	30	0.1	264	0.1	2,412	1.0	28,065	1.2
Transportation	1,038	5.0	6,308	2.1	9,796	4.2	18,930	0.8
Treasury	93	0.4	2,234	0.8	11	<0.1	4,124	0.2
United States Army Corps of Engineers[a]	147	0.7	414	0.1	967	0.4	10,485	0.4
United States Holocaust Memorial Council	—	—	—	—	2	<0.1	320	<0.1
Veterans Affairs	1,567	7.5	16,394	5.6	6,031	2.6	149,290	6.3
Washington Headquarters Services[a]	—	—	—	—	104	<0.1	7,520	0.3
Total	**20,896**	**100**	**294,392**	**100.0**	**231,511**	**100.0**	**2,367,553**	**100.0**

Legend: — = not applicable.

Source: GAO analysis of Department of Defense and General Services Administration data. | GAO-16-680

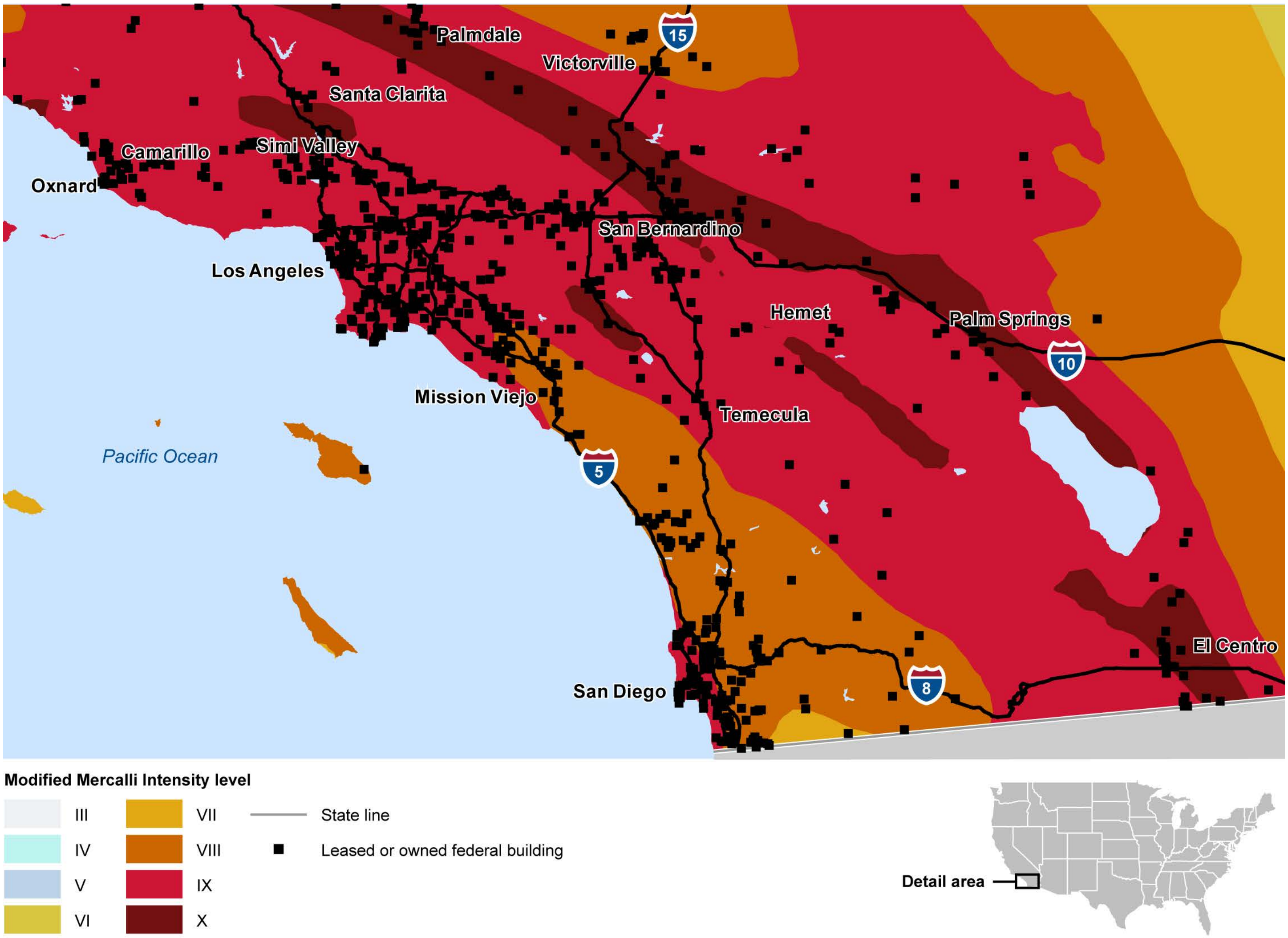
Note: Includes owned and leased federal buildings reported to the Federal Real Property Profile (FRPP) located in the 50 states and the District of Columbia as active or inactive. The FRPP database includes federal buildings under the custody and control of United States executive branch agencies or components as set out in Executive Order 13327 and certain executive branch agencies which voluntarily report. The data does not include those buildings held by the legislative branch agencies, judicial branch agencies, or other non-executive branch agencies such as the United States Postal Service. Square feet of buildings may not add to the total due to rounding.

[a]A component of the Department of Defense.

Appendix VII: Federal Buildings in Four High Earthquake Shaking Intensity Zones of the United States (Corresponds to Fig. 5)

Figures 16 through 19 include the rollover information in figure 5.

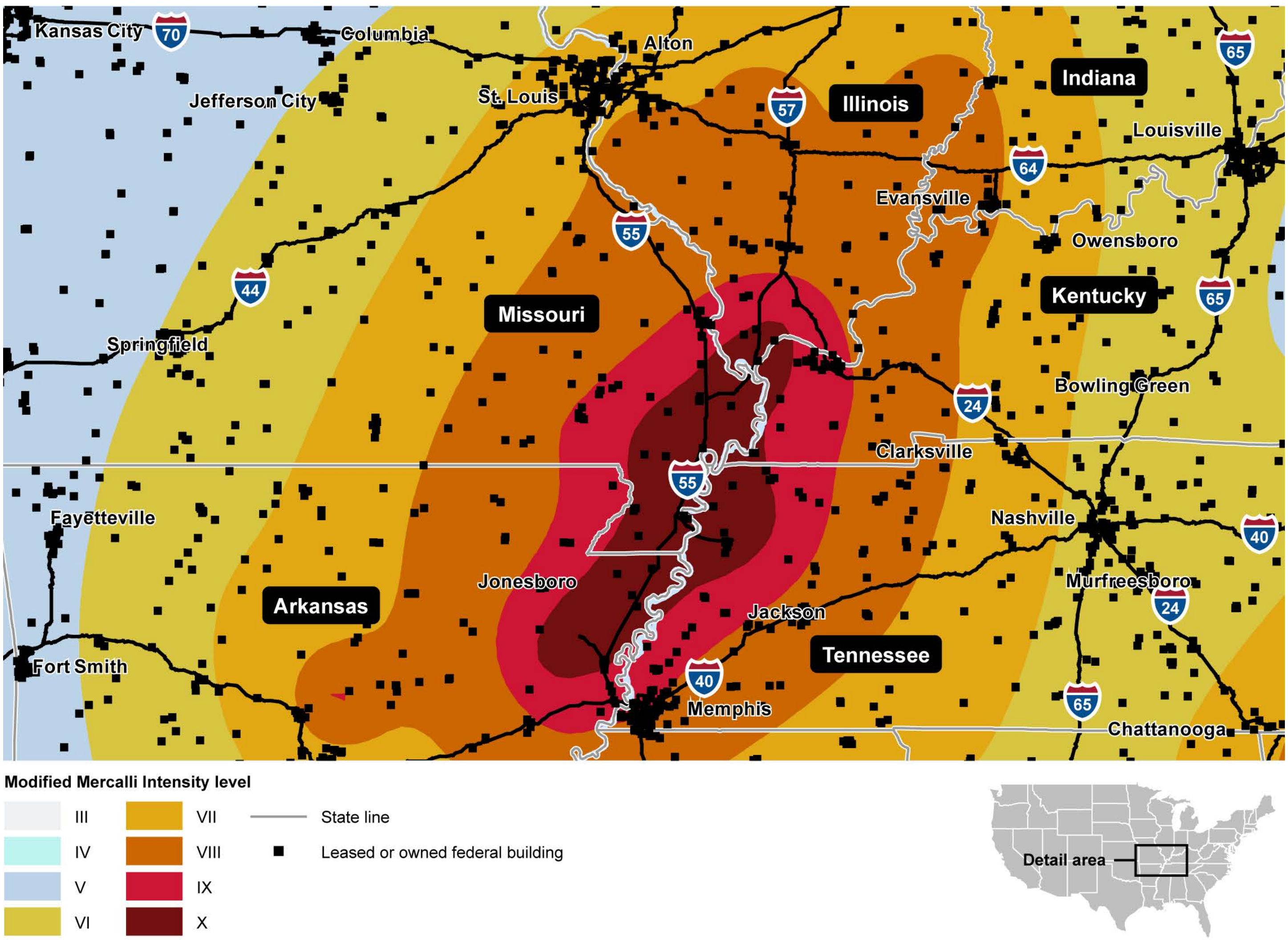
Figure 16: Federal Buildings in Los Angeles Area by Earthquake Shaking Intensity Zones, as of September 30, 2014



Source: GAO analysis of Department of Defense data, General Services Administration data, and U.S. Geological Survey mapping; MapInfo (map). | GAO-16-680

Note: Includes leased and owned federal buildings reported to the Federal Real Property Profile (FRPP) as active or inactive. The FRPP database includes federal buildings under the custody and control of United States executive branch agencies as set out in Executive Order 13327 and certain executive branch agencies which voluntarily report. The data does not include those buildings held by the legislative branch agencies, judicial branch agencies, or other non-executive branch agencies such as the United States Postal Service. Modified Mercalli Intensity (MMI) earthquake shaking intensity level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years. Approximately 2.0 percent of the total number of active and inactive buildings (1.8 percent of the square feet of buildings) in the FRPP data were not included in the analysis because they either did not have location information included in the FRPP or the location information in the FRPP had inconsistencies in the data which did not allow the building to be accurately located.

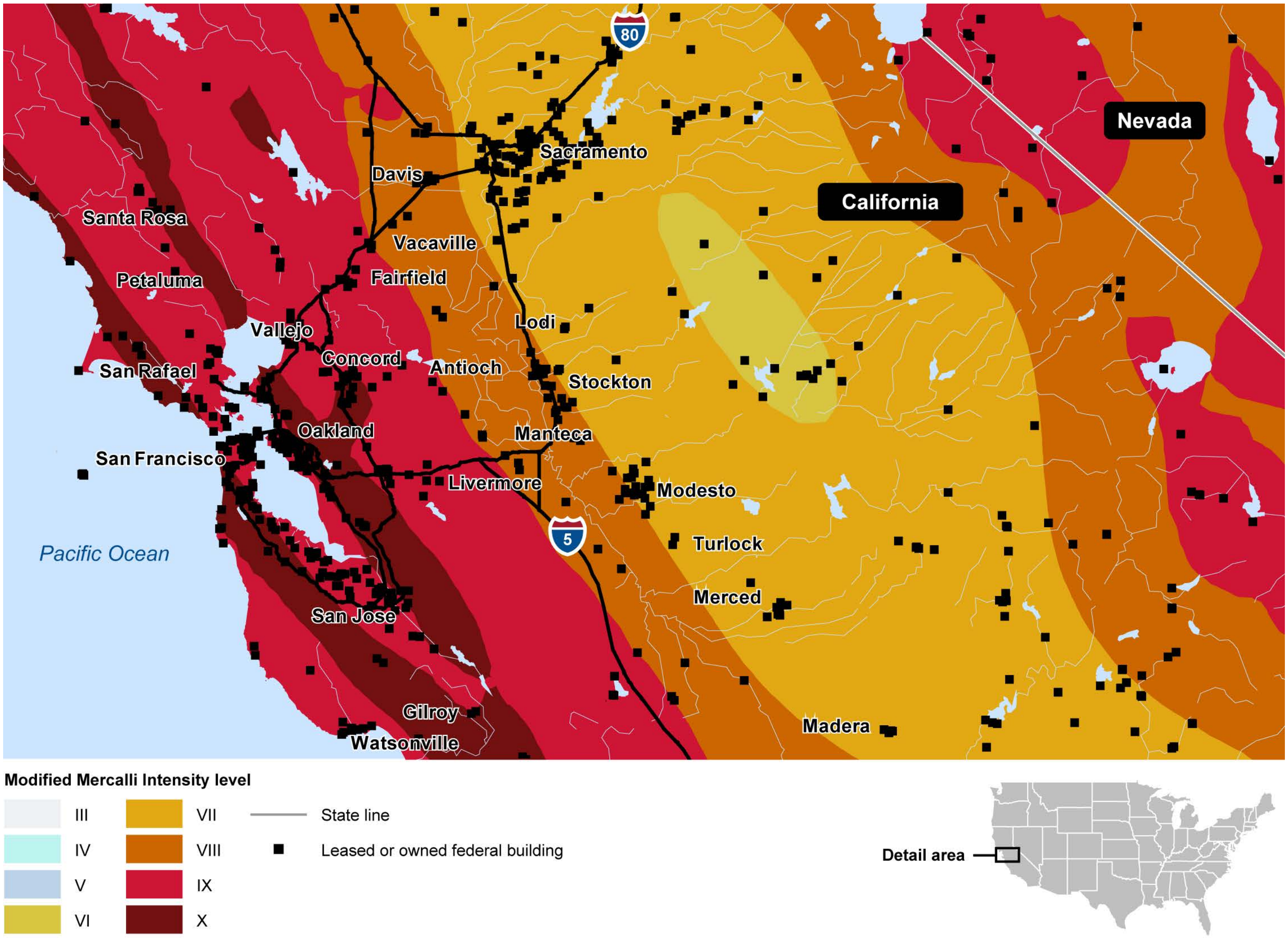
Figure 17: Federal Buildings in Memphis Area by Earthquake Shaking Intensity Zones, as of September 30, 2014



Source: GAO analysis of Department of Defense data, General Services Administration data, and U.S. Geological Survey mapping; MapInfo (map). | GAO-16-680

Note: Includes leased and owned federal buildings reported to the Federal Real Property Profile (FRPP) as active or inactive. The FRPP database includes federal buildings under the custody and control of United States executive branch agencies as set out in Executive Order 13327 and certain executive branch agencies which voluntarily report. The data does not include those buildings held by the legislative branch agencies, judicial branch agencies, or other non-executive branch agencies such as the United States Postal Service. Modified Mercalli Intensity (MMI) earthquake shaking intensity level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years. Approximately 2.0 percent of the total number of active and inactive buildings (1.8 percent of the square feet of buildings) in the FRPP data were not included in the analysis because they either did not have location information included in the FRPP or the location information in the FRPP had inconsistencies in the data which did not allow the building to be accurately located.

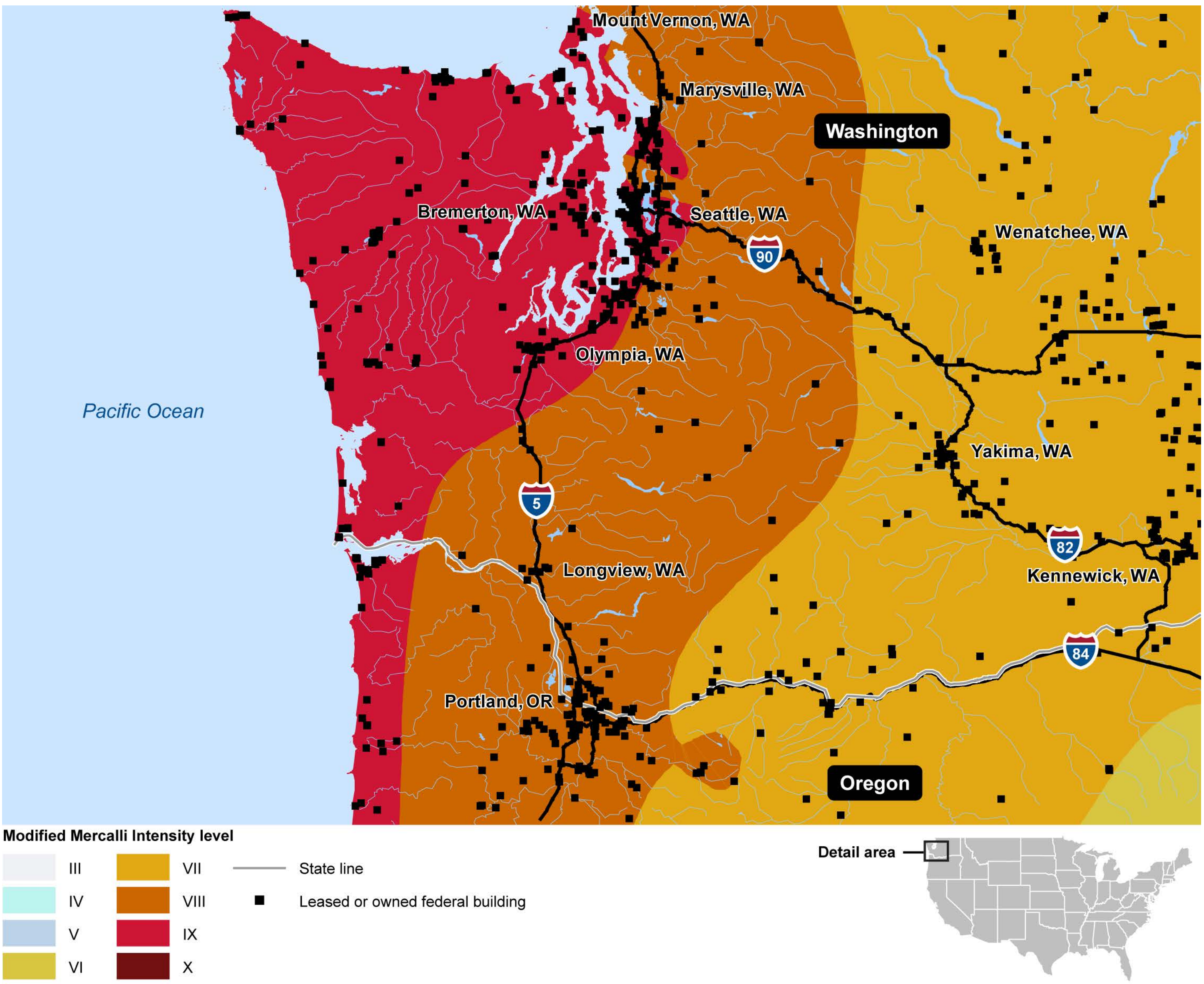
Figure 18: Federal Buildings in San Francisco Area by Earthquake Shaking Intensity Zones, as of September 30, 2014



Source: GAO analysis of Department of Defense data, General Services Administration data, and U.S. Geological Survey mapping; MapInfo (map). | GAO-16-680

Note: Includes leased and owned federal buildings reported to the Federal Real Property Profile (FRPP) as active or inactive. The FRPP database includes federal buildings under the custody and control of United States executive branch agencies as set out in Executive Order 13327 and certain executive branch agencies which voluntarily report. The data does not include those buildings held by the legislative branch agencies, judicial branch agencies, or other non-executive branch agencies such as the United States Postal Service. Modified Mercalli Intensity (MMI) earthquake shaking intensity level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years. Approximately 2.0 percent of the total number of active and inactive buildings (1.8 percent of the square feet of buildings) in the FRPP data were not included in the analysis because they either did not have location information included in the FRPP or the location information in the FRPP had inconsistencies in the data which did not allow the building to be accurately located.

Figure 19: Federal Buildings in Seattle Area by Earthquake Shaking Intensity Zones, as of September 30, 2014



Source: GAO analysis of Department of Defense data, General Services Administration data, and U.S. Geological Survey mapping; MapInfo (map). | GAO-16-680

Note: Includes leased and owned federal buildings reported to the Federal Real Property Profile (FRPP) as active or inactive. The FRPP database includes federal buildings under the custody and control of United States executive branch agencies as set out in Executive Order 13327 and certain executive branch agencies which voluntarily report. The data does not include those buildings held by the legislative branch agencies, judicial branch agencies, or other non-executive branch agencies such as the United States Postal Service. Modified Mercalli Intensity (MMI) earthquake shaking intensity level is based on 2014 United States Geological Survey mapping with a 2 percent probability of exceeding that level in 50 years. Approximately 2.0 percent of the total number of active and inactive buildings (1.8 percent of the square feet of buildings) in the FRPP data were not included in the analysis because they either did not have location information included in the FRPP or the location information in the FRPP had inconsistencies in the data which did not allow the building to be

Appendix VIII: FEMA Publications Which Provide Guidance to Mitigate Earthquake Risks

FEMA has issued several publications to assist building owners in identifying seismic risk and developing mitigation plans. For example, FEMA E-74, Reducing the Risks of Nonstructural Earthquake Damage, may be useful as a reference for scoping and prioritizing the protection of nonstructural components and contents and it also provides information on the relative risks posed by nonstructural elements, as well as appropriate mitigation techniques.

In addition, FEMA's Incremental Seismic Rehabilitation series, including FEMA 397 Incremental Seismic Rehabilitation of Office Buildings, provides office building owners who have budgetary constraints and cannot afford expensive and disruptive seismic rehabilitation projects, an affordable strategy for responsible mitigation action which can be integrated efficiently into ongoing facility maintenance and capital improvement operations. The manual was developed based on the management practices of office building owners of varying sizes located in various seismic zones in different parts of the United States. It includes guidance for building owners to address building contents mitigation and earthquake drills as part of a comprehensive seismic safety program.

Finally, FEMA has also developed additional publications on how structural and nonstructural earthquake risks can be mitigated for many building use types. In particular they have issued FEMA P-811 QuakeSmart: Earthquake Publications for Businesses. While the guidance is directed towards the private sector, it includes actionable and scalable basic guidance and tools regarding the importance of earthquake mitigation and simple things that can be done to reduce the potential of earthquake damages, injuries, and financial losses. See table 11 for a list of publications produced by FEMA which provide guidance to mitigate earthquake risks for many building use types.

Table 11: Federal Emergency Management Agency (FEMA) Publications on Earthquake Risk Mitigation

Document Title	FEMA Publication Number
Are You Ready? An In-depth Guide to Citizen Preparedness	IS-22
Catalog of FEMA Earthquake Resources	FEMA P-736B
Creating a Seismic Safety Advisory Board: A Guide to Earthquake Risk Management	FEMA 266
Design Guide for Improving Hospital Safety in Earthquakes, Floods and High Winds: Providing Protection to People and Buildings	FEMA 577
Design Guide for Improving School Safety in Earthquakes, Floods and High Winds	FEMA 424
Drop, Cover and Hold Poster	FEMA 529
Earthquake Publications for Community Planners and Public Policy Makers	FEMA P-712CD
Earthquake Resistant Construction of Electric Transmission and Telecommunication Facilities Serving the Federal Government	FEMA 202
Earthquake Resistant Construction of Gas and Liquid Fuel Pipeline Systems Serving or Regulated by the Federal Government	FEMA 233
Earthquake Safety Checklist	FEMA 526
Engineering Guideline for Incremental Seismic Rehabilitation	FEMA P-420
Expanding and Using Knowledge to Reduce Earthquake Losses: The National Earthquake Hazards Reduction Program Strategic Plan 2001-2005	FEMA 383
Financial Incentives for Seismic Rehabilitation of Hazardous Buildings – An Agenda for Action. Volume 1: Findings, Conclusions and Recommendations	FEMA 198
Financial Incentives for Seismic Rehabilitation of Hazardous Buildings – An Agenda for Action. Volume 2: State and Local Case Studies and Recommendations	FEMA 199
Global Topics Report on the Prestandard and Commentary for the Seismic Rehabilitation of Buildings	FEMA 357
HAZUS-MH Estimated Annualized Earthquake Losses for the United States	FEMA 366
Home and Business Earthquake Safety and Mitigation	FEMA P-909 CD
Incremental Seismic Rehabilitation of Hospital Buildings	FEMA 396
Incremental Seismic Rehabilitation of Hotel/Motel Buildings	FEMA 400
Incremental Seismic Rehabilitation of Multifamily Apartment Buildings	FEMA 398
Incremental Seismic Rehabilitation of Office Buildings	FEMA 397
Incremental Seismic Rehabilitation of Retail Buildings	FEMA 399
Incremental Seismic Rehabilitation of School Buildings, K-12	FEMA 395
Installing Seismic Restraints for Duct and Pipe	FEMA 414
Installing Seismic Restraints for Electrical Equipment	FEMA 413
Installing Seismic Restraints for Mechanical Equipment	FEMA 412
Multi-Hazard Mitigation and Design Concepts: Wind, Flood and Earthquake Training Videos	FEMA P-940 CD
NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings	FEMA 172
Next-Generation Performance-Based Seismic Design Guidelines: Program Plan for New and Existing Buildings	FEMA 445
Planning for Seismic Rehabilitation: Societal Issues	FEMA 275

Prestandard and Commentary for the Seismic Rehabilitation of Buildings	FEMA 356
Promoting Seismic Safety: Guidance for Advocates	FEMA 474
QuakeSmart Toolkit	FEMA P-811
Rapid Observations of Vulnerability and Estimation of Risk Version 2	FEMA P-154 ROVER 2 CD
Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook. Second Edition	FEMA 154
Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation. Second Edition	FEMA 155
Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings	FEMA 351
Recommended Specifications and Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications	FEMA 353
Reducing the Risks of Nonstructural Earthquake Damage—A Practical Guide, Fourth Edition	FEMA E-74
Seismic Considerations for Communities at Risk	FEMA 83
Seismic Considerations for Steel Storage Racks Located in Areas Accessible to the Public	FEMA 460
Seismic Evaluation and Retrofit of Multi-Unit Wood-Frame Buildings With Weak First Stories	FEMA P-807
Seismic Performance Assessment of Buildings	FEMA P-58CD
Seismic Rehabilitation of Federal Buildings: A Benefit/Cost Model. Volume 1: A User's Manual	FEMA 255
Seismic Rehabilitation of Federal Buildings: A Benefit/Cost Model. Volume 2: Supporting Documentation	FEMA 256
Seismic Rehabilitation Training for One- and Two-Family Dwellings: Program and Slide Presentations	FEMA P-593
Seismic Retrofit Guidelines for Detached, Single-Family, Wood-Frame Dwellings	FEMA P-50-1
Seismic Retrofit Incentive Programs: A Handbook for Local Governments	FEMA 254
Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous United States	FEMA 224
Simplified Seismic Assessment of Detached, Single-Family, Wood-Frame Dwellings	FEMA P-50
Societal Implications: Selected Readings	FEMA 84
Techniques for the Seismic Rehabilitation of Existing Buildings	FEMA 547
Typical Costs for Seismic Rehabilitation of Existing Buildings. Volume 1: Summary. Second Edition	FEMA 156
Typical Costs for Seismic Rehabilitation of Existing Buildings. Volume 2: Supporting Documentation. Second Edition	FEMA 157
Unreinforced Masonry Buildings and Earthquakes: Developing Successful Risk Reduction Programs	FEMA P-774

Source: Federal Emergency Management Agency. | GAO-16-680

Appendix IX: Comments from the Department of Defense

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
3400 DEFENSE PENTAGON
WASHINGTON, DC 20301-3400

ENERGY,
INSTALLATIONS
AND ENVIRONMENT

AUG 9 2016

Mr. Christopher P. Currie
Director, Homeland Security and Justice
U.S. Government Accountability Office
441 G Street, N.W.
Washington, DC 20548

Dear Mr. Currie:

This is the Department of Defense (DoD) response to the Government Accountability Office (GAO) Draft Report, GAO-16-680, "EARTHQUAKES: Additional Actions Needed to Identify and Mitigate Risks to Federal Buildings and Implement an Early Warning System" dated July 13, 2016 (GAO Code 441267). Detailed comments on the report recommendations are enclosed.

Sincerely,

Michael McAndrew
Deputy Assistant Secretary of Defense
(Facilities Investment and Management)
Performing the Duties of the Assistant Secretary of Defense
(Energy, Installations and Environment)

Enclosure:
As stated

GAO Draft Report Dated July 13, 2016
GAO-16-680 (GAO CODE 441267)

"EARTHQUAKES: ADDITIONAL ACTIONS NEEDED TO IDENTIFY AND MITIGATE RISKS TO FEDERAL BUILDINGS AND IMPLEMENT AN EARLY WARNING SYSTEM"

DEPARTMENT OF DEFENSE COMMENTS TO THE GAO RECOMMENDATION

To strengthen efforts to mitigate earthquake risks to federal buildings, the GAO recommends that the Secretary of Defense and the Administrator of GSA take the following actions:

RECOMMENDATION 1: Define what constitutes an exceptionally high risk building, identify such buildings, and develop plans to mitigate those risks, including prioritizing associated funding requests as needed.

DoD RESPONSE: Concur. DoD is participating in a Federal government effort to develop a common Federal definition for exceptionally high-risk (EHR) buildings, led by the National Institutes of Standards and Technology (NIST) as a function of the Interagency Committee on Seismic Safety in Construction (ICSSC). Once the Federal government adopts a standard definition for EHR, assessment of the DoD inventory can proceed. However, because the Department is already taking risk in a variety of facility-related areas, identifying and mitigating EHRs will compete for funding with all other Military Department priorities. The Department will determine a timeline after the interagency process defines EHR.

RECOMMENDATION 2: To the extent practicable, prioritize and implement comprehensive seismic safety measures which could include earthquake drills, seismic safety inspections, and non-structural retrofits to decrease risks and reduce damage in federally-owned and –leased buildings in earthquake hazard areas.

DoD RESPONSE: Concur. DoD policy expressed in DoD Instruction 6055.17 establishes an Installation Emergency Management program to prepare for all types of hazards, including earthquakes. The program scope includes measures such as earthquake training exercises, preparedness evaluations, and community awareness. DoD has implemented these measures on a limited basis. More comprehensive implementation would need to compete with other Military Department priorities during the program/budget development process.

Appendix X: Comments from the General Services Administration

GSA

The Administrator

August 11, 2016

The Honorable Gene L. Dodaro
Comptroller General of the United States
U.S. Government Accountability Office
Washington, DC 20548

Dear Mr. Dodaro:

The U.S. General Services Administration (GSA) appreciates the opportunity to review and comment on the U.S. Government Accountability Office (GAO) draft report entitled, *Earthquakes: Additional Actions Needed to Identify and Mitigate Risks to Federal Buildings and Implement an Early Warning System;* (GAO-16-680). As a result of its findings, GAO plans to make two recommendations to GSA:

> To strengthen efforts to mitigate earthquake risks to federal buildings, we recommend that the Secretary of Defense and the Administrator of GSA take the following actions:
>
> 1. Define what constitutes an exceptionally high-risk building, identify such buildings, and develop plans to mitigate those risks, including prioritizing associated funding requests as needed.
> 2. To the extent practicable, prioritize and implement comprehensive seismic safety measures which could include earthquake drills, seismic safety inspections, and non-structural retrofits to decrease risks and reduce damage in Federally-owned and -leased buildings in earthquake hazard areas.

GSA agrees with the overall nature of GAO's proposed findings, but has concerns with several areas mentioned. Based on the enclosed comments, GSA requests that further actions be considered to reflect the accomplishments and steps taken by GSA regarding this matter. If you have any additional questions or concerns, please contact me at (202) 501-0800 or Ms. Lisa A. Austin, Associate Administrator, Office of Congressional and Intergovernmental Affairs, at (202) 501-0563.

Sincerely,

Denise T. Roth

Denise Turner Roth
Administrator

cc: Mr. Chris Currie, Director, Homeland Security and Justice, GAO
Mr. David Wise, Director, Physical Infrastructure Issues, GAO

1800 F Street, NW
Washington, DC 20405-0002

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U.S. General Services Administration
Technical Comments
GAO Draft Report Entitled, *Earthquakes: Additional Actions Needed to Identify and Mitigate Risks to Federal Buildings and Implement an Early Warning System*
(GAO-16-680)

Draft Revision (Comments Partially Addressed)

GAO Language: (Page 1, Line 6): DOD and GSA identified their EHR buildings as part of a government-wide effort in the 1990's, and GSA has begun taking initial steps to identify its current EHR buildings.

See comment 1.

GSA Comments: GSA believes it is important to highlight the progress GSA has made to identify its EHR buildings and prioritize building seismic risk. Within the Seismic Rating Report (SRR), dated March 31, 2016, GSA developed a methodology for defining EHRs, tested the methodology and developed a partial list of prioritized EHRs.

GAO Language: (Page 1, Line 33): "What GAO Recommends" - GAO recommends that DOD and GSA (1) fully identify their exceptionally high-risk buildings; (2) prioritize and implement comprehensive seismic safety measures to mitigate earthquake risks; and (3) that USGS develop a program management plan to address, among other things, ShakeAlert implementation challenges.

See comment 2.

GSA Comments: Page 48-49 "Recommendations for Executive Action" should be updated to reflect the changes from Page 1 "What GAO Recommends."

GAO Language: (Page 3, Line 5): Table 4: GSA adopted a definition of EHR based on its engineering consultant's Seismic Rating Report, completed on March 31, 2016. Based on this report, GSA has begun training staff in the process used to calculate a seismic risk rating, which is used to determine if a building is EHR. Of GSA's federally-owned inventory, its consultant's calculation report identified eight EHR buildings among the 63 buildings for which a seismic risk rating is necessary. GSA is in the process of hiring a contractor to evaluate and develop seismic risk ratings for additional Federally-owned buildings located in high-seismic areas to determine which of these are EHR. GSA plans to complete this work by July 2017.

See comment 3.

GSA Comments: GSA has calculated a seismic risk rating for 71 buildings, not 63.

GAO Language: (Page 6, Line 13): Until they fully identify their exceptionally high-risk buildings, DOD and GSA will be unable to understand fully the most significant

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See comment 4.

earthquake risks affecting buildings for which they are responsible and develop a plan to reduce those risks—in accordance with RP 8—which could inform prioritizing funding requests for mitigations such as retrofits.

GSA Comments: GSA disagrees and believes this statement does not acknowledge the work GSA has completed to date. Through the development of its Seismic Risk Rating system, GSA has developed an understanding of the most significant earthquake risks affecting buildings in its real property inventory.

Original Draft Audit Report
(Comments not addressed after July 26, 2016, Draft Report Meeting)

GAO Language: (Page 18, Line 3): Seismic Loss Estimation: To aid seismic hazard mitigation planning, loss estimating tools such as FEMA's HAZUS program can be used to determine areas of vulnerability and to help prioritize mitigations that address these vulnerabilities. HAZUS estimates losses from potential hazards, including earthquakes, and quantifies these losses regarding potential fatalities, injuries, direct property loss and damage, and indirect economic loss for a certain event scenario or over time (annualized loss).

See comment 5.

GSA Comments: As stated in the July 26, meeting, GSA is using FEMA's HAZUS methodology to identify and prioritize buildings.

GAO Language: (Page 18, Line 25): Building Inventory: Having an inventory of buildings that includes information such as their location, type of occupancy and building construction, age, and mitigation needs is crucial for determining their exposure to seismic risks and prioritizing mitigations.

See comment 6.

GSA Comments: The GSA's SRR Report (dated March 31, 2016) includes all t of this information (location, type of occupancy and building construction, age, and structural deficiencies) except for information regarding non-structural deficiencies (e.g. furniture bracing).

GAO Language: (Page 32, Line 14): Non-structural Retrofits. Further, RP 8 references FEMA guidance that can be used to obtain information on the relative risks and appropriate mitigation techniques posed by nonstructural building components.

See comment 7.

GSA Comments: The referenced FEMA guidance is a citation included in the commentary of RP 8. American Society Civil Engineers (ASCE) codes are the mandated requirements in RP 8.

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The following are GAO's comments to the General Service Administration's letter dated August 11, 2016.[1]

GAO comments

1. We understand that GSA has made initial progress identifying its EHR buildings and modified the text of the report to describe actions GSA has taken.
2. We recognize that GSA has begun taking steps to identify its EHR buildings which will help meet the intent of our first recommendation. However, we believe that GSA needs to take additional actions to fully meet the intent of this recommendation. More specifically, GSA will need to continue identifying its EHR buildings and then develop plans to mitigate the risks that are identified. In addition, with respect to our second recommendation, we believe that GSA should prioritize and implement comprehensive seismic safety measures to decrease risks and reduce damage from future earthquakes to its buildings in earthquake hazard areas.
3. We understand that GSA's Seismic Rating report of March 31, 2016, included an assessment of 71 buildings. However, because 8 of the 71 assessed buildings were designated as "Not Rated," we concluded and stated in the report that 63 of the 71 buildings received a seismic risk rating.
4. As discussed in comments 1 and 2 above, we recognize GSA has made initial progress identifying its EHR buildings. However, GSA does not anticipate completing its Seismic Rating Report database, which it will use to determine which buildings are EHR, until January 2017. Until GSA identifies all its EHR buildings, the agency will be unable to fully understand and address the most significant earthquake risks affecting buildings for which it is responsible.
5. We understand that GSA is using FEMA's HAZUS methodology to identify and prioritize EHR buildings and modified the text of the report (e.g., see Table 4) to describe GSA's actions.
6. We understand that GSA's Seismic Rating report of March 31, 2016, contains information on GSA's building inventory and modified the text

[1]GSA's comments do not correspond to the page numbers of the final report; however, GAO comments provide the location of text changes made in response to GSA's comments.

of the report (e.g., see Table 4) to include information about the Seismic Rating report.

7. We do not dispute GSA's comment. Our reference to FEMA guidance in the report is to illustrate low-cost opportunities that agencies can use, as applicable, as part of comprehensive seismic safety programs to reduce potential damages, injuries, and casualties from future earthquakes.

Appendix XI: GAO Contacts and Staff Acknowledgments

GAO Contacts

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David J. Wise, (202) 512-5731 or wised@gao.gov

Staff Acknowledgments

In addition to the contacts named above, Mike Armes (Assistant Director), R. Denton Herring (Analyst-in-Charge), Jeffrey Fiore, Edward George, Les Locke, Gary M. Malavenda, Kristiana Moore, Samuel Woo, Aaron Safer-Lichtenstein, Eric Hauswirth, Tracey King, Dominick M. Dale, Michele Fejfar, Melinda Cordero, Amber H. Sinclair, John Mingus, Katrina E. Pekar-Carpenter, and Grant Mallie made key contributions to this report.

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