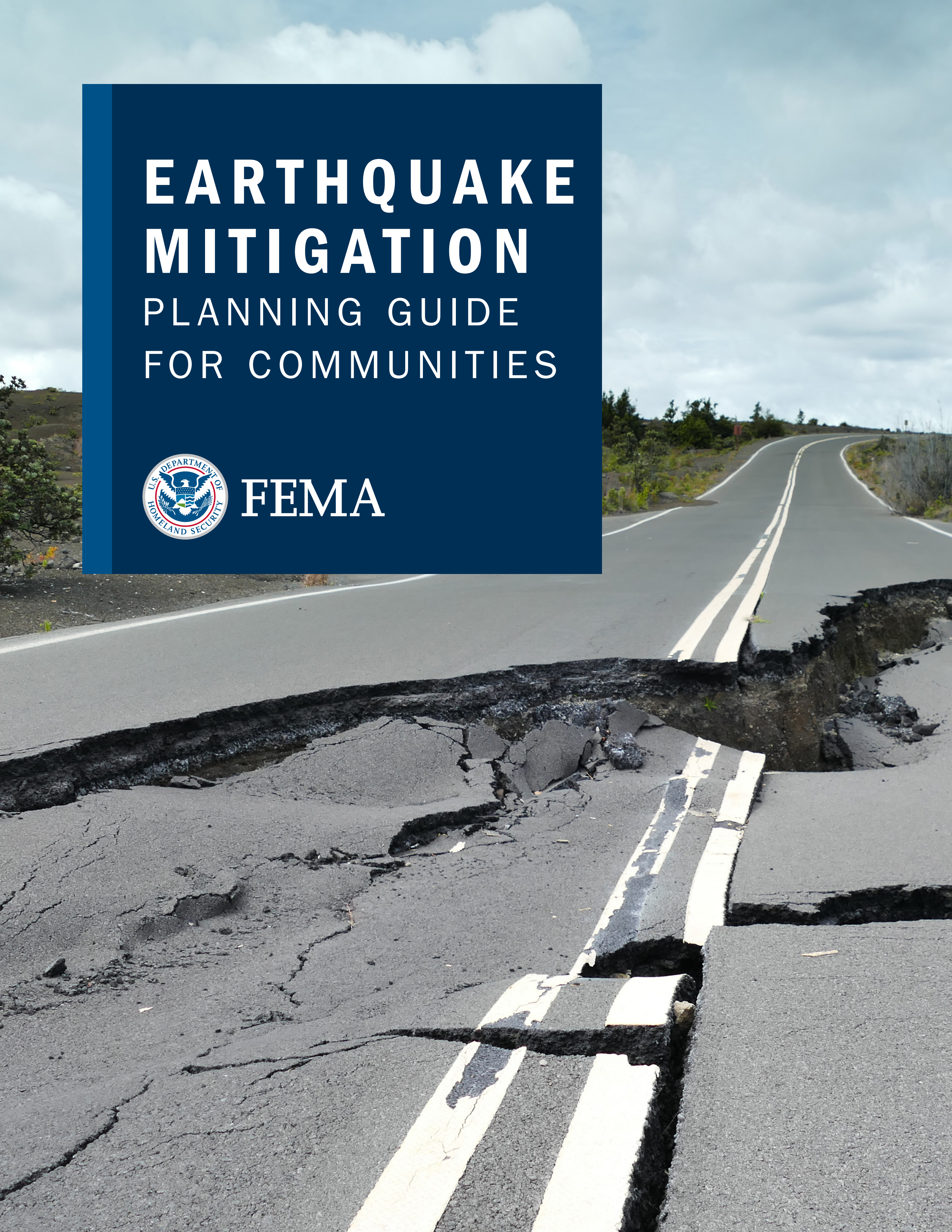

EARTHQUAKE MITIGATION

PLANNING GUIDE FOR COMMUNITIES

U.S. DEPARTMENT OF HOMELAND SECURITY

FEMA

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1.
INTRODUCTION

It is becoming more important to protect our communities from natural hazards in the United States. We want our populations, homes, businesses, and natural and cultural resources to withstand natural hazards. Planning for the impacts of natural hazards can help to reduce the loss of life and property. **Earthquakes** are one of the only natural hazards that can strike with no warning. As such, it is highly important to plan for them.

Earthquakes, also referred to as seismic activity, can happen at any time. Decades can pass between damaging earthquakes. People often forget about the risk of earthquakes as they go about their daily lives. We cannot predict when, where, or how severe an earthquake event will be. However, we know with absolute certainty that they will occur.

Think about where you live, work, worship, socialize, visit for entertainment, learn, or send your children to school. The places your community gathers, conducts business, or provides support are important to protect. The capacity and capability of each community to reduce risk to these people and places varies.

Reducing earthquake risk is very different from mitigating the risk of other natural hazards. Some hazards, such as severe storms and droughts, occur seasonally. These hazards often have warnings and take place at semi-predictable times of the year. This information can help us prepare. This is not the case for earthquakes.

KEY TERMS

Note – any term that is bolded throughout this guide is defined in the Glossary in Appendix A.

Hazard mitigation is any sustained action taken to reduce or eliminate long-term risk to life and property from hazards.

Natural hazards are environmental events that have the potential to impact societies and the human environment.

Risk is the potential for damage or loss created by the interaction of natural hazards to life or property. This includes assets like **buildings**, lifelines, infrastructure, or natural and cultural resources.

The International Code Council defines **"seismic functional recovery"** as "… buildings [that] are not only designed and constructed for life safety, but also to support the basic intended functions of the building's pre-earthquake use and occupancy within a maximum acceptable time." Both the building itself and the services, experts, technicians, and resources within that building are important to the recovery and resilience of your community.

Damaging earthquakes are rare, inconsistent, and incredibly costly. For that reason, earthquake projects may not be top of mind or as politically popular as other hazards. It is vital to keep in mind that over time, investments in mitigation have been proven to save large sums of money by reducing potential future damage. On average, earthquake hazard mitigation saves $3 for every $1 spent on federal mitigation grants.[1] This information comes from an analysis by the National Institute of Building Sciences. This analysis notes similar cost saving statistics for other hazards.

It is crucial to know that earthquake mitigation can occur even with limited funds. When looking for funding, the key is to be strategic. Many funding opportunities do not use the word "earthquake", though funding does exist.

There are many tools and resources that can help you and your community prepare for earthquakes. This FEMA guide looks at ways for communities to understand and take steps to reduce that risk. It focuses on using a local, tribal, state, or territorial **Hazard Mitigation Plan** (HMP) as the main tool to help people understand, prepare for and mitigate earthquake risk.

1.1. PURPOSE OF THIS GUIDE

This document offers guidance for plan developers, mitigation planners, emergency managers, and other partners to help communities understand, assess, and manage their earthquake risk through creating and updating an HMP.

An HMP serves many purposes. It helps state, local, tribal, and territorial governments (SLTTs) understand their local hazards and their risk from those hazards. It also recommends and provides access to funding resources that can help you build resilience. Each community has its own risks and mitigation needs. By knowing your community, you can focus on actions to reduce risk in places where it is highest.

The guidance and resources here can help you:

- Learn what hazard mitigation planning is and how it can help your community.
- Learn the types of earthquakes and earthquake hazards, and the buildings, areas, or people in your community with the most risk.
- Learn how to assess and document those hazards and impacts.
- Develop a strategy with actions to manage risk, based on your assessment.
- Find and use the available hazard mitigation funding and assistance.

GUIDE LAYOUT

This guide uses callout boxes to help provide useful information, case studies, and connections to the mitigation planning process. Throughout it, you'll find the following:

- "Connection to the HMP" call out boxes connect information on earthquake risk to the mitigation planning process and the requirements of updating or creating an approvable HMP. It does not list every HMP requirement. To learn more about all of the HMP requirements and how to meet them, see FEMA's Create a Hazard Mitigation Plan page.
- "Additional Information" call out boxes are marked with an "information" icon. These will provide additional resources, information, or relevant examples.
- "Case Study" call out boxes share success stories of how communities throughout the country are mitigating their earthquake risk.

This guide is written in plain language to adhere to the Plain Writing Act of 2010. This is done to simplify the document and make its content clear.

[1] NIBS, Natural Hazards Mitigation Saves: 2019 Report, 2019

2.

PLANNING FOR EARTHQUAKE MITIGATION

For SLTTs, an HMP is the basis of a long-term strategy to reduce disaster loss. It can help users break the cycle of repeated disaster damages. As stated in 44 CFR § 201.1(b), "The purpose of mitigation planning is for state, local and Indian tribal governments to identify the natural hazards that impact them, to identify actions and activities to reduce any losses from those hazards, and to establish a coordinated process to implement the plan, taking advantage of a wide range of resources." It is also a key tool for opening the doors to a wide range of funding sources that help to build resilience.

CONNECTION TO THE HMP

SLTTs, which include special districts (such as Water or School Districts), can develop HMPs. There are specific requirements for state, local, and tribal plans, but the framework and benefits are the same. We use "community" to mean any of these entities.

2.1. WHY HAVE AN HMP?

HMPs help communities focus on investments that manage risk. HMPs list hazards, assess vulnerabilities and risks, and note capabilities that can be used to address the hazards. HMPs use this information to create hazard mitigation strategies that meet the needs of each community. The process helps the **whole community** know the risks of local natural hazards. The HMP process also shows how community priorities were set and how mitigation may help to reduce their risk.

- *When we say "whole community," we mean any groups who work with each other to prepare for and mitigate the risk from natural hazards or other emergencies. This can include individuals, families, businesses, tribal partners, schools, academia, neighboring jurisdictions, and faith-based, community, and nonprofit groups. Plan with a whole community mindset. This puts you in a better position to find effective, inclusive ways to assess and mitigate risk. It will make sure that people from diverse backgrounds can take part in the conversation and help to make decisions. It will result in more holistic plans that help to reduce risk to your people, economy, and built and natural environments. For example, one way to plan for the whole community is to offer educational materials in Spanish for a community that may have a large Spanish-speaking population.*

To be eligible for certain types of non-emergency disaster assistance and funding for mitigation projects, FEMA requires SLTTs to develop and have an approved mitigation plan. This includes plan adoption. To stay eligible, HMPs must be updated and resubmitted to FEMA for approval every five years. To learn more, see Section 6 of this guide and visit the Mitigation Planning and Grants page on FEMA.gov.

Beyond grant eligibility, mitigation planning has many benefits:

- It helps people learn about their vulnerabilities. It identifies and supports specific actions that can help to reduce losses to life and property from future natural disasters.
- It can help build partnerships with diverse stakeholders. This offers chances to use new data and resources. It can also reduce workloads by helping partners reach shared objectives.
- It helps HMP users learn ways to reduce risk. These may include structural and regulatory tools like ordinances and building codes.
- It guides users to think of, prioritize and complete mitigation projects. This has benefits over the life of the project.
- It can help communities reduce or avoid future losses to homes, businesses, and lifelines infrastructure. By avoiding these future losses, communities can increase their resilience and bounce back faster after a disaster.
- The information can be worked into other planning efforts. This includes comprehensive plans, transportation plans, climate action plans, evacuation plans, and emergency management plans.

Keep in mind that an HMP belongs to its community. To have worth, the plan must reflect the community's current risk, needs, and values. FEMA approves plans but does not need those plans to be organized in a specific format. Write your HMP in a way that best serves your own priorities and resilience goals. The planning process should bring together diverse community-based partners. It should also fit the unique needs of each community and align with existing efforts such as land use, economic development, and transportation plans.

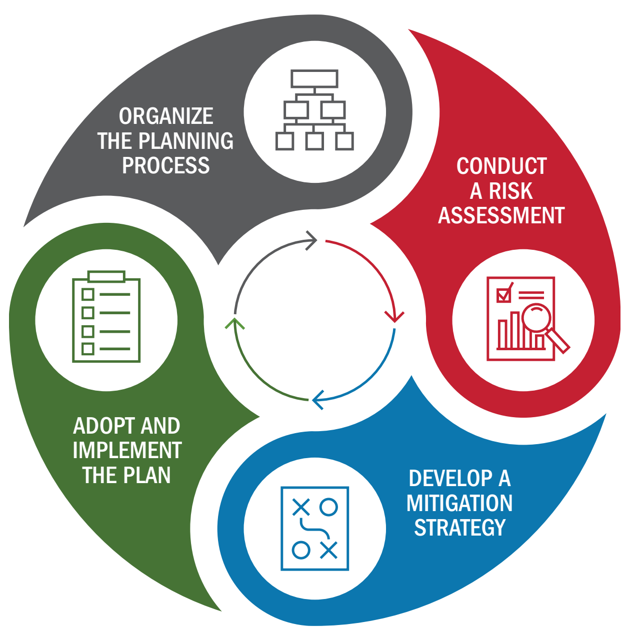
2.2. WHAT GOES IN THE HMP?

The mitigation planning process is slightly different for each government, but making or updating any plan will include four core steps, as seen in the visual below. This section will briefly describe each step in more detail. If you're interested in more information about each step, you can review FEMA's Local and Tribal Planning Handbooks.

2.2.1. ORGANIZE THE PLANNING PROCESS AND RESOURCES

At the start of the planning process, the SLTT gathers the resources it needs. They secure technical expertise, define the planning area, and find key individuals, agencies, businesses, neighboring jurisdictions, and/or others to join in. Local and tribal governments must offer the public opportunities to review and comment on the draft plan. As stated above, consider and engage with the whole community. The public can include individuals, families, businesses, faith-based and community organizations, tribal partners, nonprofit groups, schools and academia, and local and state governments.

Figure 1. The Hazard Mitigation Planning Process



- *Effective communication plays a key role in managing risks and mitigating impacts. In reducing risk, the goal is to raise awareness and give accurate and timely information to people who are at risk. Engage people throughout the life cycle of your project or planning. If you do this regularly, you will create an environment of trust and transparency. Engagement can also rally the community. It gets people to care and do something about the risk. Engage the community early and often. Work with them to find a solution. People tend to support activities to reduce risk when they are a part of the process.*

  Risk communication focuses on two things: what threatens people's security, and what a community holds dear. You have to get their attention. Still, messages should aim to inspire hope — not fear. Each step should help people progress (and feel) closer to safety and resilience. It is hard work to get communities to act. We must prove that a risk is real. We also must get the audience to believe and invest in solutions to reduce their risk. It may help to link these risks to everyday issues. Show how they threaten infrastructure, economics, business, and property values. Choose an approach that relates to the audience you want to reach.

  Communication can take many forms. Your target audience may prefer to attend an in-person town hall. Others may prefer digital contact, like email or surveys. Each approach has benefits and limits. One way to target public engagement is to make a communication plan. It will outline your objectives, audiences, key messages, and activities. The plan can help you reach your audience and achieve your goals. It also helps direct all communication to take place in a clear, consistent, and measurable way. To learn more about creating an effective communication plan, see the Communication Plan Guide from FEMA's Flood Risk Communication Toolkit for Community Officials.

2.2.2. CONDUCT A RISK ASSESSMENT

The next step is to complete a risk assessment. This includes identifying potential hazards and the features and potential consequences of those hazards. It is vital to know which areas of your community each hazard might affect. Think about what people, properties, or other assets might be at risk. Section 3 of this guide describes the hazards associated with earthquakes. Section 4 describes other key considerations for assessing earthquake risk.

A risk assessment generally has five steps:

1. IDENTIFY THE HAZARD: When you develop an HMP, you need to note which hazards occur in your planning area. Since this is an earthquake guide, the focus is just on the earthquake hazard.
2. DESCRIBE THE HAZARD: Look at where the hazard can happen, how much of an impact it might have, and when it occurred in the past. You should also address how often and with what intensity the hazard might occur in the future.
3. IDENTIFY AND INVENTORY COMMUNITY ASSETS: Find the assets that are most vulnerable to loss during a disaster. This can include the people living and working in your community, the built or human-made environment, and natural assets.
4. ANALYZE IMPACTS: Describe and quantify how the hazard could affect the assets of your community. You can describe impacts in many ways. They can be physical (damage), monetary (estimated building or economic losses), or social (disrupted community life). Impacts must include the effects of future conditions. This includes changes in population, land use, development, and climate change. Keep in mind that impacts can be affected by the community's ability to mitigate, prepare for, respond to, and recover from an event. For example, a common impact of earthquakes is furniture toppling over due to shaking. However, if large furniture has been anchored in place, this reduces the impact of the shaking.
5. SUMMARIZE **VULNERABILITY**: The other steps in the risk assessment create a great deal of information on hazards, vulnerable assets, and potential impacts and losses. By summarizing this information, you help the community understand its greatest risks and vulnerabilities. This summary of vulnerabilities will help you draw conclusions and make recommendations. These will help you create a mitigation strategy that will build the resilience of your residents, businesses, economy, and other vital assets.

2.2.3. DEVELOP A MITIGATION STRATEGY

Next, set priorities and develop long-term mitigation strategies. To start, assess each community's regulatory, administrative, and financial capabilities. Then, note any possible gaps. Consider these capabilities when you develop your strategy. This will help you make sure it is realistic and can be carried out. Capabilities should directly influence the mitigation strategy. The chosen actions should either match the capability assessed or support building capacity where resources may not exist. For example, if your city only has one engineer on staff, they likely will not be able to complete a city-wide building assessment. Instead, it may be better to apply for a grant that can help you hire a consultant to complete the work.

Once you've assessed your capabilities, create a series of mitigation actions that address each of the hazards you identified. List ways each mitigation action could best be carried out. Section 6 of this guide describes a range of mitigation options that can help to reduce risk from earthquakes. Note that for a project to be eligible for Hazard Mitigation Program funding through FEMA, the project must be consistent with the SLTT's HMP.

The mitigation strategy is your plan to address the earthquake risks and vulnerabilities listed in the risk assessment. The strategy will:

- Note cost-effective ways to reduce risk.
- Be informed by the entire planning process, including all past analyses.
- Focus resources on the greatest risks.
- Share local priorities with state and federal officials.
- Help position the community to use any resources and funding that are available.

CONNECTION TO THE HMP: PLANNING FOR EQUITABLE OUTCOMES

(Section 1.3 of FEMA's Local Mitigation Planning Policy Guide)

It is the duty of states and local jurisdictions to make sure that the HMP's mitigation strategy complies with legal requirements for civil rights. This is one way to prevent discrimination. Complying with these laws can help all communities gain more equitable outcomes. They ensure HMPs include underserved communities and socially vulnerable populations.[2]

FEMA defines equity as the consistent and systematic fair, just, and impartial treatment of all individuals. A local mitigation plan must center on equity to benefit the whole community. Inclusive planning takes time. It gives people the resources they need to meaningfully participate, make progress, and benefit. Equity is not just an important idea. It is key to reducing risk to the whole community.[3] It is notably important for those who face barriers to getting aid. This includes populations that are more affected by disasters than others.

There are three ways to think about equity in the planning process:

- PROCEDURAL EQUITY refers to equitable practices in the planning process. This means creating clear, fair, and inclusive processes. It also means giving everyone a chance to share meaningful input. Work with partners that represent underserved and historically marginalized groups to design outreach methods that will reach all members of the community. Seek input from and work with these groups throughout the whole planning process.
- STRUCTURAL EQUITY builds on the need for accountability and supports working to correct past harms. You can address this need by talking about equity early and often. Recognize and address societal systems that cause inequity. Form organizational infrastructure to address inequity. If inequities are raised during the planning process, be sure that there are ways to address them. An example of a structural inequity is when low property values affect the quality of a neighborhood's roads. One way to solve this problem could be setting up a separate fund for road maintenance based on needs rather than solely relying on property tax revenue.
- DISTRIBUTIONAL EQUITY deals with the fair sharing of benefits and burdens from programs across a community. It is crucial to think about distributional equity during the mitigation strategy. Be sure that one community is not being unfairly harmed while another receives the benefits of a mitigation action.

2.2.4. ADOPT AND IMPLEMENT THE PLAN

Once a community adopts its HMP, FEMA can approve it. Then, the SLTT can bring the plan to life. An active HMP will allow communities to carry out the mitigation actions identified in the mitigation strategy. For the plan to stay a relevant, living document, the community needs to assess its changing risks and priorities and revise the plan as needed. An HMP should receive updates each year and after a major hazard event. It must be resubmitted to FEMA at least once every five years.

[2] FEMA, Mitigation Planning Policy Updates, 2022
[3] FEMA, National Preparedness Goal, Second Edition, 2015

CONNECTION TO THE HMP: PLANNING FOR EQUITABLE OUTCOMES

(Section 1.3 of FEMA's Local Mitigation Planning Policy Guide)

The mitigation plan is a community-driven, living document. The planning process itself is as important as the resulting plan because it encourages communities to integrate mitigation with day-to-day decision-making. Putting the plan into action will be an ongoing process that may include initiating and completing mitigation projects (and documenting those successes and challenges) and integrating mitigation strategies into other community plans and programs. Monitoring the plan's implementation and updating on a yearly basis helps to ensure it remains relevant as community priorities and development patterns change – and also makes the required five year update an easier feat.

2.3. MITIGATION PLANNING POLICIES AND RESOURCES

As noted above, an HMP has no required format or template. However, each HMP must meet certain requirements to be approved. FEMA's official Local, State, and Tribal Mitigation Planning Policies explain these needs. They are based on the Code of Federal Regulations as defined in 44 CFR §201 Mitigation Planning. Territories follow the State Policy. These policies guide the review and approval of each HMP.

FEMA also has resources and training to help communities learn and apply the regulations. These include the Tribal and Local Mitigation Planning Handbooks. These handbooks explain the planning requirements. They also give examples of how to meet those rules. The National Hazard Mitigation Planning Program partners with the Emergency Management Institute (EMI) to offer a range of trainings that help SLTTs create effective HMPs that meet FEMA's requirements and reduce risk in their communities. Each of these audiences has its own requirements; as such, each training is tailored to meet their needs.

In addition, the program offers several advanced trainings and technical assistance related to key areas in hazard mitigation planning. These range from webinar recordings to on-demand workshops. Key trainings are highlighted below. To learn more about training, visit the Mitigation Planning Training webpage.

TABLE 1. KEY MITIGATION PLANNING TRAININGS

Training	Format	Summary
L-329: State Mitigation Planning (2020)	Two-day classroom delivery.	Learn about the requirements and the ways to advance mitigation at the state level.
IS-350: Tribal Hazard Mitigation Planning (2021)	Ten online modules. Hosted by EMI.	Offer tribal officials and partners an overview of the benefits of the planning process.
L/K-318: Local Hazard Mitigation Planning (2021)	Two-day training that can be delivered in person (L) or virtually (K). Hosted by EMI.	Give the basics of mitigation planning for communities. Covers the basic elements of the plan review, approval, and update cycle. Includes mitigation funding sources.

If you are interested in one of these trainings, contact your FEMA Region's Mitigation Planner or Tribal Liaison.

Keep in mind that you can also reach out to your State Hazard Mitigation Officer.

3.

UNDERSTANDING EARTHQUAKE HAZARDS

Earthquakes are a sudden release of energy that creates a movement below the Earth's surface. There are many types of earthquake hazards. This guide focuses on natural earthquakes caused by the motion of Earth's tectonic plates. It does not include **induced earthquakes**, which are events caused by humans, as classified by the United States Geological Survey (USGS).

Earthquakes can lead to a range of different hazards. However, not all of these hazards will occur in every area. This section will help you understand earthquake hazards. It will help you identify which will occur in your community and how to describe them in your HMP.

3.1. TYPES OF EARTHQUAKE HAZARDS

3.1.1. EARTHQUAKES AND FAULTS

The shallowest layer, or crust, of the Earth is made up of large rock masses called tectonic plates. The interior of the Earth is made of rock that is so hot it can flow. As the hot interior circulates beneath the Earth's surface, it drags the harder plates at the surface as well. Plates moving past each other can get stuck for long periods of time. Eventually, they shift along boundaries called **faults**, which are the fractures that allow the plates to grind past each other. Earthquakes that occur at plate boundaries are called **interplate earthquakes**. Earthquakes can also occur on faults located within the tectonic plates. These are called **intraplate earthquakes**. Intraplate earthquakes tend to be smaller than interplate earthquakes.

CONNECTION TO THE HMP: DESCRIBING HAZARDS

(Element B of FEMA's Local Mitigation Planning Policy Guide)

The risk assessment in the HMP identifies and describes local hazards. It states where, when, and how often these hazards may happen. For earthquakes, this section identifies the different types of earthquakes and related hazards. It lays out how severe an earthquake event could be. It talks about when and where earthquakes have happened in the past. It also discusses the probability of when and where they might happen again.

The plates on the Earth are always moving beneath us, but very slowly. Most plates move at about the speed that our fingernails grow. Most of the time, we are not aware of this movement and do not feel anything. Because rocks are not perfectly smooth, faults can get stuck and build up stress over time. It can take tens, hundreds, or thousands of years before enough force is applied to cause the sides of a fault to suddenly move past each other. When this happens, the fault can shift by centimeters or even up to tens of meters. If enough movement happens quickly enough, we feel it as an earthquake.

Usually, earthquakes start deep within the Earth's crust. The location within the Earth's crust where an earthquake starts is called the **hypocenter**. The location on the Earth's surface directly above the hypocenter is called the **epicenter**.

The USGS studies earth processes like earthquakes. It calculates the size of an earthquake by analyzing the amount of energy the earthquake has generated. There are many ways to describe the size of an earthquake, but most people know of "**magnitude**" or "**amplitude**." Magnitude is expressed as a number up to 10. It is calculated using the strength of the rock (**rigidity**), the area of the fault that slipped (**area**), and the distance the fault moved (**slip**). A magnitude (M) 5.3 earthquake, for example, would happen on a smaller fault (i.e., smaller area) and have less slip than an M6.3. To measure an earthquake, scientists can record the amount of energy it releases. They do this on machines called seismometers. Earthquakes release energy in waves of different sizes (amplitudes), which are measured all over the world.

Earthquakes can happen at any time and with no notice. They produce seismic waves that can affect large areas. Also, faults are not always visible at the surface. The lack of obvious, visible signs means that we don't always know where an earthquake will happen. This can make it hard to prepare for and mitigate earthquake risk. The USGS offers many free products (reports, maps, videos, and alerts) to help people learn about the impacts of earthquakes and how and where they may occur. State and local agencies (geologic surveys, transportation agencies, or building and planning departments) often make detailed maps, reports, and other resources for their local communities. Many of these agencies have websites where you can download these resources for free.

THE ROLE OF EARTHQUAKE EARLY WARNING SYSTEMS

It is not possible to predict when and where an earthquake will happen. Still, advances in technology can offer seconds of warning for some earthquakes. This is commonly known as an Earthquake Early Warning (EEW). The west coast of the United States uses USGS's ShakeAlert system as its EEW.

How do we tell if earthquake shaking is coming?

The shaking we feel is caused by the waves of energy released by the earthquake. These waves travel at different speeds. The fastest earthquake waves are called primary or P waves. They do not cause damaging shaking. The slower waves (such as the secondary or S waves) do. The difference in wave speed provides the warning. P Earthquake waves are recorded by sensors that send data to a local hub for processing. This hub sends out an EEW or ShakeAlert. This may be directly received by users such as the BART in the Bay Area, which uses the warning to slow down trains before strong shaking arrives.[4] The warning is also sent through a third-party app like MyShake[5] to the wider community that may experience shaking. This warns users that an earthquake is coming, giving them seconds of warning.

It is important to note that these warning systems do not prevent damage to buildings. They can, however, provide enough warning time for people to take steps that could reduce damage. Shut-off valves, trains, and heavy equipment can be programmed to have automated responses before shaking starts. Most importantly, they also give people precious seconds to protect themselves and their loved ones. If you get an EEW or feel the ground shaking, Drop, Cover, and Hold On (DCHO)!

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[4] Bay Area Rapid Transit, BART, Early Adopter of Earthquake Early Warning System Shares Learnings With Other Agencies Around the Country, 2022
[5] USGS, How Do I Sign Up for the ShakeAlert Earthquake Early Warning System?

In addition to the ground shaking, there may be other ways that large earthquakes cause the ground and built environment to fail. If the movement along a fault is strong enough and the fault is shallow enough, we could see a break in the ground or a **surface fault rupture**. This is where one side of the fault on the Earth's surface moves in one direction while the other side moves in the opposite direction. Faults can move left and right as well as up and down. Most often, the movement along a fault is both side-to-side and up-and-down. Surface fault rupture may not occur with every earthquake.

Shaking during a big earthquake can cause major damage. However, one of the key hazards to be aware of after an earthquake is the possibility of more motion happening after the initial earthquake. This is known afterslip.[6] This can occur either as **aftershocks** (discussed further in Section 3.1) or as slow slip where no shaking can be felt, but the ground still moves slowly. It happens when the area around a fault needs to relax or readjust after an earthquake takes place. When afterslip happens close to the surface, it can cause major damage over an extended time period. One example of afterslip happened in the Browns Valley neighborhood after the 2014 M6.0 earthquake in South Napa, California. The surface fault rupture went through several house foundations, causing major foundation damage. The homeowners could not immediately repair or replace their foundations or move as the fault continued to slip. FEMA funded a USGS study to find the duration of shallow afterslip.[7] Because of this long-term deformation, water pipes and other systems continued to break for weeks after the earthquake as the ground adjusted.[8]

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[6] USGS, Earthquake Processes and Effects
[7] USGS, USGS Open-File Report 2014-1249: Key Recovery Factors for the August 24, 2014, South Napa Earthquake, 2014
[8] GeoScienceWorld, Afterslip Behavior Following the 2014 South Napa Earthquake With Implications for Afterslip Forecasting on Other Seismogenic Faults, 2016

3.1.2. EARTHQUAKE SEQUENCES

Earthquakes are different from other hazards; when one earthquake happens, others usually follow. This is known as an **earthquake sequence**. An earthquake sequence is made up of **foreshocks**, a **mainshock**, and aftershocks. The mainshock is the biggest earthquake in the sequence. Any smaller earthquakes that happen before the mainshock are called foreshocks. Any smaller earthquakes that happen after the mainshock are called aftershocks. Because earthquakes occur in groups, it is crucial to plan for aftershocks if a major earthquake were to happen. Anywhere from tens to thousands of aftershocks can follow a significant earthquake. The biggest aftershock tends to be one magnitude number smaller than the mainshock. Aftershocks do eventually tail off, but they can go on for hours, days, weeks, months and even decades after a large earthquake. It is important to keep in mind that buildings damaged by the earlier earthquakes in the sequence may be further weakened and damaged in aftershocks. Some buildings that do not show visible signs of damage following the initial quake could even collapse during later, smaller earthquakes due to the sum of damage.

2019 RIDGECREST EARTHQUAKES

On July 4 and 5, 2019, a sequence of earthquakes occurred near Ridgecrest, California (about 120 miles northeast of Los Angeles).[9] The sequence included a large foreshock, a mainshock, and many aftershocks. Thousands more aftershocks occurred after the final M7.1 mainshock; the total number was more than 3,000 by the morning of July 7. Geologists at the USGS estimate that 34,000 more aftershocks occurred in the six months after the earthquakes.[10] The number of aftershocks within hours of the earthquake were unusually high, but not unheard of.

After large earthquakes (≥M5 in the U.S.), the USGS produces aftershock forecasts. These forecasts give the odds that earthquakes of different magnitudes will happen within a set distance from the mainshock. This is important because response and recovery personnel working near damaged buildings need to be prepared to seek shelter away from damaged buildings during an aftershock.

3.2. CASCADING HAZARDS

Some hazards pose a risk to your community in the wake of an earthquake. These are known as cascading hazards. Not all cascading hazards are sure to occur. Still, adding including them to your HMP's hazard identification can help to show the full picture of risk.

3.2.1. LIQUEFACTION

If the soil is made up of sand and similar loose sediment that has a lot of water in it, it can temporarily behave like a liquid when the ground shakes. This is called **liquefaction**. Liquefied soil loses the ability to support buildings and other structures. This causes those structures to shift and even fall over. If the ground shakes long enough and contains enough water, it can actually start to flow. This is called **lateral spread**.

[9] Jay Croft & Braden Goyette (CNN), California Earthquake Generates More Than 200 Aftershocks, 2019
[10] Alex Wigglesworth (LA Times), Expect 34,000 Aftershocks from Ridgecrest Earthquakes. But Seismic Activity Is Slowing Down, 2019

3.2.2. LANDSLIDES

Earthquake shaking can cause large blocks of hillsides and cliffs to slide off as a **landslide**. If an earthquake causes a landslide, any structure on the top of the hill may slide downward. These buildings tend to be a total loss. Landslides also cause damage downslope. The sudden downslope movement of a block of land can set large boulders and trees in motion. These can topple and roll downhill into or through any structures in their path. Slopes can remain sensitive to disturbances for months following an earthquake, making landslides more likely.

3.2.3. TSUNAMI

Tsunamis are giant waves caused by big up or down motion of the seafloor. They are often caused by an earthquake. In the deep ocean, these waves are barely noticeable. However, as they come into shallow waters and then onshore, they can grow much higher and cause destruction in coastal areas all around an ocean basin. Tsunamis can also be caused by landslides, volcanic eruptions, underwater explosions, and meteor impacts. Large tsunamis that can cross the entire ocean most often start along faults in a type of plate boundary known as a subduction zone. In the United States, subduction zones are found in southern Alaska and on the west coast from northern California through Oregon and Washington. Communities in these areas must consider the risk from tsunamis that start across the ocean. They also must consider the risk from big tsunamis that start right off their shores.

The National Oceanic and Atmospheric Administration (NOAA) conducts tsunami research and provides tsunami forecast and alert information. NOAA's National Tsunami Warning Center (NTWC) in Alaska and Pacific Tsunami Warning Center (PTWC) in Hawaii send out tsunami alerts for the United States and Canada. NOAA also manages the National Tsunami Hazard Mitigation Program (NTHMP) and provides grant funding to states and territories to study and reduce risk from tsunamis. To learn more, visit NOAA's website. State geological surveys of Pacific coast states also have information on local tsunami hazards, detection, alerts, and mitigation. Check with your state geological survey to learn more about tsunami and earthquake hazards.

EARTHQUAKE TRIGGERED TSUNAMIS

In 2004, one of the largest recorded earthquakes in the world (M9.1) and its resulting tsunami took place in the Indian Ocean, near Sumatra, Indonesia. That tsunami killed more than 225,000 people in coastal communities around the Indian Ocean rim. It caused billions of dollars in damage and spurred a renewed focus on understanding and mitigating tsunami hazards.[11] Closer to home, the 1964 M9.2 Good Friday earthquake in Alaska was the second largest earthquake ever recorded. It created a tsunami that killed 128 people, including four in Oregon and 16 in Crescent City, California.[12] In 1918, a tsunami generated by an M7.5 earthquake off the coast of Puerto Rico killed at least 116 people. It had a documented height of about 6 meters, or almost 20 feet.[13]

[11] NOAA, The Indian Ocean Tsunami of 2004: A Wake-Up Call
[12] Western States Seismic Policy Council, 1964 Alaska Tsunami
[13] Puerto Rico Seismic Network, 1918 Earthquake

3.3. CLIMATE CHANGE

The direct impacts of climate change on earthquake size and frequency are not well established. This is an area of ongoing research. Their goal is to explain the long-term links between climate change and earthquake risk and probability.

Cascading hazards of earthquakes like liquefaction, landslides, and dam water storage are relevant to this conversation. Climate change is increasing sea level rise and melting permafrost. Both of these can lead to more water in shallow soils making liquefaction more widespread. As storms and rainfall become more common and severe, this may lead to more landslide risks. Cascading impacts may worsen the impacts of an earthquake. An HMP's risk assessment should discuss them where appropriate.

Finally, earthquakes can lead to a large number of destroyed buildings. This can occur through crumbling during an earthquake or being selectively demolished after an earthquake. The rebuilding process and the disposal of the debris and materials result in high greenhouse gas emissions. This speeds up the rate at which climate change happens. This can be a key consideration in land use change and development in your community.

CONNECTION TO THE HMP: PLANNING FOR CLIMATE CHANGE

(Section 1.3 and Elements B1-e and B2-b of FEMA's Local Mitigation Planning Policy Guide and Elements B2-b of FEMA's Tribal Mitigation Plan Review Guide)

HMPs must include the probability of future events for any identified hazard. This includes earthquake hazards. Probability must include the effects of future conditions, including climate change (e.g., long-term weather patterns, average temperature and sea levels), on the type, location, and range of likely intensities of the identified hazards.

HMPs must also describe the potential impacts of future events on each participating jurisdiction and its identified assets. Impacts must include the effects of climate change, changes in population patterns (migration, density, or the makeup of socially vulnerable populations), and changes in land use and development.

3.4. EARTHQUAKE SCENARIOS

Earthquake scenarios can be developed by using specifics about your community. These can help your community learn the impacts of an earthquake and the cascading hazards that follow. Earthquake scenarios describe the effects of potential earthquakes at different known faults. They are used for planning purposes.

Earthquakes are complex hazards. They are no-notice events that can cause different levels of shaking based on your location. They can create aftershocks and afterslip that could cause damage for years after the mainshock. They can lead to cascading hazards such as liquefaction and landslides. Because of this wide range of factors to consider, mitigation planners and emergency managers should use earthquake scenarios to guide planning efforts. Earthquake scenarios are often developed by federal or state geologic organizations in partnership with the affected communities and emergency managers. They can help you know what to expect; this will help you prepare for an earthquake and mitigate the risk.

The key outputs of an earthquake scenario are maps, figures, and suggested resources. This can include **ShakeMaps**, which use the Modified Mercalli Intensity Scale (MMI) to show the intensity of shaking that a model earthquake would produce. The intensity of shaking is based on factors such as distance from the fault, surface geology, and other characteristics of the earthquake. ShakeMaps are a helpful tool for anyone who lives near a fault. This is because the MMI scale is based on real-world effects the person would experience in that location. It gives us better knowledge of how objects will move and what we are likely to see during an earthquake. With that knowledge, a ShakeMap can give you a better idea of how people can prepare their home for shaking.

HAYWIRED SCENARIO

The USGS HayWired Scenario depicts a scientifically realistic earthquake sequence and its cascading impacts. This scenario starts with an M7 earthquake on the Hayward Fault. The scenario highlights how everything connects: the hazards of an earthquake, interactions between critical infrastructure systems, and compound effects in communities and economies.

To estimate physical, economic, and social loss from a modeled earthquake, scientists and practitioners use FEMA's Hazus modeling process to pair the ShakeMap with the current population distribution, infrastructure, and building information. They also consider social demographics. This creates a forecast of damage and loss due to the modeled earthquake. This forecast is described in a scenario report that gives city, county, and state officials an idea of how much damage to expect if a similar event were to occur. This allows planners to put in place realistic plans; helps officials understand how to spend money effectively on projects that will reduce risk; and gives local organizations the information they need to prepare for a potential earthquake. Communities can also refer to earthquake scenario reports to learn the potential impact to emergency services during such an earthquake. This can help them prepare for disruptions to normal resources and services.

USGS SEISMIC HAZARD MAPS

The USGS has identified the areas of the country that face the highest earthquake hazard. The goal of this work was to determine earthquake hazards and better inform mitigation and preparedness efforts for SLTTs. You can see these data in a hazard map here: Hazards (usgs.com).

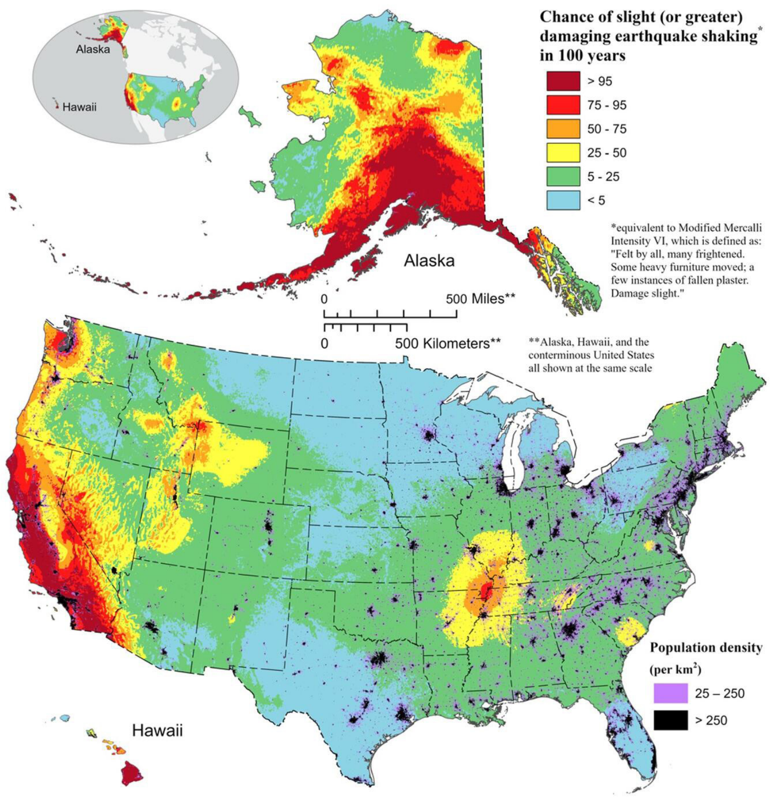


Figure 2. 2024 USGS Seismic Hazard Map

The probabilistic seismic hazard map shown above in Figure 1 shows the earthquake hazard probability in the United States. Colors on this map show the levels of horizontal shaking that have a 2% chance of being exceeded in a 50-year period. Shaking is expressed as a percentage of g (g is the acceleration due to gravity). You can find earthquake scenarios that USGS has already developed here: Earthquake Scenarios (usgs.gov).

Remember that there can never be a scenario that covers all possible earthquakes. For instance, if there are two similar faults close to each other that might produce a similar magnitude earthquake, it might make sense to produce a scenario for only one of the faults. This kind of scenario can be used as an example for planning purposes. It is also possible that the fault modeled for the scenario could produce a smaller or larger earthquake than the one chosen for the scenario. However, the earthquake scenarios that are created give the community a sense of which active faults are of greatest concern for public safety. The goal is not to try to predict what will happen. The goal is to give an example of what *could* happen to help communities think about the best ways to prepare for and mitigate their risk.

4.

IDENTIFY COMMUNITY ASSETS AT RISK OF EARTHQUAKE IMPACTS

CONNECTION TO THE HMP: IDENTIFY ASSETS

(Element B2 of FEMA's Local Mitigation Planning Policy Guide and Element B3 of FEMA's Tribal Mitigation Plan Review Guide)

After you list and describe earthquake hazards in your community, you must also describe their impact on local assets. Assets include anything that is important to the character and function of the community. All assets may be affected by hazards, but some are more vulnerable. This may come from their physical characteristics or uses.

There are many ways to determine how an earthquake might impact your community. One way that we'll outline in this section is creating an **inventory** of assets as you develop your HMP. An asset inventory takes note of the various assets in your community.

4.1. IDENTIFY ASSETS

Building inventories are the most common type of inventory. However, buildings are not the only asset important to a community. You can inventory items in the natural and/or human-made environments. You can also use an inventory to track populations, services and functions. Each community's asset inventory will look different.

CASE STUDY:
ASSESSING SEISMIC VULNERABILITY

Clark County, Nevada, took proactive steps to inventory their high number of Unreinforced Masonry (URM) buildings in an attempt to mitigate against partial or total collapse during a strong earthquake. You can listen to Episode 2 of the Level Up Audio Project, "Assessing Seismic Vulnerability in Clark County, NV," from FEMA Region 9 to learn how they made their inventory.

Types of assets you might want to consider in your inventory include the following:

4.1.1. PEOPLE/SOCIAL ASSETS

People are your community's most important asset. It is vital to clearly address underserved and socially vulnerable populations. Studies show that hazard events affect historically underserved or marginalized communities more than others. For the purposes of an asset inventory, you may want to identify buildings where people live, work, and visit. You also want to think about population characteristics such as socioeconomic status, age and race. These data affect risk and will help you prioritize mitigation projects. For example, look at the number of people living in a certain area or building, how long they have lived there, how buildings are used, etc. Risk tends to increase when more people live in or use a building.

To understand social risk, learn the traits of a community. Many tools can help you collect data on social risk, such as the U.S. Census. Another resource is FEMA's National Risk Index (NRI). It imports data from the Center for Disease Control (CDC)/Agency for Toxic Substances and Disease Registry (ATSDR) Social Vulnerability Index (SVI). In turn, tools like the Climate and Economic Justice Screening Tool pull data from the NRI for things like expected agriculture, building, and population loss rate. Tools like this can help to reduce research time. They also paint a more complete picture of local resilience. Still, the community knows the most about their history, needs and challenges.

According to the CDC, ATSDR, and SVI, themes and social factors to consider in terms of social risk include:

- Socioeconomic status (jobs, housing costs, education, insurance).
- Household characteristics (older adults or youth, people living with disabilities, single parent households, English language proficiency).
- Race and ethnicity.
- Housing type and transportation (multi-unit, manufactured homes, overcrowding, access to transportation, group quarters).

For the mitigation plan, we also need to know the risk to the occupants and users. We must think about who lives or works in areas of higher risk. To do so, we look at factors that may weaken a community's ability to prepare for or recover from a natural disaster. The income, ethnicity, age, and neighborhood of a person or household can greatly affect their risk.

In addition, think about how hazards can overlap with earthquakes. Examples include flooding, drought, wildfire, and even pandemics. The Magna Utah earthquake happened at the beginning of 2020, just as the COVID-19 pandemic started. Populations that are vulnerable to more than one hazard have a higher risk. This information will help you consider or focus on certain populations as you plan for mitigation actions.

Center your planning and decisions on keeping your community safe and protecting their assets. This will lead you to a solution that works for many, rather than just a few.

4.1.2. STRUCTURE AND INFRASTRUCTURE ASSETS

Structures might include commercial, industrial, and residential buildings (including mobile/manufactured homes). They also may include other **critical facilities** such as hospitals, emergency operations centers, fire and police stations, emergency assistance centers, and schools. Infrastructure might include hazard alerting infrastructure; water storage and distribution systems; wastewater piping and treatment facilities; power stations and distribution grids; fuel storage and distribution centers; and transportation lines and communication lines.

One of the most common types of asset inventories is a building inventory. These allow communities to identify the buildings that are most likely to be damaged by an earthquake. A building's construction or structure type and age are the two most important details to gather for such an inventory. Some common construction types that have known risks of poor earthquake performance, based on their building materials and age, include:

- URM buildings and chimneys.
- **Soft or weak story structures.**
- Non-ductile concrete structures.
- Tilt-up concrete construction.
- Steel moment frame structures.
- Residential wood frame-to-foundation connections.

Appendix B describes these construction types in more detail. It also gives examples of how they have been impacted by earthquakes in the past, and how communities have begun to address each construction type by using building codes. You can look to this Appendix for inspiration on how you might plan for **retrofitting** weaker construction types in your mitigation strategy.

4.1.2.1. SCHOOLS

Schools consistently rank near the top of a list of critical facilities that need to reduce risk. As a community, we feel a strong need to safeguard the well-being of children. Many of them attend school in structures that are prone to earthquake damage.

What may be less obvious is the vital role that schools play in longer term recovery. Without a safe learning environment, education is disrupted and family schedules change. Schools in many towns serve as a cultural hub for sporting events, the arts, and elections. They are often used as emergency shelters after disasters as well.

Many states have begun to inventory school buildings to determine their risk. One such example is Utah, which recently published its Unreinforced Masonry (URM) school inventory. Another is Washington State, which has an ongoing School Seismic Safety Program.

Other states have gone further and used grant programs to fund seismic retrofits of school buildings. One example of this is Oregon and its Seismic Rehabilitation Grant Program. Eligible projects can apply for as much as $2.5 million. California also has a program that provides earthquake mitigation funding for the seismic repair, reconstruction, or replacement of the most vulnerable school facilities. You can learn more here: Access Seismic Mitigation Funding (ca.gov).

Additionally, school districts are able to participate as special jurisdictions in a local HMP, which would make them eligible for their own types of Hazard Mitigation Assistance (HMA).

4.1.3. COMMUNITY LIFELINES

Community lifelines are the key services in a community. The National Response Framework identifies eight lifelines. They are safety and security; food, hydration, and shelter; health and medical; energy; communications; transportation; hazardous materials; and water systems. A community lifeline allows for operation of critical government and business functions to continue. They are vital to human health and safety and economic security. When community lifelines are stable, they enable all other aspects of society to function. Think about lifelines and the impacts of damage to potential local and regional recovery. This gives you a chance to broaden your view on the benefits of earthquake risk reduction projects. Example community lifelines are discussed below.

4.1.3.1. WATER SYSTEMS

Water storage and distribution may be the most import lifeline system. Communities cannot survive for long without a water supply. Los Angeles has a long-term program to replace brittle iron water supply piping to its hospitals with new ductile steel piping. This new piping will perform better in an earthquake. Utah received Building Resilient Infrastructure and Communities (BRIC) funding in 2022 to retrofit its brittle drinking water aqueduct system. The system crosses the Wasatch Fault many times. It would likely have multiple breaks during a major earthquake in Utah. Note that it is even more important to think about water in an arid state. One can easily make a case for protecting drinking water, farm irrigation supplies, cooling for industrial systems, fire suppression systems, recreational spaces, and many other resources. Another key concern is the value of a continually operating water system. This can help to prevent widespread fires after earthquakes. For example, the greatest amount of damage during the 1906 earthquake in San Francisco happened because leaking gas lines sparked fires when water was not available to put them out.[14]

CASE STUDY: EARTHQUAKE MITIGATION OF PUBLIC WATER SYSTEM

Shelby County, Tennessee, is within the impact area of the New Madrid fault system. The University of Memphis reports that the area has a 40 to 60% chance of an M6.0 to M6.3 earthquake in the next 15 years. The 2016 Shelby County Hazard Mitigation Plan noted many seismic retrofit mitigation actions that could help to reduce that risk. The county used Hazard Mitigation Grant Program (HMGP) funding to meet its needs. Memphis Light, Gas, and Water has begun a seismic retrofit project to protect its Davis Water Pumping Station. The project improves the survivability of the connections between the water distribution lines in a third of the city’s production wells. It has an estimated savings of $112 million. The estimated cost of replacing the pumping station after an earthquake is $17 million. On average, it would cost $1.4 million each day the station is out of service. The retrofitted water connectors (around $9,000 each) will withstand an M6.5 to M7.5 earthquake.

Learn more here: FEMA.gov

[14] U.S. National Park Service, 1906 Earthquake: Fire Fighting, 2015

4.1.3.2. ENERGY

As with water, modern society grinds to a halt without electricity. We need electric power for communication, heating, cooling, lighting, manufacturing, and medical facilities and equipment. We need it for life-sustaining technologies such as respirators and dialysis. As you expand your view on how vital electricity is, the benefits quickly add up. They form a strong case for mitigation.

CASE STUDY: OREGON CRITICAL ENERGY INFRASTRUCTURE (CEI) HUB

The Pacific Northwest lives with high odds of an M9.0 earthquake in the Cascadia subduction zone. Such an event would cause widespread damage. It would also raise the potential for other hazards (e.g., tsunami, landslides, liquefaction, etc.). Oregon's CEI Hub was built before the region's earthquake risk was clear. Many of its facilities are structurally weak. It also sits on unstable soil. The area is subject to liquefaction and lateral spread during an earthquake. In 2020, the Multnomah County Office of Sustainability and the City of Portland Bureau of Emergency Management commissioned a study of potential damages to the CEI Hub. They found (based on prior spills) that if the CEI hub was not retrofitted, an oil spill could cost up to $2.6 billion. The spill would range from 94.6 to 193.7 million gallons. This oil would flow into the mouth of the Columbia River. Multnomah County will work with state and local partners to determine next steps to make sure the facilities either upgrade their infrastructure to modern seismic standards or retain liability coverage to ensure the public can be made whole in case of a disaster.

Learn more here: Multnomah County

4.1.3.3. TRANSPORTATION

Viable transportation is crucial for disaster response and recovery. Emergency responders need dependable routes to reach injured people. Roads must be open to deliver needed supplies, let emergency managers access sites, and evacuate the area.

Transportation networks are also critical over the long term. They help to move food, medications, and other goods needed to sustain our economy. People also need to move about every day, for both work and play. As you identify and address these needs, mitigation projects look more important than ever.

CASE STUDY: BAY AREA RAPID TRANSIT (BART) TRANSBAY TUBE RETROFIT

BART's role as a lifeline in the Bay Area region was solidified after the 1989 Loma Prieta earthquake. Just 12 hours after the earthquake, BART was up and running to serve the public on a 24 hour emergency schedule. The Loma Prieta earthquake hit more than 50 miles south of San Francisco. Scientists predict that one or more major earthquakes will hit the Bay Area in the next 30 years. Planners saw the need to retrofit the Transbay Tube in a past study. The Tube is BART's most critical asset. The Bay Area has taken on a huge retrofitting project to strengthen BART's outer shell. This project includes adding an inner steel shell and a new pumping system. It aims to reduce flooding caused by cracks to the outer shell from a major earthquake. Most of this project is being funded locally. However, BART received $3 million from FEMA's Pre-Disaster Mitigation (PDM) program. This program has been replaced by BRIC. Thanks to these funds, BART can continue its operations even after a major earthquake, as it did in 1989.

Learn more here: BART.gov

4.1.4. NATURAL, HISTORIC, AND CULTURAL ASSETS

Natural, historic, and cultural resources add to a community's identity and quality of life.

Environmental and natural resources help the local economy through agriculture, tourism and recreation. They support ecosystem services such as clean air and water. Conserving the environment may help people mitigate risk; it can also protect sensitive habitats, develop parks and trails, and build the economy.

Historic and cultural resources help to tell the story of your community. They are unique and cannot be replaced. Historic properties offer a wide range of social and economic benefits. For example, museums, geological sites, concert halls, cultural centers, tribal heritage and ceremonial sites, parks, and stadiums can qualify. Your community should work to identify these important resources to protect them from natural hazards.

4.1.5. ECONOMIC ASSETS

After a disaster, economic resilience is one of the major drivers of a speedy recovery. Each community has its own economic drivers. Consider these as you plan; this can reduce the impacts of a hazard or disaster on the local economy. Economic assets can have direct or indirect losses. For example, building or damage to inventory inside the building. Functional downtime and loss of wages are indirect losses.

Economic losses are losses you can calculate. To help develop an accurate estimate of potential economic loss, know the main economic sectors in the community. These may include manufacturing, agricultural, or service sectors. Major employers and commercial centers are also a factor. Consider workforce housing and day care needs as well.

4.2. STEPS TO CREATING AN INVENTORY

A theme in this guide for mitigation success is to think about small, achievable tasks. These often cost less than larger projects. It is also easier to move toward your goal if you break the work into smaller chunks. An inventory is no different. See it as a large job with many manageable steps.

Before you start your inventory, think about:

- The types of earthquake mitigation projects you are considering and what kind of inventory information will support these projects.
- What information you have, and what gaps you need to fill in.
- Project scoping needs, a database and file format, and technology limits.
- The fact that others will use the inventory, too. What types of information will be valuable to them?
- If any pre-mitigation planning or other planning efforts with outreach activities support your inventory project. When possible, combine efforts to reduce engagement fatigue and find efficiencies.

Taking all of these factors into account at the start of your inventory process will help you and your partners get the most value out of the work.

FINANCIAL SUPPORT FOR INVENTORY DEVELOPMENT

It can take a long time and a lot of money to create a robust inventory with all the details you need to manage earthquake risk. However, it is vital to know which assets in your community are at risk. You may not have a full inventory, or your inventory may not have many details when you start your HMP. That's okay! Here are some options for building your inventory.

- FOLD INTO YOUR PLANNING PROCESS: If you are using a FEMA grant to fund your planning efforts, clearly state that you will create the inventory in your planning grant application or sub-application. Also, make sure you have enough time in your HMP development timeline to gather the data and use them in the plan.
- OUTSIDE THE PLANNING PROCESS: Planning-related activities are eligible for funding under the HMGP and the BRIC grant programs. You may want to pursue a planning-related activities grant. These funds can help you build your inventory, refine your vulnerability analysis, and add both to your existing HMP. To learn more about planning-related activities, see Part 11 of the Hazard Mitigation Assistance (HMA) Program and Policy Guide.

See Section 7 of this guide to learn about potential funding sources for earthquake mitigation. Your State Hazard Mitigation Officer or FEMA Regional Mitigation Planner may have more information.

4.2.1. SET THE SCOPE AND SCALE

An inventory requires resources like time, funding, and expertise. Having one for the entire community is best but may not be possible. If it isn't, you may need to set a focus area based on risk criteria.

4.2.1.1. FIND EXISTING DATA

Before you start, see what data the community already has. Identify all existing data sources with relevant information. Some possible data sources include tax assessor data, building permit data from your building department, and U.S. Census data. Appendix C for this guide includes a list of resources that can help with your inventory collection. It also contains worksheets that can help you plan an inventory collection.

USING TAX ASSESSOR DATA IN YOUR INVENTORY

Tax assessor data can be a great source of information. It is notably useful for information on buildings. These data often have the year the building was built and its number of stories, square footage, construction type and material, and occupancy or use. However, they have some limits. These data are created for tax purposes. They are often organized by parcel and may not show the actual site of each building. The parcel information can be limited, absent, or underrepresented. This is affected by whether a building is taxable and how it is assessed. You may need to translate these data from parcels to structures. To do this, combine parcel data with building footprint data in a Geographic Information System (GIS). Also, check for county and state data.

4.2.1.2. REFINE DATA AND FILL IN GAPS

Existing data sources likely will not have all of the data you are looking for. Be prepared to fill in gaps. Get help from experts when needed. If your survey is at a basic enough level, you may be able to get help from informed volunteers such as fire department personnel or local engineering college students (learn more about Rapid Visual Screening in Section 5.2.1). Set up systems to collect and manage data early in the inventory process. You may be able to use an existing system or even a spreadsheet, or you may have to create a new one. Make sure to store the data where program staff can access it.

Building an in-depth inventory is not always an option. Think about using assumptions to narrow down the inventory needs. Note the limits of these assumptions. These can apply to your community or to a focus area. For instance, your jurisdiction may have adopted a building code in 1970 that addressed hazards. It may be safe to assume that all structures built after that meet the standards for that code. This will narrow your search to buildings built before 1970. You can also use your permitting process to flag buildings that do not meet the current code. Add those to your inventory of vulnerable buildings. Think about demographics, population density, and types of businesses or housing. Note any social factors that increase the vulnerability of these buildings.

CASE STUDY: PRIORITIZING BUILDINGS IN PALO ALTO, CALIFORNIA

To address the most at-risk buildings first, the city of Palo Alto organized buildings into three categories based on occupancy load and age. This allowed them to prioritize buildings for earthquake retrofits. As time went on, the program assessed all weaknesses using the city's tax assessor records. They focused on the year built and inspected sites to check the type of building.

4.2.1.3. CONDUCT OUTREACH AND STAKEHOLDER ENGAGEMENT

The idea of a government agency taking an inventory of privately owned buildings can be sensitive. It is vital to engage the community throughout the process. This can be done through community events, surveys, social media outreach, mailers, door-to-door conversations, public meetings, etc. Be prepared with information that clearly explains the purpose and intent of the project. Make plain-language and multilingual resources available. If there is distrust, work with local partners. Use trusted voices to help explain the project, co-host events, and earn buy-in. It is important to hear the insights of those who are affected. They may help to inform your approach. Here are some potential partners to invite to outreach events:

- School districts.
- Critical infrastructure organizations.
- State and local engineering communities.
- State geologic survey.
- Building owners and managers, and other development groups.
- Renter and tenant groups.
- Home builder groups.
- Your state insurance commissioner.
- The media.
- Faith-based and spiritual organizations.
- Community organizations.
- The arts community.

SOCIAL RISK ASSESSMENT RESOURCE

The National Institute of Standards and Technology (NIST) Community Resilience Planning Guide and it's Buildings and Infrastructure Systems Playbook offer a practical and flexible approach to building resilience. It helps users set priorities, allocate resources, and manage the risks of hazards. The guide helps communities keep consistent resilience goals in various plans. This includes comprehensive, economic development, zoning, mitigation, and other local planning. These plans affect buildings, public utilities, and other infrastructure systems.

4.2.1.4. PRIORITIZE THE RESULTS

The next step is to find the target assets that you want to focus on. You can base this on the general inventory you developed. Narrow that inventory down to a priority list. When you build this priority list, think about your funding sources and the amount of funding available. Traits you might use to rank assets for mitigation needs include whether they have been identified as a critical facility that is key to post-disaster response and recovery; whether the asset has historical or community value; whether the asset supports your community's socioeconomic status; etc.

5. EVALUATING EARTHQUAKE RISKS

CONNECTION TO THE HMP: ASSESSING RISKS

(Element B of FEMA's Local Mitigation Planning Policy Guide and Element B of FEMA's Tribal Mitigation Plan Review Guide)

Having an inventory helps your community know the basic traits of its buildings. On its own, that is not enough. The next step is to assess the risk based on the hazard and vulnerability. Analyze the asset inventory to find the most vulnerable assets in your community.

Vulnerability is the chance that a negative outcome (e.g., building collapse) from a hazard (e.g., earthquake, ground shaking) will actually happen. An HMP must assess the losses that will occur when hazard meets vulnerability. Summarizing this information will help the community understand its greatest risks. A good way to summarize vulnerability is to write problem statements. For example:

- The city is in a seismic hazard area. It is subject to severe ground shaking and soil liquefaction. Models predict an M6.0 event would cause $10.5 million in structural losses and $40 million in non-structural losses. Damage will be greatest to the 100 URM buildings (built before the building code) in the downtown business district.

The summary of vulnerabilities informs the mitigation strategy. You can learn more about this in Section 5.

Now that we know the types of earthquake hazards and their general impacts, it is time to assess the specific impacts on your community. This includes risks to your critical buildings, lifelines, and local residents. Think about the whole community in this phase. Take in aspects of your community and its needs. If you plan with a whole community mindset, you are more likely to create effective, inclusive mitigation strategies.

5.1. OVERALL LOSS ESTIMATION FOR EARTHQUAKES

There are many ways to estimate loss after an earthquake. The most basic approach is to use an exposure analysis. To complete an exposure analysis, you will need a map of your asset inventory and an earthquake map. This map could be a specific earthquake scenario or a general earthquake risk map. You will then overlay the asset map and the earthquake map. Any assets that overlap the earthquake zones are at risk. This approach does not provide detail such as the level or risk (i.e., minor damage vs full destruction). It simply highlights which assets are most likely to be at risk.

You can complete a more detailed assessment through FEMA's Hazus Program.[15] Hazus provides standardized tools and data for estimating risk from earthquakes, floods, tsunamis, and hurricanes. Hazus models combine expertise from many disciplines to create actionable risk information. This information can help to build community resilience. Hazus software is distributed as a GIS-based desktop application. It includes a growing collection of simplified open-source tools. Risk assessment resources from the Hazus program are available for free and are transparently developed.

Hazus can show the spatial boundaries of potential earthquake impacts (liquefaction, ground shaking, ground deformation). These can be used to find potential areas of increased risk, the population at risk, characteristics of housing stock within the impacted area, and estimates of residential losses. Hazus can be readily used by many people and groups. It is one of the most effective ways to quickly estimate impacts from an earthquake.

Hazus produces a wide range of actionable risk information:

- Physical damage to residential and commercial buildings, schools, critical facilities, and infrastructure.
- Economic impacts, such as business interruptions and reconstruction costs.
- Estimated social impacts, including displaced households, shelter requirements, and exposure to floods, earthquakes, hurricanes, and tsunamis.
- Cost effectiveness of common mitigation strategies, such as elevating structures in a floodplain.

Keep in mind that Hazus can complete three levels of analysis. Default datasets let any community quantify risk, regardless of data availability. However, the quality of modeling inputs drives the accuracy of risk assessment information. As such, users should customize their Hazus analyses by inputting best available data from local or authoritative sources whenever possible.

FEMA has pre-run Hazus models for many historic or potential earthquakes. These models are curated in the Hazus Loss Library. FEMA's Hazus program supports data-driven decision making for mitigation, preparedness, response, and recovery. Learn more about using Hazus for mitigation planning here.

5.2. TYPES OF BUILDING ASSESSMENTS FOR EARTHQUAKES

As noted above, the more you know about your assets, the more detailed and specific your risk assessment will be. With the hazard of earthquakes, building characteristics (such as construction materials, foundation type, and number of stories) play a key role in the vulnerability of each asset. Appendix B describes a handful of building types that are notably at risk of earthquake damage. There are a few ways to assess the physical assets in your community. Three methods are described below. Pick the way that works best for you. When you develop your HMP, describe the method you used and include the results. This supports the requirement to summarize risks and impacts.

5.2.1. RAPID VISUAL SCREENING (RVS) (FEMA P-154)

RVS is a tool that you can use to prioritize the highest-risk buildings in a defined area. Often, a large group of structures (such as all the brick buildings in a city) may need to be studied. In this case, it is helpful to rule in the buildings with clear or suspected risks; rule out those that can be quickly deemed safer. The ones that fall somewhere in the middle can be flagged for a more detailed study as time and resources permit. An organization can use RVS to prioritize the buildings with the highest risk of damage in a future earthquake.

[15] FEMA, Hazus, 2022

The standard process for RVS is provided in "Rapid Visual Screening of Buildings for Potential Seismic Hazards" (FEMA P-154). This document gives a consensus screening methodology. Use its case studies and checklist forms to assess buildings for earthquake risk. In 2022, Utah used FEMA P-154 to carry out RVS. In this way, it found all known or suspected URM in K-12 public schools across the state. To learn more about this thorough work, read the Utah K-12 Public Schools URM Inventory report.

5.2.2. TIER 1 SCREENING PROCEDURE (ASCE/SEI 41-17)

The ASCE/SEI 41 standard, "Seismic Evaluation and Retrofit of Existing Buildings" (ASCE/SEI 41-17), contains a series of tools that you can use to assess a building's earthquake vulnerability. The first step is often to use the Tier 1 screening procedure. It is specific to the building type being checked. For each building type, checklist statements help users find common defects. The lists are based on flaws seen in that building type after past earthquakes. Use the tool's more general checklists to find nonstructural earthquake risks. These apply to building systems and contents. This process requires original construction documents and a site visit. It is meant to be fairly simple. However, a structural engineer should review the original construction drawings and make the simple engineering calculations. The Tier 1 procedure is somewhat conservative. The Tier 2 procedure is more complicated but less conservative. Later analysis that uses this procedure may show that a building that was listed as having a high earthquake risk is actually more resilient to earthquakes.

5.2.3. SEISMIC PERFORMANCE ASSESSMENT OF BUILDINGS (FEMA P-58)

By far the most detailed and complex assessment procedure is FEMA's Seismic Performance Assessment of Buildings Methodology, or FEMA P-58. The FEMA P-58 method assesses and describes the performance of individual buildings. It defines repair costs and downtime; odds of life safety; continued use; and environmental impacts. It is specific to each building type. It can be used to design new buildings to a seismic performance target. It can also be used to assess the risk to an existing building against a performance target. It includes an electronic calculation program called the Performance Assessment Calculation Tool (PACT).

FEMA P-58 uses advanced methods to assess building safety. It can predict important metrics of building resilience based on quantitative engineering. This differs from most other loss prediction methods, which are based on experience. Other methods use a building class, rather than data specific to the building. The associated methods and the products are open-source, standardized, and repeatable. The FEMA P-58 project created a wide range of databases to support the assessment. It is most effective if engineers who already know the seismic assessment of buildings use this process.

BUILDING ASSESSMENT RESOURCE

FEMA set up the National Earthquake Technical Assistance Program (NETAP) to help SLTTs obtain knowledge, tools and the ability to analyze their earthquake risk and develop effective mitigation strategies. It helps them make a plan and act to reduce risk. The program supports community resilience. FEMA uses NETAP to quickly train organizations and communities. The NETAP Resource Guide for Earthquake Program Managers explains what training topics are available. This includes trainings on the FEMA P-154 RVS assessment method described above. It also describes how states and territories can request NETAP assistance.

6.

SETTING THE EARTHQUAKE MITIGATION STRATEGY

CONNECTION TO THE HMP: USE THE RISK ASSESSMENT TO DEVELOP A MITIGATION STRATEGY

(Element C of FEMA's Local Mitigation Planning Policy Guide and Element C of FEMA's Tribal Mitigation Plan Review Guide)

A mitigation strategy is the heart of the HMP. It serves as the long-term blueprint for reducing the potential losses identified in the risk assessment. The mitigation strategy describes how the community will carry out the mission of the planning process.

A mitigation strategy includes making goals, setting mitigation actions, and ranking those actions. Goals are what the community wants to achieve with the plan. Actions are the projects and activities that will help it reach those goals. The mitigation action plan details and prioritizes each action.

A mitigation strategy must have three main parts: goals, actions, and a plan to carry the actions out.

The mitigation strategy must analyze a thorough range of actions or projects. Actions must focus on reducing the risk to people, the environment, and the existing buildings, structures, and lifelines infrastructure. They must also limit the risk to new buildings and redevelopment. A thorough range means that you consider actions that span all types of solutions. Mitigation actions tend to fit in four categories. These include:

- PLANS AND REGULATIONS: These are government authorities, policies, or codes that affect the ways land and buildings are developed or reused. This can include programs that financially support mitigation.
- STRUCTURE AND INFRASTRUCTURE PROJECTS: These are ways to upgrade current public and private buildings and lifelines infrastructure, or build new structures, to protect them from hazards.
- EDUCATION AND AWARENESS PROGRAMS: These programs teach community members, elected officials, and property owners about hazards and ways to mitigate their risk. Consider the whole community in education and awareness programs. Target property owners, renters, and the unhoused populations.
- NATURAL SYSTEMS PROTECTION: These actions reduce damage and losses while preserving or restoring the functions of natural systems.

The following sections give examples of earthquake mitigation actions for three of the four action types. Note that commonly recognized natural systems protection actions do not reduce the impacts of earthquakes. As this guide will continue to point out, *earthquakes are different from most other hazards*. What might apply for more frequent hazards like flooding might not apply here.

As you consider these mitigation action examples, remember to align the mitigation actions you choose to the assets and the capabilities you have identified in your community. Mitigation strategies need to be tailored to be successful.

6.1. PLANS AND REGULATIONS

Plans and regulations can ensure that future development does not increase hazard losses. Plans can identify current development patterns and trends. They can also note areas where future development should or should not occur. Local regulations and review processes affect the way land and buildings are developed and built.

6.1.1. ADOPT AND ENFORCE BUILDING CODES

Building codes and consensus design standards provide a minimum level of life safety protection throughout the country for all natural hazards, including earthquakes. Every $1 spent on mitigation that results in seismic building codes being met saves $12 in disaster repair and recovery costs.[16] Consider taking the following actions:

- Existing buildings present the greatest risk to the public. Adopt the International Existing Building Code (IEBC) and International Residential Code (IRC) or an equivalent. These contain seismic provisions for existing buildings and residential structures, respectively. These provisions may trigger retrofit requirements. This helps to mitigate the risk of notably hazardous buildings and conditions.
- Adopt and enforce up-to-date building code provisions. This helps to reduce the risk of earthquake damage. You may want to adopt requirements that are made to meet your community's specific conditions and go above the code minimum. Going beyond minimum code and standards provides greater protection.
- Adopt local retrofit programs to improve the resilience of some building types. To get started, refer to FEMA's Natural Hazard Retrofit Program Toolkit. This is a guide for designing a resilient building retrofit program in your community. Appendix C for this guide has worksheets to help you plan an inventory collection. They were developed as part of a FEMA Region Inventory Analysis Workshop in 2021. They are also in the Appendix of the Natural Hazard Retrofit Program Toolkit. These worksheets will help you take a more holistic approach as you build your retrofit inventory. Some examples of local retrofit programs include:
  - The California Earthquake Authority provides earthquake insurance to state residents. It launched the Brace + Bolt Retrofit Program, partially funded by FEMA's BRIC grant program, to build the resilience of homes throughout the state. This subsidized program is a model of balancing low cost, effectiveness, and public engagement. It even lists pre-trained, licensed contractors who can do the retrofit work.
    - Los Angeles and San Francisco have a mandatory retrofit program for multi-unit, wood-framed buildings with soft or weak first stories.
    - The Los Angeles Non-Ductile Concrete Retrofit Program is a mandatory retrofit program in one of America's largest cities. Los Angeles determined in 2015 that it needed to retrofit or tear down all non-ductile concrete buildings in the city by 2040. You can learn more about this program on their website.
    - Seattle has adopted a plan for residential seismic retrofitting. This will make it easier for homeowners to retrofit qualified homes. This plan was made in partnership with FEMA and the Seattle Office of Emergency Management.

[16] NIBS, Natural Hazards Mitigation Saves: 2019 Report, 2019

PUTTING IT TOGETHER: RETROFITTING EXAMPLE

The mitigation planning process builds on itself. Putting together an inventory helps you know what might be at risk in an earthquake. The analysis of the inventory highlights buildings and areas that are good targets for mitigation. Problem statements in your HMP are the bridge between the risks and the actions in your strategy. The analysis and problem statements should help you narrow them down. You can pick and prioritize activities to reduce your risk. Consider these factors when you prioritize buildings to mitigate the risk. Think about physical characteristics and social traits:

- Type of construction.
- Building design.
- Distance from other buildings.
- Building size.
- Building age.
- Number of occupants, by hours occupied.
- Number of occupants, by building size.
- Whether the structure is needed for post-disaster response and recovery.
- Building use (residential, commercial, public, industrial, etc.).
- Tenure (owner-occupied or rental).
- Socioeconomic status of the neighborhood.
- Historical and community value.

The mitigation strategy must describe the criteria used to prioritize actions. This applies to all actions in the strategy -- not just the ones from your inventory analysis. However, it is helpful to show in your HMP how you prioritized the structures in your inventory.

Once you have prioritized the structures, build the details of the retrofit project for the HMP's action plan. Start with the specific action you want to take. From that, identify the buildings whose risk you will reduce first. Write out how you plan to retrofit those buildings. Then, identify:

- The position, office, department, or agency that will carry out the action.
- Possible funding sources.
- Likely time frames for completion.

6.1.2. PROVIDE FINANCIAL INCENTIVES

Financial incentives can be a strong driving force to get people to act. They can help provide the means to reduce risk in areas with a lower average income, or for property or building owners who are in poverty. To see what approach could have the most impact for your community, find the areas with the greatest need for financial support. Examples include:

- Provide financial incentives such as low interest loans, tax breaks, or grants, for home and business owners who retrofit their structures.

6.1.3. INCORPORATE EARTHQUAKE MITIGATION INTO PLANNING

Local planning and ordinances can be help to reduce earthquake risk:

- Create a working group or safety committee to recommend policy changes. They can assess and comment on seismic safety and mitigation actions. They can also assess earthquake safety improvements each year.
- Develop guidelines or pass ordinances to keep lifelines, buildings, critical facilities, and hazardous materials out of near-fault areas that are at high risk from earthquakes. You could model this after California's Alquis-Priolo Special Study Zones Act. This act prevents construction on the surface trace of known, active faults.
- Add actions to ongoing plans and activities in the capital improvement plan to seismically strengthen structural and non-structural features. Add priorities and timelines for actions to be achieved. This will let facilities operate and improve in safety for years to come.

CONNECTION TO THE HMP: FUTURE DEVELOPMENT

(Element B2-b of FEMA's Local Mitigation Planning Policy Guide)

Think about the structures that already exist as well as what might be built in the future. Your HMP must describe land uses, identified growth areas, development trends, and demographic changes. This positions mitigation options to be considered in future land use decisions.

6.1.4. MAP AND ASSESS COMMUNITY RISK TO EARTHQUAKE HAZARDS

These activities help you understand and assess local earthquake risk. They will also inform other planning or investment decisions. On their own, they do not lower earthquake risk. However, they provide data that can inform decisions that lead to lower risk. Consider the following:

- Create an inventory of public and commercial buildings that may have a high risk of earthquake damage. Include URM structures, pre-1940s homes, and homes with cripple wall foundations. This can be a powerful action if you do not have the resources to do a full inventory for the HMP. As an action in the mitigation plan, this signals a need for more investment in the inventory.
- Collect geologic information on seismic sources, soil conditions, and related potential hazards.
- Create or find an earthquake scenario to estimate a community's potential loss of life, injuries, types of damage, and existing risk. This will help you set priorities to manage the earthquake risk.
- Use Hazus to estimate losses from an earthquake.
- Use GIS to identify and map hazard areas and at-risk structures. Map areas with related hazards, such as liquefaction and landslide risk.
- Update review processes to include inspections of bridges. This will show if they are prone to collapse and need a retrofit.

6.1.5. INSPECT FOR BUILDING SAFETY

Inspections reduce risk by catching potential problems, fixing them, and assessing risks more regularly:

- Set up a school survey procedure and guidance document to use for taking inventory of all the school buildings in the jurisdiction. Use it to inventory structural and non-structural hazards in and around school buildings.
- Use RVS (see Section 5.2.1) to quickly inspect a building. RVS could reveal disaster damage. It could also reveal potential seismic structural and non-structural weaknesses. Use these data to prioritize retrofit efforts or inventory high-risk structures and critical facilities. These data can also be added to the ATC-20 Post Earthquake Safety Evaluation of Buildings Program. Then, you could use them to assess post-disaster risk to see if buildings are safe to reoccupy.
- Determine if at-risk buildings can withstand tsunami loads. The latest edition of the consensus design standard is ASCE/SEI 7-22. It contains a chapter on tsunami loads and effects. This chapter provides design criteria for Tsunami Risk Category III and IV structures. These larger and more critical structures can be designed to withstand tsunami loads. However, a community evacuation program addresses the tsunami risk to less critical residential structures. This program is based on NOAA's tsunami warning system.

6.2. STRUCTURE AND INFRASTRUCTURE PROJECTS

These projects involve modifying existing structures and infrastructure to protect them from a hazard or remove them from a hazard area. This could apply to public or private structures as well as critical facilities and infrastructure. This type of action also involves projects that build structures to reduce the impact of hazards.

Reduce the potential for seismic events to damage critical facilities and infrastructure. Critical facilities include all public and private facilities that a community deems key to the delivery of vital services (including post-disaster response and recovery); protection of special populations; and other crucial services.[17] Examples of ways to reduce risk to critical facilities and lifelines include:

- Retrofit critical facilities with the greatest earthquake risk.
- Require hospitals to brace generators, elevators, and other vital equipment. Bracing prevents them from moving, falling, or breaking during a hazard event.
- Identify and harden critical lifeline systems, such as utilities and roads. Refer to American Lifelines Alliance guidance. This may keep a small to moderate event from becoming a social, environmental, and economic disaster.
- Use flexible piping when extending water, sewer, or natural gas service into buildings and to equipment or where infrastructure, such as pipelines, crosses active faults.
- Find out where water mains cross fault lines. Then, install shutoff valves and emergency connector hoses where water mains cross fault lines.

[17] FEMA Risk Management Series Design Guide, 2007

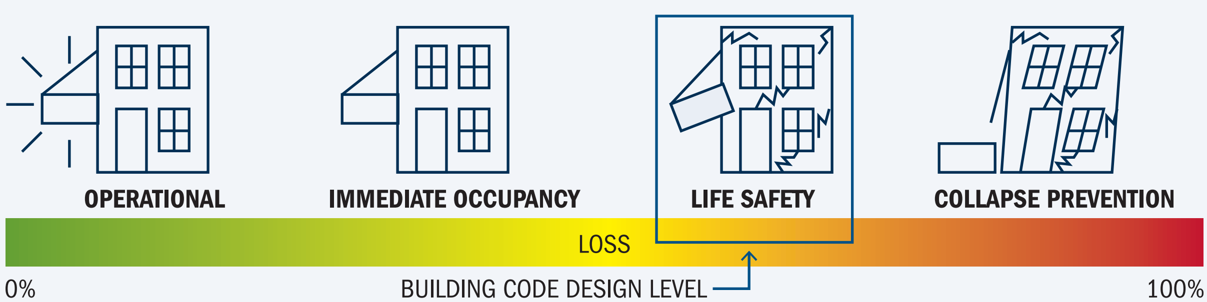
6.2.1. USE STRUCTURAL TECHNIQUES TO REDUCE RISK

Structural measures can reduce the damage from earthquake events.

- **URM buildings** have a high risk of collapse from ground shaking. For these buildings, there are many options. The safest would be to demolish the building and replace it with a new, code-compliant building. Another would be to install a new structural system that would carry the load for the URM walls. Other measures include strengthening the wall-to-floor or wall-to-roof connection. However, these should be designed by a registered design professional. A temporary measure could be to brace the roof parapets. Parapets are a small half-wall that surrounds the roof. They often fall, even in minor earthquakes. Use triangular metal braces to anchor them to the roof.
- Strengthen soft story buildings at the ground level. Refer to "Seismic Evaluation and Retrofit of Multi-Unit Wood Frame Buildings with Weak First Stories" (FEMA P-807) and "Guidance and Recommendations for the Seismic Evaluation and Retrofit of Multi-Unit Wood Frame Buildings with Weak First Stories" (FEMA P-807-1).
- Assess **non-ductile concrete buildings** using "Seismic Evaluation of Older Concrete Buildings for Collapse" (FEMA P-2018). If the building is found to be a collapse hazard, retrofit the structure using ASCE/SEI 41.
- For older **tilt-up concrete buildings**, have an engineer inspect the wall panel to roof framing connections to make sure they are strong enough. If they are not, have the engineer design a new connection detail that will strengthen them to withstand earthquake loads.
- For **residential cripple walls**, anchor the cripple wall to the foundation. Then, properly secure wood sheathing to the interior of the cripple wall. Compared to all other retrofit options mentioned here, retrofitting cripple walls is cheap and simple.
- Consider how earthquake retrofitting can overlap with energy savings upgrades. Combining retrofits to reduce earthquake risk and increase energy efficiency can save a lot of money. Spending on energy efficiency can be a waste of resources if a building will not withstand an earthquake.
- Some communities cannot reach high ground within the time available for a near-source tsunami. You can learn about building a Vertical Evacuation Structure (VES) in "Guidelines for Design of Structures for Vertical Evacuation From Tsunamis" (FEMA P-646).

FUNCTIONAL RECOVERY AND LIFE SAFETY

The focus of current building codes is keeping lives safe. This means they aim to have a high chance that damage from an earthquake will not be enough to injure or kill people. However, earthquakes can still damage buildings enough to make them unfit for immediate operation or occupancy. The figure below shows the different levels of building design. If the community's goals go beyond life safety, it may need to plan to build and retrofit to levels beyond code.



6.3. EDUCATION AND AWARENESS PROJECTS

Public education and awareness activities teach community members, elected officials, and property owners about hazards and potential ways to mitigate them. Although this type of mitigation reduces risk less directly than structural projects or regulation, it is a vital foundation. Greater knowledge of hazards and risk among local officials, stakeholders, and the public is more likely to lead to direct actions.

6.3.1. INCREASE EARTHQUAKE RISK AWARENESS

There are many ways to raise awareness of earthquake risk:

- Work with the insurance industry to help boost public awareness of earthquake insurance. In some states, home improvements may help to lower your deductible. Teach homeowners and renters about earthquake insurance coverage which could be part of their earthquake recovery plan. Earthquake insurance is not included in homeowner's insurance and must be purchased separately. In many cases, federal loans or aid can help to cover the insurance deductible. The insurance policy would then cover the rest of the damage.
- Create a community outreach program on reducing earthquake risk in homes, schools, and businesses. Empower people to reduce their own risk.
- Create and run a public safety campaign on steps to follow before, during, and after an earthquake. Provide outreach materials and programming in all languages the community speaks. Make sure materials are available both online and in paper for residents who may have little to no internet access. Some campaign examples include:
  - Use the FEMA Earthquake Safety Checklist. This quick reference guide helps people prepare for an earthquake and prevent earthquake-related damage to their homes.
  - Teach the public what to do when they feel the ground shake or receive an earthquake early warning alert: Drop, Cover, and Hold On. People should get to the floor, cover their head, and if possible, get under a sturdy table and hold on in case it moves.
  - Encourage people to take part in the Great Shakeout. This is a day of earthquake awareness where communities worldwide join in an earthquake drill.
- Offer GIS hazard mapping online for residents and design professionals.
- Use tabletop exercises to understand earthquake scenarios.

Cascadia Rising was a tabletop scenario exercise run by Washington State. It was based on a Cascadia Subduction Zone (CSZ) event. It tested how to prioritize critical ground transportation routes. It also assessed the area's emergency mass care service and support. The State Military Department and Emergency Management Division hosted this exercise. Over 600 participants took part in it. This included tribal partners, the private sector, faith-based organizations, healthcare providers, higher education and school districts, nongovernmental and nonprofit organizations, cities, counties, state agencies, and federal partners. Cascadia Rising helped the state find ways to improve in high-priority areas. Tabletop exercises are a great way to find gaps. They can help you learn what to expect from an earthquake on a given fault. Cascadia Rising events have also been hosted in other states, such as Oregon and California.

6.3.2. REACH OUT TO BUILDERS, ARCHITECTS, ENGINEERS, AND INSPECTORS

Buildings prone to earthquake damage can be improved. Professionals may need to know the proper designs and requirements. Reach out relevant staff to help improve capabilities:

- Hold information sessions or other events on earthquake codes. Discuss the codes for new and existing buildings. The goal is to improve code use by local architects, engineers, contractors, and others, and improve enforcement by the community.
- Train building department staff and officials on using ATC-20 for post-earthquake building evaluation. The Applied Technology Council prepared the ATC-20 report and its addendum. They have guidelines for on-the-spot evaluations and deciding about the continued use of buildings damaged by earthquakes.

6.3.3. PROVIDE INFORMATION ON STRUCTURAL AND NON-STRUCTURAL RETROFITTING

Help property owners learn more about how to retrofit existing structures to reduce damage from earthquakes:

- Teach residents how to find and hire a qualified contractor to perform structural and non-structural retrofitting of at-risk homes.
- Create a technical assistance information program for homeowners and their contractors. Teach them how to strengthen their houses to resist earthquake damage. The program can also offer local government building departments copies of existing earthquake or seismic retrofitting and repair information to share. One example of these materials would be the "South Napa Earthquake Recovery Advisory: Earthquake Strengthening of Cripple Walls in Wood Frame Dwellings" (FEMA P-1024).
- Encourage efforts to follow FEMA's "Earthquake Safety at Home" (FEMA P-530). This includes securing furnishings, storage cabinets, and utilities, to prevent injuries and damage. Examples include anchoring tall bookcases and file cabinets; installing latches on drawers and cabinet doors; restraining desktop computers and appliances; using flexible connections on gas and water lines; mounting framed pictures and mirrors securely; and anchoring and bracing propane tanks and gas cylinders.
- Promote Earthquake Early Warning (EEW) technology where available. This may include encouraging the public to download a warning app. In addition, communities may want to install automated failsafe systems for critical equipment or facilities when they receive an EEW. For example, the Bay Area's BART train system can automatically slow trains if it receives an EEW alert. This helps to reduce the likelihood of injuries.

7.

USING THE HMP TO FUND EARTHQUAKE MITIGATION PROJECTS

Identifying potential funding sources for earthquake mitigation projects can be challenging. Before you take a deep dive into funding, review your priorities and goals. Many funding options may be available. Some might not actually use the word “earthquake” in the funding name or description. However, there are sources that have broad categories of allowable activities that do include earthquake mitigation.

Another strategy for earthquake mitigation work is to fund individual tasks of large projects. This may be easier than seeking funds for the entire project. Often, smaller tasks can be completed for much less than the cost of the overall project. Also, smaller tasks such as inventory data and collection or project outreach may have deliverables that can be used for many other projects.

Multi-hazard mitigation can open the door to even more chances to reduce risk. Let’s say an earthquake mitigation project is in a flood-prone area. You may be able to add an analysis of earthquake hazards into the scope of flood mitigation work. If you are working to improve energy efficiency or reduce carbon related to climate change, you may be able to take on both efforts. Many funding sources prioritize multi-hazard mitigation when choosing which projects to fund. Many funding sources also give a high priority to projects that engage a collaborative group. As such, it helps to include partners on your project proposal.

It is key to choose the funding source that best supports your community’s goals.

CONNECTION TO THE HMP: FUNDING YOUR MITIGATION ACTION PLAN

(Element C1-a of FEMA’s Local Mitigation Planning Policy Guide and Element C2 of FEMA’s Tribal Mitigation Plan Review Guide)

The mitigation strategy includes an action plan. This must identify the details of the action and potential funding sources. Keep in mind that you do not have to use the specific grant or funding stream that is listed in your mitigation strategy. Still, you must list potential funding sources to provide some initial guidance.

As described in Section 2.1, some grant programs require an HMP.

7.1. AVAILABLE FUNDING SOURCES

Many local, state, and federal funding sources are available. Look for funds from emergency services or emergency management departments, natural resource departments (such as Fish and Wildlife), and housing and community programs. Reach out to agencies with similar interests. This may be your state insurer's office or congressional representatives. Non-profits and other organizations may also have funding. Express your interest in hazard mitigation investment.

7.1.1. LOCAL FUNDING

Local funding sources might include capital improvements project funding or the authority to levy taxes for specific purposes. Other options include taking on debt through general obligation bonds or special tax bonds.

7.1.2. STATE FUNDING

Individual states manage grant programs. For instance, Business Oregon runs a competitive grant program with funding for critical public buildings in Oregon. This program is called the Seismic Rehabilitation Grant Program. In other states, you may have access to Governor's Emergency Funds or competitive programs through state agencies.

FEMA works with the USGS, the National Institute of Standards and Technology (NIST), and the National Science Foundation (NSF) to manage the National Earthquake Hazards Reduction Program (NEHRP) Earthquake Assistance Grant Programs. The mission of the NEHRP is "to reduce the risks of life and property from future earthquakes in the United States through the establishment and maintenance of an effective earthquake risk reduction program."

FEMA NEHRP provides direct funding to eligible high earthquake hazard states through Individual State Earthquake Assistance (ISEA). It also offers regional funding through Multi-State and National Earthquake Assistance (MSNEA). Both aim to reduce earthquake risk at the national, state, and local levels. Allowable activities for ISEA funding include:

- Seismic mitigation planning.
- Inventories and safety evaluations of buildings and critical and lifeline infrastructure.
- Updating building and zoning codes and ordinances to improve seismic safety.
- Increasing earthquake awareness and education.
- Taking part in emergency management exercises that greatly benefit earthquake mitigation efforts.
- Promoting earthquake insurance.
- Helping multi-state groups support activities allowed under ISEA funding.

Applications for NEHRP ISEA funding are submitted through your state. Review the seismic hazards section of your state and local mitigation plans to find specific priorities when you develop your application.

7.1.3. FEDERAL FUNDING

FEMA's HMA provides funding for eligible mitigation measures that reduce hazard impacts and disaster losses. HMA includes the HMGP, BRIC, and Flood Mitigation Assistance (FMA). FEMA's HMA Guidance describes all HMA programs. HMA grants require that the applicant or subapplicant provide a cost share. In other words, FEMA normally funds 75% of the project cost; the applicant or subapplicant must pay 25% of the project costs.

7.1.3.1. HAZARD MITIGATION GRANT PROGRAM

HMGP offers SLTTs funds to plan and reduce risk and the loss of life and property from future natural disasters. HMGP funding is available when authorized through a major disaster declaration. A governor, tribal chief executive, or equivalent may request that HMGP funding become available to the state or territory that was affected by the declared disaster. To learn more, see FEMA's "How a Disaster Gets Declared" webpage. Many earthquake activities are eligible under HMGP. This includes structural and non-structural retrofits and improvements to existing earthquake early warning systems (both equipment and installation).

CASE STUDY: MURRAY, UTAH, SCHOOL DISTRICT SEISMIC RETROFITS

Around 2010, the Murray School District chose to mitigate its risk of future earthquakes and other hazards through a multi-year retrofit program. It brought all of its campuses to current earthquake safety standards. PDM and HMGP grants made this work possible. It had been some time since any seismic activity had been seen along the Wasatch Front. However, Murray County's school buildings were built between the 1950s and the 1970s. Retrofits were found to be more cost effective than building new structures. When HMGP funds were made available in 2011 after severe flooding, Murray County applied for funding through the state. It was granted $910,516 for the seismic retrofit of Riverview Junior High. In 2013, FEMA approved Murray County's Multi-Hazard Mitigation Plan. This let them apply for yearly PDM grants. FEMA awarded the county two grants (about $2 million). These funds allowed them to seismically retrofit four elementary schools. They used local bond funds to retrofit the other campuses. In March 2020, these retrofit efforts paid off when the Magna Earthquake hit. Only one campus reported damage, which was nonstructural. Had more serious damage occurred, a new building could have cost $40 million. This project is seen as a success because it started with local planning and priorities. Murray County used two federal grant programs and raised local funds to carry out these efforts.

To find out more, read the full story.

7.1.3.2. BUILDING RESILIENT INFRASTRUCTURE AND COMMUNITIES

BRIC supports SLTTs as they take on projects to reduce their risk from disasters. The BRIC program's guiding principles are to support communities through:

- Building capability and capacity.
- Encouraging and enabling innovation.
- Promoting partnerships.
- Enabling large projects.
- Staying flexible.
- Providing consistency.

The BRIC program funds projects and offers communities non-financial Direct Technical Assistance (DTA). DTA can support overall planning and project work. Communities do not need an approved HMP to be eligible to apply for BRIC DTA.

Note that BRIC applicants who are classified as Economically Disadvantaged Rural Communities (EDRC) are eligible for an increased FEMA cost share. In other words, FEMA would pay for 90% of the project costs; the applicant would only have to match that with a 10% cost share. EDRCs are communities of 3,000 or fewer people with residents having an average per capita annual income no more than 80% of the national per capita income.

7.1.3.3. MULTI-HAZARD MITIGATION FUNDING

Flood Mitigation Assistance (FMA) is focused on flood hazards but presents a chance to make a multi-hazard mitigation project to address both flood and earthquake vulnerabilities. FMA is a grant program that offers funds to SLTTs. The funds can be used for projects that reduce or eliminate the risk of repetitive flooding to buildings insured by the National Flood Insurance Program.

7.1.4. UNDERSTANDING FEMA PROJECT GRANTS

7.1.4.1. ELIGIBILITY AND REQUIREMENTS

Entities eligible to apply to the HMA programs include the emergency management agency or a similar office of each state, the District of Columbia, territories, and federally recognized tribal governments. This includes Alaska Native villages and organizations. Each of these groups must choose one agency to serve as the applicant for each HMA program. Therefore, in most cases, the state emergency management agency is the primary applicant.

A subapplicant must apply following their required state, territorial, or tribal process. Be sure to work closely with your State/Territory Hazard Mitigation Officers (SHMO), Tribal Mitigation Officer, or other critical partners to meet agency and FEMA requirements.

TABLE 2. ELIGIBLE SUBAPPLICANTS BY GRANT PROGRAM

Eligible Subapplicants			
Entity	**HMGP**	**BRIC**	**FMA**
State agencies	X	X	X
Federally recognized tribes	X	X	X
Local governments/ communities†	X	X	X
Private nonprofit organizations	X		

† Local governments may include non-federally recognized tribes. A local government as defined in 44 CFR 201.2 may include any Indian tribe or authorized tribal organization, or Alaska Native village or organization that is not federally recognized per 25 U.S.C. 479a et seq.

Before you apply for a grant, look into how to manage external funding sources. Determine whether your team has the experience it needs to successfully manage the funds. It is best to know ahead of time if you will need more support or resources.

When you apply for a grant, you will have to submit a Scope of Work (SOW). This will define all tasks, costs, and effects of the project. Preparing the SOW and its timeline and budget can take a lot of time and money (see the project scoping/advance assistance below as a funding resource). However, the SOW is key to a successful application for grant funding. Common parts of a SOW include:

- A detailed description of the project. This should include the problem the project will address, the decision process to carry out the project, task details and who will do them, and existing conditions.
- Timeline (major milestones).
- Cost estimate (itemized budget, federal-share and non-federal match/cost share).
- Maintenance plan. This may be required, based on the project.
- Complete information about environmental or historic preservation issues.

7.1.4.2. ELIGIBLE ACTIVITIES

To be eligible, activities must meet all requirements referenced in the HMA Guide. Eligible activities fall into three categories:

1. Capability and capacity building (non-construction):
   - Mitigation planning and planning-related activities.
   - Project scoping/advance assistance.
   - Partnerships.
   - Technical assistance (financial/non-financial).
   - Codes and standards.
2. Mitigation projects (construction).
3. Management costs.

Examples of some eligible earthquake-related projects are provided below. You can learn more in the HMA Program and Policy Guide.

TABLE 3. EXAMPLE EARTHQUAKE-RELATED ELIGIBLE ACTIVITIES

Example Eligible Activities			
Activities	**HMGP**	**BRIC**	**FMA**
1. Capability and Capacity Building			
Planning-Related Activities	Yes	Yes	No
Project Scoping/Advance Assistance	Yes	Yes	Yes
Codes and Standards	Yes	Yes	No
Innovative Capability and Capacity Building[†]	Yes	Yes	Yes
2. Mitigation Projects			
Retrofit	Yes	Yes	Yes[†]
Secondary Power Source (i.e. Generators, microgrids)	Yes	Yes	No
Earthquake Early Warning System	Yes	Yes	No
Innovative Mitigation Project[††]	Yes	Yes	Yes
3. Management Costs	Yes	Yes	Yes

[†] Only flood-related retrofitting projects are eligible.

[††] Innovative capability- and capacity-building activities and innovative mitigation projects not described in the HMA Guide will be evaluated on their own merit against program requirements. Eligible activities will be approved on a case-by-case basis if assistance is available.

7.1.4.3. CAPABILITY- AND CAPACITY-BUILDING FUNDING ACTIVITIES

HMA programs offer options to assist applicants and subapplicants during the project scoping and development process.

Planning-Related Activities

SLTTs rely on HMA planning grants to create a thorough planning process. To strengthen these processes, FEMA supports activities that relate to planning under HMGP, HMGP Post Fire, and BRIC. This aid reduces risk and works hazard mitigation principles into planning for resilience. Planning related activities include creating and updating mitigation plans; conducting risk and vulnerability assessments for earthquakes; and adding climate adaptation information.

Project Scoping/Advance Assistance

Project scoping and advance assistance activities let applicants and subapplicants create strategies and sort their data to prioritize, select, and develop timely and complete applications. Advance assistance projects are authorized under HMGP and HMGP Post Fire. Project scoping is authorized under BRIC and FMA. Eligible earthquake activities include scoping, engineering design, and feasibility studies. They also include outreach with subapplicants and the owners of substantially damaged structures. This involves reviewing project options and giving engineering and design support.

7.1.4.4. PROJECT COST-EFFECTIVENESS

Per authorizing statutes, only cost-effective mitigation measures are eligible for potential funding from FEMA. FEMA will often assess the cost-effectiveness of hazard mitigation projects through a Benefit-Cost Analysis (BCA).

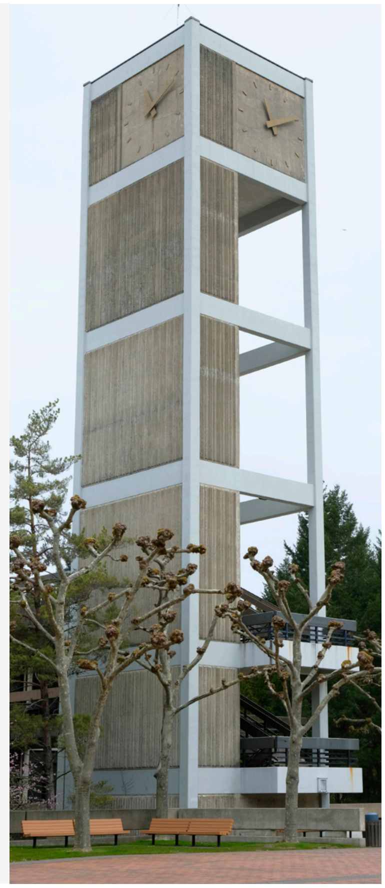
Benefit-Cost Analysis

BCA is a quantitative analysis used to assess the cost-effectiveness of a hazard mitigation measure. It compares the project's avoided future damage to the costs over the project lifetime. The result is a Benefit-Cost Ratio (BCR). When the estimated project benefits are greater than the project's costs, the project is considered cost effective. Benefits may include avoided damage, loss of function, and displacement. FEMA has BCA software that guides subapplicants through the BCA process. For BCA policies, an overview, and software, see FEMA.gov.

CASE STUDY:
THE EVERGREEN STATE COLLEGE SEISMIC RETROFITS

In February 2001, the M6.8 Nisqually earthquake hit on a fault more than 35 miles under the Nisqually Delta, 11 miles north of Olympia, Washington. Olympia and the Evergreen State College were strongly impacted. The earthquake cracked walls in core academic buildings. At first, epoxy injections were used to stabilize the structure. In light of this earthquake, the area needed a functional emergency response plan and an Emergency Operations Center. Evergreen's Environmental Health and Safety Coordinator focused on seismically retrofitting buildings. This work used planned renovations, as well as grants for standalone projects. In 2003, Evergreen joined Thurston County in their first HMP. Most funds for this work came from the HMGP. A few years after the college adopted the HMP, the Environmental Health and Safety Coordinator studied FEMA grants in depth. She attended online and in-person training, including on the BCA. With this knowledge, she secured HMA funds. The college completed four retrofit projects by 2018. This work will ensure the safety of students in future earthquake events. It will also boost the continuity that colleges and universities depend on.

To learn more, visit: FEMA.gov.



5% Initiative

Some mitigation activities are hard to evaluate with FEMA-approved cost-effectiveness methods. Up to 5% of the recipient's HMGP ceiling may be set aside to pay for such activities. The 5% Initiative allows a wide range of earthquake activities to be eligible. This includes public awareness and education; evaluation of building codes; and hazard identification and mapping.

To learn more about FEMA's mitigation opportunities, please refer to the Hazard Mitigation Assistance Program and Policy Guide.

FEDERAL FUNDING OPPORTUNITIES

FEMA is not the only source of federal funding for earthquake mitigation projects. Grants are available through various agency programs including, but not limited to:

- The U.S. Department of Housing and Urban Development's (HUD's) Community Development Block Grant Program.
- HUD's HOME Investment Partnerships Program.
- HUD's Office of Community Planning and Development.
- The U.S. Bureau of Land Management's Wildland Urban Interface Community Fire Assistance Program.
- The U.S. Department of Agriculture's Programs and Services.

8.
CONCLUSION

Earthquakes are unique among natural hazards. They are no-notice events that are impossible to predict and may not occur often. They can have serious impacts in a community. Knowing this, you can act now to reduce the risk of damage, injuries, and deaths from earthquakes. This guide walked you through how to plan for and reduce earthquake risk. Using the lens of the HMP, you now know:

- The wide range hazards from earthquakes and their impacts on different types of buildings.
- How to build and use an inventory for mitigation action.
- How to set a risk reduction strategy for earthquakes.
- How to use funding sources to move from the plan to action.
- How to plan with the whole community in mind and focus on those with the highest risk.

Remember, you are not in this alone. The FEMA staff in your region can help. Work with the mitigation planners to understand the HMP. Engage with the engineers to learn risks and retrofit options. Talk to the grant managers to connect to funding opportunities. You can also work with your Tribal, Territorial, or State Hazard Mitigation Officer.

9.
APPENDIX

APPENDIX A. GLOSSARY

Aftershocks
Earthquakes that occur after a large earthquake. These can go on for hours, days, weeks, months, or even years.

Afterslip
The ground can continue to deform after an earthquake happens. This process is known as afterslip. This can occur through aftershocks or slower slip that doesn't produce shaking. When afterslip occurs near the surface, it can cause major ongoing damage for months to years after a large earthquake.

Amplitude
Earthquakes release energy in waves of different sizes. The size of a wave is known as its amplitude.

Area
The area of the fault that slips.

Building
A building can be a structure with two or more outside rigid walls and a fully secured roof and is affixed to a permanent site. A building may also be a manufactured (mobile) home built on a permanent chassis or moved to its site in one or more sections and affixed to a permanent foundation. It may be a travel trailer without wheels that is built on a chassis, affixed to a permanent foundation, and regulated under the community's floodplain management and building ordinances or laws. "Building" cannot refer to a gas or liquid storage tank, a recreational vehicle, a park trailer, or another similar vehicle, except as described above.

Critical Facilities
All public and private facilities deemed by a community to be vital to the delivery of vital services, protection of special populations, and provision of other services of importance for that community.

Earthquakes
A sudden release of energy that creates a movement in the Earth's crust. An earthquake sequence usually includes foreshocks, a mainshock, and aftershocks.

Earthquake Scenarios
A scenario to show the potential results of damaging earthquakes at a known fault. Scenarios do not show the "worst case" event. They show the most likely size and impacts that can reasonably be expected to occur. Earthquake scenarios describe the fault, including its location and length. They also note the type of earthquake, expected magnitude, and range of impacts to people, structures, and communities. Scenarios include maps, figures, and suggested resources. They help you know what to expect so you can prepare for an event and mitigate the risk.

Environmental and Historic Preservation (EHP)
This process ensures that people follow federal laws to preserve the environment and historic features when using federal grant funds. It also considers how this work could affect, protect, and enhance natural and cultural resources.

Epicenter
The location on Earth's surface directly above the hypocenter.

Fault
The boundary or fracture between two rocks, where movement occurs. Faults are common at plate boundaries where two or more tectonic plates touch.

Foreshock
Earthquakes that happen before the largest earthquake in a sequence (i.e., the mainshock).

Hazard Mitigation
Actions that reduce or eliminate the long-term risk to people and property from the effects of hazards. A mitigation activity is a measure, project, plan or action designed to reduce the risk of future damage, hardship, loss, or suffering from disasters.

Hazard Mitigation Plan (HMP)
The basis of a long-term strategy to reduce disaster loss. It can be prepared by an SLTT. It helps to break the cycle of disaster damage, reconstruction, and repetitive damage. As stated in 44 CFR § 201.1(b), "The purpose of mitigation planning is for state, local and Indian tribal governments to identify the natural hazards that impact them, to identify actions and activities to reduce any losses from those hazards, and to establish a coordinated process to implement the plan, taking advantage of a wide range of resources."

Hypocenter
The location within the Earth where an earthquake starts.

Induced Earthquake
An earthquake caused by human activity (as defined by USGS).

Interplate Earthquakes
Earthquakes that occur in a plate boundary where two or more tectonic plates touch.

Inventory
A list of community assets. It usually has specific information on or features of each asset. It is used to help find gaps, shortages, needs, and changes to assets. It can also help measure successes.

Landslide
Large blocks of a hillside or cliff that destabilize and move downhill.

Lateral Spread
The flow of land on a gentle slope. It occurs if the ground is shaken long enough and contains enough water.

Liquefaction
The movement of soil like a liquid. It can occur when large amounts of water are in a soil made up of sand and similar loose and visible grains. Shaking from an earthquake can cause the mixture of water and soil to flow like a liquid. Liquefied soils cannot support buildings and structures.

Magnitude
Magnitude is expressed as a number up to 10. It is calculated using the strength of the rock (rigidity), the area of the fault that slipped (area), and the distance the fault moved (slip). A magnitude (M) 5.3 earthquake, for example, would happen on a smaller fault (i.e., smaller area) and have less slip than an M6.3.

Natural Hazard
Environmental events that can impact societies and the human environment. These hazards can be:

- Atmospheric (tropical cyclones, thunderstorms and lightning, tornadoes, windstorms, hailstorms, snow avalanches, severe winter storms, and extreme summer weather).
- Geologic (earthquakes, tsunamis, landslides, land subsidence, volcanic eruptions, and expansive soils).
- Hydrologic (floods, storm surges, coastal erosion, and droughts).
- Other (wildfires and volcanic eruptions).

Nature-Based Solutions
Actions defined by the World Bank as those taken "… to protect, sustainably manage, or restore natural ecosystems that address societal challenges such as climate change, human health, food and water security, and disaster risk reduction effectively and adaptively, simultaneously providing human well-being and biodiversity benefits."[18]

Non-Federal Match/Cost Share
The proportion of the costs of a federally assisted project or program not borne by the federal government. It may include any combination of cash, third-party in-kind services, or materials. For FEMA, both the federal and the non-federal shares must be eligible costs used in direct support of activities that FEMA has approved in the grant award.

Retrofitting
Making changes to existing structures to reduce the impacts of natural hazards. This is a way to adapt to evolving hazards and a tool for reducing disaster risk.

Rigidity
The strength of a rock.

Risk
The potential for damage or loss when natural hazards interact with communities and community assets.

Seismic Functional Recovery
Per the International Code Council, "… buildings are not only designed and constructed for life safety, but also to support the basic intended functions of the building's pre-earthquake use and occupancy within a maximum acceptable time."

ShakeMaps
A product of the USGS Earthquake Hazards Program in conjunction with the regional seismic networks. ShakeMaps provide near-real-time maps of ground motion and shaking intensity following significant earthquakes.[19]

Slip
The distance a fault moves.

Soft or Weak Story Buildings
A building without enough structural support at the ground floor.

Surface Fault Rupture
A crack or fracture that can appear in the ground when one side of a fault moves in one direction and the other side moves in another.

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[18] World Bank, What You Need to Know About Nature-Based Solutions to Climate Change, 2022
[19] USGS, ShakeMap, 2024

Tsunami
Giant waves caused by an earthquake on an underwater fault or another event that causes a big up and down movement on the seafloor (e.g., underwater landslides or volcanic eruptions).

Whole Community
One of the guiding principles in preparedness. It refers to involving all types of people in this process and making sure their roles are reflected in the content of materials. By working together, everyone can help keep the nation resilient. The whole community includes:

- Individuals and families. This includes those with access and functional needs.
- Businesses.
- Faith-based and community organizations.
- Nonprofit groups.
- Schools and academia.
- Media outlets.
- All levels of government. This includes state, local, tribal, territorial, and federal partners.

The benefits of the whole community include a more informed, shared understanding of community risks, needs, and capabilities; more resources through the empowerment of community members; and more resilient communities. More knowledge of a community's needs and capabilities also leads to a more efficient use of existing resources.

Vulnerability
The chance that a negative outcome from a hazard will actually happen (e.g., building collapse).

APPENDIX B. CONSTRUCTION AND STRUCTURE TYPES

A building's construction or structure type and age are the two most vital pieces of information on how it will perform in an earthquake. This section describes some common construction types. It also explains the known risks of poor earthquake performance based on their building materials and ages. Finally, it shares how communities have worked mitigation against each construction type into their existing building codes.

9.1.2.1. UNREINFORCED MASONRY BUILDINGS AND CHIMNEYS

Description

URM structures are built with bricks (like standard red clay bricks) or concrete masonry units (otherwise known as concrete or cinder blocks) that are held together with mortar. They excel at supporting the building vertically under normal use and snow accumulation. They also tend to be fire resistant. URM structures were a popular building type for centuries. However, as the term "unreinforced" suggests, they do not use any metal reinforcing bars to make them stronger and more durable (ductile). Most URM buildings have weak connections between the walls and the roof as well as between the walls and floors/foundation. This makes URM structures weak to the extreme side-to-side movement caused by earthquakes. They can be heavily damaged even during medium-sized earthquakes and can easily collapse.

URM is now rarely used in areas of moderate to high earthquake risk. However, since bricks resist fire, they were commonly used to build chimneys in more recent buildings that otherwise used more modern methods. Today, the codes for modern brick chimneys tend to require reinforcing steel. Such codes are acceptable.

Historic Earthquakes and Impacts to URMs

URM buildings unfortunately have a long history of heavy damage during earthquakes. Long Beach, California, had an M6.4 earthquake in 1933. This earthquake caused heavy damage to many URM school buildings. Fortunately, school had been dismissed for the day when the earthquake occurred. Still, this was the first step toward the 1936 Field Act, which, along with some other laws, banned the use of URM in California.[20]

The 1935 M6.2 Helena Valley, Montana, earthquake also caused heavy damage to URM buildings.[21] Other examples of earthquakes that have damaged URMs include Nisqually, Washington (2001, M6.8),[22] Wells, Nevada (2008, M6),[23] Trinidad, Colorado (2011, M5.3), Mineral, Virginia (2011, M5.8),[24] and Magna, Utah (2020, M5.7).[25] These earthquakes are notable examples and have driven local, state, and federal actions related to earthquake mitigation.

Building Codes and URMs

URM damage has been addressed in building codes throughout regions of the country in the past several decades. As noted above, URM construction was effectively banned in California in 1936. Widespread use of URM in some areas of high earthquake hazards was limited by the 1960s. In areas such as Utah, where the earthquake risk was not as well understood, URM construction was allowed into the 1970s.

Since the 1990s, most jurisdictions in California have had mandatory retrofit programs for URM buildings. In Los Angeles and San Francisco, the locally adopted and amended building codes required all existing URM buildings to be retrofitted. To date, there are no required retrofit programs outside of California. However, jurisdictions such as Seattle and Portland are developing such programs.

Required retrofits for URM buildings can be triggered by major renovation work or reroofing. This applies in areas of high seismic hazard, under provisions in the IEBC, from 2012 onward.

9.1.2.2. SOFT OR WEAK STORY STRUCTURES

Description

A soft or weak story building is one without enough structural support at the ground floor to withstand horizontal loads (like those caused by earthquakes). Buildings with soft or weak stories can suffer serious damage at that level. The entire ground floor can collapse, bringing down the entire building.

It may seem strange to have a building weak where it needs the most strength. Soft or weak stories are an accidental byproduct of designing or altering the ground floor to be accessible to pedestrians. They might have store display windows, restaurant patios, large doors, etc. The ground floor might be designed for vehicle access or parking. It might include garage doors or entrance ramps. Making room for this access can result in walls that are not long enough to fully support the structure or are missing altogether. The most common example is a multi-unit, wood-framed residential building with an open side or sides for ground floor parking. This is known as “tuck-under parking.”

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[20] California Department of Conservation, The 1933 Long Beach Earthquake
[21] KTVH News, 86th Anniversary of the 1935 Helena Earthquake, 2021
[22] Washington Military Department, Remembering the Anniversary of the Nisqually Earthquake, 2023
[23] Utah Geological Survey, UGS Responds to the Magnitude 6.0 Wells, Nevada, Earthquake, 2008
[24] USGS, 10-Year Anniversary of US’s Most Widely Felt Earthquake, 2021
[25] Utah, 2020 Magna Earthquake, 2021

Historic Earthquakes and Impacts to Soft Story Structures

The M6.9 Loma Prieta earthquake in California's San Francisco Bay Area in 1989 and the M6.7 Northridge earthquake in southern California in 1994 showed the impact on soft -story buildings. Many buildings, including multi-unit residential buildings, collapsed.

Building Codes and Soft Story Structures

The soft or weak story condition is most common in multi-unit wood-frame buildings. However, not every building of this type has a soft story. This was more common before the mid-1970s, when building codes first addressed "irregular" structures. This type of structure was defined as those that have a lower story with less lateral strength or stiffness than the story immediately above it. However, building codes didn't clearly define this condition and impose major limits until the 1990s. FEMA P-807 gives a detailed history of the types and building code requirements for soft or weak story wood-framed structures. Soft or weak story buildings are no longer an allowable structure type where earthquake resistant design is necessary.

9.1.2.3. NON-DUCTILE CONCRETE STRUCTURES

Description

Concrete is extremely strong under compression. It is much weaker and more brittle when bent or pulled. Steel reinforcing rods (rebar), on the other hand, are strong when bent or pulled but can buckle easily when the ends are compressed. Reinforced concrete joins the two materials. It combines their strengths and minimizes their weaknesses.

Since concrete is brittle when bent, engineers must pay close attention to how much rebar is used, where it is placed, and how it connects in the areas where beams and columns come together (known as joints) as well as within columns and walls. This is known as "detailing." If this detailing is not done properly, the reinforced concrete will be more brittle than intended. That is known as non-ductile concrete.

Non-ductile concrete is significant because:

- Reinforced concrete can be used to construct buildings that can hold a lot of people (schools, medium-sized office buildings, apartment buildings, etc.).
- It can fail suddenly and violently during earthquakes.

Historic Earthquakes and Impacts to Non-Ductile Concrete Structures

One notable example of non-ductile concrete failure took place during the M6.6 San Fernando earthquake in 1971. A brand-new hospital building at the Olive View Hospital in Sylmar, California, that had just opened was severely damaged. Three people died as a result of the earthquake. This dramatic failure served as a wakeup call for the risk of non-ductile buildings.

Building Codes and Non-Ductile Concrete Structures

After the surprising damage caused by the San Fernando earthquake, the 1976 edition of the Uniform Building Code (UBC) addressed several issues. One of these issues was the reinforcement of non-ductile concrete buildings.

However, many older concrete frame buildings were built before these guidelines. These non-ductile concrete buildings present a big risk. Thankfully, not all older concrete buildings are collapse hazards. However, finding those that are collapse hazards can be a complex process.

9.1.2.4. TILT-UP CONCRETE CONSTRUCTION

Description

Tilt-up concrete buildings are built using massive reinforced concrete walls. The walls are poured to harden flat at ground level at a project site. As the name suggests, they are then tilted up to stand vertically. Metal attachments fasten the walls to each other, the foundation, and the metal- or wood-framed roof. This structure type allows for a rapid construction of large, open buildings such as warehouses, industrial facilities, and “big box stores.”

The major concern with tilt-up buildings is that the walls are very large and heavy. The engineering details connecting the wall panels to each other, the roof, and the foundation are crucial. Good seismic performance requires strong connections of the wall panels to the roof framing. If not designed and built properly, these buildings can fall down as easily as they were put up.

Historic Earthquakes and Impacts to Tilt-Up Construction

Tilt-up buildings were damaged and walls failed in both the San Fernando (1971) and Northridge (1994) earthquakes in California.

Building Codes and Tilt-Up Construction

After the Northridge earthquake, building codes in the late 1990s began to require stronger connections between wall panels and roof framing. Los Angeles set up a program of mandatory mitigation for these buildings. Retrofit of their wall-to-roof connections can be triggered by major renovation work in areas of high seismic hazard. These are addressed under provisions in the IEBC from 2012 onward. Tilt-up construction is still allowed, but has stricter requirements in the building code now than before the late 1990s.

9.1.2.5. STEEL MOMENT FRAME STRUCTURES

Description

Structural steel is a ductile and durable material for buildings designed to resist earthquakes. Steel moment frames have a grid of steel beams and columns connected by rigid joints. Their frame stiffness resists horizontal earthquake forces. This system has often been used in mid- and high-rise office buildings dating back to the early 1960s. The type of beam-to-column connection is an important feature of these buildings where useable space is key. Older structures used bolted or riveted connection assemblies. Structures built from the late 1960s on used welded connections.

Historic Earthquakes and Impacts to Steel Moment Frame Structures

For many years, steel moment frames were considered to be one of the most ductile and resilient types of structural systems. The 1994 Northridge, California, earthquake exposed a flaw in the design of the welded steel connections. When subjected to extreme side-to-side swaying of the building, they could fracture. No collapses of steel moment frame buildings from earthquakes have been documented.

Building Codes and Steel Moment Frame Structures

An emergency code change to the 1994 UBC prohibited the pre-Northridge welded connection in new buildings. New connection requirements and design provisions were adopted into building codes. This began with the 2000 International Building Code (IBC). Many updates to the connection detailing requirements came in later codes.

No mandatory retrofit requirements exist for steel moment frame buildings. However, Los Angeles and San Francisco are both developing programs. These will likely consist of two main parts. The first will require looking for connection damage in moment frame buildings that were subjected to strong earthquakes. The second will require a structural evaluation and potential retrofit.

9.1.2.6. RESIDENTIAL WOOD FRAME-TO-FOUNDATION CONNECTIONS

Description

Wood frame buildings are the standard single-family home type across much of the United States today. They use wooden studs, flat sheets of plywood or oriented strand board, and gypsum board walls. Wood frame homes are relatively light, flexible, and redundant. This means that damage to one piece of wood will not result in a collapse. Of the structure types described here, they are among the most resistant to earthquake damage.

However, some wood frame homes have one glaring weakness. Many have a crawlspace that separates the first story from the foundation. These crawlspaces have benefits. They allow for airflow to reduce moisture buildup. They also separate habitable space from small-scale floods. The habitable space must be connected to the foundation by a short foundation wall. These foundation walls are normally made of concrete. However, a west coast practice up through the 1980's was to use wood frame "cripple walls." If not designed and built properly, these cripple walls can be a point of major weakness during an earthquake. When they fail, they cause the house to fall to the ground.

Historic Earthquakes and Impacts to Residential Homes

Damage to these buildings had been observed in many earthquakes (for example, the 1983 Coalinga and 1989 Loma Prieta). However, the 1994 Northridge, California, earthquake revealed the full risk posed by weak cripple walls in homes built before the 1970s. Widespread damage concentrated in the cripple walls of otherwise undamaged structures was repeatedly linked to this small-scale but impactful issue.

Building Codes and Residential Homes

Design practices, code requirements, and code enforcement for one- and two-family dwellings vary widely. They differ from jurisdiction to jurisdiction. The 1976 UBC is most often cited as a benchmark code for building a cripple wall. Homes built before the late 1970s or early 1980s with a crawlspace or basement could be at risk of this weak cripple wall anchorage or bracing.

Retrofitting of Existing Cripple Wall Residential Homes

The seismic retrofitting of existing cripple wall homes is a common practice. It normally consists of installing interior wood panel sheathing on the interior of the cripple wall and properly securing it to the frame. Then, the frame is properly anchored to the foundation. The California Earthquake Authority (CEA) "Brace and Bolt" program is a great example of a seismic retrofitting program that does such work.

APPENDIX C. ASSET INVENTORY WORKSHEETS AND TOOLS

The following worksheets were developed as part of a FEMA Region Inventory Analysis Workshop in 2021. They are included here to help you assemble your asset inventory. These tools will help you take a more complete approach to your inventory.

INVENTORY ANALYSIS WORKSHEET AND TOOLS

EXAMPLE LISTS

BUILDING INFORMATION EXAMPLES

- Building type
- Building materials
- Building purpose/use
- Design
- Age
- Degree of openness
- Number of stories
- Location
- Size
- Location in relation to other buildings

DATA SOURCES:

- U.S. Census
- County tax assessor parcel data
- Local housing element
- Local general or specific plans
- Local zoning code
- Open source maps (e.g. Google Earth/Maps)

COMMUNITY/NEIGHBORHOOD CHARACTERISTIC EXAMPLES

- Demographics
- Socioeconomic status
- Population density
- Historical and community value
- Housing type (single or multi family, etc.)
- Business type (corporate, small, family-owned, etc.)
- Number of occupants (by building size, by hours occupied, etc.)

DATA SOURCES:

- U.S. Census
- American community survey
- Priority development areas
- County quick facts
- Local general or specific plans
- Local housing element
- Local zoning codes
- County health department status reports
- Local general plan or specific plans
- Local housing element
- Nonprofit or community-based organizations

KNOW WHAT YOU WANT TO KNOW

Based on your risk assessment, you know where the vulnerable assets are in your community and what hazard(s) you want to address. Consider these questions to focus your search criteria.

What are your objectives? What will you be addressing with your building retrofit program (e.g., certain vulnerable construction types, particular housing types, etc.)?

INVENTORY ANALYSIS WORKSHEET AND TOOLS

What data will you collect? Consider the who, what, where, when, why and how for each building. Use the Building Information Examples and Community/Neighborhood Characteristic Examples above to help you define what data is required for your project.

Remember, not all information is relevant for all projects, so choose and collect only the data that is important for achieving your objectives. Sometimes, less is more.

Who uses the building? Owns it? Manages it?	**What** materials, techniques and codes were used in its construction?
Where is it located (in the community, in relation to other buildings, etc.)?	**When** was it built?
Why was it built? Was its original purpose different than its current use?	**How** is the building used (housing, commercial, industrial, etc.)?

TAKE A STEP BACK

Take a whole-community approach, collaborate with others and look at how an inventory could contribute to larger community goals. Consider these questions as you look at the big picture. What community goals could an inventory help address and how?

INVENTORY ANALYSIS WORKSHEET AND TOOLS

How could the data be used to support other ongoing or future projects?
Can it be used to serve multiple purposes?

What colleagues and departments could you collaborate with?
What datasets have they collected or used in the past?

Who is the target audience for the data? How will you present and deliver it for maximum impact and clarity?

SURVEY THE EXISTING DATA

Before starting, try to find all the data that has already been collected. Try to use existing datasets, rather than starting from scratch. Maybe all the information you need has already been collected. Consider these questions as you look for available datasets.

What datasets do other departments, agencies, partners, organizations, etc. have?

INVENTORY ANALYSIS WORKSHEET AND TOOLS

What information is available online from studies, research institutions, etc.?

Where else could you look for data?

Once you've surveyed the available datasets, see if they provide all the information you need. Is there any information you still need? If so, what?

COLLECT INFORMATION TO FILL DATA GAPS

Now that you know what information you still need, you can plan how to fill the gaps. Consider these questions as you review your options for collecting the data you still need.

Where might you be able to find the information you still need? Can you find it with research, mail-in or online questionnaires for building owners, or will you have to conduct a field survey?

INVENTORY ANALYSIS WORKSHEET AND TOOLS

If you must conduct a field survey, how will you do it and what technical expertise is required? Will you use current staff, volunteers, students, etc. to support the survey? What partners, organizations or agencies could you collaborate with?

LOOK FORWARD

Clearly document your data collection and management efforts. Give some thought to the format of your data. If feasible, avoid using proprietary data formats that will prevent or limit others from using the data. That way, you and others can easily go back and collect more information, if needed.

How will you manage the data so that it will get updated regularly and not lose its value? How can you incorporate it into your larger planning efforts and budget for it in the future?

APPENDIX D. ADDITIONAL RESOURCES

9.1.4.1. FEMA PUBLICATIONS

FEMA has published resources for the public to help mitigate risk of earthquakes. These include:

- Seismic Considerations for Communities at Risk (FEMA 83).
- Earthquake Safety and Mitigation for Schools (FEMA 395).
- Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds (FEMA P-424).
- Earthquake Safety at Home (FEMA P-530).
- Techniques for the Seismic Rehabilitation of Existing Buildings (FEMA 547).

9.1.4.2. DATA RESOURCES FOR YOUR INVENTORY

The following resources contain information on how to create an inventory and what it may include.

- National Center for Education Statistics.
- Critical Infrastructure Resilience Institute.
- SimCenter, Computational Modeling and Simulation Center.
- USA Structures, FEMA.
- Regional Resilience Toolkit - 5 Steps to Build Large Scale Resilience to Natural Disasters, Environmental Protection Agency (EPA).
- Open Geospatial Consortium, Data Implementation Standards.
- Creating a Global Building Inventory for Earthquake Loss Assessment and Risk Management, USGS.
- Central U.S. Earthquake Consortium Rapid Visual Screening App.
- Earthquake Engineering Research Institute.
- National Earthquake Hazards Reduction Program.
- The Central United States Earthquake Consortium (CUSEC), with support from Department of Homeland Security Science and Technology Directorate and NEHRP, has a series of templates for information sharing and field reporting. These resources can also be used for inventory collection. If your organization has GIS software, you can explore the CUSEC resources.

9.1.4.3. URM RESOURCES

The following resources contain information on how to reduce earthquake risk for URM structures.

- Unreinforced Masonry Buildings and Earthquakes: Developing Successful Risk Reduction Programs (FEMA P-774).
- Wasatch Front Unreinforced Masonry Risk Reduction Strategy (fema.gov).
- Unreinforced Masonry Buildings - What & Why - SDCI | seattle.gov.

9.1.4.4. SOFT OR WEAK STORY STRUCTURE RESOURCES

The following resources contain information on how to reduce earthquake risk for soft or weak story structures.

- Seismic Evaluation and Retrofit of Multi-Unit Wood-Frame Buildings with Weak First Stories (FEMA P-807).
- Guidance and Recommendations for the Seismic Evaluation and Retrofit of Multi-Unit Wood-Frame Buildings with Weak First Stories (FEMA P-807-1).
- San Francisco Mandatory Soft Story Seismic Retrofit Program.
- Los Angeles Soft Story Retrofit Program.

9.1.4.5. NON-DUCTILE CONCRETE STRUCTURE RESOURCES

The following resources contain information on how to reduce earthquake risk for non-ductile concrete structures.

- Seismic Evaluation of Older Concrete Buildings for Collapse Potential (FEMA P-2018).
- Techniques for the Seismic Rehabilitation of Existing Buildings (FEMA P-547).
- Non-Ductile Concrete Retrofit Program | LADBS.

9.1.4.6. TILT-UP CONCRETE STRUCTURE RESOURCES

The following resources contain information on how to reduce earthquake risk for tilt-up concrete structures.

- Seismic Retrofit: Strengthening Tilt-Up Structures.

9.1.4.7. STEEL MOMENT FRAME STRUCTURE RESOURCES

The following resources contain information on how to reduce earthquake risk for steel moment frame structures.

- Seismic Provisions for Structural Steel Buildings (AISC 341-16).
- Seismic Design of Steel Special Moment Frames: A Guide for Practicing Engineers, NEHRP Seismic Design Technical Brief No. 2, NIST GCR 16-917-41.
- Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment Frame Buildings (FEMA 351).
- Recommended Post Earthquake Evaluation and Repair Criteria for Welded Steel Moment Frame Buildings (FEMA 352).
- Recommended Specifications and Quality Assurance Guidelines for Steel Moment Frame Construction for Seismic Applications (FEMA 353).
- A Policy Guide to Steel Moment-Frame Construction (FEMA 354).

9.1.4.8. RELATED EARTHQUAKE INFORMATION FOR HOMEOWNERS

The following resources contain information for how homeowners can reduce earthquake risk to their homes.

- Homebuilder's Guide to Earthquake-Resistant Design and Construction (FEMA P-232) | FEMA.gov.
- Earthquake Country Alliance: Welcome to Earthquake Country!
- What Are the Structural Earthquake Risks of a Stem-Wall House? | CEA (earthquakeauthority.com).
- Earthquake Safety at Home (FEMA P-530).
- Earthquake County Alliance.