Tsunami Vertical Evacuation Structures (TVES)

Bringing High Ground to a Location Near You!

Version 01/27/22

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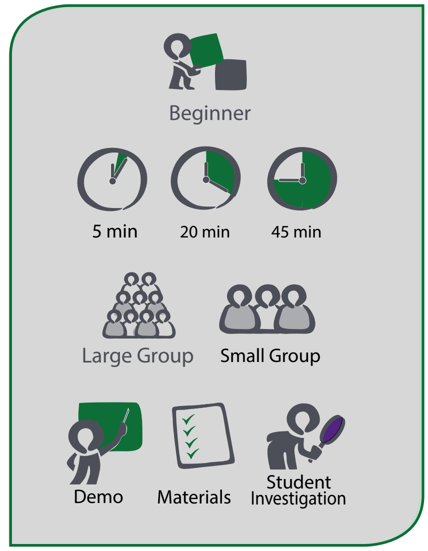
OVERVIEW

An earthquake-generated tsunami is a critical hazard for people who live, work, and visit the coast of the Pacific Northwest and Northern California. Even with earthquake early warning, there is limited time to Drop, Cover and Hold on and then evacuate to higher ground after shaking stops. High ground may be available but too far away for vulnerable populations to reach in time. Tsunami Vertical Evacuation Structures (TVES; Appendix A—Vocabulary) can provide a viable option to escape a rising tsunami surge.

In the 5-minute activity, learners discover why TVES are important and how Westport, Washington built North America's first TVES at their newly rebuilt Ocosta Elementary School. The 15- to 20-minute activity allows learners to build a model TVES tower. In the 45-minute activity, learners apply basic tsunami structural engineering design principles to construct a model TVES with specific design criteria.

Why is it important to learn about earthquakes and their effects, like tsunamis? Over 100,000 people along the Pacific Northwest and Northern California coastal areas could be affected by a major tsunami. Earthquake hazard mitigation strategies improve the preparedness of communities and households prior to an earthquake event. The ShakeAlert® Earthquake Early Warning system for the West Coast of the U.S. aims to complement earthquake mitigation and preparedness efforts. ShakeAlert detects significant earthquakes quickly so that alerts can be delivered to people and automated systems.



Time: 5-, 20-, and 45-minute activities that can be adapted for audience and venue.

Audience: This can be done with novice and experienced geoscience learning groups.

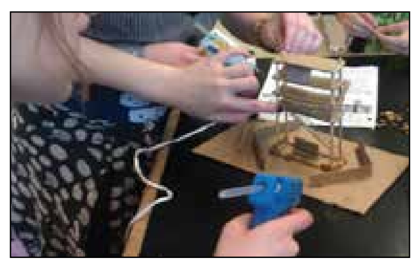


Figure 1: Small learner group constructing a tower TVES.

OBJECTIVES

Learners will be able to:

- Explain risks for people in a tsunami inundation zone.
- Identify different types of tsunami evacuation structures and their advantages.
- Design and build a model TVES using basic tsunami engineering concepts and emergency preparedness needs.

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MATERIALS

Materials for the 5-minute activity:

- Computer with projection system
- Optional: model TVES (Figure 2)

Materials for the 20-minute activity

- Construction supplies for each learner group assembled into sets (Figure 3):
  - Cardboard base approximately 5" X 6"
  - Cardboard platform floors precut to 4" x 5" ***Options***: lightweight cardboard (cereal boxes, poster board, file folders) or 4" x 6" notecards work well since they can be cut with scissors
  - 12 bamboo skewers
  - 10 pieces of spaghetti
  - Glue gun and 1 extra glue stick
  - Scissors
  - Wire cutters or heavy-duty snips (to cut skewers)
  - Ruler
  - Extra supplies: cardboard for an additional floor, stairs, extra skewers and spaghetti, glue sticks for glue guns

Valuable Tips!

To complete the activity in 20 minutes:

1) Precut the 5" x 6" and 4" x 5" cardboard platforms
2) Provide extra supplies: cardboard for an additional floor or stairs, extra skewers and spaghetti, glue sticks for glue guns.

Materials for the 45-minute activity:

- Same supplies as above except cardboard is not pre-cut
  - Provide a larger base for the berm option approximately 23" X 23"
  - Lightweight cardboard (cereal boxes, poster board, file folders)
  - Multipurpose glue
  - green construction paper for berm
  - Optional: Box cutter or utility knife (if using heavier cardboard)
  - Optional: Balsa wood

Figure 2: Example of a Tsunami Vertical Evacuation Structure (TVES) tower model.

Figure 3: Materials and tools needed for the 20- and 45-minute activities. (Box cutter optional.)

RESOURCES

Videos used in activities:

- Surviving a Tsunami: Vertical Evacuation - Science Nation (2 min. 31 sec.) (NSF)
- What is a Tsunami Vertical Evacuation Site? (5 min. 50 sec.)

Videos as relevant background:

- World Tsunami Awareness Day: Built to Last (1 min. 19 sec.) Ocosta Elementary School Westport, Washington UN Office for Disaster Risk Reduction
- Vertical Evacuation; Learner Demos (4 min. 53 sec.)

Publications as relevant background

- FEMA Guidelines for Design of Structures for Vertical Evacuation from Tsunamis Examples of berm and tower designs found on pages 170-174.
- Project Safe Haven Tsunami Vertical Evacuation on the Washington Coast Examples of berm, tower and building designs found on pages 10–12.
- Tsunamis and what to do
- Tsunami safety
- Shoalwater Bay Tribe Builds Evacuation Tower to Provide Tsunami Safety for Community

INSTRUCTOR PREPARATION

A tsunami is one of the most powerful and destructive natural forces. It is a series of wave surges (not just one) caused by a large and sudden displacement of the ocean. Tsunamis radiate outward in all directions from the disturbance and can move across entire ocean basins. Most tsunamis are caused by large earthquakes below or near the ocean floor, though they can also be caused by landslides into or under the water.

Tsunamis pose the greatest risk for low-lying coastal areas, such as beaches, bays, harbors and river mouths, and areas along rivers and streams that lead to the ocean. A large tsunami can flood low-lying coastal areas more than a mile inland. Tsunamis can wrap around headlands, islands, and sand spits, so coasts facing away from the tsunami source may also be at risk.

Familiarize yourself with both the Resources and Appendices A–F:

- Appendix A—Vocabulary
- Appendix B—Tsunami evacuation signs
- Appendix C—Examples of Tsunami Vertical Evacuation Structures
- Appendix D—Construct a TVES Tower in 15–20 minutes
- Appendix E—Construct a TVES Tower or Berm in 30 minutes
- Appendix F—More About Tsunamis

ACTIVITIES AND DEMONSTRATIONS

IF YOU HAVE 5 MINUTES

Did You Know?

- Did you know that tsunami waves can travel 500 miles per hour in the deep ocean and 20-30 miles per hour once the waves are in shallow water closer to shore?
- Did you know that when tsunamis reach land, their waves range from 10 feet, to over 100 feet in height depending on location?

Tsunami waves are powerful, destructive, and a serious risk to life and communities particularly in low-lying coastal areas of the Pacific Ocean. Since you cannot outrun a tsunami, it is essential to get to high ground or to a tsunami vertical evacuation structure (TVES) as quickly as possible. Depending on your location, you may have only a few minutes to get to safety when a tsunami siren sounds or after you feel the ground shake from an earthquake (Figure 4). The first wave in a tsunami may not be the last, the largest, or the most damaging. Stay out of the tsunami hazard zone until local officials tell you it is safe, as the danger may last for hours or days.

Preparation

- Computer and projection system with URL links and pages open to:
    - Surviving a Tsunami: Vertical Evacuation - Science Nation (2 min. 31 sec.)
    - Examples of TVES berm, tower and building from Project Safe Haven (pages 10-12)
    - Appendix B—Tsunami evacuation signs
    - Appendix C—Examples of Tsunami Vertical Evacuation Structures (Ocosta Elementary School Westport, Washington and the Gladys Valley Marine Studies Building at the Hatfield Marine Sciences Center in Newport, Oregon)
- Optional: Show a physical model of a TVES (For directions to construct a simple TVES tower, see Appendix D)

Procedure

1. Introduce the topic of TVES by asking learners if they ever spent any time near an ocean coast or beach. Have you ever noticed signs indicating that you are entering a tsunami hazard zone or a tsunami evacuation route? (Figure 4 and Appendix B)
2. Introduce the short video on how engineering helps solve problems around tsunami vertical evacuation. Surviving a Tsunami: Vertical Evacuation - Science Nation (2 min. 31 sec.)
3. Now that we understand that tsunami vertical evacuation structures (TVES) are an important engineering solution, let's look at three different types of

Figure 4: Tsunami evacuation signs. Higher-resolution copy is available in Appendix B

structures. Show examples of TVES berm, tower and building from Project Safe Haven (pages 10-12) or show Figures 5a and b, and Figure 6. These designs take into consideration the forces of both the earthquake ground shaking and the immense lateral forces of a tsunami.

If there is time, point out the advantages for each type of structure.

Type and advantage:

- **Berm**:
    - Easy access for many people, including those with limited mobility.
    - Allows people to follow instinct to evacuate to high ground.
    - Eliminates fear of entering a structure that may not be safe.
    - Multifunctional
- **Tower:**
    - Economical
    - Small footprint
    - Due to lower cost, more towers could be distributed throughout the affected areas to increase accessibility and availability.
    - Multifunctional
- **Structure:**
    - Lower levels of a building can be designed as "open space," allowing the water to flow through without compromising the engineering parameters.
    - Multifunctional
    - Top level of a parking structure could provide a helicopter landing pad after the event to deliver much needed supplies.
    - Buildings have the potential to generate money through other, non-tsunami uses.

4. Finally, let's look at two actual tsunami vertical evacuation structures. Show Appendix C, Example A: Ocosta Elementary School in Westport, Washington with evacuation space for 1000 people, and Example B: The Gladys Valley Marine Studies Building at the Hatfield Marine Science Center in Newport, Oregon provides an evacuation space for up to 920 people.

Figure 5: a) Classroom model of tsunami vertical evacuation tower showing stairways and b) berm designs with a broad ramp designed to deflect floating debris.

Figure 6: The Gladys Valley Marine Studies Building in Newport, Oregon is designed and built to sustain a magnitude 9.0 earthquake and the ensuing tsunami. The 47-foot ramp leads to the roof of the three-story structure, which is designed to serve as a vertical evacuation site for more than 900 people.

Questions for Discussion:

- What are some of the challenges to building tsunami vertical evacuation structures along our coastlines? (*Answers vary and may include: cost, learning curve for residents [time for residents to learn about TVES and why they are important, provide practice drills for residents and visitors], political will to engage in the process, time, and ability to write grant proposals with governmental agencies.*)

IF YOU HAVE 20-MINUTES

Did You Know?

- Did you know that tsunami vertical evacuation structures (TVES) can be designed for multiple purposes?

TVES towers (see Figures 2 and 5a for tower models) have multiple purposes that make them more cost effective and an asset to their communities. For instance, TVES can be used for wildlife and scenic viewing. Berms can be used for recreation, parks, and community outdoor gathering spaces. Newly constructed or retrofitted parking structures, offices, schools, and hotels can be used as TVES if they meet FEMA P-646 design criteria.

Preparation

- Content presented in the 5-minute demonstration should precede this activity.
- Computer and projection system with link programed to show: What is a Tsunami Vertical Evacuation Site? (5 min. 50 sec. Start at min. 3:11. If time is limited, stop the video at 5:08)
- Construction supplies listed in the materials section above for each learner group
- Print construction criteria (Appendix D) for each learner group
- Since construction time is limited to 15 of the 20 minutes, construction supplies should be prepared in advance as directed. The intent is to provide a short hands-on experience for learners to reinforce the engineering design concepts presented in the video.

Procedure

1. Review key concepts from the 5-minute activity.
   - Why are TVES important? (*where nearby high ground is not available, TVES provides a place of refuge, with sufficient height to elevate evacuees above the tsunami water depth (flow depth), designed and constructed to resist tsunami load effects*)
   - Types of TVES (towers, berms, and structures)
2. We are going to build a simple tsunami vertical evacuation tower in 15 minutes. By building a small model, we will become more aware of some of the key structural elements that engineers take into consideration when designing a TVES. We will watch a short video clip which describes 5 of these elements. For reference, the five (5) key tsunami structural elements are:
   - Strong systems with reserve capacity to resist extreme forces.
   - Open systems that allow water to flow through with minimal resistance.
   - Flexible systems that resist and absorb extreme forces without failure.
   - Redundant systems that can experience partial failure without larger collapse.
   - Foundation systems that can support tsunami loads, erosion, subsidence, and long duration shaking.
3. If you haven't already done so, show a 2-minute portion of the video: What is a Tsunami Vertical Evacuation Site? (5 min. 50 sec.)
   Start video at minute 3:11 and stop at 5:08 which is the section that presents the 5 key elements of tsunami structural design.
4. Show one set of supplies and explain that learners will use cardboard, bamboo skewers, spaghetti, and a glue gun. Point out the location of extra supplies if needed: cardboard, skewers, and glue gun sticks (from the instructor).
5. Distribute the Construction Criteria (Appendix D for the 20-minute activity) to each learner group. Review the instructions from Appendix D.
   - Use the supplies provided to construct a vertical evacuation tower that will have a finished elevation of 50' using a scale of 1" = 10'. Thus, your tower will be at least 5" tall.
   - Decide as a team which material will be used for the top platform: the pre-cut 4" X 5" rectangle cardboard or one of the other options listed in the materials. Using a 1" = 10' scale, the actual dimensions of the tower would provide 2,000 sq. ft. which is enough for 200 evacuees.
   - Design your own structural support system (number and location of vertical girders).
   - Include stair locations if time permits.
   - Optional: You can add an additional floor (above 5"), add a roof for shelter from rain, add a storage container to hold emergency supplies as time allows.

6. Distribute construction materials to each learner group and get them started. Provide time checks reminding learners that basic construction is great. The fine details are just not possible in a short amount of time.

Questions for Discussion

- In summary, what were some of the challenges to design and build your structure? How did a short time period impact your decisions? What did you discover about the TVES towers and their structural elements? (*Answers vary. A tower can be simple and effective with proper construction.*)

IF YOU HAVE 45 MINUTES

Did You Know?

- Did you know that tsunamis create unique forces that place added strain on a structure?

Tsunamis create forces that last far beyond the duration of earthquake shaking. While earthquake ground shaking can last up to several minutes and cause tremendous damage, an earthquake-generated tsunami can also cause severe damage with flooding and dangerous currents that can last for days. The time between waves ranges from five minutes to two hours. The first wave to reach the shore may not be the largest or the most damaging. It is not possible to predict how long a tsunami will last, how many waves there will be, or how much time there will be between waves. Tsunami forces on buildings and infrastructure need to be understood and steps need to be taken to strengthen structures to survive, save lives, and protect communities.

Preparation

- Learners will be split into teams to build either a berm TVES or tower TVES (Figures 5a and b).
- Content presented in the 5-minute demonstration should precede this activity.
- Computer and projection system with link programed to show: [What is a Tsunami Vertical Evacuation Site?] (5 min. 50 sec.)
- Be prepared to show examples of two completed TVES structures and the Shoalwater Bay Indian Tribe TVES tower design in Tokeland, Washington (Appendix C).
- Construction supplies listed in the materials section above for each learner group.
- Print one copy of the Construction criteria (Appendix E) for each learner group.
- Optional: Have learners use the engineering design process (see Appendix G) to design and test their TVES.

Procedure:

1. Review key concepts from the 5-minute activity.
   - Why is Vertical Evacuation important? (*where nearby high ground is not available, a tsunami vertical evacuation structure (TVES) provides a place of refuge, with sufficient height to elevate evacuees above the tsunami water depth (flow depth), designed and constructed to resist tsunami load effects*.)
   - Types of TVES (Towers, berms, and structures)
2. We are going to build a model of either a tsunami vertical evacuation tower or berm to better understand the tsunami forces that act on structures as well as structural elements that engineers take into consideration when designing a TVES. We will watch a short video which describes these factors.
3. Show the video [What is a Tsunami Vertical Evacuation Site?] (5 min. 50 sec.)
   - For reference, the 5 types of forces that a TVES must withstand are:
     - **Hydrostatic force**—caused by an imbalance of pressure, when the water is deeper on one side of a building or room to another side.
     - **Buoyant force**— is the upward force exerted by any fluid upon a body placed in it.
     - **Hydrodynamic (or drag) force**—a combination of the pressure of the moving mass of water and its density, as well as the friction generated as the water flows around the structure.
     - **Debris impact force**—the combined impact by driftwood, lumber, cars, boats, and shipping containers during a tsunami surge, causing progressive collapse if a column or wall is damaged by debris.
     - **Debris dams**—are caused by debris piling up against a structure adding to the hydrodynamic force by displacing water which had been moving around the structure.
   - For reference, the 5 key tsunami structural elements are:
     - **Strong systems** with reserve capacity to resist extreme forces.
     - **Open systems** that allow water to flow through with minimal resistance.

- **Flexible (ductile) systems** that resist and absorb extreme forces without failure.
- **Redundant systems** that can experience partial failure without disproportionate collapse.
- **Foundation systems** that can support tsunami loads, erosion, subsidence, and long duration earthquake shaking.

4. Now that we have a better understanding of the forces and engineering principles that go into designing a TVES, let's look at two completed structures and one structure that is currently under construction.

   Show the TVES at Ocosta Elementary School Westport, Washington (Appendix C, Example A) built in 2015. Ocosta Elementary is the first vertical evacuation structure built in North America and can help evacuate 1000 people. The second TVES in North America is located at the Gladys Valley Marine Studies Building at the Hatfield Marine Science Center in Newport, Oregon (Appendix C, Example B). Completed in 2019, the rooftop provides an evacuation place for up to 920 people in case of a tsunami.

   Question for Discussion:

   - What did you notice about the TVES structures with your new knowledge of tsunami load design? (*Answers vary, but may include: strong concrete materials to withstand forces, strong foundations, accessible and height appropriate*)

   Next, show the Shoalwater Bay Indian Tribe TVES tower design in Tokeland, Washington, currently under construction (Appendix C, Example C).

   Questions for Discussion:

   - What did you notice about the design of the TVES tower based on what you have just learned? (*The structure has a deep, strong foundation. It is made of steel and has an open design. It is accessible by stairs and height appropriate*.)
   - Did you notice any cross X or V bracing? Why do you think that is? (*There is horizontal bracing between the vertical beams, but lack of vertical bracing leaves open space for tsunami surge and materials to flow around and through the structure. Bracing could create a debris dam increasing the hydrodynamic load on the tower.*)

5. We are going to apply our new understanding of engineering principles into a model TVES tower or berm. You will have approximately 30-minutes (revise based on your available time). Distribute and review the design criteria found in Appendix E.

6. Explain supplies:
   - Each team: one glue gun, 2 glue sticks, scissors, ruler.
   - Teams building a tower: set of 12 bamboo skewers, 10 pieces of spaghetti
   - Teams building a berm: green construction paper, all-purpose glue
   - Common supplies: cardboard (note: lightweight cardboard can be cut with scissors; however, heavier cardboard may require a utility knife (available from instructor), additional bamboo skewers, spaghetti, and glue gun sticks (available from instructor).

7. Final instructions:
   - The model TVES is constructed on a base that should be only 1" larger than the structure on all sides.
   - Label the base with the team member's names and period number.
   - Caution about appropriate use of glue guns, glue sticks, and glue threads getting on the floor!
   - Assign the amount of time available for construction.
   - Where to place the completed model.
   - *Optional*: Assign a team write-up or oral presentation to include: :
     - TVES design the team built
     - Engineering design elements they included from the video
     - Alternate uses of the TVES
     - Describe a design challenge and how it was addressed
     - Describe one or more insights they learned from doing the activity.

   * For an example of a classroom presentation see [Vertical Evacuation Structures—Learner Demos]

   Questions for Discussion

   In summary, what were some of the challenges to design and build your structure? What did you discover about the TVES towers, their structural elements to withstand the tsunami forces? (*Answers vary. The designs for a TVES berm and tower must incorporate more structural elements to withstand tsunami forces*.)

APPENDIX A—VOCABULARY

Berm—A mound of soil or other earthen material.

Breakaway wall—A wall that is not part of the structural support of the building and is intended, through its design and construction, to "break away" when struck from the side, without causing damage to the building or supporting foundation system. The goal of a breakaway wall is to allow substantially free passage of flood waters.

Bulkhead—A wall or other structure, often of wood, steel, stone, or concrete, designed to retain or prevent sliding or erosion, and occasionally used to protect against wave action.

Debris—Solid objects or masses carried by or floating on the surface of moving water.

Fill—Material such as soil, gravel, or crushed stone placed in an area to increase ground elevations or change soil properties.

Flow depth—The depth of expected tsunami water level, including relative sea level change, with respect to the ground plane at the structure.

Footing—The enlarged base of a foundation wall, pier, post, or column designed to spread the load of the structure so that it does not exceed the soil bearing capacity.

Freeboard—Separation between the level of water and level of refuge in a vertical evacuation structure.

Impact loads—Loads that result from waterborne debris transported by tsunami waves striking against buildings and structures or parts thereof.

Liquefaction—A phenomenon that occurs in saturated soils when the net pore pressure exceeds the gravity force holding soil particles together. Soil strength and stiffness decrease dramatically as the soil behaves like a fluid.

Loads—Forces or other actions that result from the weight of all building materials, occupants and their possessions, environmental effects, differential movement and restrained dimensional changes.

Refuge—An evacuation facility that is intended to serve as a safe haven until an imminent danger has passed.

Retrofit—Any change made to an existing structure to reduce or eliminate potential damage to that structure from flooding, erosion, high winds, earthquakes, or other hazards.

Runup or Runup elevation—Ground elevation at the maximum tsunami inundation limit, including relative sea-level change.

Scour—Removal of soil or fill material by the flow of water, frequently used to describe localized conical erosion around pilings and other foundation supports where the obstruction of flow increases turbulence.

Shelter—An evacuation facility that is intended to provide safe, accessible, and secure short-term housing for disaster survivors, typically including a place to sleep along with extended food and water supplies.

Subsidence (as a coastal tectonic process)—a vertical drop of the coastal land during an earthquake.

Tsunami—A naturally occurring series of ocean waves resulting from a rapid, large-scale disturbance in a body of water, caused by earthquakes, landslides, volcanic eruptions, and meteorite impacts.

Tsunami Vertical Evacuation Structure (TVES)—A vertical structure designated as a place of refuge in the event of a tsunami with sufficient height to elevate evacuees above the level of tsunami inundation. TVES are also designed and constructed to resist tsunami load effects.

APPENDIX B—Tsunami Evacuation Signs

Image source: United States Geological Survey

APPENDIX C—Examples of completed Tsunami Vertical Evacuation Structures (TVES)

Example A: Ocosta Elementary School Westport, Washington built in 2015. This is the first vertical evacuation structure built in North America.

Image source: Staff Sgt. Tom Conning, 122nd Public Affairs Operations Center U.S. Army Corps of Engineers

Schematic rendering of the Ocosta Elementary School campus

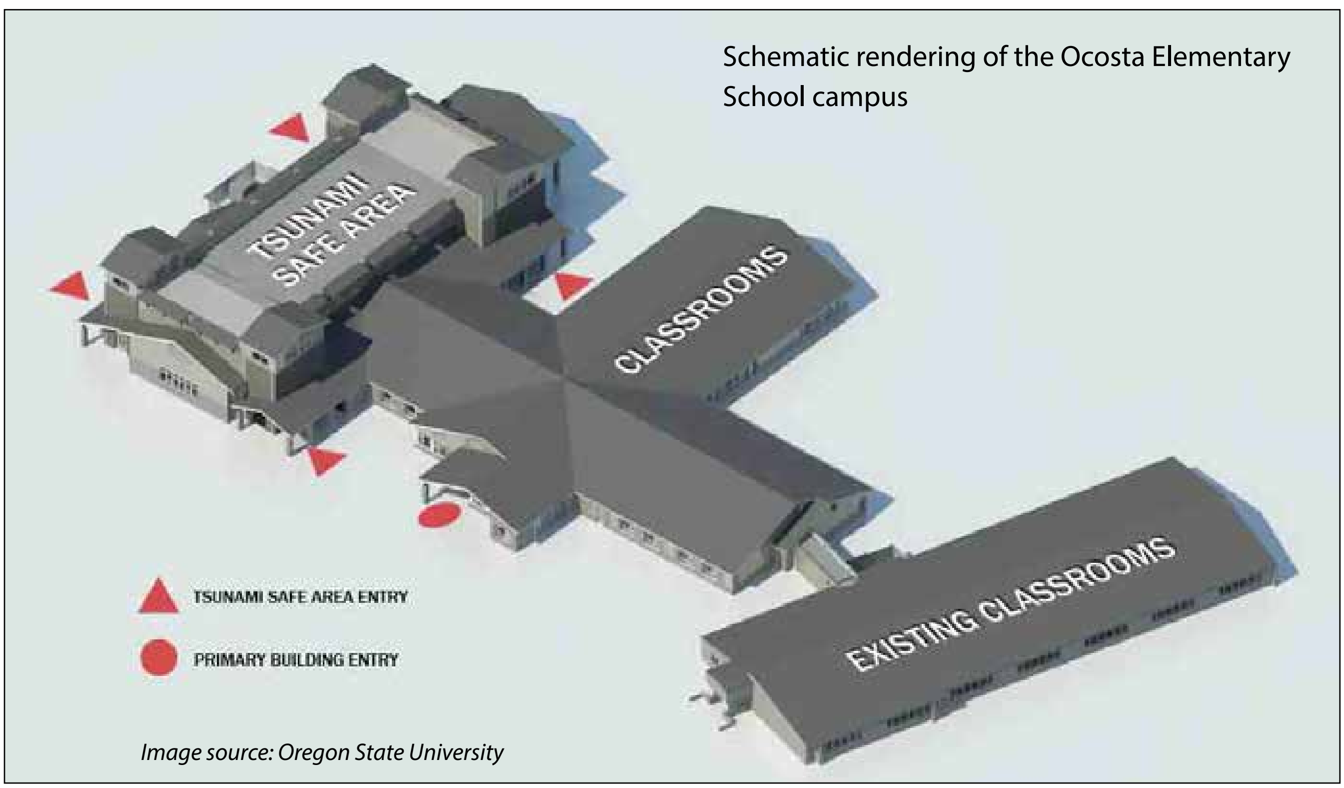


Image source: Oregon State University

Example B: The Gladys Valley Marine Studies Building at the Hatfield Marine Science Center in Newport, Oregon provides an evacuation place for up to 920 people in case of a tsunami. Middle image: alternate artistic rendering from the Hatfield Marine Science Center in Newport, Oregon provides an evacuation place for up to 920 people in case of a tsunami. Lower image: schematic side view of the Hatfield Marine Science Center

Image source: [Oregon State University]()

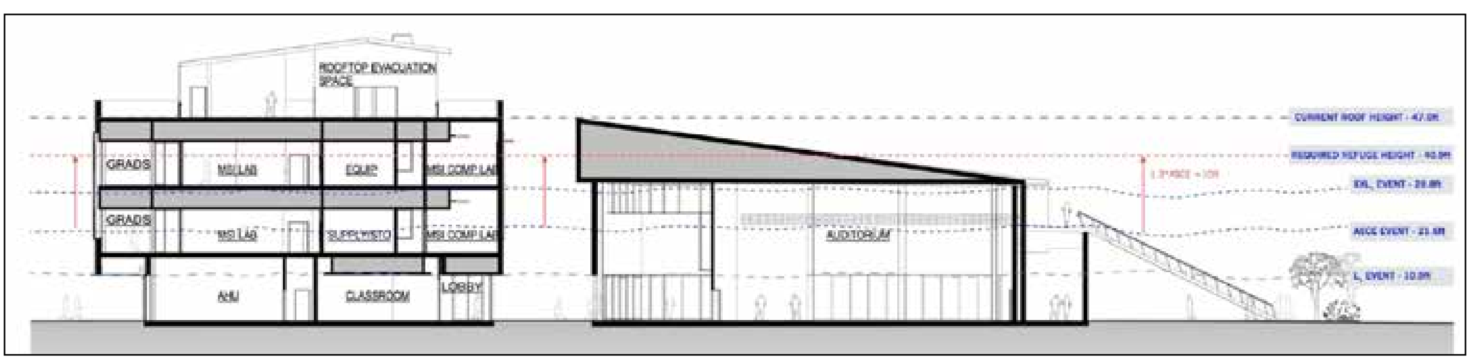


Image source: [Oregon State University]()

Example C: Shoalwater Bay Indian Tribe TVES tower design (schematic below) in Tokeland, Washington.

The safe refuge platforms being constructed by the Shoalwater Bay Indian Tribe TVES tower will be two levels, built at 40 and 50 feet above grade, which is greater than the tsunami wave crest height of 32 feet above grade. With a total usable area of 3,400 square feet, it will accommodate 386 people. The structure will be built of steel with concrete pilings that go down 45 to 50 feet.

Image source: Washington Military Department

APPENDIX D—Learner Handout: Construct a TVES Tower in 15 minutes

- You have 15 minutes to construct your tower.
- Use the supplies provided to construct a vertical evacuation tower that will have a finished elevation of 50′ using a scale of 1″ = 10′. With this scale, your tower will be at least 5″ tall.
- In your team, decide which top platform to use: the pre-cut 4″ X 5″ rectangle cardboard or one of the other options listed in the materials. Using a 1″ = 10′ scale, the actual dimensions will provide 2,000 sq. ft. enough for 200 evacuees.
- Design your own structural support system (number and location of vertical girders).
- Include stair locations if time permits.
- Optional: You can add an additional floor (above 5″), add a roof for shelter from rain, add a storage container to hold emergency supplies as time allows.

Figure A: Rendering of the Shoalwater Bay Indian Tribe TVES in Tokeland, Washington. Photo courtesy of Washington State Military Department Emergency Management Division.

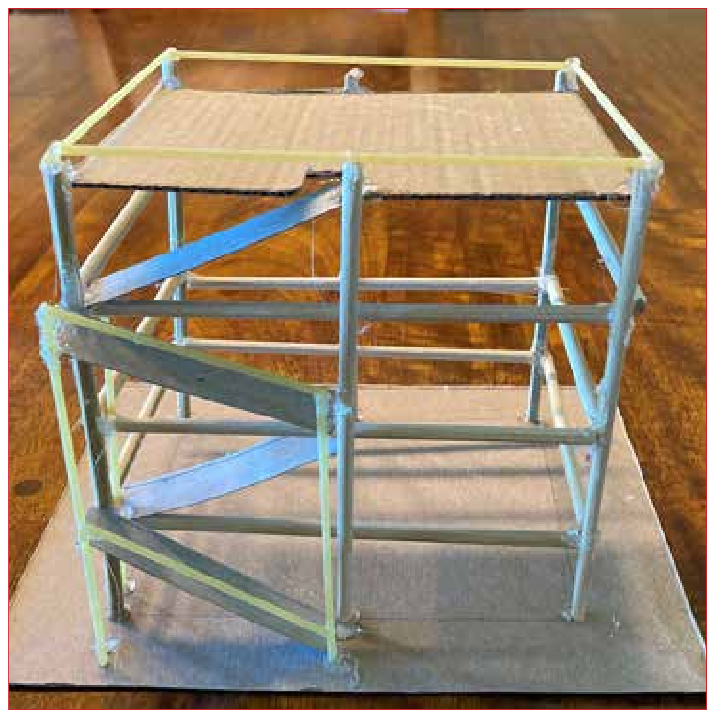


Figure B: Model tower built in 15 minutes.

APPENDIX E— Learner Handout: Construct a TVES Tower or Berm in 30 minutes

- You have 30 minutes to construct your tower or berm.
- Use the supplies provided to construct a vertical evacuation structure that will have a finished elevation of 50′ using a scale of 1″ = 10′. With this scale, your tower will be at least 5″ tall.
- The model TVES is constructed on a base that should be only 1″ larger than the structure on all sides.
- Label the base with the team member's names and period number.

Tower:

- Provide "refuge" space for 200 people. (FEMA requirement is a minimum 10 square feet per person = 2,000 square feet.)

Tower shape	Dimensions	Scale: 1″ = 10′
Square	44.72′ X 44.72′	approximately 4.5″ X 4.5″
Rectangle	40′ X 50′	approximately 4″ X 5″
Height of finished floor*	50′	5″

- Design your own support system (number and location of vertical girders)
- Include stair locations
- Create a storage space for emergency supplies
- * Optional: you can add an additional floor (above 5″), and a protective roof for shelter from rain.

Berm:

- 2,000 sq ft = a semi-circle with a diameter of 71.36′. With a scale of 1″ = 10′, the diameter will be 7.1″.
- Construct a ramp to the finished elevation. FEMA recommended a 1:4 ratio slope. (The 35′ safe elevation requires a 140′ ramp.) With a scale of 1″ = 10′, the ramp length will be 14″. (Note, the ramp can double back to save space.)

Note on TVES elevations: The finished elevation height includes an additional allowance for freeboard, or separation between the level of water and level of refuge. The required minimum freeboard is one story height, or 10 feet (3 meters), whichever is greater, above the tsunami inundation elevation used in tsunami force calculations.

Figure A: Example of a model vertical evacuation structure.

Figure B: Example of model berm evacuation structure.

APPENDIX F—More Background About Tsunamis

From NOAA: "**About Tsunamis**"

A tsunami is one of the most powerful and destructive natural forces. It is a series of waves (not just one) caused by a large and sudden displacement of the ocean. Tsunamis radiate outward in all directions from the disturbance and can move across entire ocean basins. Most tsunamis are caused by large earthquakes below or near the ocean floor, but tsunamis can also be caused by landslides, volcanic activity, certain types of weather and near-earth objects (e.g., asteroids, comets). Not all earthquakes cause tsunamis.

Tsunami Risk

Tsunamis are among the most infrequent of Earth's natural hazards. Each year, there are approximately two tsunamis that cause damage near their source. Tsunamis that cause damage or deaths on distant shores (more than 1,000 kilometers or 620 miles away) occur about twice per decade.

Tsunamis can strike any U.S. coast, but the risk is greatest for states and territories with Pacific and Caribbean coastlines. Low-lying coastal areas, such as beaches, bays, lagoons, harbors and river mouths, and areas along rivers and streams that lead to the ocean, are the most vulnerable. Tsunamis can wrap around headlands, islands, and sand spits, so coasts facing away from the tsunami source may also be at risk.

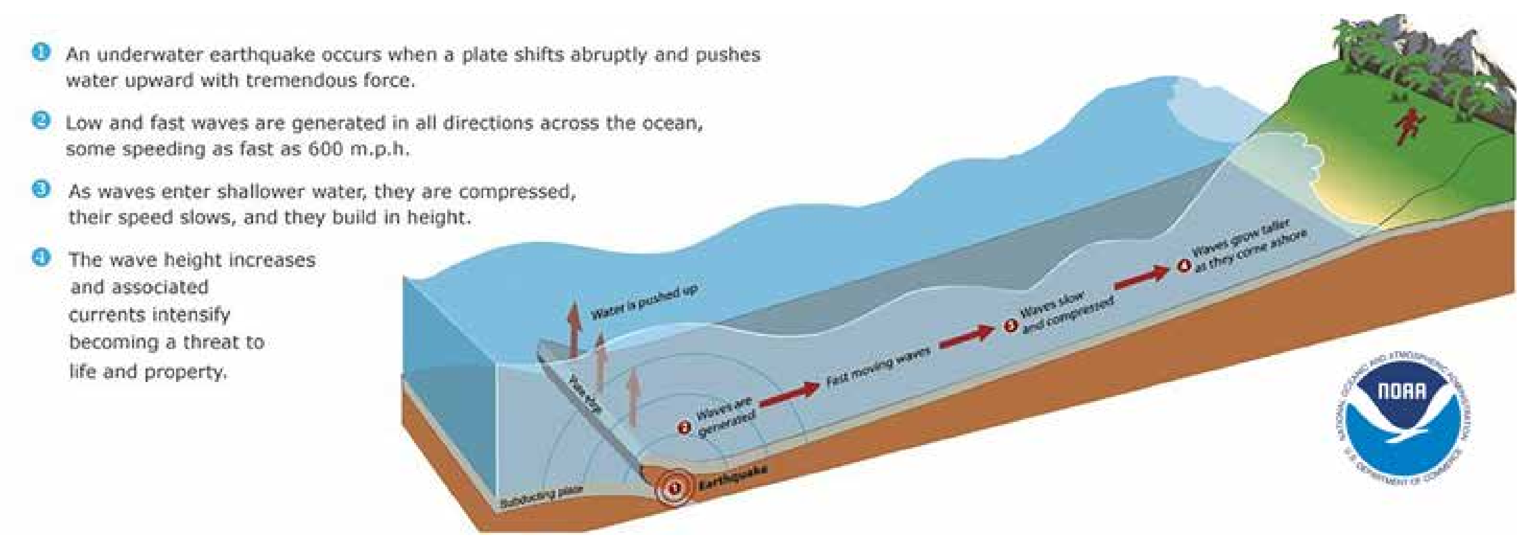
Tsunamis are often referred to as local or distant. The type of tsunami depends on the location of the source of the tsunami and where it may strike land. The source of a local tsunami is close to the coast and may arrive in less than one hour. The danger is greatest for local tsunamis because warning time is limited. A distant tsunami is generated far away from a coast, so there is more time to issue and respond to warnings.

Tsunami Characteristics

Not all tsunamis act the same and an individual tsunami may impact coasts differently. A small tsunami in one place may be very large a few miles away.

The speed of a tsunami depends on the depth of the ocean. In the deep ocean, tsunamis are barely noticeable, but can move as fast as a jet plane, over 500 mph. As the waves enter shallow water near land, they slow to approximately 20 or 30 mph, which is still faster than a person can run.

As the waves slow down, they can grow in height and currents intensify. Most tsunamis are less than 10 feet high, but in extreme cases, can exceed 100 feet. When a tsunami comes ashore, it will not look like a normal wind wave. It may



look like a fast-rising flood or a wall of water. Sometimes, before the water rushes on land, it will drain away suddenly, showing the ocean floor, reefs, and fish, like a very low, low tide. Tsunamis can travel up rivers and streams that lead to the ocean. A large tsunami can flood low-lying coastal areas more than a mile inland.

The series of waves that flood, drain away and then reflood the land may last for hours. The time between waves ranges from five minutes to two hours. The first wave to reach the shore may not be the largest or the most damaging. It is not yet possible to predict how long a tsunami will last, how many waves there will be, or how much time there will be between waves.

Tsunami Dangers

A tsunami can be very dangerous to coastal life and property, such as buildings, highways, etc. It can produce unusually strong currents, rapidly flood land, and cause great destruction. The flow and force of the water and the debris it carries can destroy boats, vehicles, buildings, and other structures; cause injuries; and take lives as the tsunami moves across the land. It only takes six inches of fast-moving water to knock over an adult and two feet of fast-moving water to carry away most vehicles. The water can be just as threatening (if not more so) as it returns to the sea, taking debris and people with it. Flooding and dangerous currents can last for days.

Even small tsunamis can pose a risk. Strong currents can injure and drown swimmers and damage and destroy boats in harbors. And be aware, a tsunami is not surfable. Tsunamis are not like wind waves. They do not have a face, do not curl and break like wind waves and are full of hazardous debris.

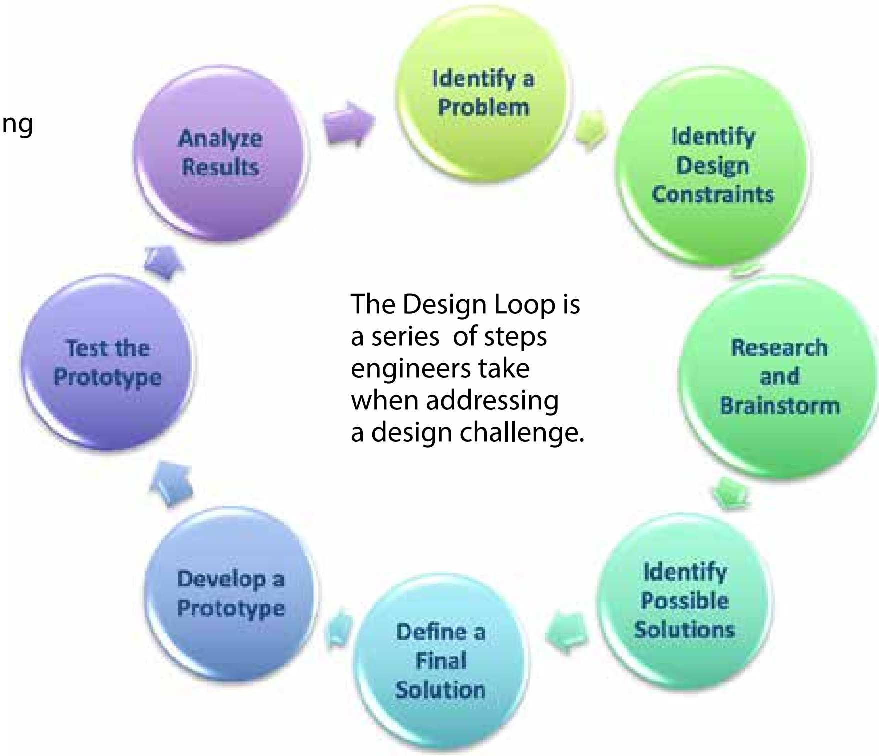
APPENDIX G—NGSS Science Standards and 3 Dimensional Learning , NGSS Science and Engineering Resources

NGSS Science and Engineering Practices

1. Asking Questions (for science) and Defining Problems (for engineering)
2. Developing and Using Models
3. Planning and Carrying Out Investigations
4. Analyzing and Interpreting Data
5. Using Mathematics and Computational Thinking
6. Constructing Explanations (for science) and Designing Solutions (for engineering)
7. Engaging in Argument from Evidence
8. Obtaining, Evaluating, and Communicating Information

NGSS Engineering Design Process

1. Identify a problem
2. Identify design constraints
3. Research and brainstorm
4. Identify possible solutions
5. Define a final solution
6. Develop a prototype
7. Test the prototype
8. Analyze and communicate results



NGSS Science and Engineering Standards

Earth and Human Activity

MS-ESS3-2. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis	**ESS3.B: Natural Hazardss** Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces can help forecast the locations and likelihoods of future events. (MS-ESS3-2)	**Patterns** Graphs, charts, and images can be used to identify patterns in data.(MS-ESS3-2)

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