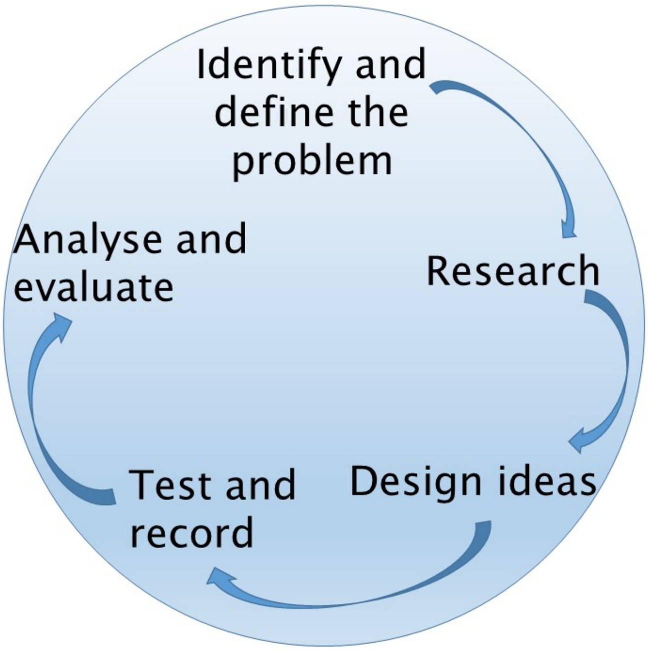
Earthquake Engineering – Student Booklet

The Challenge

Designing earthquake resistant buildings can be lifesaving, especially for people living near tectonic boundaries. Your job is to investigate the causes of earthquakes and their effects on different ground types and building designs. You should select a particular location that you think would benefit from better earthquake engineering and design a building that would be suitable for this location.



Background Information

Earthquakes can be devastating, destroying structures and buildings and taking lives. In 2017 there were 12,527 earthquakes recorded with a magnitude of 4 or higher globally. The deadliest of which was a 7.3 magnitude earthquake which occurred on November 12, killing 630 people in Iran and 10 in Iraq. Interestingly, Russia and New Caledonia both experienced earthquakes of similar depth and magnitude of that in Iran in 2017 and had no fatalities.

Figure 1. Devastation caused by the Iran - Iraq Earthquake of 2017. (By Tasnim News Agency, 2017)

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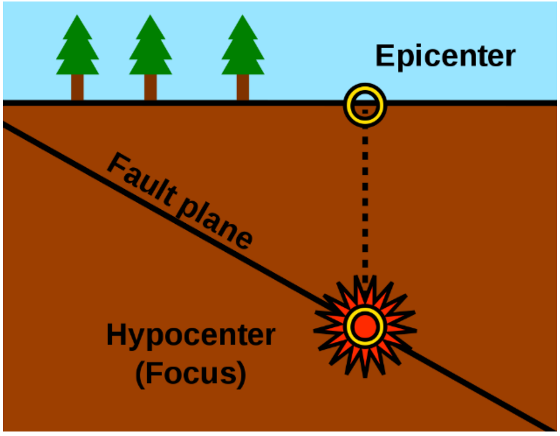

Figure 2. Diagram of the epicenter of an earthquake, where movement along a fault plane has caused it. (Hocevar, 2014)

Earthquakes are caused by fault movement. This can occur on a micro to mega scale. Most earthquakes that cause damage are due to movement of tectonic plates, however volcanic activity, and crustal adjustments can also cause earthquakes. Earthquakes have also been linked to anthropogenic causes, such as fracking and mining.

Figure 3. Three story building on springs in North Carolina to dampen earthquake waves. (Shustov, 1999)

Damage caused by earthquakes can be catastrophic economically for families, businesses and whole countries. With infrastructure and buildings often having to be completely rebuilt. The design of buildings is therefore of paramount importance to avoid being damaged.

Due to the causes of earthquakes some countries are much more likely to experience them. This makes it easier for governments to decide if they should prioritise earthquake engineering to protect their people. Unfortunately a lot of the current designs that do work well are very costly, and unaffordable for many.

Background Research

Research earthquakes and earthquake engineering. Below are some suggested research questions.

1. What causes earthquakes?
2. What are the different types of earthquake waves?
3. Which type of earthquake waves cause most devastation to houses?
4. Where did the three most devastating earthquakes occur last year, in terms of fatalities?
5. Where did the 5 strongest earthquakes occur last year?
6. What are the top 3 most earthquake prone countries?
7. What is the gross domestic product (GDP of those countries?
8. Describe and explain other hazards caused by earthquakes.
9. What are the common causes of death/ injury by an earthquake?
10. What are the most important design considerations when building on an earthquake prone area?

Where in the World?

Objective

To explore the relationship between earthquake location and tectonic plates through use of GIS (Geographical Information Systems) and secondary data.

There are two possible methods for this investigation.

- Using secondary data and paper maps
- Using secondary data and Google maps

Tips

- A list of recent earthquakes with location, magnitude and depth data can be accessed on Wikipedia or through Geoscience Australia or through the USGS - https://earthquake.usgs.gov/earthquakes/search/
- When using Google maps select 'My Places' from the menu tab from there you can create a map and import your spreadsheet of earthquake data.

Results and Analysis

1. Can you link the results of your explorations with tectonic plate boundaries of the world?
2. Which countries are particularly at risk of earthquakes, with numerous plate boundaries passing through them?
3. Can you see any relationship between the depth of the earthquakes and the type of tectonic boundary?

Earthquake Energy

Objective

To be able to calculate the energy released by different magnitude earthquakes and discuss this in relation to building design for a particular region.

Background

Earthquakes are generally reported by their magnitude, or more correctly – Moment Magnitude. This is a modified version of the Richter scale which was devised in the 1930s by Charles Richter.

You will have heard the magnitude of earthquakes being reported on the news, and probably have a good understanding that the larger the earthquake the more energy – and therefore the more destructive power it has. However, the earthquake magnitude is not measured on a linear scale, in fact for each unit of increase (1, 2, 3…) the earthquake will be **10** times bigger and release around **31.6** times more energy.

Complete the table below to show how much bigger each earthquake is and how much more energy it releases expressing the number using scientific notation (where possible).

Results

Magnitude	Times bigger than magnitude 1	Times stronger than a magnitude 1 (energy released)
1		
2		
3		
4		
5		
6		
7		
8		
9		

1. How much more energy does a magnitude 8 earthquake release compared to a magnitude 4?

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Below is a table listing the number of earthquakes which occurred for each magnitude reading in 2017. Use this information to assist you to answer question 2.

Magnitude	Number of Earthquakes
9.0+	0
8.0–8.9	1
7.0–7.9	6
6.0–6.9	106
5.0–5.9	1,451
4.0–4.9	11,296

2. Which released more energy the single magnitude 8+ earthquake or the 11,296 magnitude 4 – 4.9 earthquake events. Show your working.

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3. In 2017 Australia experienced 721 Earthquakes, the largest of which was a magnitude 5. Did you feel any of the earthquakes?

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The Mercalli scale is measurement used to describe the effects of earthquakes. This does not always relate to the actual magnitude and the size of the earthquake – as it depends on people's observations, and the masonry in a particular area. The table on the next page gives a general outline of the effects of different magnitude earthquakes, based on the Mercalli scale.

Magnitude	Earthquake effects
< 2	Rarely even felt by people and may, at most, make light fittings swing
2 – 3	Sometimes felt, but not usually recognised by people as an earthquake – feels like a passing truck.
3 – 4	Felt by most people nearby, may cause cracks to appear in plaster.
4 – 5.5	Felt by all nearby, can cause chimneys to collapse and damage to buildings depending on the quality of construction.
> 5.5	Buildings will be damaged, ground will be cracked and underground pipes broken.

4. For an area prone to earthquakes at which point on the Mercalli scale would you start considering specialising your building designs.

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5. Do you think engineers and architects in Australia should consider earthquakes as a high priority when designing new buildings?

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Case Studies

Objective

To be able to explain the design features of buildings which have enabled them to withstand earthquakes.

Background

There are buildings which are hundreds of years old still standing in seismically active areas. With increasing population size more and more people are living in seismically unstable areas and are at risk of being affected by earthquakes. Better building designs are much more in demand, and new ideas, to prevent building collapse, are being engineered.

Research earthquake engineering ideas, as well as case studies of previous earthquakes where buildings have stayed standing. Using scientific language, explain the principles behind the building design and how it will help to reduce structural failure caused by earthquakes. Where possible add labelled diagrams.

Analysis

1. Consider the social, economic and environmental impact of each design – what are the positive and negative aspects?

2. Would you recommend the same design ideas for Indonesia as you would for Japan? Explain which principles you think would be best for each country and why, with respect to their social, economic and environmental impact?

Flexural Strength Testing

Objective

To design and conduct an investigation into the flexibility of different materials, and analyse their suitability as a building material for earthquake prone zones.

Method

1. Research flexural strength experimental techniques
2. Create a method for your investigation (using materials available at your school), including how you will ensure it is conducted safely, add diagrams to show the set up.
3. Create a table to record data collected from your experiments. What data will you need to collect? How will you collect the data?
4. Show your method and data collection table to your teacher before carrying out the investigation.

Analysis

- What are anomalies and why might there be some in these results?
- Plot the results on a scatter graph, ensuring you make it clear which material is which (use different colours, or shapes for data points), and add lines of best fit to the data (remember lines do not have to be straight.)
- If you are plotting your graph in Excel or Google Sheets add the line equations. – You may have to check which type of line fits it best (e.g. polynomial).
- What does the R^2 value show, why is it important?
- How do your results compare to your predictions?
- How do the materials compare in price? – try to use actual data to answer this question.
- Do all the materials have similar trend line?
- Which material do you think would be best to use to allow the building to sway rather than crack and crumble? Use your data to justify your decision.
- Did all the materials return back to their original shape and height? If not do you think that is an important property for a building material? Explain your answer.
- Are there any other properties other than cost which are worth considering in terms of how suitable the material is for building and earthquake resistant building (e.g. availability of material, how environmentally friendly the material is etc.?)
- Overall which material(s) do you think are best to use? Why?

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Modelling Liquefaction

Objective

To design and conduct an investigation into the behaviour of different ground types when shaken, and relate that to engineering considerations for building in an earthquake prone zone.

Method

1. If you have not already, research liquefaction.
2. Create a method for your investigation (using materials available at your school), including how you will ensure it is conducted safely, add diagrams to show the set up.
3. Create a table to record data collected from your experiments. What data will you need to collect? How will you collect the data?
4. Show your method and data collection table to your teacher before carrying out the investigation.

Analysis

- Which substrate was most affected by liquefaction?
- Which substrate was least affected by liquefaction?
- Considering your prior research into liquefaction, were your predictions correct? If not, why do you think they were not? Use scientific understanding to aid your explanation.
- What were the strengths and weaknesses of your investigation? Discuss equipment, measurement techniques and trials.
- What improvements would you make to your experiment? Explain why they would make your test better/ fairer.
- Which substrate would you rather build your house on: granite, sandstone or unconsolidated sand/silt? Use your data and observations as well as scientific knowledge and understanding to explain your decision.
- In Perth and a lot of WA the substrate is sand – how does that affect the architecture and buildings in the area? Consider factors such as the number of stories, the foundations of the houses and also the age of most houses compared to other countries, such as Scotland, where they have more solid bedrock to build on.

Strength of Shapes

Objective

To design and conduct an investigation determining which shapes are strongest and most likely to withstand applied forces from different directions and relate this to building design in an earthquake prone area.

Background

Earthquake waves can make the ground move in various ways, which leads to many different types of forces (stresses) acting on the buildings. It is vital that buildings in earthquake prone zones can withstand these stresses.

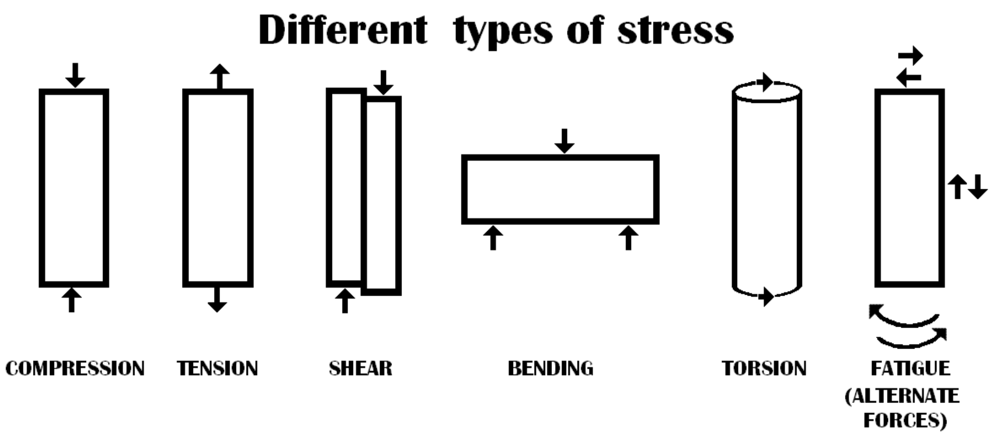

Figure 3. Different stress types which can be caused by an earthquake on a building. (Almazi, 2016)

Method

1. Create a method for your investigation (using materials available at your school), including how you will ensure it is conducted safely, add diagrams to show the set up. Make sure you consider how you will make it a fair test between the shapes, considering factors such as type or material used and size of shapes. You may want to compare the strength of 2D and 3D shapes.
2. Create a table to record data collected from your experiments. What data will you need to collect? How will you collect the data?
3. Show your method and data collection table to your teacher before carrying out the investigation.

Analysis

- Which shape(s) were strongest under compression?
- Which shape(s) resisted tension best?
- Which shape(s) resisted bending most?
- Which shape(s) resisted torsional forces the most?
- Overall which shape was the strongest?
- Calculate the surface area and volume of each shape.
- Which shape used the most material?
- Which shape used the least material?
- Which shape was the easiest to build?
- Which shape would be the cheapest to build? Consider time and material.
- Which shape would be the most expensive to build?
- Which shape would resist the movement cause by earthquakes most?
- In terms of living spaces, which shape is the most functional / practical? Explain why, considering furniture and white goods that would need to be installed.
- Why do you think that rectangular prisms are the most common base shape for most buildings?
- How could you strengthen the rectangular prism to make it more earthquake proof?
- Why do you think a lot of buildings have not been strengthened to make them more resistant to stresses caused by earthquakes?
- What were the strengths and weaknesses of your investigation? Discuss equipment, measurement techniques and trials.
- What improvements would you make to your experiment? Explain why they would make your test better/ fairer.

Protostorming

Objective

Protostorm a model of an earthquake resistant building to be tested on a "shake plate", to gain better understanding of structural strength and consider how to improve your designs.

Equipment

Your teacher will give you a range of materials to choose from.

Method

1. Using the equipment available to you build a structure that you think will withstand an earthquake (to be tested on the shake plate) – you only have 15 minutes to complete this task.
2. After this time test your structure on the shake plate, timing how long it stays standing. (If your building is standing well, start adding weight to test its strength).
3. You now have 10 minutes to make improvements/build a new structure.
4. Test your new/improved structure on the shake plate. (If your building is standing well, start adding weight to test its strength).

Evaluation

How much better was your new/improved structure compared to your first structure? Add labelled photos/diagrams to show what changes you made and explain why they worked. Also add the length of time the structure stayed standing.

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Designing and Building an Earthquake Resistant Building

Objective

To select a particular global location that you think would benefit from better earthquake engineering and design and create a model building that would be ***suitable for this location***.

Equipment

Your teacher will give you a range of materials to choose from.

Method

1. First decide which country/location you think would most benefit from earthquake engineering assistance.
2. Find out more about the country/location, such as
    - What is their gross domestic project (GDP) figure?
    - How dense is their population (are people clustered into cities)?
    - What are their preferred living styles (apartments, double story houses or large properties)?
    - What is the maximum and average magnitude of earthquakes in the location?
    - Is there a high risk of tsunami/landslide in the location if there is an earthquake nearby?
3. Research design ideas/materials and consider their strengths and weaknesses ***in relation to your chosen location.*** Record these in results table one.
4. Now draw and label some design ideas, comparing the pros and cons of each. Either fill these into table two or use CAD.
5. Choose the best design for your chosen location and complete the project plan (below), ensuring you have completed a risk assessment. Show this to your teacher and make any necessary changes before making the model building.

Testing the Design

Test your design using a shake plate or just by shaking the building vigorously. If your chosen location was near the sea, test the buildings ability to withstand a tsunami, by putting it in a tray of sand and pouring lots of water in quickly (do this outside to avoid possible mess). You could also add model trees and toy cars to the tray to represent what may get smashed into the building during a tsunami.

Evaluation

- How well did your design stand up to the test(s)?
- What were the strengths and weaknesses of your design?
- What improvements could you add to your design? Create a labelled diagram of your modified design below – highlighting the modifications.