

PDH Academy

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SEISMIC DESIGN BASICS FOR ARCHITECTS DESIGNING BUILDINGS FOR EARTHQUAKES

Course #: AIAPDH278
3 LU | HSW Hours

SEISMIC DESIGN BASICS FOR ARCHITECTS

DESIGNING BUILDINGS FOR EARTHQUAKES

FINAL EXAM

- Earthquake resistant design is also referred to as?**
 - Tectonic design
 - Seismic design
 - Resilient design
 - None of the above
- “A table holding up a lamp” is an example of what type of force?**
 - Normal Force
 - Gravitational Force
 - Applied Force
 - Electrostatic Force
- What kind of force causes earthquakes?**
 - Centripetal force
 - Gravitational force
 - Lateral force
 - Electromagnetic force
- Which of the following are classifications of earthquakes by origin?**
 - Tectonic
 - Volcanic
 - Explosion
 - All of the above
- Energy released by earthquakes travels in which of the following types of “Body” waves?**
 - P, S
 - W, R, P
 - Both a & b
 - None of the above
- The Richter scale measures what characteristic of an earthquake?**
 - Magnitude
 - Intensity
 - Location
 - Relative strength
- Which of the following are considered collateral hazards of an earthquake?**
 - Landslides
 - Tsunamis
 - Fires
 - All of the above
- Which earthquake resulted in the passage of the Field and Riley Acts in California?**
 - 1923 Kanto earthquake
 - 1908 San Francisco earthquake
 - 1933 Long Beach earthquake
 - 1978 Palm Springs earthquake
- Which agency is considered the foremost global body representing national earthquake engineering societies?**
 - UNESCO Global Seismic Code and Guidelines Platform
 - International Association for Earthquake Engineering (IAEE)
 - Global Seismographic Network (GSN)
 - International Seismological Centre (ISC)
- Which of the following are partners within NEHRP?**
 - USGS
 - FEMA
 - NIST
 - All of the above
- An example of a building in IBC Risk Category III would be:**
 - Fire Station
 - A luxury residence
 - Hospital
 - Agricultural storage structure
- The structure widely cited as the oldest surviving earthquake resistant building is:**
 - Taj Mahal
 - The Wall of Constantine
 - Machu Pichu, Peru
 - Tomb of Cyrus the Great, Iran
- In Seismic Design, who is considered the “captain of the team”?**
 - Structural Engineer
 - Architect
 - Geotechnical Engineer
 - Seismic / Structural Peer Reviewer

14. **In which phase of design does an architect coordinate structural grids, shear wall placements and diaphragm layout for seismic design?**
- A. Construction Documents
 - B. Design Development
 - C. Schematic Design
 - D. These are structural engineering responsibilities, and the architect does not engage
15. **In the United States, which state requires a supplemental exam focused on seismic design to grant an architectural license?**
- A. Nevada
 - B. New York
 - C. Idaho
 - D. California
16. **Structural solutions for seismic design include which of the following?**
- A. Moment-Resistant Frames
 - B. Diaphragms
 - C. Braced Frames
 - D. All of the above
17. **What is “Isostatic” design?**
- A. A foundation designed to absorb strong dead loads
 - B. Use of cantilevered, irregular floors
 - C. A specialized, low-strength truss system that extends from the ground up to the top floor
 - D. A technique that inherently provides superior performance against lateral loading conditions
18. **The Taipei 101 building is famous for which seismic design element?**
- A. X-Bracing
 - B. Tuned Mass Damper
 - C. Mat foundation
 - D. Very tall mast at the top of the building
19. **One of the objectives of computational modelling and developing digital twins is?**
- A. To reduce embodied carbon of the life of the building
 - B. Eliminate the need for building codes
 - C. Simulate structural response under multiple earthquake scenarios
 - D. Replace the need for engineers in the design process
20. **ASCE 7 will likely continue to move _____ Performance-Based, _____ design.**
- A. In synch with, integrated
 - B. Away from, prescriptive
 - C. Toward, Risk-targeted
 - D. Into, Flexible

SEISMIC (EARTHQUAKE) DESIGN BASICS DESIGNING BUILDINGS FOR EARTHQUAKES

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Course Summary

When architects and engineers build structures, a fundamental aspect of designing the building is to enable it to withstand the many forces acting upon it and stand firm and stable. Regardless of where a building or structure is located, it must respond to the natural forces it encounters. These can range from the always present hydrostatic pressures on foundations and wind loads on the superstructure to more extreme and geography specific forces like Seismic, ice and thermal loads. This course will focus on Seismic (earthquake) forces and how buildings are designed to withstand the challenges posed by these forces.

The course is structured into four parts as noted below:

PART 1: BACKGROUND – The Nature of Seismic Forces

PART 2: REGULATIONS – The Codes and Categories Guiding Seismic Design for Public Safety

PART 3: SOLUTIONS – The Architectural and Engineering Responses to Mitigate Seismic Challenges

PART 4: FUTURE – Looking Beyond Surviving Earthquakes to Resilience and Active Adaptability

Learning Objectives

There are five main learning objectives of the course:

1. Understand the nature of dynamic Lateral forces and Seismic forces in particular.
2. Become familiar with how Seismic forces impact structures and the fundamental engineering used to provide stability and resilience in response to earthquakes.
3. Familiarization with the primary codes and regulations governing seismic design in the United States, including Seismic Design Categories, Seismic Zone Maps and key state specific requirements and broader Nationwide requirements.
4. Understand the complimentary roles of the Architect and Structural Engineer in addressing Seismic design solutions.
5. Examine how seismic design is evolving with the use of Smart structures, A.I., and new techniques that move beyond just preventing collapse to creating adaptive, resilient buildings that can regain rapid functionality following a design-level seismic event.

PART 1 – BACKGROUND: THE NATURE OF SEISMIC FORCES

1.1. INTRODUCTION

The Earth and everything on it are always in a state of motion. Some of the movements are obvious, others more subtle but still perceptible to human senses, yet others are seemingly static, even though at a molecular level nothing is ever completely stationary, not even things that are inanimate. What makes everything dynamic are the various types of forces in play throughout the universe. These forces of motion are pushes or pulls that change an object's movement. Based on current levels of understanding, these are categorized mainly as Contact Forces, Non-Contact Forces, Fundamental Forces and Specialty Forces.

• CONTACT FORCES¹

These types of forces result from physical contact between two objects. Examples are:

- Frictional Force: Opposes the relative motion between two surfaces in contact (e.g., brakes slowing a car).
- Normal Force: The upward support force exerted by a surface (e.g., a table holding up a lamp).
- Applied Force: A force directly applied to an object by a person or another object (e.g., pushing a door).
- Tension Force: Transmitted through a string, rope, or cable when it is pulled tight by forces acting from opposite ends.
- Spring (Elastic) Force: The force exerted by a compressed or stretched spring upon any object that is attached to it.
- Air Resistance (Drag): A type of friction that acts on objects as they travel through the air.

• NON-CONTACT FORCES²

Also known as “Action-at-a-Distance” forces, these act even when two objects are not in physical contact. Examples are:

- Gravitational Force: The attraction between any two objects with mass (e.g., the Earth pulling objects toward its center).
- Magnetic Force: Attraction or repulsion between magnetic poles.
- Electrostatic Force: Attraction or repulsion between two charged particles

• FUNDAMENTAL FORCES³

At the most basic level, scientists recognize four fundamental interactions that govern everything in the universe:

- Gravitational Force: Responsible for planetary orbits and keeping objects on the ground.
- Electromagnetic Force: Responsible for electricity, magnetism, and the structure of atoms.
- Strong Nuclear Force: The strongest force, which binds protons and neutrons together in an atom's nucleus.
- Weak Nuclear Force: Involved in certain types of radioactive decay and nuclear fusion.

• SPECIALTY FORCES⁴

Sometimes also called “Derived Forces”, these are specific manifestations or combinations of forces often used in engineering and daily life applications. Examples are:

- Buoyant Force (Upthrust): An upward force exerted by a fluid on an immersed object.
- Lift Force: An upward force that opposes weight, typically generated by wings moving through air.
- Centripetal Force: A center-seeking force that keeps an object moving in a curved path.
- Thrust: A force that moves an object forward, such as that produced by an engine.
- Van der Waals Force: Weak intermolecular forces that occur between neutral molecules.

Several of the above forces and many combinations of them act on buildings or structures in a variety of ways that can cause the structure to destabilize, in whole or in part. Of course, the intensity and direction of the force or forces play a significant role in how a structure is affected. Understanding the likely forces and their potential impacts on a structure is crucial to determining how to address, mitigate and, preferably, neutralize the impacts so that the structure remains stable and the motions have minimal to no perceptible effect on the users.

1 Physicsclassroom.

2 Ibid

3 www.science.nasa.gov: The Four Fundamental Forces

4 www.google.com

Since the scope of this course is on design for earthquakes (seismic design conditions), the most relevant set of forces are a special subset of forces known as “Lateral Forces”. These are generally Contact Forces (physical interaction of the structure with motion on the ground) or an applied force such as tectonic displacement). Lateral forces can sometimes be classified as non-contact such as wind loads (considered a microscopic contact force and categorized separately from mechanical contact forces). The term “lateral” typically describes the direction of a force (horizontal or sideways relative to an axis), the force is generally classified as a contact force, but that can depend on the context of the physical interaction.

For this course, the main forces of interest are those that directly lead to earthquakes. Lateral forces cause earthquakes when immense tectonic plate movements create horizontal stress (shear stress) along faults in the Earth’s crust. As plates slide, collide, or pull apart, friction locks them in place, causing deformation and energy buildup until the rock breaks, releasing energy as seismic waves.⁵

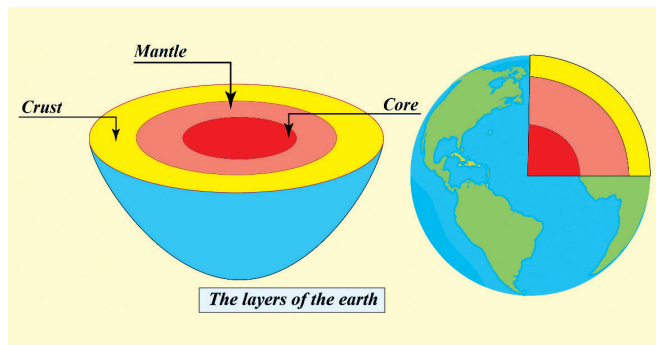
The next section will go into a deeper exploration of the way earthquakes develop and the seismic forces that create discernable ground movement.

1.2. SEISMIC FORCES – THOSE THAT CAUSE EARTHQUAKES

The word seismic will be used extensively in the course, often synonymously with earthquakes. “Seismic” literally means “relating to earthquakes or other vibrations of the earth and its crust”.⁶ A seismic force is the lateral, inertial or vertical force exerted on a structure due to ground acceleration during an earthquake. Unlike gravity loads, these dynamic forces are generated internally by the structure’s mass trying to resist movement. This typically causes horizontal shaking, or “base shear”.

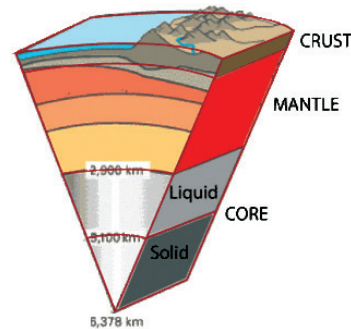
To better understand how seismic forces and earthquakes develop, it is worthwhile to understand basic earth geology and plate-tectonics.

In the most basic terms, the Earth is made up of three layers as illustrated below:



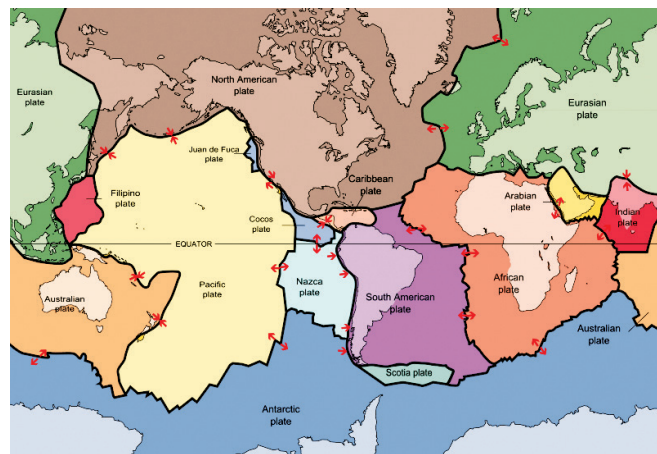
Source: Wikimedia Commons: Rajneesh Kumar Thakur; “The layers of the Earth model.jpg”.

Within these layers, the core has a liquid and solid part as illustrated below:



Source: USGS.gov /Public Domain
A simplified diagram of the crust (brown), mantle (orange), and core (liquid in light gray, solid in dark gray) of the earth.

The crust and the top of the mantle make up a thin “skin” on the surface of our planet. This rigid outermost shell is also referred to as the lithosphere. This is the layer humans and most life on earth lives on and where earthquakes are felt. This “skin” is not all in one piece – it is made up of many pieces like a puzzle covering the surface of the earth.⁷ The Earth’s lithosphere is divided into 7 major, 8 secondary, and dozens of minor/micro-plates that constantly move. The seven primary plates—Pacific, North American, Eurasian, African, Antarctic, Indo-Australian, and South American—make up roughly 94% of the Earth’s surface.



Source: USGS, <http://pubs.usgs.gov/publications/text/slabs.html>, public domain, via Wikimedia Commons

These pieces or plates keep slowly moving around, sliding past one another and bumping into each other. Geologists call these pieces tectonic plates, and the edges of the plates are called the plate boundaries. The plate boundaries are made up of many faults, and most of the earthquakes around the world occur on these faults. Since the edges of the plates are rough, they get stuck while the rest of the plate keeps moving. Finally, when the plate has moved far enough, the edges unstuck on one of the faults and there is an earthquake.⁸

An earthquake happens when two blocks of the earth suddenly slip past one another. The surface where they slip is called the fault or fault plane. The location below the earth’s surface where the earthquake starts is called the hypocenter, and the location directly above it on the surface of the earth is called the epicenter.⁹

5 Ibid

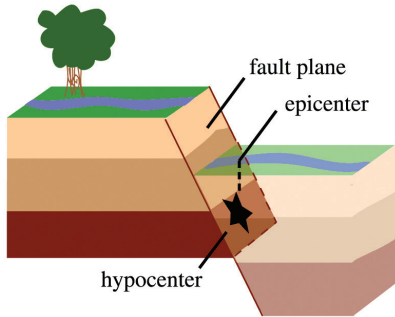
6 <https://languages.oup.com/google-dictionary-en/>

7 USGS.gov: The Science of Earthquakes

8 Ibid

9 Ibid

See illustration below:



Source: USGS.gov /Public Domain

A normal (dip-slip) fault is an inclined fracture where the rock mass above an inclined fault moves down

All earthquakes are not the same and the lateral forces that generate them cause different dynamics on the surface. These dynamics and how to navigate and manage them are what concern architects and engineers.

Earthquakes can be classified by fault movement or by trigger origin.

1. Classification by Fault Movement

The most common way to describe earthquake movement is through the type of fault rupture that occurs:

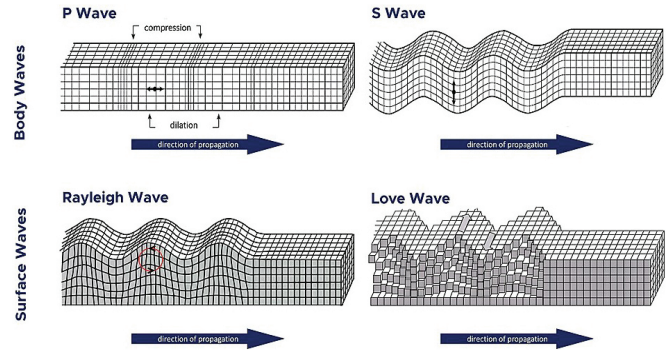
1. **Normal Earthquakes (Tensional):** These occur when two plates pull apart (divergent boundaries). One block of rock (the hanging wall) slides downward relative to the other (the footwall).
2. **Reverse or Thrust Earthquakes (Compressional):** These occur when plates push together (convergent boundaries). One block is forced upward and over the other. These are responsible for the world's most powerful "megathrust" quakes.
3. **Strike-Slip Earthquakes (Horizontal):** These occur when plates slide horizontally past one another (transform boundaries). The movement is side-to-side with little to no vertical displacement.
4. **Oblique-Slip Earthquakes:** These involve a combination of both vertical (dip-slip) and horizontal (strike-slip) movement.

2. Categories by Origin

- **Tectonic:** The most common type, caused by the sudden release of energy as tectonic plates slide past, collide, or pull away from each other. 90-95% of all earthquakes are of this type, occurring at plate boundaries.¹⁰
- **Volcanic:** Triggered by the movement of magma beneath the surface before or during a volcanic eruption.
- **Collapse:** Small earthquakes occur when underground caverns or mines collapse.
- **Explosion:** Caused by the detonation of chemical or nuclear devices

1.3. SEISMIC WAVES AND EARTHQUAKE INTENSITY

As we have seen in the previous section, the dynamics of tectonic movements and other geological phenomenon can create earthquakes. When the earthquakes do occur the energy, they unleash travels in waves that move the ground as "Body Waves" or "Surface Waves". These in turn are made up of a subset of waves as illustrated below:



Source: Wikimedia Commons Overview Seismic Waves

- **P-Waves (Primary):** Compressional waves that push and pull the ground in the same direction the wave travels (like a slinky).
- **S-Waves (Secondary):** Shear waves that move the ground up and down or side to side, perpendicular to the wave's path. These arrive after P-waves and cause more damage.
- **Surface Waves:** These travel along the Earth's surface and create a rolling or swaying motion, often responsible for the most severe structural damage.

Since all earthquakes are not the same, their impact is also variable. This makes it important to be able to measure or scale an earthquake. Measuring earthquake intensity (ground shaking/damage) and magnitude (energy released) is critical for assessing immediate danger, directing emergency response, and improving infrastructure resilience. These measurements allow engineers to design safer, earthquake-resistant structures based on local soil conditions and help officials update building codes to reduce future risks.

- **Intensity:** Measures the effects of an earthquake (what people felt, and damage caused) at a particular location. It is not a single value; it decreases farther from the epicenter.
- **Severity:** Describes the overall impact or damage level, sometimes synonymously with magnitude (energy released) or high-intensity shaking. This is helpful in determining the emergency response.

A single earthquake typically has one value for magnitude but may have multiple intensity values.

The above are measured differently. Intensity is rated by Roman numerals (e.g., MMI), while the overall size of an earthquake is measured by magnitude (e.g., Richter or Moment Magnitude scale). The description and illustrations below explain these scales:

The Modified Mercalli Intensity (MMI) scale: Measures the intensity of an earthquake at a given location. Intensity estimates are important because they allow us to characterize parts of any region into areas that are especially prone to strong shaking versus those that are not. The key factor in this regard is the nature of the underlying geological materials, and the weaker those are the more likely it is that there will be strong shaking. Areas underlain by strong solid bedrock tend to experience much less shaking than those underlain by unconsolidated river or lake sediments.¹¹

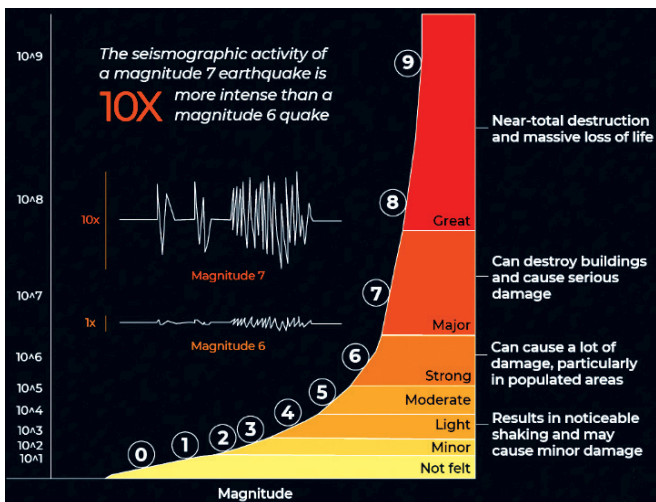
10 Google AI

11 Thompson Rivers University: ENVIRONMENTAL GEOLOGY; 6.3 measuring Earthquakes

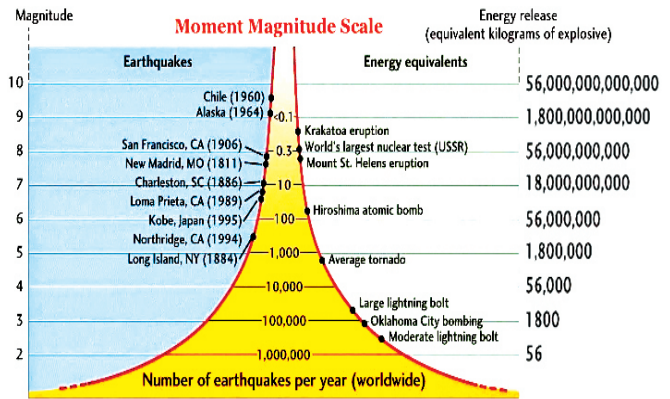
I	NOT FELT	Not felt except by a very few under especially favorable conditions.
II	WEAK	Felt only by a few persons at rest, especially on upper floors of buildings.
III	WEAK	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to that of a passing truck. Duration estimated.
IV	LIGHT	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	MODERATE	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	STRONG	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	VERY STRONG	Damage negligible in buildings of good design and construction; considerable damage in poorly or badly designed structures; some chimneys broken.
VIII	SEVERE	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	VIOLENT	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	EXTREME	Some well-built structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI	EXTREME	Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

The Modified Mercalli Intensity Scale ¹²

For measuring earthquake magnitude, the scale most people are familiar with is the Richter scale (ML). However, there is another, arguably more effective method called the Moment Magnitude Scale (MMS or Mw). Both are logarithmic scales (meaning each whole number increase represents a 10-fold increase in measured wave amplitude). Richter is an older, amplitude-based method suitable for small-to-medium earthquakes. The Moment Magnitude Scale is the modern, preferred standard for accurately calculating the total energy of large, distant earthquakes. The Richter scale “saturates” for large earthquakes, meaning it underestimates their size. The Moment Magnitude Scale is more reliable for massive earthquakes (i.e., Magnitude 7.0 or higher) ¹³



Richter Scale Source: United States Geological Survey.



Source: *Geology n*; “Moment Magnitude Scale: Definition, Importance, Uses”

Even though the Moment Magnitude Scale is preferred in the scientific community, The Richter scale remains the most popular in public discourse, partly because of its relative simplicity, familiarity and apparent scale of 10. It should be noted that neither of these scales has an upper limit since they are logarithmic but 10 is generally considered the theoretical limit for tectonic earthquakes. The largest earthquake recorded by instruments has been the 1960 Chilean Earthquake – the Valdivia Earthquake with a magnitude of 9.5 on the Moment magnitude Scale.

To measure the effect of an earthquake on the ground (ground motion), the following definitions are commonly used:¹⁴

- **Acceleration** is the rate of change of speed, measured in “g”s at 980 cm/sec² or 1.00 g.
 - For example,
 - 0.001g or 1 cm/sec² is perceptible by people
 - 0.02 g or 20 cm/sec² causes people to lose their balance.
 - 0.50g is very high but buildings can survive it if the duration is short and if the mass and configuration have enough damping
- **Velocity** (or speed) is the rate of change of position, measured in centimeters per second.
- **Displacement** is the distance from the point of rest, measured in centimeters.
- **Duration** is the length of time the shock cycles persists.
- **Magnitude** is the «size» of the earthquake, measured by the Richter scale, which ranges from 1-10. The Richter scale is based on the maximum amplitude of certain seismic waves, and seismologists estimate that each unit of the Richter scale is a 31 times increase of energy. *Moment Magnitude Scale* is a recent measure that is becoming more frequently used as noted above.

If the level of acceleration is combined with duration, the power of destruction is defined. Usually, the longer the duration, the less acceleration the building can endure. A building can withstand very high acceleration for a very short duration in proportion with damping measures incorporated in the structure.

Intensity is the amount of damage the earthquake causes locally, which can be characterized by the 12 level *Modified Mercalli Scale* (MM) where each level designates a certain amount of destruction correlated to ground acceleration. Earthquake damage will vary depending on distance from origin (or epicenter), local soil conditions, and the type of construction.

12 Ibid

13 Wikipedia; 2006

14 WBDG.org: Whole Building Design Guide; “Seismic Design Pribciples”

1.4. HOW EARTHQUAKES CAUSE DAMAGE TO BUILDINGS AND STRUCTURES

Given the nature of the forces that create earthquakes, it is clear that depending on the intensity and magnitude, these can cause severe disruption to the stability of the earth's surface where most buildings and structures are built and people live. The violent shaking of the ground leads to the destructive effects of earthquakes. The ground shaking is what triggers the vicious cycle of ruptures in the earth, which can result in landslides, tsunamis, tidal waves, liquefaction and fires. All these together, or individually, can lead to damage of personal property, infrastructure, and loss of lives.¹⁵

The magnitude of the earthquake is a factor in its destructive power but another, even more relevant factor for structures is the depth of the earthquake. Even if two earthquakes have the same magnitude, their depths can make a big difference in how much damage they cause and how strongly they are felt on the surface. Shallower quakes tend to be much more destructive because their energy has less distance to travel before reaching people and buildings.¹⁶

In deeper earthquakes, much of the energy dissipates as it moves through layers of rock. By contrast, shallow ones release their energy closer to the ground, producing stronger shaking and greater damage in populated areas.¹⁷

There are typically three measurements used to classify earthquake depth: shallow focus (0-70 km or 0-43 miles), intermediate focus (70-300 km or 43-186 miles), and deep focus (300-700 km or 186-435 miles).¹⁸

The degree to which earthquakes cause damage to buildings is influenced by the following primary factors:

Earthquake Characteristics:

- Magnitude and Depth: Higher magnitude and shallower earthquakes generally cause more intense, destructive shaking.
- Distance to Epicenter: Proximity to the fault determines the intensity of ground motion, with closer structures sustaining more damage.
- Duration and Frequency: Longer duration and specific frequencies of shaking can cause greater structural damage.

Site and Geological Conditions:

- Soil Type: Loose, water-saturated, or soft soils (e.g., clay) can amplify seismic waves and trigger liquefaction, increasing damage compared to solid rock.
- Topography: Hills or steep slopes can amplify ground shaking.

Building Characteristics:

- Design and Materials: Unreinforced masonry (URM) and rigid, non-ductile concrete buildings are highly vulnerable to collapse. Steel frames and wood-frame structures often offer better flexibility and resilience.
- Structural Configuration: Irregular shapes, tall buildings with flexible lower levels, and lack of reinforcement in joints increase risk.
- Age: Older buildings, built before modern seismic codes, are more susceptible to damage.
- Foundation: A solid foundation can mitigate damage, while weak foundations fail during violent shaking.

Secondary Effects:

- Pounding: Adjacent buildings colliding with each other.
- Collateral Hazards: Landslides, fires, and tsunamis initiated by the earthquake.

Below are some pictures showing the devastation that can result from earthquakes. The pictures are representative of various forms of damage incurred in a variety of places in the world and from quakes of varying intensity.



Muzaffarabad, Pakistan, 2005

Source: Wikimedia Commons; Gregory Takats / AusAID



Seward, Alaska after the Good Friday Earthquake of 1964.

Source: Wikimedia Commons; Public Domain



Earthquake damage in San Francisco's Marina District on the north side of the city from the Loma Prieta Earthquake October 17, 1989.

Source: Wikimedia Commons; Nancy Wong

15 CRMP.org: "How earthquakes cause Damage and Destruction"

16 aljazeera.com/news/2025/9/1/why-do-shallow-earthquakes-cause-more-destruction-than-deep-ones; by Marium Ali

17 Ibid

18 Ibid



Fukui Earthquake 1948 - damaged building.

Source: Wikimedia Commons; Bert Cohen; Public Domain



2023 Turkey Earthquake Damage Diyarbakir

Source: Wikimedia Commons; VOA; Public Domain



Earthquake Damage - Roads Christchurch, NZ

Source: Wikimedia Commons; Martin Luff; Public Domain



Semi-collapsed building - 2024 Hualien earthquake, China.

Source: Wikimedia Commons; Shufu Liu; Creative Commons

It is estimated that there are 500,000 detectable earthquakes in the world each year. 100,000 of those can be felt, and 100 of them cause damage.¹⁹ The damage that comes in the aftermath of an earthquake is magnified in areas of concentrated human habitation. Damage – physical, financial and psychological – increases in direct proportion to the population density of the area. As urbanization increases and our knowledge of seismic forces increases, it becomes imperative that regulations and design guidelines be put in place and practiced to mitigate the worst outcomes of an earthquake event.

This section has primarily focused on providing an introductory understanding of the forces that create earthquakes and the impacts of these. The next section will look at how we start the process of mitigation by examining the codes and regulations that have already been developed and those that may be evolving for future implementation.

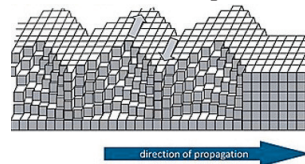
END of PART 1

PART 1 REVIEW QUESTIONS

1. Which layer of the earth is the portion where earthquakes are felt?
 - A. Mantle
 - B. Core
 - C. Lithosphere
 - D. Stratosphere

2. The location below the earth's surface where the earthquake starts is called the _____.
 - A. Fault plane
 - B. Hypocenter
 - C. Epicenter
 - D. Crust

3. This illustration depicts what kind of seismic wave?



- A. W wave
 - B. S wave
 - C. Love wave
 - D. Rayleigh wave
4. An earthquake of intensity “V” on the MMI scale would be classified as:
 - A. Violent
 - B. Weak
 - C. Severe
 - D. Moderate

5. Which of the following building characteristics are better for seismic design?

- A. Flexible steel frames
- B. Unreinforced masonry
- C. Irregular shape
- D. All of the above

PART 2 – REGULATIONS: GUIDING SEISMIC DESIGN FOR PUBLIC SAFETY

Awareness of earthquakes has existed for a long time, and builders have developed many techniques to enable seismic-resistant buildings. Most of these have been experience and observation based, not due to any formal codes, regulations or design guidelines.

The early seismic regulations emerged in the early years of the 20th century. Among the first were those developed in Italy in 1909. These were based on the performance of wood-framed buildings that experienced the earthquake of 1908. A commission ruled that buildings be designed to resist a lateral force of 1/12 (0.083) of their self-weight.²⁰

In the United States, it was not until 1906 when, following the San Francisco earthquake which, combined with the resulting fires, destroyed most of the city, consideration for lateral forces was introduced requiring a wind load of 30 lb./sq ft. While the intent may have been to address wind and seismic, no consideration was given to earthquake forces. However, this did prompt, albeit non-mandatory, research into addressing seismic design.

The first national seismic design code was adopted in Japan in 1924 following the 1923 Kanto earthquake in Japan, which destroyed large parts of Tokyo and Yokohama. This law required that a design seismic coefficient of 0.1g or more should be used for all important new structures.²¹

2.1. DEVELOPMENT OF SEISMIC CODES IN THE UNITED STATES

It was not until 1927 that the first appearance of seismic provisions appeared in the Uniform Building Code (UBC) enacted by the International Conference of Building Officials (ICBO). The seismic provisions were not mandatory and only featured in an appendix, but awareness and concern had been noted. In 1933 the Long Beach earthquake and its consequent damage to public buildings resulted in the passage of the Field Act and Riley Act in California.

- The Riley Act mandated that local governments establish building departments and ensuring structures are designed to withstand specific lateral forces (earthquake safety). It was a critical, early seismic safety measure, setting minimum structural standards for buildings across the state.²²
- The Field Act mandated strict seismic safety standards, plan reviews, and construction inspections for K-14 public schools, enacted following the 1933 Long Beach earthquake. It authorizes the Division of the State Architect (DSA) to approve designs and inspect construction to ensure earthquake resistance.²³

After these landmark pieces of legislation, the development and adoption of regulations for seismic design gained momentum and by 1943 Lateral forces requirements were introduced into the UBC. The Key details of the 1943 lateral force requirements include:

- Coefficient Formula: The 1943 UBC introduced a lateral force coefficient (C) based on the number of stories (N) above the story under consideration.

Formula: $C = 0.6 / (N+4.5)$

- Application: Each story was designed to resist a lateral shear force calculated as C times the dead load above that level.
- Height Limit: The code limited buildings designed under this formula to 13 stories, though this restriction was removed in later editions.

These provisions marked a shift from earlier, purely static, fixed-percentage lateral load calculations (such as the 8% rule in Los Angeles) toward methods accounting for building dynamics.

Below is a timeline of how the building codes have developed in the United States with respect to seismic design:²⁴

DATE	SIGNIFICANT MILESTONE
1906	San Francisco Earthquake prompts initial, non-mandatory research and improved building practices
1927	First appearance of seismic provisions in the Uniform Building Code (UBC), featuring a non-mandatory appendix for seismic design.
1933	Long Beach Earthquake triggers the Field Act and Riley Act in California, mandating the first statewide seismic regulations
1959	Lateral force requirements were adopted in the UBC, leading to stricter standards.
1971	Structural Engineers Association of California (SEAC) releases the "Blue Book," introducing lateral force recommendations that heavily influenced the UBC.
1977	San Fernando Earthquake highlights vulnerabilities in concrete buildings, spurring more rigorous, dynamic, and ductility-focused code changes.
1988	Passage of the National Earthquake Hazards Reduction Act (NEHRP), establishing a federal, coordinated approach to seismic safety.
	UBC adopts significantly updated, stringent seismic design, raising base shear requirements.
1994	Northridge Earthquake reveals severe vulnerabilities in welded steel connections, initiating major revisions to design standards.
2000	The first International Building Code (IBC) is published, consolidating regional codes (BOCA, SBC, UBC) and creating a unified national standard that is updated every three years.
2000 +	Evolution toward Performance-Based Design, focusing on limiting damage to structures rather than just preventing collapse.

20 Onlinelibrary.wiley.com: "Basic Structural Dynamics"; APPENDIX–HISTORICAL DEVELOPMENT OF BUILDING CODE SEISMIC PROVISIONS by James C. Anderson and Farzad Naeim - 2012

21 Ibid

22 Wikipedia

23 Ibid

24 Table developed by Author based on public information, Wikipedia and Google AI

2.2. GOVERNMENTAL AND REGULATORY AGENCIES INFLUENCING SEISMIC DESIGN

Building codes are the direct mechanism requiring architects and engineers to meet specific minimum design standards to address seismic conditions for a project. However, these codes are not developed in a vacuum. Behind the requirements are a host of supporting global organizations and agencies, both governmental and academic, that inform the seismic landscape globally and locally. The collective information provides the context for any seismic response that building designers must respond to. As discussed in Part 1, tectonic earthquakes are most likely to occur at the edges of the tectonic plates, and these are spread all over the globe. The plates do not recognize political boundaries and, therefore, beneficial understanding of tectonic movements and potential earthquakes requires a degree of international cooperation and consistency of regulatory response. To this end, there are several notable international organizations that study, track and provide guidelines on various seismic topics. The major organizations can be grouped in three categories as noted below. (*Note: These are not hard industry standard classifications but just way to help organize by focus*)

1. Primary Global Organizations with a Design and Engineering Focus

- **International Association for Earthquake Engineering (IAEE):** The foremost global body representing national earthquake engineering societies. It promotes international cooperation through the World Conference on Earthquake Engineering and maintains the influential publication *“Regulations for Seismic Design: A World List”*.
- **Global Earthquake Model (GEM) Foundation:** A public-private partnership that develops open-source software and data for seismic hazard and risk assessment. It recently launched the Global Seismic Regulations Database to analyze how building codes influence resilience across different regions.
- **UNESCO Global Seismic Code and Guidelines Platform:** consolidates international data on seismic codes to support disaster risk reduction.
- **International Code Council (ICC):** While based in the U.S. and largely adopted in the United States, the ICC provides the International Building Code (IBC), which serves as a global model for seismic design requirements in commercial and residential construction. The ICC family of codes is a source for many other national and regional codes worldwide.
- **European Association for Earthquake Engineering (EAEE):** Focuses on advancing seismic design practices across Europe.
- **Structural Engineers Association of California (SEAOC):** Develops seismic data and code recommendations, widely used internationally.

2. Tracking & Data Networks

- **Global Seismographic Network (GSN):** A permanent digital network of over 150 stations worldwide. It provides real-time data for earthquake location, tsunami warnings, and nuclear test monitoring in partnership with the USGS and EarthScope.
- **International Federation of Digital Seismograph Networks (FDSN):** Coordinates the international deployment of broadband seismometers and facilitates open data exchange between global networks.

- **International Seismological Centre (ISC):** A non-governmental organization that compiles the most definitive summary of world seismicity by collecting and re-analyzing data from global agencies.

3. Specialized Research, Regulatory & Policy Bodies

- **Earthquake Engineering Research Institute (EERI):** A multidisciplinary technical society that conducts post-earthquake reconnaissance through its Learning from Earthquakes program to improve future seismic design.
- **International Atomic Energy Agency (IAEA):** Establishes specific Safety Standards for Seismic Design for nuclear installations globally.
- **Pacific Earthquake Engineering Research Center (PEER):** A multi-institution center that develops performance-based earthquake engineering (PBE) technologies and guidelines for tall buildings and infrastructure.
- Numerous Geophysics Institutions throughout the world. In the United States the main body is the **USGS (United States Geological Survey)**. The USGS is part of the U.S. Department of the Interior. It began in 1879 to study the nation’s lands and resources. Today, the USGS mission is to monitor, analyze, and predict Earth’s changing systems. Among one of its primary functions is earthquake and volcano notifications.²⁵
- **National Earthquake Hazards Reduction Program (NEHRP) (USA):** Led by agencies like NIST (National Institute of Standards and Technology), NSF (National Science Foundation), and USGS to enhance seismic resilience through research and guidelines.
- **Geotechnical Extreme Events Reconnaissance (GEER):** An NSF-sponsored organization documenting earthquake impacts.
- **Lettis Consultants International (LCI):** Provides specialized seismic hazard analysis for critical infrastructure. LCI is reputed to have performed many Probabilistic Seismic Hazard Analysis (PSHA) studies for high-consequence facilities and are *“recognized throughout the United States and internationally as a leader in seismic hazard analysis for critical and other high consequence facilities”*.²⁶ Competitor firms to LCI, offering similar services, include Fugro, AECOM, WSP/Golder, Wood/AMEC, URS/AEI.

As is clear from the above discussion, there are many groups working on examining seismic activity and influence on building designs. In the United States, the following are the primary seismic regulatory and oversight bodies that govern earthquake safety (some are repetitive from the above list, but the focus of this part is on the US rather than a global view):

1. Building Codes (IBC, ASCE 7)

Building codes set minimum seismic design requirements for structures to protect life safety. They govern how buildings are designed, constructed, altered, and maintained.²⁷

- **Overseen By:**
 - International Code Council (ICC) publishes the International Building Code (IBC). Seismic design is part of Chapter 16; Section 1613. While Chapter 16 dictates the loads, specific material requirements for seismic resistance are also found in Chapter 18 (Soils and Foundations), Chapter 19 (Concrete), and Chapter 21 (Masonry).

25 Adapted from USGS website

26 MS CoPilot

27 Seismic Building Codes - FEMA.gov. <https://www.fema.gov/emergency-managers/risk-management/earthquake/seismic-building-codes>

- Local and state governments — adopt and enforce the codes.
- ASCE (American Society of Civil Engineers) — publishes ASCE 7, which defines seismic loads used in IBC.

- **Role in seismic safety:**

These codes are the primary mechanism for reducing earthquake risk in the built environment.

2. NEHRP (National Earthquake Hazards Reduction Program)

A federal program that coordinates national efforts to understand earthquake hazards and reduce risk. It shapes seismic provisions used in building codes.²⁸

- **Overseen By:**

NEHRP is a partnership among four federal agencies:

- FEMA — implementation, building codes, public safety.
- NIST — program lead, research coordination
- USGS — seismic hazard maps and science
- NSF — academic research funding

- **Role in seismic safety:**

NEHRP develops the Recommended Seismic Provisions, which form the technical basis for seismic requirements in the IBC.²⁹

3. Federal Seismic Safety Regulations (Executive Order 12699 & 49 CFR Part 41)

Federal rules require seismic safety for federally owned, assisted, or regulated buildings. CFR Part 41 implements Executive Order 12699, mandating seismic safety in federal construction.³⁰

- **Overseen By:**

- U.S. Department of Transportation (DOT)— responsible for developing and implementing seismic safety regulations for its mission areas.
- Other federal agencies implement similar requirements for their own facilities.

- **Role in seismic safety:**

Ensures federal buildings meet seismic safety standards, often referencing NEHRP provisions.

The table below summarizes the key seismic regulations and the bodies that regulate them:

REGULATION / PROGRAM	PURPOSE	OVERSIGHT BODY
IBC / ASCE 7	Seismic design requirements for buildings	ICC, ASCE, state/local governments
NEHRP	National coordination of earthquake hazard reduction	FEMA, NIST, USGS, NSF
49 CFR PART 41 / EO 12699	Seismic safety for federal buildings	U.S. DOT + other federal agencies
NEHRP RECOMMENDED SEISMIC PROVISIONS	Technical basis for seismic code updates	FEMA + Building Seismic Safety Council

For building design, perhaps the most important standard is the ASCE 7, which forms the backbone of seismic design for buildings in the United States and is widely used in other parts of the world. ASCE 7, titled “*Minimum Design Loads and Associated Criteria for Buildings and Other Structures*,” is the primary U.S. standard for determining the structural loads (forces) that buildings must withstand. Developed by the American Society of Civil Engineers (ASCE) and the Structural Engineering Institute (SEI), it is legally adopted by codes like the International Building Code (IBC) to ensure safety and structural integrity. It effectively is the seismic chapter in the IBC.

While architects and engineers take their cues for seismic design from the building codes, almost all buildings requiring seismic design in the United States follow a rigorous pipeline of governance that starts with a PSHA (Probabilistic Seismic Hazard Analysis), is filtered through USGS and NEHRP guidelines that feed the ASCE 7, which is incorporated by the IBC, which guides architects and engineers and whose provisions are ultimately enforced at the local level.

PSHA>USGS>NEHRP>ASCE7>IBC>Architects/Engineers>Local enforcement

2.3. THE TOOLS AND TERMINOLOGY FOR UNDERSTANDING SEISMIC DESIGN.

Since earthquakes are difficult to predict – in terms of when, where or how big, it is helpful if we can narrow down the statistically likely places and circumstances so that designers can take actions to apply appropriate seismic resistance into their projects. Similarly, having a system of classifications for building responses can help balance the financial risk for the degree of protection relative to the risk of the severity and likelihood of an event. Of course, as a means of safeguarding public safety and welfare, building codes provide minimum seismic design criteria. However, it would be grossly burdensome if seismic requirements were imposed universally across the board. Just as it does not make sense to impose hurricane or tornado resistance requirements in areas where such events are unlikely. Similarly, there is no reason to impose seismic design requirements in areas where geology suggests little to no likelihood of a significant event. Conversely, it is essential to know which areas are susceptible to seismic events and the degree of severity so that designers are mandated to account for these. While the codes and regulations are intended to safeguard life and keep structures from collapse, essential public service facilities may be required to be designed to stricter standards, so they not only do not collapse but remain functional through and after the event. In addition, various property owners and businesses may elect to have their buildings designed to varying degrees of “survivability”. In this section, we will examine the various tools that help guide how seismic design is applied by location and type. In addition, we will look at some of the classifications and terms used to qualify seismic resistance and integrity of a building or structure.

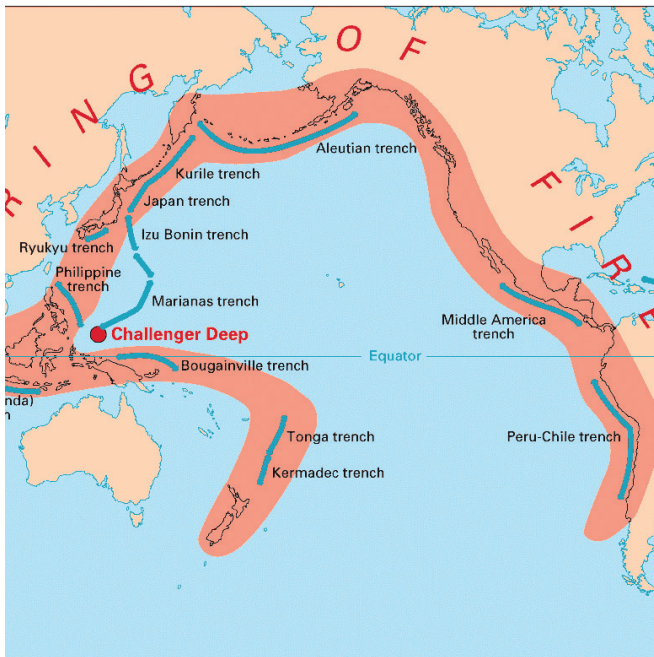
As was noted in Part 1, most earthquakes happen at the edges of tectonic plates. That helps narrow down the most active regions for seismic concern. From among the tectonic boundaries, there is one region that is especially notable. Known as the “Ring of Fire”, also called the Circum-Pacific belt, is the zone of earthquakes surrounding the Pacific Ocean — about 90% of the world’s earthquakes occur there (*See graphic below*). The next most seismic region (5-6% of earthquakes) is the Alpid belt (extends from Mediterranean region, eastward through Turkey, Iran, and northern India.³¹

28 NEHRP - National Earthquake Hazards Reduction Program - A research and <https://www.nehrp.gov/>

29 The Role of the NEHRP Recommended Seismic Provisions in the Development https://drupal.nibs.org/files/pdfs/FEMA_P-2156_bssc-35-year-ret.pdf

30 eCFR :: 49 CFR Part 41 -- Seismic Safety. <https://www.ecfr.gov/current/title-49/subtitle-A/part-41>

31 USGS.gov: Cool Earthquake Facts

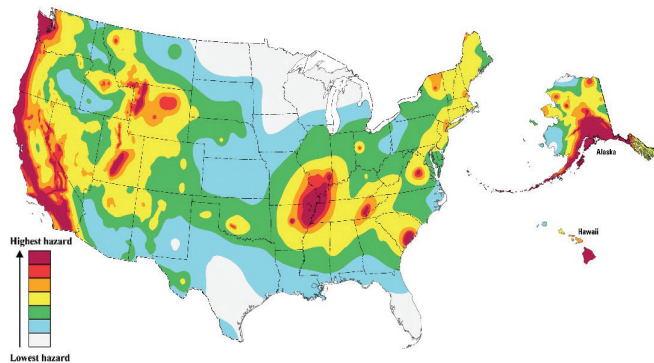


The Ring of Fire

Source: Public Domain; Earthquake Hazards Program; USGS.gov

Even though the “Ring of Fire” accounts for so many earthquakes, it is still a very large area. Along its perimeter, many countries have all developed their own localized zones for seismic activity and levels of intensity.

In the United States, the US Geological Survey (USGS) develops the National Seismic Hazard Maps for the United States, with the latest 2023 model created in collaboration with federal, state, and local partners. These maps, which have been updated periodically since 1996, identify areas prone to significant ground shaking to inform building codes.³²



Seismic Hazard Map. Source: USGS.gov; Public Domain

An interesting observation from the above map is that, contrary to a common misunderstanding, all the seismic areas of concern in the US are not only along the west coast. There are also significant seismic activity zones in the Mid-west and along the East coast.

Prior to 2000, under the old UBC, the US was mapped into 5 seismic zones (0-4) with the following breakdown:

- **Zone 4** – Highest hazard (California, parts of Alaska, Hawaii)
- **Zone 3** – High hazard (Pacific Northwest, parts of Nevada/Utah)
- **Zone 2A/2B** – Moderate hazard (Intermountain West, New Madrid, Charleston)
- **Zone 1** – Low hazard
- **Zone 0** – Very low hazard

These are still used in Probable Maximum Loss (PML) and Seismic Risk Analysis (SRA). **But not for building design.**

For applications related to building design, the IBC does not use “zones” but seismic design categories (SDCs, A-F) that come from ASCE 7 which has been noted earlier in this course. These are:

- SDC A – Very low hazard
- SDC B – Low hazard
- SDC C – Moderate hazard
- SDC D (D0, D1, D2) – High hazard
- SDC E – Very high hazard
- SDC F – Nearfault / special study zones

These categories are developed using:

- USGS seismic hazard maps
- Site soil class
- Building occupancy/importance

OTHER REGULATORY CLASSIFICATIONS

In most cases, the IBC and ASCE 7 are the primary design basis for architects and engineers. However, there are other agencies or institutions that provide classification categories for seismic design or response. It is quite possible that an architect’s client may refer to one or more of these in their design program. Of course, code requirements cannot be reduced but they can be augmented. These have been summarized in tabular form for quick reference rather than narrative treatment.

Summary Table for Seismic Requirements Established by Various Agencies (United States only)

CATEGORY	EXAMPLES	PRIMARY USERS	WHEN IT MATTERS
FEDERAL REGULATIONS (EXECUTIVE ORDERS AND AGENCY STANDARDS)	EO 12699, 49 CFR 41	Federal agencies	Ensures seismic safety for federal buildings
NEHRP PROVISIONS	FEMA P750, P2082	Code developers, engineers	Basis for ASCE 7 & IBC seismic rules
DOD / UFC (UNIFIED FACILITIES CRITERIA)	UFC 331004, RC V	Military projects	Much stricter performance requirements
PBSD (PERFORMANCE-BASED SEISMIC DESIGN) FRAMEWORKS	FEMA P58, Tall Building Guidelines	Highperformance or complex buildings	Allows targeted performance levels
Tsunami DESIGN	ASCE 7 Ch. 6, FEMA P646	Pacific Northwest, Alaska	Adds tsunami loads & evacuation structures

32 USGS.gov

CATEGORY	EXAMPLES	PRIMARY USERS	WHEN IT MATTERS
NONSTRUCTURAL STANDARDS	FEMA E74, DoD RC V	Hospitals, labs, military	Protects equipment & life safety
LEGACY CODES	UBC Zones 0–4	Existing buildings	Needed for renovations & evaluations
FEMA SEISMIC DESIGN CATEGORY (SDC) MAPS	Classification of areas from A- F (same as ASCE 7)	Federal Agencies; Projects seeking Federal funding	Resilience planning; Hazard Mitigation planning
NRC (NUCLEAR REGULATORY COMMISSION)	Seismic categories: Category I – Safety related buildings -must remain functional.; Category II – Non-Safety related must maintain structural integrity though not functionality; Category NS – Non-Seismic.	Nuclear projects involving NRC approval	Safety of the public; preventing failure at a nuclear facility.

33 34 35 36

In addition to the above, another classification often mentioned is the Seismic Use Groups (SUG). These are classifications assigned to structures based on their occupancy, function, and the risk associated with their failure during an earthquake, defining the necessary level of seismic resistance. They are used in conjunction with seismic ground motion data to determine the Seismic Design Category (SDC). These range from Group I (standard) to Group III (essential facilities). These SUGs are related to the risk categories (I – IV) used in the IBC and ASCE 7 based on building function (IBC Table 1604.5 – Risk Category of Buildings and Other Structures)³⁷.

Below is a comparison of how the SUGs correspond to the IBC risk categories:

SEISMIC USE GROUP	ROUGH EQUIVALENT IN IBC/ASCE 7	TYPE OF OCCUPANCY
SUG I	Risk Category I–II	Standard occupancy
SUG II	Risk Category III	Essential facilities
SUG III	Risk Category IV	Critical or hazardous facilities

The descriptions for SUGs and Risk Categories are listed below:

SEISMIC USE GROUPS (SUG)

UFC documents define three main groups; each tied to the importance of the facility and the consequences of failure.

- **SUG I — Low Hazard / Standard Facilities**

These are buildings where failure would not cause significant loss of life, mission impact is minimal and no hazardous materials are present.

Typical examples:

- Warehouses
- Small administrative buildings
- Nonessential support structures

- **SUG II — Essential Facilities**

These are structures where failure would pose moderate risk to life, and mission impact would be significant. The facility must remain functional after an earthquake. Examples:

- Fire stations
- Emergency response facilities
- Key operational buildings
- Utility plants serving critical operations.

- **SUG III — High Hazard / Critical or Hazardous Facilities**

These are the highest importance structures. They include facilities critical to mission continuation, buildings with no redundant backup or structures containing hazardous materials that could endanger life or the environment if released. Examples:

- Chemical storage facilities
- Highhazard industrial buildings
- Critical command centers

(Note: Some UFC documents further refine this group into subcategories such as IIH for hazardous material intensive facilities.)

IBC /ASCE 7 SEISMIC RISK CATEGORIES

The IBC seismic risk categories I-IV classify buildings based on the potential risk to human life and the consequences of failure during an earthquake. Here's a summary of each category:

- **Risk Category I:** Buildings that represent a low hazard to human life in case of failure. Examples include agricultural facilities, certain temporary facilities, and minor storage building.
- **Risk Category II:** Buildings that are not classified in other categories and represent a normal risk to human life. This includes most residential, commercial, and industrial buildings.
- **Risk Category III:** Buildings that are essential facilities where failure could pose a substantial risk to human life or where the building is critical for post-disaster recovery. Examples include schools, community centers, and fire stations.
- **Risk Category IV:** Buildings that are critical facilities whose failure would pose a high risk to human life or have a significant impact on the community. These include hospitals, power plants, emergency response centers, and structures housing hazardous materials.

The above material shows that there are several regulations and standards that may need to be evaluated and which may impose requirements when designing a building that requires seismic design. This will depend primarily on the location and type of the project but also may need to consider the client's specific safety and/or risk considerations. It is beyond the scope of this course to investigate the various permutations arising from the intersectionality of the various regulations and codes. The intent is to provide architects with an awareness of the many regulations that should be filtered to ensure that

33 FEMA 389 - Primer for Design Professionals.

34 Overview of the Seismic Design Process Based on ASCE/SEI 7-22.

35 Introduction to 2024 Edition Seismic Design Category Maps.

36 Nuclear Regulatory Commission.gov

37 Table not reproduced due to ambiguity about Fair usage as defined by ICC for educational purposes.

proper consideration is being given. It is sometimes a misconception that seismic design is purely, or largely, a structural engineering concern. Both roles are critical, but they hold different, equally essential responsibilities in seismic design. Structural engineers are responsible for ensuring the building's safety, stability, and compliance with codes to withstand seismic forces, while architects define the structural configuration and layout, which fundamentally influences how the building responds to earthquakes.

In the next part of the course, we will look at how architects and structural engineers play their roles in developing solutions to design seismic resistant buildings.

END of PART 2

PART 2 REVIEW QUESTIONS

- The first U.S. state to adopt a seismic code was:**
 - Oregon
 - Colorado
 - California
 - Alaska
- The most significant standard for seismic design related to buildings is _____?**
 - ASCE 7
 - IBC Chapter 7
 - BOCA 1943
 - UN Building Council Sec. 33-2
- What is the popular name for the Circum-Pacific belt seismic zone?**
 - Sino-American Plate
 - Ring of Fire
 - Trans Andean Zone
 - Middle America trench
- How does the IBC guide seismic building design?**
 - Defers to states
 - Use of hazard classifications
 - Use of seismic Zones
 - Use of seismic design categories (SDCs)
- A building in IBC II would be classified as what type of occupancy?**
 - Standard occupancy
 - Non-combustible
 - Essential facility
 - Critical occupancy

PART 3 – SOLUTIONS: RESPONSES TO MITIGATE SEISMIC CHALLENGES

So far, we have reviewed how earthquakes come about and identified the main regulatory and scientific bodies that provide guidelines and/or mandates on how building designers must provide public safety for their projects. This Part will focus on how architects and engineers respond to the challenges posed by seismic risks in areas where earthquakes are a likely occurrence.

In earthquake prone areas of the world, builders have been aware of the threat for as long as humans started settling in these areas. Long before modern seismology, early civilizations tried to understand and predict earthquakes through observation, mythology, rudimentary instruments and even scientific thinking. Some of these methods are still applicable today and are in use in some parts of the world where the rigor and institutional resources are not available to the extent they are in wealthy, developed countries like the United States. In this section we will examine how we addressed earthquakes prior to contemporary technological benefits and how that process has changed in present times.

3.1. SEISMIC DESIGN IN PRE-INDUSTRIAL TIMES

As noted above, pre-industrial societies did endeavor to predict earthquakes based on a variety of ways as listed below:

- Observation of Animal Behavior:** Many ancient societies believed animals sensed earthquakes before humans. Some of these included:
 - Sudden agitation in dogs, horses, snakes
 - Mass animal migrations
 - Birds behaving erratically.

These ideas appear in multiple cultures and are mentioned in modern historical analyses of ancient prediction attempts.³⁸

While not scientifically reliable, these observations show early attempts to link environmental cues to seismic events. These notions persist in folklore and cultural norms even today. It is not unusual to see these themes highlighted in movies with earthquake themes.

- Environmental and Atmospheric Signs:** Ancient observers often looked for unusual natural phenomena, including:
 - Changes in groundwater levels
 - Strange smells (e.g., sulfur)
 - Unusual weather or sky color
 - Ground cracking or rumbling noises.

Greek and Roman writers documented such “prodigies,” interpreting them as precursors to earthquakes.³⁹

- Mythological or Cosmological Models:** Before naturalistic explanations emerged, many civilizations explained earthquakes through myth:
 - Japan: A giant catfish (Namazu) thrashing underground
 - China: A cosmic dragon or turtle shifting
 - Greece: Poseidon striking the earth.
 - Native American cultures: Giant animals moving beneath the land.

These myths weren't predictions, but they shaped how societies interpreted seismic events.⁴⁰

- Early Natural Philosophies (ProtoScience):** Some ancient thinkers tried to explain earthquakes using natural—not supernatural—causes.

38 forgottenexus.blogspot.com/2026/02/ancient-earthquake-prediction-methods

39 WorldHistoryEdu.com

40 projects.eri.ucsb.edu: A Brief History of Seismology to 1910

- Aristotle (4th century BCE) - Proposed that winds trapped in underground caverns caused the ground to shake. This was wrong, but it represented a shift toward naturalistic reasoning.⁴¹
- Greek & Roman Observers - Historical analyses show they sometimes recognized patterns such as:
 - Foreshocks
 - Groundwater anomalies
 - Atmospheric changes

Researchers have found that ancient Greeks and Romans occasionally made explicit predictions, but there is little evidence to support their accuracy.⁴²

5. Earthquake Detecting Instrument (China, 132 CE): One of the most remarkable innovations came from the Han Dynasty: Zhang Heng's Seismoscope, the first known instrument for seismic detection.

- A large bronze vessel with dragon heads holding balls.
- When a distant earthquake occurred, a ball would drop into a frog's mouth.
- It could detect quakes hundreds of miles away.

This device didn't predict earthquakes, but it was the first scientific instrument for seismic detection, showing a sophisticated understanding of ground motion.⁴³

6. Pattern Recognition and Historical Memory: Civilizations with long written traditions—China, Mesopotamia, Mesoamerica—sometimes tracked and kept records of:

- Recurrence intervals
- Seasonal patterns
- Regional seismicity

These weren't predictions in the modern sense, but they helped communities identify which areas were more dangerous.

While pre-industrial societies used a combination of things noted above to attempt to understand and predict seismic activity, none of these societies had knowledge of some key scientific information that informs current understanding and technological sophistication. These are:

- A theory of plate tectonics
- Instruments to measure ground motion.
- Scientific models of stress accumulation
- Evidence based maps and more accurate historical trends to identify areas of high concern.

So, even though pre-industrial societies tried to predict earthquakes, their methods were largely observational or symbolic. And yet presently, even with the most advanced instruments and techniques in modern seismology, no scientist or agency can currently predict earthquakes – not the USGS, not any research group. Modern science states that a prediction must specify time, location, and magnitude, and no method (currently known) can do this.⁴⁴ We do, however, have a much better understanding about the nature and zonal geography of earthquakes and so can plan better, more effective solutions to resist the impact when an event does occur.

While the ability to predict remains almost as elusive now as it was in the past, societies that had to deal with seismic activity did not remain oblivious to the damage these incidents caused. Over time, many techniques were developed in various regions that established some successful techniques to mitigate the impact of earthquakes. We know that there were successful seismic resistant designs because many old structures have survived centuries of major earthquakes. General speculation is that in the absence of plate tectonics theory, seismic codes, or reinforced concrete, what they used instead were intuitive, practical, and often creative seismic resistant design strategies. Some of the earliest solutions to withstanding earthquakes established are noted below:

1. Flexible Timber Construction (Japan, China, Southeast Asia): Wooden structures — especially multistory pagodas — have been demonstrably resilient. Some of their features include:

1. Central wooden columns acting like a flexible spine.
2. Interlocking joinery (*Dougong*) that allowed controlled movement.
3. Lightweight materials reducing inertial forces.

These pagodas have survived dozens of major earthquakes because their frames sway instead of crack.⁴⁵

2. Polygonal Stone Masonry (Inca Empire, Peru): Inca builders created some of the most earthquake resistant stonework in history. These structures have the following characteristics:

- Precisely cut, interlocking stones (sometimes called “Lego-Style”) with no mortar.
- Tapered blocks that fit like 3D puzzles
- Walls leaning slightly inward for stability.
- Stones that “dance” during shaking and settle back into place.
- *Shicras*, which were woven fiber bags filled with stones, provide a flexible base that dissipated seismic energy.

These walls at Machu Picchu and Cusco routinely survive earthquakes that destroy modern buildings.⁴⁶

3. Base Isolation Using Sand, Gravel, or Timber Layers (India, Middle East, Mediterranean): Some ancient builders intuitively used primitive base isolation, a technique that uses layers of sand, gravel, or charcoal beneath foundations; Timber beams embedded horizontally in masonry; and Foundations designed to absorb and dissipate seismic energy.

Northern India's ancient stone buildings show evidence of such layered foundations (Kath Kuni Architecture) that help absorb shaking.⁴⁷

4. Symmetry, Proportion, and Mass Distribution (Greece, Rome, Persia): Ancient architects understood, through experience, that: i) Symmetrical layouts reduce torsion; ii) Regular column spacing distributes loads; and iii) Heavy lower stories + lighter upper stories improve stability.

These principles appear in temples, palaces, and fortifications across the Mediterranean.⁴⁸

5. Earthquake Absorbing Wall Systems (Various Civilizations): Across cultures, builders developed wall systems that could flex or dissipate energy. Examples of these are:

- Doublewythe walls with rubble cores.
- Timberlaced masonry (e.g., *dhajjidewari* in the Himalayas)

41 Ibid

42 NASA Goodard Institute for Space Studies: Earthquake prediction in antiquity; Slothers, R. B., 2004.

43 WorldHistoryEdu.com

44 USGS.gov

45 curiosmos.com/earthquake-proof-stone-structures; Did ancient builders know how to earthquake-proof stone structures?

46 Ibid

47 The Ancient Architecture that Defies Earthquakes - Nautilus. nautilus.us/the-ancient-architecture-that-defies-earthquakes-301285/

48 Exploring Ancient Techniques for Earthquake Resistance in Historical <https://ancientrix.com/ancient-techniques-for-earthquake-resistance/>

- Stone walls with internal voids to reduce mass.

These systems acted like early forms of energy dissipation.⁴⁹

6. **Precision Stone Fitting Without Mortar (Inca, Aegean, Anatolia):** Some civilizations mastered mortarless construction with the following features:

- Stones shaped to fit perfectly
- Joints designed to **slide slightly** during shaking
- No brittle mortar to crack

This technique is highlighted in studies of ancient “earthquakeproof walls” that still puzzle engineers today.⁵⁰

As can be extrapolated from the above, even without modern scientific theory and tools, earlier builders used **Empirical observation** (learning from past collapses); **Material intuition** (using wood, stone and soil strategically); **Redundancy and flexibility** (allowing structures to move) and understanding the basic rules of **Low stiffness & high ductility** (the same principles used by modern engineers). With these methods many ancient structures have survived centuries and still outperform poorly designed modern buildings.

SOME EXAMPLES:

(these are some buildings that have survived for several centuries in some of the most active seismic areas of the world)

Tomb of CYRUS the GREAT (Pasargadae, Iran)⁵¹



Age: ~2,500 years

Why it survived:

- Massive stone blocks with tight joints
- A broad, stepped base that distributes seismic forces
- Simple, symmetric geometry that minimizes torsion

This structure is widely cited as one of the oldest earthquake-resistant buildings still standing.

Source: Wikimedia Commons; Common usage

Historic Japanese Pagodas (Japan)



Age: Many over 1,000 years old

Why they survived:

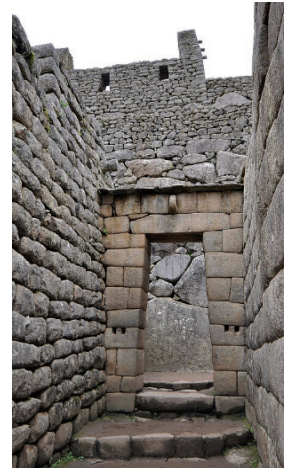
- Central “shinbashira” column acting like a flexible spine

- Interlocking wooden joints that slide instead of crack
- Lightweight timber construction that reduces inertial forces

Remarkably, no traditional pagoda in Japan has ever collapsed from an earthquake, despite centuries of major seismic events.

Source: Wikimedia Commons; Common usage

Inca Stone Walls (Cusco, Peru)



Age: 500 - 700 years old

Why they survived:

- Polygonal stones cut with extreme precision
- Mortarless construction allowing stones to “dance” during shaking
- Slightly inclined walls for added stability

These walls have withstood repeated earthquakes that destroyed much more recent nearby colonial era masonry structures.

Source: Wikimedia Commons; Common usage

Traditional Japanese Machiya & Minka Houses (Japan)



Age: 200 - 400 years

Why they survive:

- Flexible timber frames
- Lightweight infill walls
- Redundant bracing patterns

This structures have survived repeated earthquakes demonstrating the power of ductility over mass strength.

Source: Free Stock Photo; Free to Use license

49 Exploring Ancient Methods for Earthquake Absorption in Historic <https://archaforge.com/ancient-methods-for-earthquake-absorption/>

50 The Ancient Earthquake-Proof Walls That Puzzle Engineers. <https://www.youtube.com/watch?v=SNopZ0ovUtA>

51 webuildvalue.com/en/facts/from-ancient-temples-to-futuristic-skyscrapers-10-extraordinary-earthquake-resistant-structures.html

Gutenberg Castle (Balzers, Lichtenstein)⁵²



Age: ~800 years

Why it survived:

- *Dense stone masonry with excellent mass distribution*
- *Elevated bedrock foundation*
- *Structural continuity that resists shear failure*

This is a frequently cited example of why certain medieval structures endure earthquakes so well.

Source: Wikimedia Commons; Common usage

Taj Mahal (Agra, India)



Age: ~400 years

Why it survived:

- *Floating Foundation: which prevents the building from cracking by absorbing shockwaves.*
- *Inclined Minarets: The four minarets are slightly tilted outwards to ensure they fall away from the central mausoleum.*

The Taj Mahal has survived for nearly 400 years in an area now considered part of seismic zone III

Source: Wikimedia Commons; Antrix3; Common usage, August 2016

3.2. POST INDUSTRIAL AND CONTEMPORARY SEISMIC DESIGN

With the advent of the Industrial Revolution (circa 1750 – 1914), two significant changes happened – i) people started to migrate to urban areas, creating a mass concentration of humanity in larger numbers than ever before, and ii) rapid advances in science, technology and research / education resulted in exponential expansion of scientific knowledge across the industrialized countries and then throughout the world. As population centers grew, many were in earthquake prone areas. It was only a matter of time that the impact of a major earthquake would expose the weaknesses of cities that had expanded hastily during industrialization with little to no regulatory oversight or even a comprehensive understanding of the risks faced by densely populated areas in the face of natural disasters. 1906 was the year and San Francisco was the American city where a massive earthquake [see inset below] struck that is widely considered the first to highlight the extreme vulnerability of modern, industrial urban cities to seismic

events, especially regarding fire risks. It showed how high-density, interconnected urban systems could catastrophically fail, leading to widespread structural damage, fires, and infrastructure collapse.⁵³

1906 San Francisco Earthquake⁵⁴

The 1906 San Francisco earthquake is widely estimated to have had a magnitude of **7.9 M_w** (moment magnitude). While older sources often cite a Richter magnitude of 8.3, modern re-evaluation indicates 7.7 to 7.9 is more accurate, with the rupture extending nearly 300 miles along the San Andreas Fault.

Key details regarding the 1906 earthquake:

- **Time and Location:** April 18, 1906, at 5:12 a.m. PST, with an epicenter offshore just south of San Francisco.
- **Magnitude:** Generally cited as 7.9 M_w

Impact: The earthquake and *subsequent fires* destroyed over 80% of San Francisco, resulting in over 3,000 deaths and 200,000 people left homeless.

Fault Rupture: The tremor involved a massive rupture of the San Andreas Fault, spanning from San Juan Bautista to Humboldt County.

Scientific Significance: The event led to the development of the elastic rebound theory, forming the foundation of modern earthquake science



Source: Wikimedia Commons; San Francisco Earthquake 1906; Public Domain

In Part 1 of the course, we have traced how, after the San Francisco earthquake, industrialized countries with susceptibility to seismic activity started developing codes and standards to regulate how buildings needed to address earthquake and resulting fire risks. This brings us to the current state of seismic design, as it is applied in the United States. The codes and regulations have been discussed in Part 2. We will now look at the role of the major design professionals who are tasked with developing and constructing buildings and structures that respond to seismic threats and provide damage mitigation.

The development of an effective and responsive building that will perform as intended during a seismic event is the result of cooperation among and mutual respect for the skills of several professionals:

1. Structural Engineer (SE) The Lead Seismic Designer

- **Role:** Primary authority on seismic design
- **Responsibilities:**
 - Determine **Seismic Design Category (SDC), Risk Category, and Response Modification Coefficients (R, C_d, Ω_0)**
 - Select the **lateral force-resisting system** (shear walls, braced frames, moment frames, base isolation, etc.)
 - Perform **ASCE 7 seismic analysis** (equivalent lateral force, modal response spectrum, nonlinear analysis)
 - Design and detail all structural components for **strength, stiffness, ductility, and drift limits.**

⁵² garlicsoda.com: 30 timeless buildings that have survived modern disasters

⁵³ BGS - British Geological Survey

⁵⁴ UC Berkeley Seismology Lab +4 and Wikipedia

- Coordinate with architects to avoid torsion, soft stories, irregularities.

In seismic design, the Structural Engineer is the “captain” of the team.

2. Geotechnical Engineer (GE) The Ground & Foundation Specialist

- **Role:** Defines the seismic hazard at the site.
- **Responsibilities:**
 - Determine **Site Class (A–F)**
 - Provide **geotechnical seismic parameters:**
 - S_s, S₁, F_a, F_v
 - Liquefaction potential
 - Lateral spreading, settlement, slope stability
 - Recommend **foundation type** (mat, piles, caissons, ground improvement)
 - Evaluate **fault rupture hazards** and **site amplification**.

Without accurate geotechnical input, the structural design is guesswork.

3. Architect — Geometry, Massing, and Irregularity Control

- **Role:** Shapes the building’s seismic behavior.
- **Responsibilities:**
 - Control **building configuration**, which is the #1 driver of seismic performance.
 - Avoid:
 - Soft/weak stories
 - Torsional irregularities
 - Vertical discontinuities (an abrupt change or break in the structural, geometric, or stiffness characteristics of a building along its vertical axis (height).
 - Heavy roofs or appendages
 - Coordinate **nonstructural seismic design** (ceilings, facades, partitions, equipment anchorage)
 - Ensure code compliance for **egress, fire separation, and drift compatibility**.

Architects don’t calculate seismic forces, but they determine whether the building will behave well or fight the earthquake.

4. MEP Engineers — Nonstructural Seismic Protection

- **Role:** Protect systems that must remain functional
- **Responsibilities:**
 - Design seismic bracing for:
 - Mechanical equipment
 - Electrical gear
 - Fire protection systems.
 - Piping, ducts, conduits
 - Ensure **anchorage** meets ASCE 7 Chapter 13
 - Coordinate with structural engineer for attachment points.

Nonstructural failures cause most earthquake damage and downtime.

5. Civil Engineer — Site & Lifeline Resilience

- **Role:** Ensure the site and utilities survive shaking
- **Responsibilities:**
 - Design **site retaining walls, grading, drainage, utility lines.**

- Address **soil–structure interaction** with SE and GE
- Ensure **lifelines** (water, sewer, storm, gas) have seismic flexibility.

6. Seismic/Structural Peer Reviewer (SPR)

- **Role:** Independent expert review
- **Responsibilities:**
 - Required for **highrise, essential facilities, or performancebased design.**
 - Validate modeling, assumptions, detailing, and performance objectives.
 - Provide thirdparty oversight for jurisdictions like LA, SF, Seattle.

7. Seismic Hazard Specialist / Seismologist (for complex projects)

- **Role:** Advanced hazard characterization
- **Responsibilities:**
 - Develop **sitespecific ground motion studies.**
 - Model nearfault effects, basin amplification, longperiod demands.
 - Essential for tall buildings, hospitals, nuclear facilities, and baseisolated structures.

8. Building Official / Authority Having Jurisdiction (AHJ)

- **Role:** Code enforcement
- **Responsibilities:**
 - Approve seismic design criteria.
 - Review structural calculations and drawings.
 - Oversee special inspections and testing.

9. Special Inspector & Testing Agency

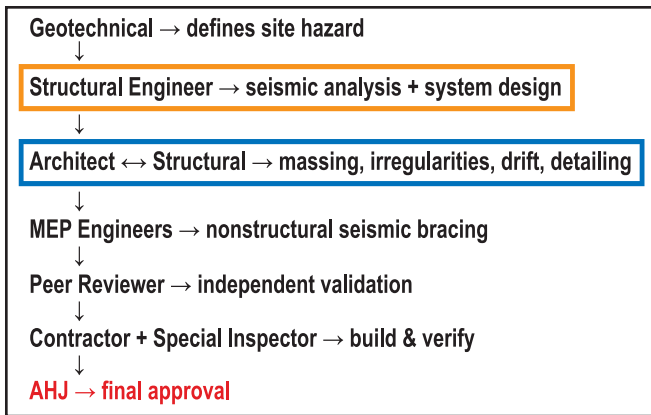
- **Role:** Ensure seismic detailing is built correctly.
- **Responsibilities:**
 - Inspect welds, anchors, rebar, concrete, shotcrete, masonry.
 - Verify seismic bracing for nonstructural components.
 - Required by IBC Chapter 17

Even a perfect seismic design fails if it is not built as detailed.

10. Contractor & Subcontractors

- **Role:** Execute the seismic detailing in the field.
- **Responsibilities:**
 - Install holddowns, collectors, boundary elements, anchors.
 - Coordinate sequencing to avoid weakening the structure.
 - Maintain quality control during construction.

To deliver an effective seismic solution all the members of the “Team” as noted above work together in sequence. Below is a simplified diagram showing how each member of the design and delivery team connects with the others.



Since this course is primarily developed for architects, we will examine specifically how the Architect’s role is carried out, and which parts of the many codes and regulations require an architect’s attention. The role of the architect cannot be understated even though the primary seismic design responsibility is that of the structural engineer who also assumes the primary liability in case of design failure. However, the Architect shares some of the liability and many of the responsibilities as noted above. The main reason architects have a significant influence on the seismic performance of the design is because even though the structural engineer defines the “Skeleton” of the building, performs the safety analyses and ensures structural integrity, it is the Architect who determines the shape, layout, and structural configuration, which are primary factors in seismic performance. They also integrate structural requirements with aesthetic and functional needs and make material specifications that affect the building’s mass and flexibility. Because of these critical factors that the Architect controls, architects and structural engineers cannot work in isolated silos.

When it comes to code compliance, the bulk of the burden falls on the structural engineer. However, there are parts of the IBC / ASCE 7 that the Architect needs to be familiar with for doing their part. The table below summarizes the key portions of the code that apply to architects:

Key ASCE 7 Chapters

ARCHITECT RESPONSIBILITY	ASCE 7 CHAPTER
Control irregularities	Ch. 12.3
Drift compatibility for cladding	Ch. 12.12.5
Nonstructural components (coordination)	Ch. 13
Architectural components (ceilings, partitions, doors, windows)	Ch. 13.5–13.6

The involvement of the Architect is also continuous throughout the design and construction of the project. Below is a summary of the Architect’s role in seismic design across the phases of a project:

PHASE	ARCHITECT RESPONSIBILITIES
CONCEPTUAL	Massing, symmetry, vertical continuity, avoid soft stories.
SCHEMATIC DESIGN (SD)	Coordinate structural grids, shear wall placement, diaphragm layout.
DESIGN DEVELOPMENT (DD)	Detail cladding joints, drift allowances, façade anchorage.

PHASE	ARCHITECT RESPONSIBILITIES
CONSTRUCTION DOCUMENTS (CD)	Coordinate with SE/MEP on penetrations, anchorage, and ceilings.
CONSTRUCTION ADMINISTRATION (CA)	Review submittals, ensure seismic detailing is not valueengineered out.

Another indicator of the importance of the architect’s role in seismic design, several US states have special seismic design requirements that impact the licensing and / or the practice of architecture. These tend to be states with high seismic risk zones as stated below:

- **California:** Has extensive seismic design requirements under the California Building Code (CBC), which incorporates and often exceeds ASCE 7 seismic provisions. The CBC is more stringent than the standard International Building Code (IBC) used elsewhere, particularly for hospitals. Architects must be familiar with these for licensing and practice.⁵⁵ California also specifically mandates a California Supplemental Exam (CSE) focused on seismic safety and design.
- **Alaska:** Due to high seismic risk, Alaska has specific seismic design provisions architects must follow.
- **Washington:** The state enforces seismic design requirements aligned with ASCE 7 and IBC, with additional local amendments.
- **Oregon:** Similar to Washington, Oregon has seismic design requirements that architects must consider.
- **Nevada:** Has seismic provisions due to its seismic activity.
- **Hawaii:** Has seismic design requirements due to its location on tectonic boundaries.

Other states with notable seismic provisions include Utah, Idaho, and Montana, but the level of special licensing or design requirements for architects varies.

Architect licensing boards in these states often require architects to demonstrate knowledge of seismic design principles relevant to their jurisdiction, either through education, exams, or continuing education.

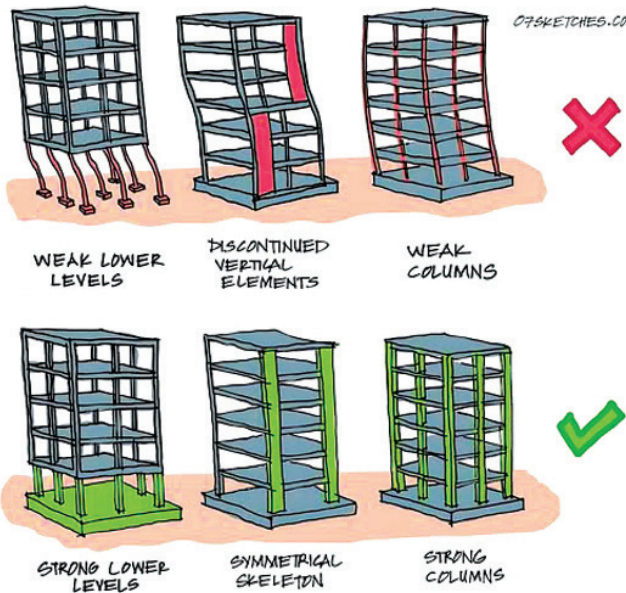
3.3. SEISMIC DESIGN AND ARCHITECTURAL RESPONSES

The structural engineer bears the major responsibility to ensure a building responds to earthquakes without collapsing and maintains the designed degree of survivability after the seismic event. But the architect must make certain that the non-structural elements also survive and maintain the desired level of functionality. It is pointless for a building to remain structurally sound but have all its interior walls, exterior skin and penetrations and mechanical / electrical systems rendered useless. Therefore, the architectural response must work with the structural response. For the degree of movement that the structure permits, architectural detailing, connections and supports must allow for the same level of flexibility.

For the building skeleton, the illustration below is a simple guide about the main elements of earthquake design:

NOTE: These are diagrammatic sketches intended to illustrate principles rather than literal solutions and should be viewed in that context.

EARTHQUAKE RESISTANT DESIGN



Source: NMR Glass and Mirror Facebook Post.
Courtesy 07Sketches by Bhupesh Kumar.

Seismic design response focuses on creating structures that can absorb, dissipate, and redirect the energy of an earthquake to prevent collapse and ensure occupant safety.

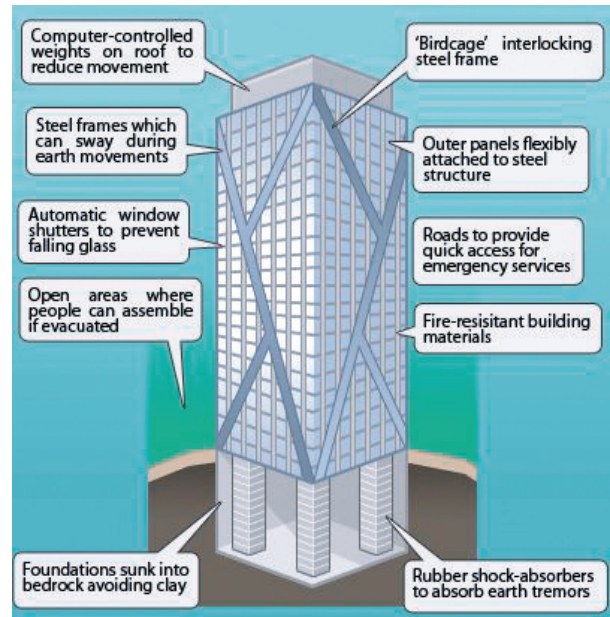
This differs from standard structural design which focuses on resisting gravity. Seismic design treats the building as a dynamic system that must "dance" with the ground's movement⁵⁶

For "seismic architecture" or "earthquake architecture"⁵⁷ design, the main considerations are:

- **Building Massing and Symmetry:** Avoiding irregular shapes and asymmetry that can cause torsional forces.
- **Vertical and Horizontal Continuity:** Ensuring load paths are continuous to transfer seismic forces effectively.
- **Structural System Coordination:** Placement and coordination of shear walls, braced frames, and diaphragms with architectural layouts.
- **Soft Story Avoidance:** Designing floors with consistent stiffness and strength to prevent weak stories.
- **Drift Compatibility:** Allowing for lateral movement without damage to cladding, partitions, and nonstructural components.
- **Façade and Cladding Anchorage:** Detailing connections to accommodate seismic movement.
- **Partition and Ceiling Systems:** Designing nonstructural elements to accommodate seismic forces and movement.
- **Penetrations and Openings:** Coordinating locations and detailing around structural elements to maintain integrity.
- **Doors and Windows:** Focusing on flexibility, material resilience, and secure anchoring to prevent failure during intense ground shaking.

- **Nonstructural Components:** Including mechanical, electrical, plumbing (MEP) equipment bracing and anchorage.
- **Foundation and Soil Interaction:** Architectural considerations for foundation types and site conditions affecting seismic response.

Seismic Effects on Structures and Responses



Source: aboutCivil.com⁵⁸

SEISMIC DESIGN APPROACHES AND MECHANISMS

In order to develop design solutions, some of the main techniques used are described below⁵⁹ (While the primary system is structural, the choice is usually the result of collaboration between the architect and structural engineer so that the structural system supports the building configuration and functional needs):

Structural Systems:

- **Diaphragms:** Floors and roofs can be used as rigid horizontal planes, or diaphragms, to transfer lateral forces to vertical resisting elements such as walls or frames.

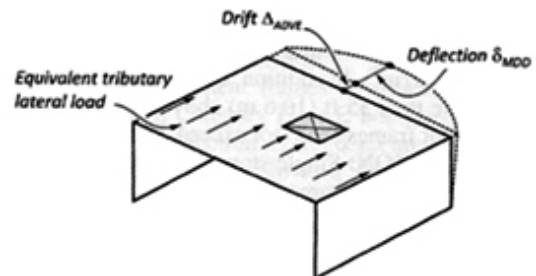


FIGURE 12.3-1 Flexible Diaphragm

Source: theStructuralEngineer.info / education/diaphragms.
Illustration credit: Bentley Systems

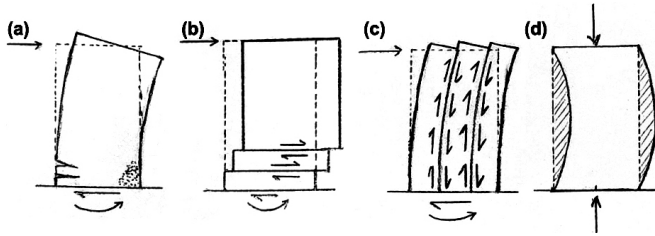
56 fiveable.me/earthquake-engineering/unit-6

57 [NOTE: These terms were first introduced in 1985 by Robert Reitherman. The phrase "earthquake architecture" is used to describe a degree of architectural expression of earthquake resistance or implication of architectural configuration, form or style in earthquake resistance.] - Google AI

58 aboutCivil.com: Earthquake Resistant Building Design by Haseeb Jamal; May 02, 2017

59 wbdg.org: seismic design principles

- **Shear Walls:** Strategically located stiffened walls are shear walls and are capable of transferring lateral forces from floors and roofs to the foundation.

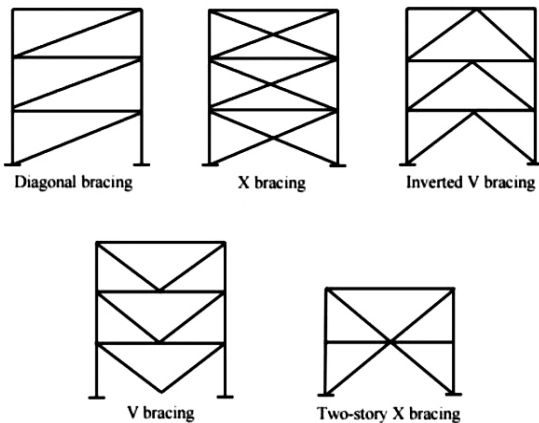


Failure mechanisms of shear walls.

- (a) flexural failure, (b) horizontal shear, (c) vertical shear, (d) buckling.

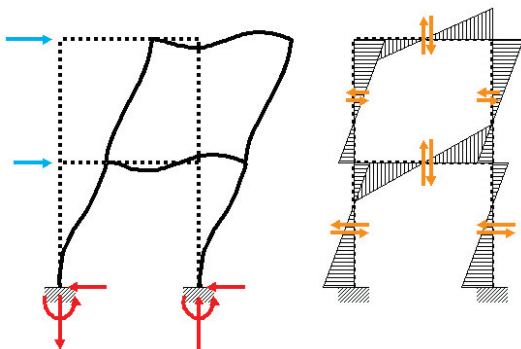
Source: Wikimedia Commons - Fair Usage.

- **Braced Frames:** Vertical frames that transfer lateral loads from floors and roofs to foundations. Like shear walls, Braced Frames are designed to take lateral loads but are used where shear walls are impractical.



Source: BEATO Consulting Engineers, LLC; Blogpost. ⁶⁰

- **Moment-Resistant Frames:** Column/beam joints in moment-resistant frames are designed to take both shear and bending thereby eliminating the space limitations of solid shear walls or braced frames. The column/beam joints are carefully designed to be stiff yet to allow some deformation for energy dissipation taking advantage of the ductility of steel (reinforced concrete can be designed as a Moment-Resistant Frame as well).



Source: Wikimedia Commons - Fair Usage. Rahmen Kouzou

- **Energy-Dissipating Devices:** Making the building structure more resistive will increase shaking which may damage the contents or the function of the building. Energy-Dissipating

Devices are used to minimize shaking. Energy will dissipate if ductile materials deform in a controlled way. An example is Eccentric Bracing whereby the controlled deformation of framing members dissipates energy. However, this will not eliminate or reduce damage to building contents. A more direct solution is the use of energy dissipating devices that function like shock absorbers in a moving car. The period of the building will be lengthened, and the building will “ride out” the shaking within a tolerable range.



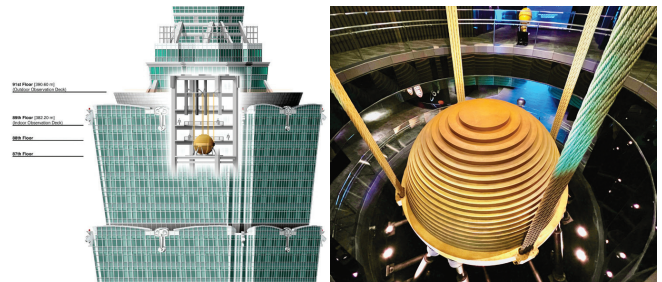
Base isolation dampers used to improve seismic performance.

Source: Wikimedia Commons - Fair Usage.

- **Base Isolation and Dampers:** This seismic design strategy involves separating the building from the foundation and acts to absorb shock. As the ground moves, the building moves at a slower pace because the isolators dissipate a large part of the shock. The building must be designed to act as a unit, or “rigid box”, of appropriate height (to avoid overturning) and have flexible utility connections to accommodate movement at its base. Base Isolation is easiest to incorporate in the design of new construction. Tall buildings cannot be base-isolated or they would overturn. Being very flexible compared to low-rise buildings, their horizontal displacement needs to be controlled. This can be achieved using **Dampers**, which absorb a good part of the energy, making the displacement tolerable. Retrofitting existing buildings is often easier with dampers than with base isolators, especially if the application is external or does not interfere with the occupants.

There are many types of dampers used to mitigate seismic effects, including:

- Hysteretic dampers utilize the deformation of metal parts.
- Visco-elastic dampers stretch an elastomer in combination with metal parts.
- Friction dampers use metal or other surfaces in friction.
- Viscous dampers compress a fluid in a piston-like device.
- Hybrid dampers utilize the combination of elastomeric and metal or other parts.

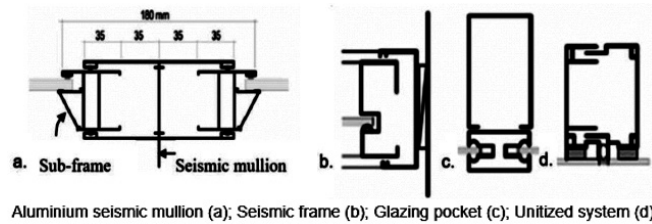


The Tuned Mass Damper in Taipei 101.

Source: Wikimedia Commons - Taipei 101 Tuned Mass Damper.png and photograph by author - 2025

Architectural Systems:

- **Flexible Joints and Seismic Gaps:** Designed to accommodate movement between building sections or components.
- **Base Isolation Systems:** Architectural integration of isolation bearings to reduce seismic forces transmitted to the structure. (see above discussion)
- **Reinforced Openings:** Doors and windows detailed to maintain structural integrity during seismic events.



a. Sub-frame Seismic mullion b. c. d.

Aluminium seismic mullion (a); Seismic frame (b); Glazing pocket (c); Unitized system (d)

Source: Researchgate.net

- **Seismic-Resistant Façade Systems:** Cladding and curtain walls designed with anchorage and flexibility to withstand seismic drift.



UC Berkeley University Hall retrofit with seismic façade;
Source: Interactive Resources

- **Nonstructural Anchorage:** Secure attachment of ceilings, partitions, and MEP equipment to prevent damage or hazards.
- **Redundancy and Regularity in Layout:** Architectural planning to avoid irregularities and ensure balanced seismic response.
- **Avoidance of Soft Stories:** Design strategies to prevent weak floors, often by distributing shear walls or frames evenly.
- **Roof Diaphragm Design:** Roof structures designed to transfer lateral forces effectively. (see discussion on diaphragms earlier)
- **Foundation Detailing:** Architectural coordination with foundation design to accommodate seismic loads and soil-structure interaction.
- **Tensile Structures:** These structures use flexible steel reinforcement, braces, and specialized materials to handle the stretching forces (tension) created during earthquakes, preventing brittle failure. By combining high-tensile steel with concrete, these systems allow buildings to sway, absorb seismic energy, and maintain structural integrity rather than cracking.⁶¹
- **Fabric or Tension Fabric Seismic Structures:** These are highly resilient, lightweight buildings featuring engineered fabric stretched over rigid steel frames. Their inherent flexibility, low mass, and ductile design allow them to absorb and dissipate seismic energy without failing, making them ideal for high-risk earthquake zones and providing a durable, cost-effective alternative to traditional, rigid concrete or steel buildings.⁶²



(Image courtesy of Legacy Building Solutions.)
Explosives storage for a mining facility in the Atacama Mountains, Chile.

These examples illustrate how seismic design principles translate into tangible architectural features that enhance building resilience.

Given the many constraints that seismic design imposes, this does not imply that all seismic resistant buildings end up being boring and rigid. In fact, some very creative and innovative designs have been built that took their forms and responses to functional requirements directly from the seismic responses required. Below are some examples of unique buildings where architects developed very innovative and dramatic solutions in response to earthquake design:

Imperial Hotel (1923) by Frank Lloyd Wright.

Seismic Qualities:

- Famously survived the 1923 Great Kanto Earthquake with minimal damage.
- Utilized a “**floating**” foundation on soft mud. interconnected
- Cantilevered, balanced floors
- Structural concrete
- Employed flexible, curved pipes for utility joints to dissipate earthquake energy
- Used lightweight fire-resistant materials



Source: Wikimedia Commons; Common Usage;
Imperial Hotel in Meiji Mura 2022.jpg

Petronas Towers, Kuala Lumpur Malaysia by Cesar Pelli

Seismic Qualities:

- The towers utilize high-strength, reinforced concrete to create a stiffer structure that is more effective at reducing sway
- **Tube-in-Tube Design:** An inner core wall and an outer ring of columns work together as a rigid tube-in-tube system, which resists lateral forces from both winds and earthquakes
- **Skybridge Connection:** Located 170 meters above ground, the 58.4-meter-long skybridge is designed to handle the movement of the two towers, withstanding tremors

61 ferrofabriktd.com/ "The Role of High Tensile Reinforcing Bars in Earthquake-Resistant Structures"; October 20, 2023

62 domeshelter.com.au; "Are Fabric Structures Effective in Earthquakes?"; December 22, 2022



Source: Author – muhammad a siddiqui © 2019

Palazzetto dello (1957), Rome, Italy by Pier Luigi Nervi

Seismic Qualities:

- The building features a 61-meter diameter ribbed concrete shell dome constructed from 1,620 prefabricated “ferrocement” pieces.
- This foundation is designed to absorb the strong horizontal and vertical forces, which is critical for earthquake resistance.
- **“Isostatic” Design:** a technique that inherently provides superior performance against lateral loading conditions, such as those during an earthquakes



Source: Wikimedia Commons; Public Domain;
Palazzetto dello Sport di Pier Luigi Nervi

Transamerica Pyramid (1969), San Francisco by William Pereira

Seismic Qualities:



Source: Wikimedia Commons Public Domain

The pyramid shape and wide base lower the center of gravity, increasing stability against horizontal and vertical seismic forces.

Foundation: The building sits on a 9-foot-thick concrete mat, placed during a 3-day continuous pour, and reaches 52 feet deep.

Truss System: A specialized, high-strength truss system extends from the ground up to the 45th floor, enabling the building to resist extreme torsional (twisting) forces.

Flexibility: The structure is designed to sway or “bend” during an earthquake rather than remain rigid, which prevents cracking.

Performance: During the 1989 magnitude 7.1 Loma Prieta earthquake, the building swayed more than 12 inches but sustained no damage

101 Taipei (2004), Taipei, Taiwan by C.Y. Lee and Partners



Source: Author – Muhammad A Siddiqui © 2025

Seismic Qualities:

Tuned Mass Damper (TMD): A 660-ton (5.5-meter diameter) steel sphere suspended between the 87th and 92nd floors acts as a pendulum, reducing building sway by up to 40%.

Foundation: 380 concrete piles, driven 262 feet into the ground with the deepest extending 100 feet into the bedrock, securely anchor the tower.

Structural Flexibility: The tower uses a high-performance, flexible steel-and-concrete structure, allowing it to sway during earthquakes and typhoons while maintaining integrity.

Mega-Frame System: The structural design incorporates a braced-frame core, perimeter moment frames, and outrigger trusses to handle heavy lateral loads.

Seismic Design Standards: The tower was designed to withstand the strongest earthquakes expected in a 2,500-year cycle.

Dynamic Behavior: The building’s translational modal frequencies range from 0.15 Hz to 0.78 Hz, with higher temperatures increasing frequency and higher wind speeds decreasing it.

Apple Park, Cupertino, California by Norman Foster & Partners

Seismic Qualities:

- The building sits on 700 base isolators (also called “saucers”), each 7ft. in diameter (wt. 15,000 lbs) {*Engineering News Record, ENR*}
- The “campus” building can shift up to 4 ft on those saucers. {*Business Insider*}



Source: Wikimedia Commons; Creative Commons;
Apple Park.jpg. January 22, 2025

The above are just a sampling of prominent, architecturally significant and ground-breaking designs which included effective seismic responses in their design. There are numerous other examples. In fact, it can be argued that almost all recent major buildings along the US west coast cities are seismic solutions since they are built to comply with building codes.

So, while seismic design is engineering centered, the architectural contributions cannot be understated. In the next part we will look at how seismic design is set to evolve in future as part of broader architectural and regulatory focus to make buildings not simply able to survive earthquakes but to become part of an adaptable and resilient design approach.

END PART 3

PART 3 REVIEW QUESTIONS

1. **In pre-industrial times seismic design was:**
 - A. Ignored
 - B. Based on observations, trial and error and pattern recognition
 - C. Based on scientific calculations
 - D. Developed using plate tectonic theory
2. **Which of the following is a characteristic of why Gutenberg Castle in Lichtenstein and similar medieval structures have survived seismic events?**
 - A. Flexible timber frames
 - B. Inclined turrets
 - C. Dense masonry with excellent mass distribution
 - D. Polygonal stones with precision cuts

3. **A foundational theory of modern earthquake science is _____?**
 - A. Zonal relativity theory
 - B. Elastic rebound theory
 - C. Seismic Uplift theory
 - D. None of the above
4. **Which chapter of the IBC requires special inspection and testing for seismic structures?**
 - A. 12
 - B. 32
 - C. 21
 - D. 17
5. **Which of the following is not a consideration for seismic architecture?**
 - A. Building color
 - B. Doors and windows
 - C. Façade and Cladding Anchorage
 - D. Drift Compatibility

PART 4 – FUTURE: BEYOND SURVIVING EARTHQUAKES TO ADAPTABILITY

Building codes and governmental agencies are currently the primary guardians of ensuring that structures in seismic zones respond appropriately to the severity of the region and type of occupancy. However, in recent years, seismic design is shifting from a codeminimum, forcebased mindset towards an adaptive, “intelligent”, and sustainabilitydriven resilience. The direction seems to indicate that buildings will increasingly sense, respond, and **recover rather than simply resist**. In this part we will look at developments and trends that reflect what researchers, architects, and engineers are already exploring and deploying.

4.1. MAJOR TRENDS AND DIRECTIONS SHAPING THE FUTURE OF SEISMIC DESIGN

1. **Smart, Sensor Rich, A.I. Enabled Structures:** Buildings are moving toward continuous, real time seismic awareness.
 - **IoT (Internet of Things) sensor networks** track drift, acceleration, and structural health during and after earthquakes.
 - **AI assisted modeling** improves prediction of building response and optimizes design decisions.
 - **Machine learning based damage detection** supports rapid post event re-occupancy.
- These trends are highlighted in emerging “smart seismic design” approaches that integrate AI and IoT monitoring.⁶³
2. **Advanced Materials That Adapt or “SelfHeal”:** Material science is accelerating seismic innovation.
 - **Shapememory alloys** can recenter structures after shaking.
 - **Highperformance composites** reduce mass and increase ductility.
 - **Selfhealing concrete** minimizes longterm degradation.

63 buildings.com; “Next-Gen Seismic Design: How Smart Tech Is Reinventing Earthquake-Resistant Buildings”; Emily Newton; May 27, 2025

Current research on new materials for highrise seismic design shows rapid progress in this area.⁶⁴

- 3. NextGeneration Energy Dissipation and Isolation:** Traditional base isolation is evolving into more sophisticated systems.
 - **Hybrid base isolation** combines elastomeric bearings with sliding or damping mechanisms.
 - **Seismic cloaking** concepts aim to redirect seismic waves around structures.
 - **Tuned mass dampers** are becoming smarter and more adaptive, especially in tall buildings.

These technologies are increasingly central to nextgen earthquakeresistant buildings.⁶⁵

- 4. PerformanceBased and ResilienceBased Design:** Codes are shifting from “life safety only” to functional recovery.
 - Buildings are expected not just to avoid collapse but to resume operations quickly.
 - Performancebased design frameworks allow tailored seismic objectives for hospitals, data centers, and highrise towers.
 - Urban resilience planning integrates buildinglevel performance with communityscale recovery.
- 5. Computational Modeling and Digital Twins:** virtual replicas (digital twins) of buildings are becoming part of seismic engineering workflows. These models perform the following:
 - Simulate structural response under multiple earthquake scenarios.
 - Integrate sensor data to update models continuously.
 - Support predictive maintenance and rapid postevent assessment.
- 6. Integration of Sustainability and Seismic Resilience:** Future seismic design aims to balance carbon reduction with structural safety.
 - Lowcarbon materials and optimized structural systems reduce environmental impact.
 - Energydissipating devices and base isolation reduce repair needs and embodied carbon over a building’s life.
 - Sustainable seismic design is emerging as a unified discipline.⁶⁶
- 7. Architectural Innovation for Seismic Safety:** Architects are increasingly shaping seismic performance through form, massing, and material choices.
 - New architectural strategies emphasize redundancy, controlled deformation, and distributed damping.
 - Innovations in façade systems, cores, and modular construction are improving resilience.

These trends reflect a broader architectural shift toward seismicaware design.⁶⁷

- 8. CommunityScale and Urban Seismic Resilience:** The underlying theme here is that the future of seismic design extends beyond individual buildings.
 - Cities are adopting seismic micro-zonation, lifeline resilience planning, and regional recovery modeling.

- Infrastructure, utilities, and buildings are being designed as interconnected systems.
- Policy is moving toward functional recovery mandates, already emerging in some jurisdictions, especially where Resilient Design is gaining roots such as in California.

The above are the trends that will shape the application of seismic design in the coming years and decades. There are specific implications for structural engineers and architects as we will explore in the next section. Nonetheless, in general, the broader implications for seismic design across all professions and regulatory bodies are likely to emphasize the following attributes:

- a. Datadriven decisionmaking.
- b. Adaptive systems rather than static resistance.
- c. Sustainable, lowcarbon structural strategies.
- d. Rapid recovery and continuity of operations.
- e. Integration of smart technologies from concept through lifecycle.

4.2. EVOLUTION OF SEISMIC DESIGN AND IMPACT ON DESIGN PROFESSIONALS

The design professions most likely to be impacted by the trends described above will be structural engineers and architects. Since the focus of this course is on architects, those impacts will be addressed in greater detail. Still, the main likely effect on structural engineering practice needs to be noted and understood by architects because as the roles of any of the “team” members (as noted earlier in then course) affects all other members and adaptation is critical.

IMPACT ON STRUCTURAL ENGINEERING PRACTICE

The role is expanding from “designing for forces” to designing for resilience, recovery, and lifecycle performance.

Engineers are likely to do more of the following:

- Use nonlinear analysis as a standard tool.
- Collaborate with A.I. driven monitoring systems.
- Design structures that can be repaired quickly or avoid damage altogether.
- Integrate sustainability metrics into seismic system choices.
- **Enhanced Geotechnical–Structural Integration:** The boundary between geotechnical and structural engineering is tightening. This integration reduces uncertainty and improves performance predictions.
 - Soil–structure interaction (SSI) is being modeled more accurately with nonlinear analysis.
 - Sitespecific ground motion simulations are replacing generic spectra in many regions.
 - Foundation systems (e.g., rocking foundations, isolation at the foundation level) are becoming part of the seismic system rather than an afterthought.

IMPACT ON ARCHITECTURAL PRACTICE

Perhaps the most significant shift in seismic design will be in the way architects practice. One reason for this is that architectural practice in general is undergoing a sort of revolution, arguably a paradigm shift from a myopic focus on solving a functional program for a single building to a more gregarious role where considerations of sustainability and resilience are requiring architects to think beyond simply solving the client’s program to assessing how their designs

64 sciencepublishinggroup.com; “Advances in Seismic Design for High-Rise Buildings: A Systematic Review of New Techniques and Materials”; *American Journal of Civil Engineering (Volume 13, Issue 2)*; Girmay Mengesha Aznaw; 22 April, 2025

65 buildings.com; “Next-Gen Seismic Design: How Smart Tech Is Reinventing Earthquake-Resistant Buildings”; Emily Newton; May 27, 2025

66 icsecm.org; “Innovations in Seismic Design for Sustainable Structures”; 07/05/2025

67 Architizer.com; “Seismic Safety: Architectural Innovations in Earthquake Zones”; Eric Baldwin;

impact and are impacted by their environment – natural and human created. This is not to say that architects’ primary responsibility will move away from their clients. On the contrary, the convergence of regulatory restructuring towards sustainability and resilience coupled with the economic realities of the cost of poor design will force and / or influence building owners (clients) to either require or at least accept the shift. Accessibility, energy efficiency and even seismic design in its current form are all examples of how shifts in priorities and codification of these leads to changes in how buildings are designed and how the professional practices morph in response. The dramatic changes in the way performance based regulatory thinking and Artificial Intelligence supported technologies and tools are starting to shape the practice discourse gives clear indications that all aspects of the practice of architecture will be restructured – not unlike how CAD and the PC replaced the drafting board and the paper practice binders. Here are some of the likely ways in which the role of the architect is changing relative to seismic design:

- A. Perhaps most importantly, Architecture must **integrate resilience from the earliest concept stage**. Emerging research emphasizes that architectural decisions – geometry, mass distribution, façade systems – directly influence seismic behavior. Architects are expected to design with seismic forces in mind from the outset, not as a late coordination step.⁶⁸ This means that architects will increasingly be expected to understand seismic behavior at a conceptual level and collaborate earlier and more deeply with structural and geotechnical engineers.
- B. **Performance based design requires deeper collaboration** with the “team”: As performancebased and functionalrecovery standards grow, architects must coordinate closely with structural engineers to meet specific performance targets. This shifts practice toward early multidisciplinary modeling sessions, iterative formfinding that balances aesthetics, drift limits, and damping strategies. In addition, it requires designing nonstructural components – ceilings, partitions, cladding – to meet seismic performance goals.
- C. **Nextgeneration seismic systems**: For architects, this means greater freedom to explore expressive forms because advanced damping and isolation can manage irregularities. New façade and envelope strategies to enable integration of sensors or adaptive components. These can lead to options to design buildings that communicate their “health” to occupants and owners.
- D. **Architecture tied to community resilience**: In seismic regions, buildings are expected to serve as symbols of safety and recovery. Architectural publications highlight that earthquakeresistant design is becoming a cultural and civic responsibility, not just a technical one.⁶⁹ This affects practice by elevating resilience as a visible design value and encouraging architects to design public spaces and forms that support postevent gathering and recovery. By integrating seismic resilience into the narrative of the project, similar to sustainability.
- E. **Sustainability and seismic resilience are converging**: Perhaps, even merging as contemporary architecture increasingly integrates lowcarbon materials with seismic performance goals. For example, mass timber systems (CLT walls, braced frames) are being tested for seismic regions; lightweight, ductile materials reduce seismic forces and embodied carbon, and lifecycle monitoring supports longterm sustainability by reducing repair needs. This means that Architects must now evaluate how material

choices affect both carbon footprint and seismic behavior.

- F. **Use of “Digital Twins”**: Virtual models updated by realtime sensor data are becoming part of seismic design and building management. For architects, this means designing buildings with embedded monitoring infrastructure and considering how operational data will influence future renovations or adaptive reuse. This expands the architect’s role to involve participating in longterm resilience planning beyond construction.
- G. **Urban-scale seismic resilience and site design**: As cities adopt microzonation* and resilience planning, architects must respond to sitespecific seismic conditions. This impacts site planning, orientation, and massing decisions and the integration of open spaces that can serve as emergency gathering areas. It also fosters coordination with lifeline infrastructure (utilities, transportation) to support community recovery.

*** MICROZONATION:**

the process of dividing a region (often urban areas) into smaller, localized zones with similar hazard levels, based on how different soil and geological conditions amplify shaking during an earthquake. It maps hazards like liquefaction, landslides, and ground motion, directly informing safer, site-specific building codes and land-use planning to reduce risk.

[Harvard.edu: “Seismic Microzonation: A Comprehensive Summary of Principle, Practices and Case Studies of Indian Cities” by Patel, Neelu search by orcid ; Singh, V. P. search by orcid ; Ahamad, Md Naseem; June 2025]

4.3. THE FUTURE OF SEISMIC BUILDING CODES AND THE REGULATORY OVERSIGHT

Regulatory frameworks for seismic design are moving toward functional recovery, riskbased precision, and integration with climateresilience policy. The direction seems to be clearly moving towards codes expecting buildings not just to survive earthquakes, but to remain usable, with design decisions tied to communityscale resilience.

- A. **Functional Recovery Will Become a Core Requirement**: The biggest shift is the move from lifesafety to functional recovery, meaning buildings must be safe and usable within a defined time after an earthquake.
 - Federal agencies are prioritizing modernization of building codes to improve climate and hazard resilience, including seismic events.⁷⁰
 - This will likely lead to new performance targets for hospitals, schools, housing, and essential facilities.
 - Architects and engineers will need to design for limited damage, rapid repair, and continuity of operations.

This is the most transformative regulatory change since the introduction of seismic design categories.

- B. **ASCE 7 Will Continue to Move Toward PerformanceBased, RiskTargeted Design**: *ASCE 722 (Minimum Design Loads and Associated Criteria for Buildings and Other Structures)*, released by the *American Society of Civil Engineers (ASCE)* in late November/early December 2021 has already introduced major updates to

68 mdpi.com; “Earthquake Consideration in Architectural Design: Guidelines for Architects”, Sardar S. Shareef, 15 Sept. 2023

69 Architizer.com; “Seismic Safety: Architectural Innovations in Earthquake Zones”; Eric Baldwin;

70 NIBS.org: “Introduction to 2024 Edition Seismic Design Category Maps & FEMA’s Building Code Strategy and the National Initiative to Advance Building Codes” by Kelly Cobeen S.E., Wiss Janney Elstner Associates, Jonathan Westcott, P.E., Civil Engineer, Building Science Branch, FEMA-Resilience; 7/11/2024.

seismic provisions, and future editions will deepen this trend. ASCE 722 includes updated risk categories and “importance” factors that influence seismic design forces.⁷¹

New load combinations and refined seismic hazard tools are now embedded in design workflows and future editions are expected to expand alternative performance-based pathways, allowing designers to demonstrate acceptable performance through nonlinear analysis rather than prescriptive rules.⁷² This means more modeling, more simulation, and more coordination between architects and engineers.

C. **IBC 2024 and Beyond:** Expect more granular Risk Categories and Hazard Mapping.

The 2024 IBC incorporates ASCE 722 and introduces significant structural changes with updates to risk categories in IBC Chapter 16 which reflect a more nuanced understanding of building importance and occupancy.⁷³ Additionally, FEMA’s 2024 seismic design category maps emphasize modernized hazard data and resilience priorities.⁷⁴

Future IBC cycles will likely integrate even more sitespecific hazard modeling, including basin effects and nearfault motions. Architects will need to understand how massing, irregularities, and program distribution affect risk category assignments and seismic demands.

D. **Integration of MultiHazard and ClimateResilience Requirements:** Federal policy is pushing for building codes that address multiple hazards—flood, wind, seismic—under a unified resilience strategy. FEMA highlights modernization of codes as a key national priority for hazard mitigation.⁷⁵

Future seismic provisions will likely integrate with climatedriven requirements such as energy efficiency, sustainability, and extremeevent resilience. This means seismic design will no longer be siloed; it will be part of a broader resilience framework.

E. **Greater Emphasis on Existing Buildings and Retrofit Standards:** ASCE 722 explicitly notes that additions, alterations, and repairs to existing buildings require separate criteria.⁷⁶ Future codes are expected to strengthen mandatory retrofit triggers, expand requirements for nonstructural seismic bracing (MEP, façades, ceilings) and also tie retrofit funding to compliance with modern seismic standards. These changes will notably impact renovation and adaptivereuse projects.

F. **More Explicit Requirements for Soil–Structure Interaction and Tsunami Design:** ASCE 722 already includes expanded guidance on soilstructure interaction and tsunami loads.⁷⁷ And trends suggest that future codes will likely:

- Require nonlinear SSI modeling for certain building types.
- Expand tsunami design zones and criteria in coastal regions.
- Increase geotechnicalstructural coordination requirements.

This will influence site planning, foundation strategies, and early architectural decisions.

G. **Digital Tools and Hazard Mapping Will Likely Become Mandatory:** The ASCE 7 Hazard Tool is now the standard for retrieving seismic parameters. It provides precise hazard data for seismic, wind, flood, snow, and tsunami risks.⁷⁸ In the near future, codes may require digital hazard lookups rather than static maps. This will streamline design but also demand more technical literacy from architects.

These foreseeable changes in both trajectory and substance of regulatory requirements is consistent with an overall tendency of regulators to make codes and guidelines more integrated and have the ability to respond to project and site nuances rather than current prescriptive model that, while reasonably applicable to a broad set of projects and locations, can be problematic or even counterproductive in unique circumstances. Hence the move towards a performance-based approach that can be more flexible and therefore meet the public safety welfare requirements more fully as intended for each project, especially those that are functionally multifaceted or must address complex site conditions. As these codes and rules change, enforcement of these will also have to take different arrangements. Building officials and other governing enforcement officials will need to be more technically versed as they will have to understand the performance models presented by designers and be able to challenge these in a meaningful dialog rather than simply enforce the prescriptive dictate of a code. The positive outlook of this potential model is that building designers and regulatory officials can work collaboratively to find the best practical solution while safeguarding public welfare, safety, and building survivability. One potential downside of these emerging trends is that currently codes and regulations provide designers with a shield that limits liability and, in some ways, makes the design process a series of checkboxes and formula compliance. In the new model, liabilities may get redefined and more attention to the design performance will be needed by engineers and architects instead of simply “meeting code”.

4.4. SUMMARY & CONCLUSION

This course examined the various natural forces and the geological construct of the Earth that impact building design and focused on those that generate earthquakes. Understanding how earthquakes develop provides the basis for developing an informed response in building design to counter those forces and maintain stability of the building or structure. We also looked at how pre-industrial societies dealt with earthquakes, whether by intuition, observation or trial and error. In the post-industrial era, with greater scientific understanding of the seismic forces, design techniques improved and, while prediction of earthquakes still remains elusive, the ability to withstand and survive the event is greatly improved. At the same time, regulations and codes have evolved to provide guidance and mandate seismic design requirements. We have discussed the many agencies and regulatory bodies that govern seismic design. The 3rd part of the course examined the impacts of seismic design requirements on the practice of Engineering and architecture and how design professionals respond. In the last part, we reviewed the future direction of seismic design and how the nature of codes, regulations and design practice is becoming less prescriptive and more integrated with resilient based design philosophies.

Seismic design, a relatively nascent specialization, is very critical to the regions of the Earth where earthquakes are frequent. Architects and engineers who build in these areas must be alert to the implications

71 STRUCTURE magazine: “2024 IBC Significant Structural Changes Risk Categories (IBC Chapter 16)–Part 5” by John “Buddy” Showalter, P. E., M. ASCE, M. NCSEA, and Sandra Hyde P. E., M. ASCE, M. NCSEA; March 9, 2024.

72 RISA.com: “What’s New in ASCE 7-22?”; September 16, 2025.

73 See Note 72

74 See Note 71

75 Ibid

76 SEAU.org: “Significant Changes in ASCE 7-22”; by S.K. Gosh Associates; Presentation to SEAU. February 20, 2024.

77 cedEngineering.com: “Overview of the Seismic Design Process Based on ASCE/SEI 7-22”; PDH Course No. S02-039; By Ibrahim M. Metwally, Ph.D, P.E.

78 See Note 77

of seismic forces, a focus that will only become more pronounced in future. With advances in materials, technologies and targeted design approaches, seismic design continues to advance, albeit with greater complexity. With a paradigm shift that extends seismic design beyond earthquake resistance and collapse prevention to a more resilient approach where buildings will be expected to not only survive an earthquake but remain effectively functional in the aftermath. These approaches bode well for the public and while they place more responsibilities on architects and engineers, they are likely to yield more rewards for everyone.

END PART 4

PART 4 REVIEW QUESTIONS

1. Which of the following are true statements?
 - A. Buildings are moving toward continuous, real time seismic awareness
 - B. Material science is accelerating seismic innovation
 - C. A & B
 - D. Building codes are becoming more prescriptive

2. Seismic cloaking is _____?
 - A. Combining elastomeric bearings with sliding mechanisms
 - B. Redirecting seismic waves around structures
 - C. When S and P waves overlap
 - D. A shift in building structure that appears seismic but is not

3. Future focus of seismic design is likely to...?
 - A. Expand from “designing for forces” to designing for resilience, recovery, and lifecycle performance
 - B. Develop highly prescriptive codes
 - C. Replace Resilient design trends
 - D. Be limited to California and the Pacific states

4. For architects, next-generation seismic systems could mean...?
 - A. Greater freedom to explore expressive forms because advanced damping and isolation can manage irregularities
 - B. Totally AI generated buildings with no need for human interaction
 - C. Government mandated pre-determined design templates
 - D. B & C

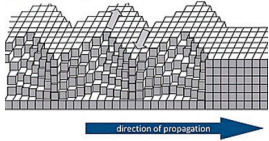
5. Which of the following is/are true statements?
 - A. Seismic design is now able to predict earthquakes up to 72 hours in advance
 - B. Sustainability and seismic resilience are converging
 - C. Functional recovery will likely become a core requirement of seismic design
 - D. B & C

REVIEW QUESTION ANSWERS

Part 1 Review Questions

1. Which layer of the earth is the portion where earthquakes are felt?
 - A. Mantle; Incorrect.
 - B. Core; Incorrect.
 - C. Lithosphere; Correct. The rigid outermost shell is referred to as the lithosphere, this is the layer humans and most life on earth lives and where earthquakes are felt.
 - D. Stratosphere; Incorrect

2. The location below the earth’s surface where the earthquake starts is called the _____.
 - A. Fault plane; Incorrect.
 - B. Hypocenter; Correct. The location below the earth’s surface where the earthquake starts is called the hypocenter, and the location directly above it on the surface of the earth is called the epicenter.
 - C. Epicenter; Incorrect.
 - D. Crust; Incorrect.

3. This illustration depicts what kind of seismic wave?
 

- A. W wave; Incorrect.
 - B. S wave; Incorrect.
 - C. Love wave; Correct. In the image of Seismic Waves, this wave illustration depicts a Love Wave.
 - D. Rayleigh wave; Incorrect.
4. An earthquake of intensity “V” on the MMI scale would be classified as:
 - A. Violent; Incorrect.
 - B. Weak; Incorrect.
 - C. Severe; Incorrect.
 - D. Moderate; Correct. According to the figure showing the MMI scale, an intensity of “V” is a “Moderate” earthquake.

 5. Which of the following building characteristics are better for seismic design?
 - A. Flexible steel frames; Correct. Steel frames and wood-frame structures often offer better flexibility and resilience.
 - B. Unreinforced masonry; Incorrect.
 - C. Irregular shape; Incorrect.
 - D. All of the above; Incorrect

Part 2 Review Questions

1. The first U.S. state to adopt a seismic code was:
 - A. Oregon; Incorrect.
 - B. Colorado; Incorrect.
 - C. California; Correct. In response to the 1933 Long Beach earthquake, California became the first US state to mandate statewide minimum structural standards.
 - D. Alaska; Incorrect.

2. The most significant standard for seismic design related to buildings is _____.
 - A. ASCE 7; Correct. For building design, perhaps the most important standard is the ASCE 7, which forms the backbone of seismic design for buildings in the US and is widely used in other parts of the world.
 - B. IBC Chapter 7; Incorrect.
 - C. BOCA 1943; Incorrect.
 - D. UN Building Council Sec. 33-2; Incorrect.

3. What is the popular name for the Circum-Pacific belt seismic zone?
- A. Sino-American Plate; *Incorrect.*
 - B. Ring of Fire; Correct. Know as the “Ring of Fire”, also called the Circum-Pacific belt, is the zone of earthquakes surrounding the Pacific Ocean.**
 - C. Trans Andean Zone; *Incorrect.*
 - D. Middle America trench; *Incorrect.*
4. How does the IBC guide seismic building design?
- A. Defers to states; *Incorrect.*
 - B. Use of hazard classifications; *Incorrect.*
 - C. Use of seismic Zones; *Incorrect.*
 - D. Use of seismic design categories (SDCs); Correct. For applications related to building design, the IBC uses seismic design categories (SDCs, A-F) that come from ASCE 7.**
5. A building in SUG II would be classified as what type of occupancy?
- A. Standard occupancy; *Incorrect.*
 - B. Non-combustible; *Incorrect.*
 - C. Essential facility; Correct. Buildings in SUG II are Essential Facilities.**
 - D. Critical occupancy; *Incorrect.*

Part 3 Review Questions

1. In pre-industrial times seismic design was:
- A. Ignored; *Incorrect.*
 - B. Based on observations, trial and error and pattern recognition; Correct. Pre-industrial societies tried to predict earthquakes in a variety of ways, including observations, trial and error, and pattern recognition.**
 - C. Based on scientific calculations; *Incorrect.*
 - D. Developed using plate tectonic theory; *Incorrect.*
2. Which of the following is a characteristic of why Gutenberg Castle in Lichtenstein and similar medieval structures have survived seismic events?
- A. Flexible timber frames; *Incorrect.*
 - B. Inclined turrets; *Incorrect.*
 - C. Dense masonry with excellent mass distribution; Correct. The Gutenberg Castle has survived due to dense stone masonry with excellent mass distribution, elevated bedrock foundation, and structural continuity that resists shear failure.**
 - D. Polygonal stones with precision cuts
3. A foundational theory of modern earthquake science is _____?
- A. Zonal relativity theory; *Incorrect.*
 - B. Elastic rebound theory; Correct. The 1906 San Francisco Earthquake led to the development of the elastic rebound theory, forming the foundation of modern earthquake science.**
 - C. Seismic Uplift theory; *Incorrect.*
 - D. None of the above; *Incorrect.*
4. Which chapter of the IBC requires special inspection and testing for seismic structures?
- A. 12; *Incorrect.*
 - B. 32; *Incorrect.*
 - C. 21; *Incorrect.*
 - D. 17; Correct. Special inspections and testing to ensure seismic detailing is built correctly is required by IBC Chapter 17.**

5. Which of the following is not a consideration for seismic architecture?
- A. Building color; Correct. For seismic architecture, main considerations include drift compatibility, façade and cladding anchorage, doors and windows, etc. Building color is not a listed consideration.**
 - B. Doors and windows; *Incorrect.*
 - C. Façade and Cladding Anchorage; *Incorrect.*
 - D. Drift Compatibility; *Incorrect.*

Part 4 Review Questions

1. Which of the following are true statements?
- A. Buildings are moving toward continuous, real time seismic awareness; *Incorrect.*
 - B. Material science is accelerating seismic innovation; *Incorrect.*
 - C. A & B; Correct. As described in section 4.1, buildings are moving towards continuous, real time seismic awareness and material science is accelerating seismic innovation.**
 - D. Building codes are becoming more prescriptive; *Incorrect.*
2. Seismic cloaking is _____?
- A. Combining elastomeric bearings with sliding mechanisms; *Incorrect.*
 - B. Redirecting seismic waves around structures; Correct. Seismic cloaking concepts aim to redirect seismic waves around structures.**
 - C. When S and P waves overlap; *Incorrect.*
 - D. A shift in building structure that appears seismic but is not; *Incorrect.*
3. Future focus of seismic design is likely to...?
- A. Expand from “designing for forces” to designing for resilience, recovery, and lifecycle performance; Correct. The role of seismic design is expanding from “designing for forces” to designing for resilience, recovery, and lifecycle performance.**
 - B. Develop highly prescriptive codes; *Incorrect.*
 - C. Replace Resilient design trends; *Incorrect.*
 - D. Be limited to California and the Pacific states; *Incorrect.*
4. For architects, next-generation seismic systems could mean...?
- A. Greater freedom to explore expressive forms because advanced damping and isolation can manage irregularities; Correct. For architects, next-generation seismic systems means greater freedom to explore expressive forms because advanced damping and isolation can manage irregularities.**
 - B. Totally AI generated buildings with no need for human interaction; *Incorrect.*
 - C. Government mandated pre-determined design templates; *Incorrect.*
 - D. B & C; *Incorrect.*
5. Which of the following is/are true statements?
- A. Seismic design is now able to predict earthquakes up to 72 hours in advance; *Incorrect.*
 - B. Sustainability and seismic resilience are converging; *Incorrect.*
 - C. Functional recovery will likely become a core requirement of seismic design; *Incorrect.*
 - D. B & C; Correct. According to the course, sustainability and seismic resilience are converging, and functional recovery will become a core requirement of seismic design.**