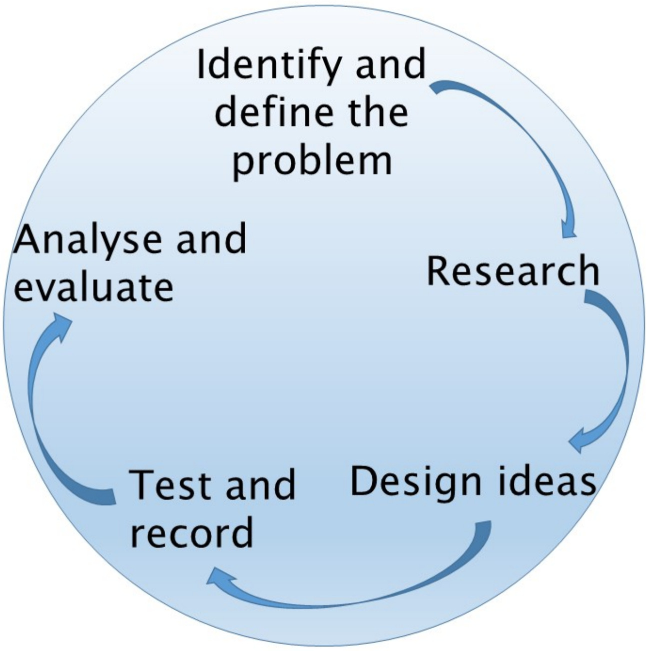
The Challenge

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)

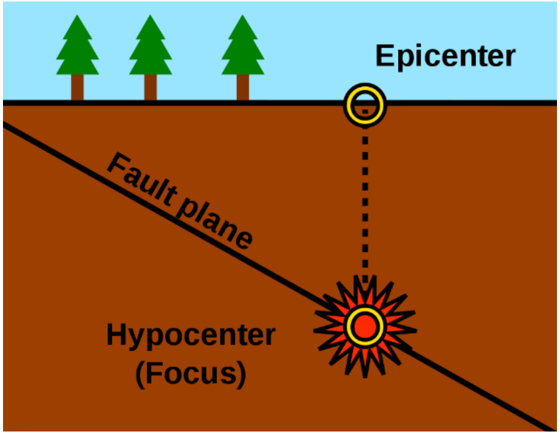


Figure 2. Diagram of the epicenter of an earthquake, where movement along a fault plane has caused it. (Hocevar, 2014)

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

1. What causes earthquakes? Add labelled diagrams/pictures to aid your explanation.

2. Which type of earthquake waves cause most devastation to houses, and how do they move?

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3. Where did the three most devastating earthquakes occur last year, in terms of fatalities?

Location	**Number of fatalities**

4. Where did the 5 strongest earthquakes occur last year?

Location	**Magnitude**

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5. What are the top 3 most earthquake prone countries?

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6. What is the gross domestic product (GDP of those countries?

Country	GDP

7. Describe and explain other hazards caused by earthquakes.

Hazard	How an earthquake can cause it	Damage it can cause
Tsunami		
Liquefaction		
Fire		
Landslide		

8. What are the common causes of death/ injury by an earthquake?

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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.

Option 1 – Using secondary data and paper maps

Equipment

- List of recent earthquakes with location, magnitude and depth data (can be accessed on Wikipedia or through Geoscience Australia).
- Map of the world with longitude and latitude lines on it
- Sticky dots or different coloured pens

Method

1. Locate the epicenter of the each of the earthquakes on the map using the latitude and longitude coordinates. (+ Latitude = North, - latitude = South. + longitude = East, - Longitude = West)
2. Place a sticky dot, or mark on the location with a pen.

Option 2 – Using secondary data and Google maps

Equipment

- Computer
- Access to Google maps
- Access to the USGS site or Wikipedia
- Excel

Method

1. Create a spreadsheet in Excel with the following headings: Magnitude, Latitude, Longitude and Depth (km). Use information from Wikipedia, add details for earthquakes for the past year.

Or

go to the USGS website and in the earthquake catalogue create a new search request - https://earthquake.usgs.gov/earthquakes/search/

- Select custom for the magnitude and set to 6
- Select custom for date and time (1 year).
- Select World under Geographic location
- Under the Output tab select CSV file

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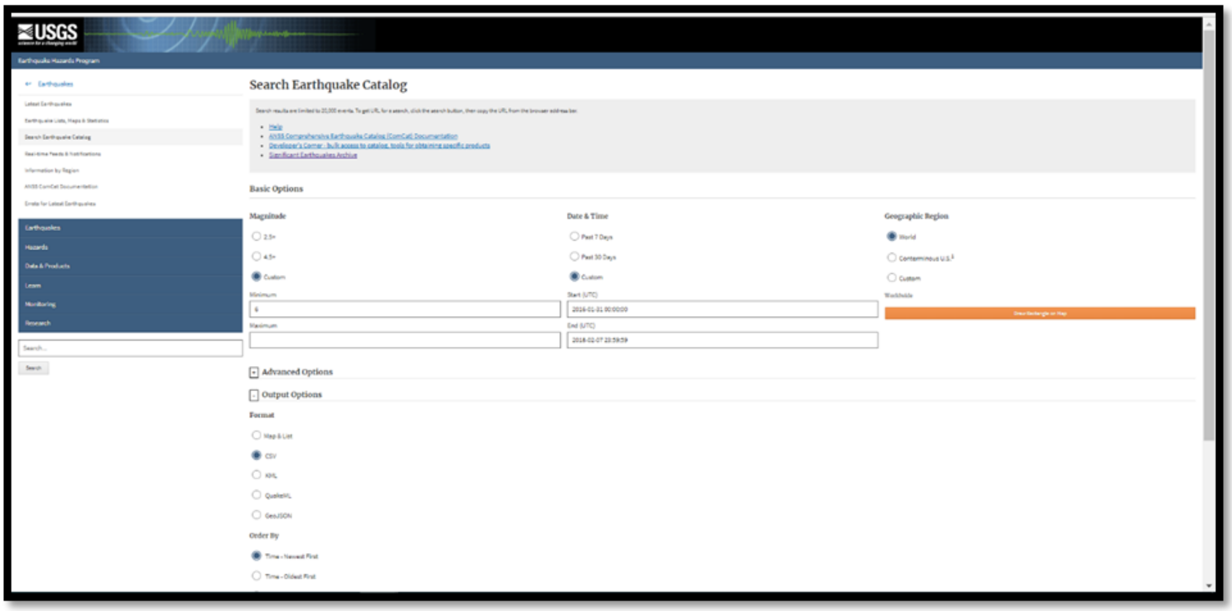

Figure 4. Screenshot showing what to select on the USGS Earthquake catalogue.

2. Open Google maps and click on the menu tab. Then select “My Places.”

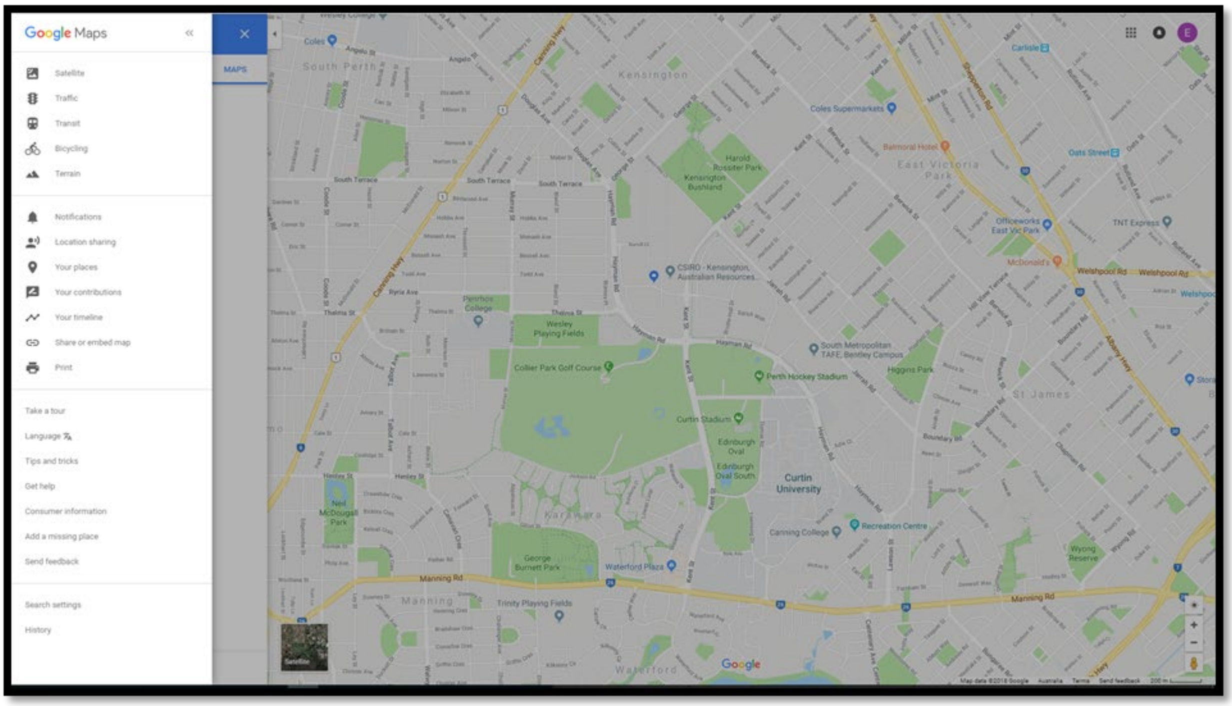

Figure 5. Screen shot of google maps showing the menu bar.

3. Next select Maps -> create map.

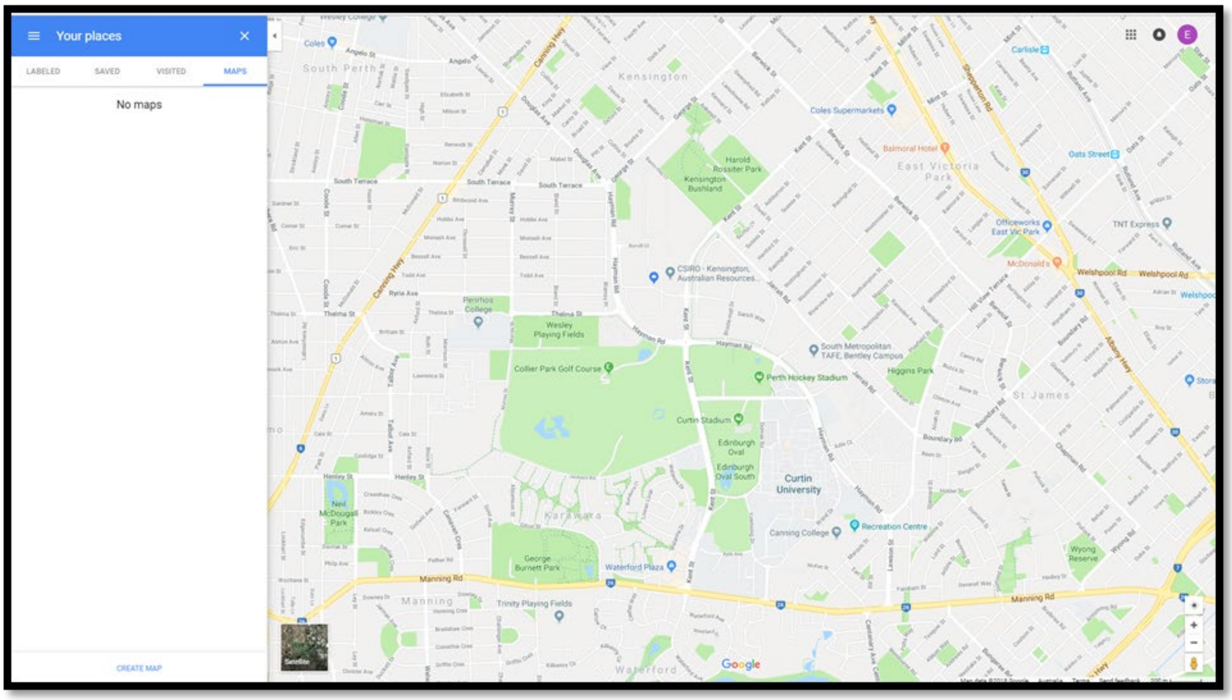

Figure 6. Screenshot of Google maps, select MAPS on the top bar, then CREATE MAP at the bottom of the menu bar.

4. Now you can either individually add each data point by selecting "add marker" tool (highlighted in yellow circle) OR you can import data directly from your spreadsheet by selecting "import".

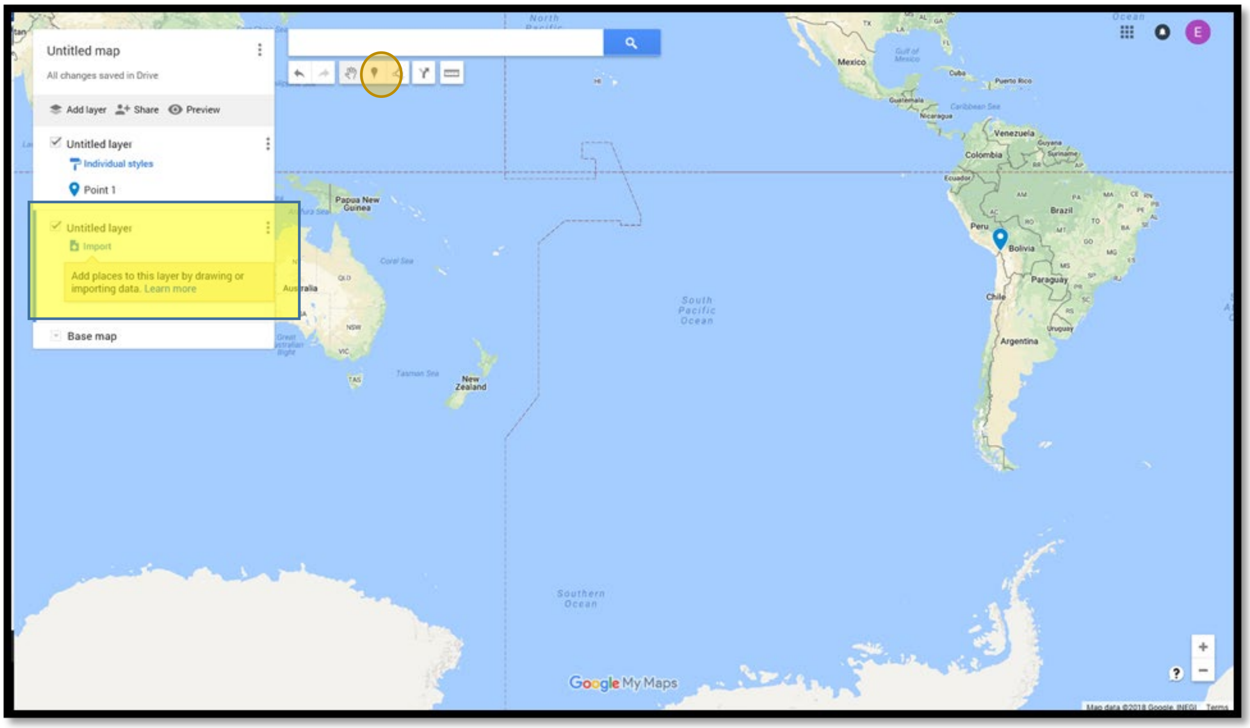

Figure 7. Screenshot highlighting where to select if you wish to add individual data points manually, or where to select if you wish to import a whole CSV file.

Results and Analysis

1. Connect the data points, where you feel it is appropriate, either on your paper map or on Google maps using the drawing tool – attach a copy of this to your work.

2. Compare your outline to a map of tectonic plates of the world. What do you notice?

3. Are there any countries that look particularly at risk of earthquakes, with numerous plate boundaries passing through them? If so, which ones?

4. Can you see any relationship between the depth of the earthquakes and the type of tectonic boundary? Hint: You will need to use your earthquake data and the map of tectonic plates of the world to answer this question.

5. What could you do to improve your map and investigation into the relationship between earthquakes and plate boundaries?

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.

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 the following engineering ideas to explain the principles behind the design and how it will help to reduce structural failure caused by earthquakes.
Add any extra ideas to the table that you find during your research.

Results

Principle	**How it works**	**Example of building using this design (give location as well)**
Steel-reinforced concrete		
Base isolation systems		
Diagonal bracing		
Tuned mass damper		
Springs		

Principle	How it works	Example of building using this design (give location as well)
Earthquake curtains		
Flexible materials (e.g. bamboo)		

Analysis

1. Which, if any, of the designs have worked (withstood numerous earthquakes)?

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

Design principle	Positives	Negatives
Steel- reinforced concrete		
Base isolation systems		
Diagonal bracing		
Tuned mass damper		

Design principle	Positives	Negatives
Springs		
Earthquake curtains		
Flexible materials (e.g. bamboo)		

3. 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?

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Flexural Strength Testing

Objective

To investigate the flexibility of different materials, and analyse their suitability as a building material for earthquake prone zones.

Before setting up the experiment complete the table below:

Independent variable	
Dependent variable	
Control variables	
Predicted outcomes	

Equipment

- Four lengths of different material of the same or very similar dimensions (around 30 mm x 300 mm x 3 mm) e.g. steel rule, wooden ruler, plastic, clay, ceramic tile etc. N.B. although glass is a common building material, for health and safety reasons we do not recommend using it for this investigation.
- Blocks/supporting pins
- Slotted masses (increments of 50 g)
- Ruler
- Safety glasses

Method

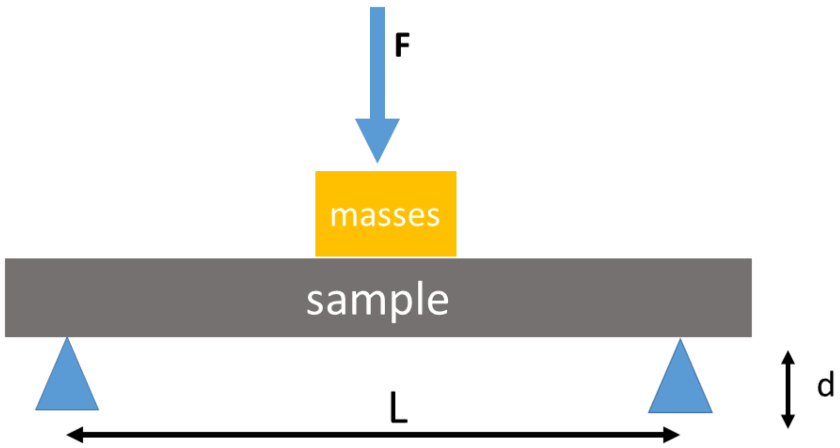

Figure 8. Suggested set up to test the flexural strength of materials.

1. Place the sample onto two blocks/supporting pins, as pictured.
2. Measure the length of the space from block/pin to block/pin (the length, L). Why is it important to keep this measurement the same throughout the testing?

   ____

3. Measure the height from the table to the bottom of the sample (the distance, d) using the ruler and record in the results table.
4. Place a 50 g mass on the middle of the sample, ensuring it is an equal distance from both blocks/supporting pins. Measure the new distance (d) from the table and calculate the deflection. Why is it important to place the mass right in the centre?

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5. Keep adding 50 g masses and calculating the deflection after each new mass is added until you have reached 500 g, or the material looks like it will break (do not break the material!).
6. Repeat for all materials making sure that the length is the same for each – you will need a table for each sample.

Results and Analysis

Material: ___________ Material: ______________ Material: ______________

Mass (g)	Deflection (original distance from table – new distance from table) (mm)		Mass (g)	Deflection (original distance from table – new distance from table) (mm)		Mass (g)	Deflection (original distance from table – new distance from table) (mm)
0			0			0	
50			50			50	
100			100			100	
150			150			150	
200			200			200	
250			250			250	
300			300			300	
350			350			350	
400			400			400	
450			450			450	
500			500			500	

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Material: ___________ Material: ______________ Material: ______________

Mass (g)	Deflection (original distance from table – new distance from table) (mm)		Mass (g)	Deflection (original distance from table – new distance from table) (mm)		Mass (g)	Deflection (original distance from table – new distance from table) (mm)
0			0			0	
50			50			50	
100			100			100	
150			150			150	
200			200			200	
250			250			250	
300			300			300	
350			350			350	
400			400			400	
450			450			450	
500			500			500	

- Share your results with the class to gather at least three sets of data, to determine the average reflection for each stage of the experiment, on each material, removing any anomalies. Why is it important to have at least three sets of data?

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- Plot the results on a scatter graph, with mass along the x-axis and average deflection up the Y-axis, 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.

1. Which material was the most flexible (had the largest deflection)?

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2. Which material was the least flexible?

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3. How did you results compare to your predictions?

4. How do the materials compare in price? – Try to use actual data to answer this question.

Material	Price

5. Do all the materials have a similar trend line on your scatter graph?

6. 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.

7. 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.

8. Which material (s) would you suggest using to build a more earthquake resistant building? Use your data to justify your answer.

9. 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.?)

Modelling Liquefaction

Objective

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

Equipment

- 1 x transparent storage box/ large Tupperware box
- Sand and soil
- Rocks
- Water
- 2 x ping pong balls
- Model house (you could make a small one from Lego or Duplo)

Method

1. If you have not already – research liquefaction in response to an earthquake. Use a labelled diagram to explain your answer.

2. Read through the rest of the method and make predictions of what will occur in the first two scenarios given.

Scenario	Sand and ping pong balls	Sand, water and ping pong balls
Predicted Outcome		

3. Pour enough sand into the box so that it is around 8 – 12 cm high.
4. Bury the ping pong balls in the sand and place the house on top of the sand.
5. Shake or tap on the side of the container for 30 seconds to simulate an earthquake. Make sure that you try to use the same force and speed throughout. How could you ensure that you were using the same speed and force? Is there a piece of equipment you could use, or another simple way?

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6. Record your observations, taking photos/videos if possible.
7. Remove the house and ping pong balls and slowly add water to the sand to dampen it, there should be no water visible on the surface. Ensure the sand is evenly damp throughout. Record how much water you added.
8. Re –bury the ping pong balls and place the house back on top of the sand.
9. Shake the container using the same speed and force as in step 5 to simulate an earthquake. Why is it important to use the same force and speed? Is there anything else that needs to be kept the same?

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10. Record your observations, taking photos/videos if possible.
11. Empty the container of sand and repeat the experiment using the other substrates suggested in the results table.
12. Record your observations for each test.

Results and Analysis

1. Record your results in the table below.

Substrate	Observations
Dry Sand	
Wet Sand	
Dry Soil	
Wet Soil	

Substrate	Observations
Dry sand with rocks in it	
Wet sand with rocks in it	

2. Which substrate was most affected by liquefaction?

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3. Which substrate was least affected by liquefaction?

____

4. What happened to the ping pong balls when the "earthquake" hit, and why do you think that happened? Use scientific understanding to aid your explanation.

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5. 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.

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6. 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.

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Strength of Shapes

Objective

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

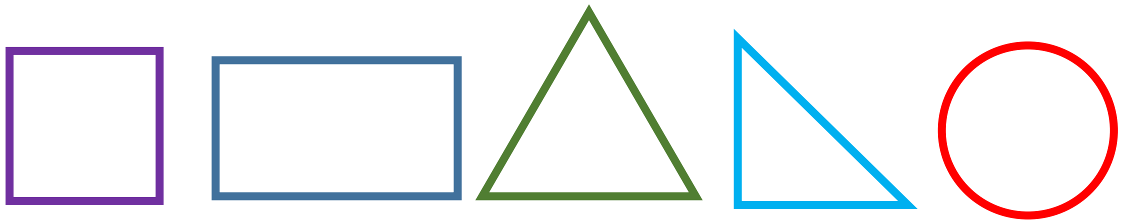
Equipment

- Straws
- String
- Scissors

Method

1. Create the following shapes, endeavouring to make them similar in size:
   - A square
   - A rectangle
   - An equilateral triangle
   - A right angled triangle
   - A circle

Thread the string through the straws and tie a knot at every corner, ensuring good tension.



2. Test the strength of the shapes by applying forces in different directions sequentially to, model the stresses caused by an earthquake. Record your observations in the table below.

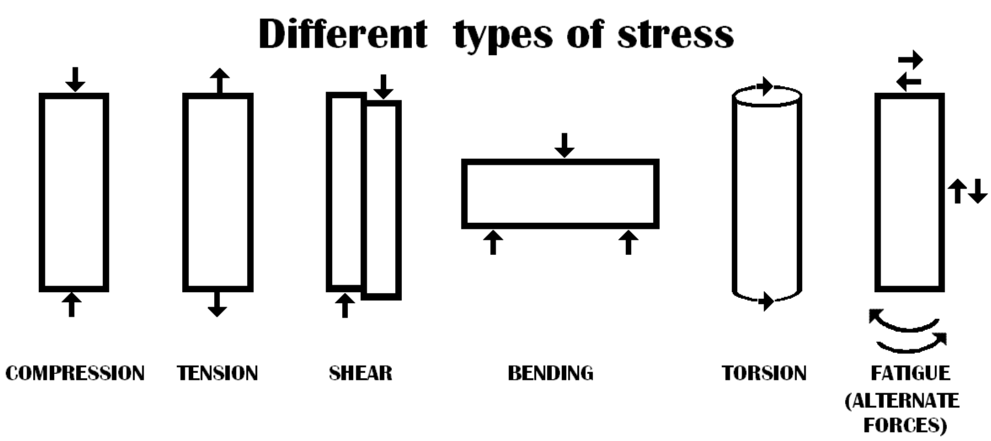


Figure 9. Different stress types which can be caused by an earthquake on a building. (Almazi, 2016)

3. Add straws to each to turn them into three dimensional objects of about the same height.

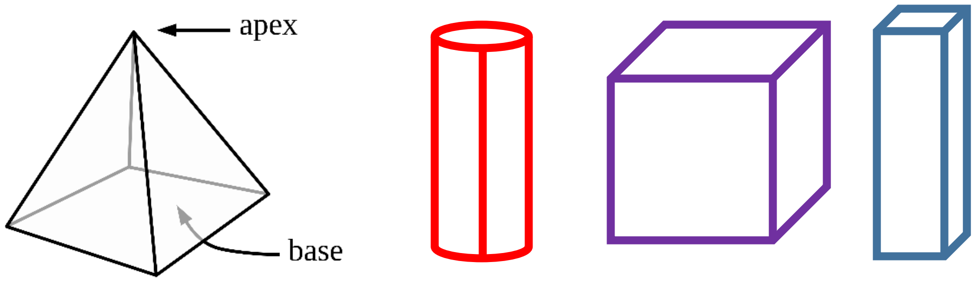


Figure 9. Pyramid and prisms

4. Re- test the these three dimensional objects for their response to different stresses, recording your results in the table.

Results

Shape	**How it was affected by each type of stress**					
	Compression	Tension	Shear	Bending	Torsion	Fatigue
Square						
Rectangle						
Equilateral triangle						
Right angle triangle						
Circle						

Shape	**How it was affected by each type of stress**					
	Compression	Tension	Shear	Bending	Torsion	Fatigue
Cube						
Rectangular prism						
Pyramid						
Right angle triangle prism						
Cylinder						

Assuming that each of the three dimensional shapes could be buildings (and therefore the surfaces would be walls), calculate their surface area and volume, showing your working.

Shape	**Surface area (cm^2)**	**Volume (cm^3)**
Cube		
Rectangular prism		
Pyramid		
Right angled triangle prism		
Cylinder		

Analysis

1. Which shape(s) were strongest under compression?

2. Which shape(s) resisted tension best?

3. Which shape(s) resisted bending most?

4. Which shape(s) resisted torsional forces the most?

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5. Overall which shape was the strongest?

____

6. Which shape would be cheapest to build (used the least material)?

____

7. Which shape would be the most expensive to build (used the most material)?

____

8. Calculate the surface area to volume ratio for the shapes used.

Shape	**Surface area (cm^2)**	**Volume (cm^3)**	**Surface area:Volume**
Cube			
Rectangular prism			
Pyramid			
Right angled triangle prism			
Cylinder			

9. Using your calculations which shape would give the largest amount of living space for materials used to build it?

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10. 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.

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____

11. Why do you think that rectangular prisms are the most common base shape for most buildings?

____

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12. How could you strengthen the rectangular prism to make it more earthquake proof?

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13. Which shape would be the best for building in an earthquake prone zone? Justify your answer.

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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.

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 the risk assessment table. Show this to your teacher and make any necessary changes before making the model building.

Planning

Table 1: Earthquake resistant design and material comparisons.

Design/Material	Strengths	Weaknesses
Steel reinforced concrete		
Base isolation systems		
Diagonal bracing		
Tuned mass damper		

Design/Material	Strengths	Weaknesses
Springs		
Earthquake curtains		
Flexible materials		

Table 2: Draw and label possible designs below, outlining their pros and cons.

Design	Pros	Cons

Chosen design: ____

Project Planning:

Equipment

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Method

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Risk assessment

Hazard	**Risk**	**Prevention**
e.g. chopping wood	Could cut fingers/ hand	Use equipment with care and under supervision. Keep focused. Use the right equipment.

Don't forget to have your project plan signed off by your teacher before commencing construction!

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

1. How well did your design stand up to the test(s)?

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2. What were the strengths and weaknesses of your design?

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3. What improvements could you add to your design? Create a labelled diagram of your modified design below – highlighting the modifications.