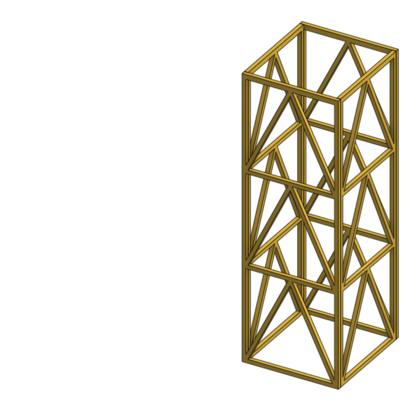
Industrial Technology Engineering

# Under pressure

## Engineered structures



### Student workbook

Student name:

Class:

Teacher:

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## Unit Overview

In this unit you will develop a fundamental understanding of engineers work and the underlying scientific principles and practices that form the foundation of engineering.

You will take on the role of the engineer and use the theoretical principles learned throughout this unit to prototype, test, and then build a water tower within a set of applied constraints.

### Assignment Overview

You are to work in pairs to design and construct a water tower out of hoop pine cut to 4 x 4mm. The water tower must stand a minimum of 300mm high and weigh no more than 50g. To be successful the tower must hold a minimum of 50kg (1000x its mass). You will need to apply your knowledge of forces and structures gained through theory components in this unit. Once towers are complete they will be tested until failure and filmed in slow motion to document and analyse the failure of the tower.

You are required to keep a log of your construction timeline, as well as any successes and failures you face whilst constructing the prototype and final build, and use this information to prepare an engineering report on the tower addressing aspects such as its design, ultimate hold weight at failure, where/why it failed and an evaluation of the overall project.

Finally, you must also research a landmark structure of your choosing and provide a brief report on its construction and the challenges that engineers faced at the time as well as how they were able to overcome these challenges to complete the project.

#### Constraints

As an engineer your tower must adhere strictly to imposed constraints in the assessment otherwise you have not met your brief. The constraints of the project are:

* The tower must be made from 4 x 4mm hoop pine,
* stand a minimum of 300mm tall,
* weigh a maximum of 50g and
* support at least 50kg (1000 x its mass)

## Glossary

Many of the following words will gather more meaning to you as you work through this booklet.

Each time you see a new word in bold throughout this workbook you can add its definition in the table below in case you need to refer back later.

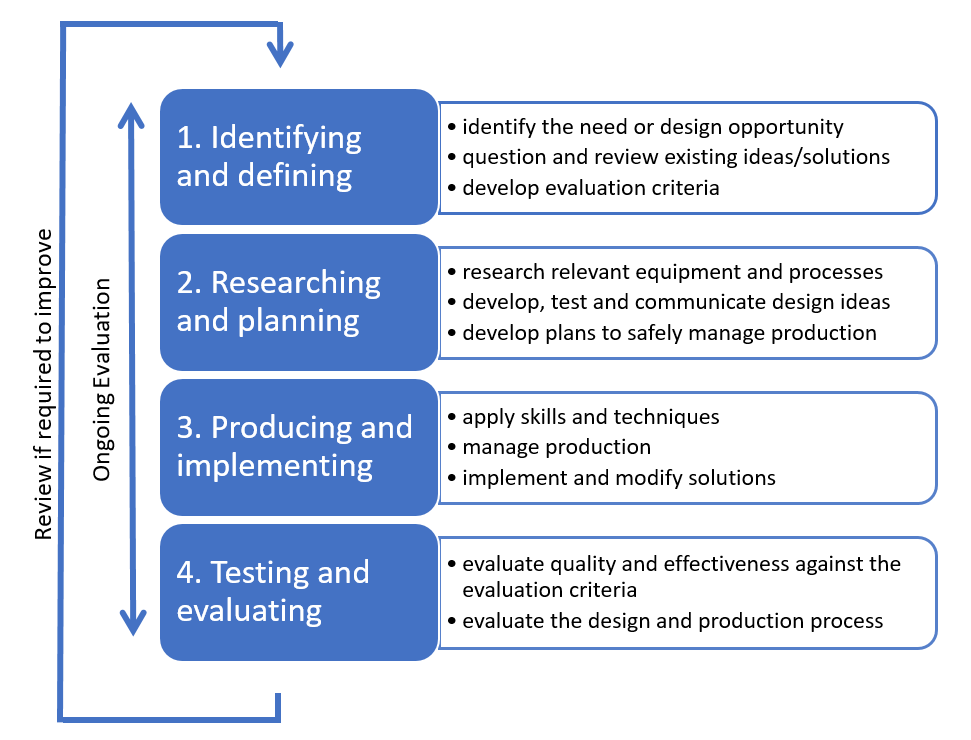
|  |  |
| --- | --- |
| Word | Definition |
| Arch |  |
| Beam |  |
| Cable stay |  |
| Cantilever |  |
| Compression |  |
| Deflection |  |
| Dynamic |  |
| Engineer |  |
| Ethics |  |
| Equilibrium |  |
| Force |  |
| Load |  |
| Magnitude |  |
| Mass |  |
| Net force |  |
| Newton |  |
| Prototype |  |
| Resultant |  |
| Rigidity |  |
| Sense |  |
| Shear |  |
| SI Units |  |
| Static |  |
| Suspension |  |
| Tension |  |
| Torsion |  |
| Truss |  |
| Vector |  |
| Weight |  |
| Warren Truss |  |

## The design and production process

Throughout your study of Engineering, you will learn about design processes and how to apply them. You will explore different types of design processes and learn how to apply them in your design project.

The design and production process:

* Involves a sequence of organised steps which provide a solution to design needs and opportunities
* May take a few seconds or minutes, such as when you select what clothes to wear, or may take years as in the case with the design of a motor vehicle
* May involve one person or may involve many people
* May be simple or complex, depending on the task
* Involves the designer questioning (or evaluating) throughout the process



## Engineers work

Answer the following questions in the space below.

What are the roles and responsibilities of a civil or structural engineer?

|  |
| --- |

If a civil or structural engineer was given the task of designing a water tower to be built on a site, what considerations would the engineer take into account before designing the tower?

|  |
| --- |

What types of building materials would an engineer typically use to build a project such as a water tower?

|  |
| --- |

What forces would/could act on the tower? Why is it important that the engineer considers these when designing a structure?

|  |
| --- |

## Ethics in engineering

Ethics is an important topic for engineers of every level and field as engineers do work that has the potential to affect people’s lives. Whether you’re engineering a bridge, a car, a nuclear reactor, or a computer system, the quality and character of engineered systems are hugely important. Additionally, engineers need ethics because it is very difficult to ensure good behaviour through any other mechanism. Law can never anticipate every possible issue in engineering, and law-enforcement can’t oversee every single detail of every engineer’s job.

In the space below, define ethics.

|  |
| --- |

Why is it important that engineers work ethically in relation to safety? Answer in the space below.

|  |
| --- |

Why is it important that engineers work ethically in relation to honesty and integrity? Answer in the space below.

|  |
| --- |

### Ethics in Engineering- Emerging Technology

Watch the YouTube video “[Genetic engineering will change everything forever – CRISPR](https://www.youtube.com/watch?v=jAhjPd4uNFY&t=3s)” (duration 16:03).

As CRISPR is a new and emerging technology there are very few rules and regulations around how it should be used and what it should be used for. It has the potential to be an incredibly powerful tool, but how do we decide what is ethical and unethical use of this tool.

Answer the following questions in the space below.

What would you consider to be ethical use of CRISPR?

|  |
| --- |

What would you consider to be unethical use of CRISPR?

|  |
| --- |

With a partner share your answers and discuss any differences in your ideas around ethical use of emerging technology such as CRISPR. In the space below, make note of key differences between you and your partner’s ethical views of CRISPR.

|  |
| --- |

## Types of Structures

Brainstorm as many types of engineered structures as you can in the space below (for example, bridges).

|  |
| --- |

Choose some of the structures from above and briefly describe how they impact peoples’ lives in the table below.

|  |  |
| --- | --- |
| Structure | Impact on peoples lives |
| answer |  |
| answer |  |
| answer |  |
| answer |  |
| answer |  |

## Bridges

Complete the table below by matching the type of bridge listed:

| Cantilever | Suspension | Cable Stay | Truss | Arch | Beam |
| --- | --- | --- | --- | --- | --- |

|  |  |  |
| --- | --- | --- |
| Bridge | Bridge name | Type |
| Sydney Harbor Bridge | Sydney Harbor Bridge (sourced from [Wikimedia Commons](https://commons.wikimedia.org/w/index.php?curid=175220) CCBY 3.0) |  |
| ANZAC Bridge | ANZAC Bridge (sourced from [Wikimedia Commons](https://commons.wikimedia.org/w/index.php?curid=1151209) CCBY 3.0) |  |
| Golden Gate Bridge | Golden Gate Bridge (sourced from [Wikimedia Commons](https://commons.wikimedia.org/w/index.php?curid=348268) CC BY 3.0) |  |
| **Firth of Forth Bridge** | Firth of Forth Bridge (sourced from [Wikimedia Commons](https://commons.wikimedia.org/w/index.php?curid=46405130) CC BY 3.0) |  |
| Taylor South Gate Bridge | Taylor South Gate Bridge (sourced from [Wikimedia Commons](https://commons.wikimedia.org/w/index.php?curid=48074095) CC 4.0) |  |
| Pont de Noirmoutier | Pont de Noirmoutier (sourced from [Wikimedia Commons](https://commons.wikimedia.org/wiki/File:Pont-Noirmoutier.JPG) CC 3.0) |  |

### Bridge Trusses

Truss bridges are designed in a way to efficiently distribute loads so that the structure can withstand forces it is subjected to in its day-to-day application.

There are many different designs of trusses that all use the same underlying principles. One of the most common types of bridge truss is the Warren truss, which is made by alternating equilateral triangles as shown below.



Warren Truss (sourced from [Wikimedia commons](https://commons.wikimedia.org/w/index.php?curid=65126128) CC 4.0)

All truss designs utilize the rigidity of triangles to ensure that loads are distributed appropriately and the truss will withstand anticipated loads.

#### Practical activity – Triangles in Trusses

1. Using paddle pop sticks and thumb tacks, create a triangle that is ‘pinned’ in each corner with a thumb tack. Stand the triangle upright and apply a force to it with your hand. Try applying angular and varied forces, you should find that the triangle will not lose the integrity of its shape.
2. Now create a square using the paddle pop sticks and again ‘pin’ each corner with thumb tack. Stand the square upright and again apply varied forces with your hand.

What happened with the square that was different to the triangle? Answer in the space below.

|  |
| --- |

This is a good representation of why triangles are used in bridge trusses. Joints in trusses are not welded together they are ‘pinned.’ This is because bridges are not the static objects we observe them to be, they need to be able to move and flex slightly, to effectively manage forces/loads and cope with expansion/contraction from differing temperatures

## International System of Units (SI Units)

The International System of Units (SI units) is the modern form of the metric system, and is the most widely used system of measurement. It encompasses a system of units of measurement that can all be derived from seven base units. The seven base units can be measured with exceptional accuracy as they are all derived from invariant constants of nature such as the speed of light in a vacuum.

For each of the SI units in the table below outline what they measure and the symbol for each unit.

|  |  |
| --- | --- |
| Unit | Explanation |
| Ampere |  |
| Candela |  |
| Kelvin |  |
| Kilogram |  |
| Metre |  |
| Mole |  |
| Second |  |

For each of the unit in the table below, identify how they are derived from SI units and the name of the unit (if it has one).

|  |  |
| --- | --- |
| Unit | Explanation |
| Force |  |
| Velocity |  |
| Acceleration |  |
| Pressure |  |
| Energy/Work |  |
| Power |  |

## Prefixes

Prefixes are added to unit names to produce multiples and sub-multiples of the original unit. All of these are multiples of 1000 or 103. For example kilo denotes a multiplier of 1000 therefore 1 kilogram is equal to 1000 grams. (Kilogram is the only SI unit that has a prefix as standard).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Name | Symbol | Base 10 | Name | Symbol | Base 10 |
| Kilo | k | 103 | Milli | m | 10-3 |
| Mega | M | 106 | Micro | µ | 10-6 |
| Giga | G | 109 | Nano | n | 10-8 |
| Tera | T | 1012 | Pico | p | 10-9 |
| Peta | P | 1015 | Femto | f | 10-10 |

Simplify the quantities in the table below using the appropriate prefix.

|  |  |
| --- | --- |
| Quantity | Simplified |
| 1000 metres |  |
| 25000 Newtons |  |
| 876 Joules |  |
| .003 seconds |  |
| 2300 kiloPascals |  |
| .000103 metres |  |
| 7500 gigabytes |  |
| .653 Amps |  |

### Practical Activity- Engineering Method

One of the constraints within the assessment states that your water tower must weigh less than 50g. By calculating the density of the timber you can manipulate that information and estimate how many linear metres of timber you can use in the production of your final build.

Once you have calculated the total amount of timber that you can use in the build you can divide that number by three for a triangular base or four for a square base and that will be the amount of timber you can use in each side of the tower.

Begin by taking a sample length of timber and calculate its volume in metres cubed

| Calculated volume of timber: |  |
| --- | --- |

Now weigh the timber and document its mass in kilograms

| Mass of timber: |  |
| --- | --- |

Density is an international system derived unit which is the amount of mass an object has per volume or kg/m³.

Write the fraction that is the mass of the timber over its volume

| Mass of timber/volume: |  |
| --- | --- |

To make this information useful we need to simplify this fraction so that we know how much one cubic metre of timber weighs. To do this you simply multiply the numerator of your fraction by 1 over the denominator.

For example if a piece of timber had a:

* volume of .013m³
* mass of 5.44kg

Write the fraction and then convert this number to a whole unit by multiplying the numerator by

In this case the density of the timber is kg/m³

Once you have calculated the density of your timber divide 1m³ by the density in kg over 0.050kg. For example .

Calculate the amount of timber you are allowed in m³ in the space below.

| Material allowed in m³: |  |
| --- | --- |

Finally if you divide the amount of material allowed by 0.0042 or 0.000016 (because the material is 4 x 4mm) you will get a number in linear metres of how much material you can use.

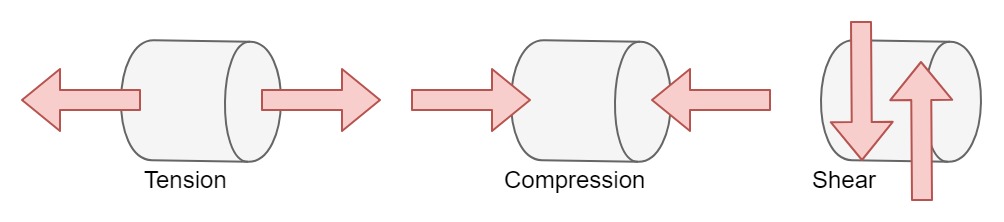
Calculate the amount of timber you are allowed in lineal m in the space below.

| Material allowed in m: |  |
| --- | --- |

This simulates how engineers understand the relationship between SI units and SI derived units. We began by measuring an SI unit and calculating an SI derived unit, then manipulated that data using simple mathematics to gain the information that we needed.

## Forces in structures

A **force** is a push or pull upon an object resulting from the object's interaction with another object. When the interaction ceases, the two objects no longer experience the force. Forces only exist as a result of an interaction. Forces can be classified depending on how they are applied, see the image below.



When engineers design structures such as bridges and large buildings, they consider all the forces that could affect it over its lifespan. For example, a bridge in winter has to support snow as well as the cars and trucks. Buildings in areas prone to earthquakes must be designed to withstand the forces created by earthquakes.

The forces that structures experience can be classified as ‘**static**,’ where a force is applied and does not change, or ‘**dynamic’** where the force is constantly changing.

In the table below list examples of forces that a bridge would experience and classify them as static or dynamic.

|  |  |
| --- | --- |
| Forces | Static or dynamic |
| answer |  |
| answer |  |
| answer |  |
| answer |  |
| answer |  |
| answer |  |

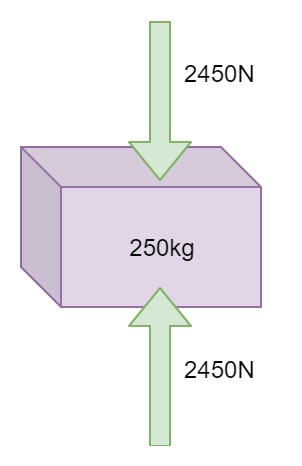
Why is it important that engineers are aware of, and consider these forces when designing and building structures?

|  |
| --- |

## Calculations involving forces

When designing structures such as bridges, engineers must consider all forces that may affect the bridge, and ensure that the structure is strong enough to resist all of those forces and remain in equilibrium. Equilibrium is where an object may experience forces, but there are sufficient equal and opposite forces to oppose them and therefore the object does not accelerate. If a body is in equilibrium the sum of all forces will equal zero.

In the example below a 250kg crate that is under the effects of gravity exerts a force of 2450N down into the Earth, however, because the Earth is able to exert an equal and opposite 2450N force directly up the **net force** is zero and the object is said to be in equilibrium.



**Newton**’s second law describes a force (in Newtons) as being equal to mass (in kilograms) multiplied by acceleration (in metres per second squared) or F=ma.

In this case the force acting down is calculated by multiplying the mass of the object in kg by the acceleration due to gravity which is equal to 9.8m/s2, and therefore if the object is in equilibrium the Earth must be exerting a force of equal **magnitude** and opposite **sense**.

If we explore this relationship further, it can be demonstrated that an object which is moving can be in equilibrium as long as it is not accelerating in any direction. Let’s use an example of a train travelling along a track in a straight line at a constant velocity (acceleration = 0m/s2) which has a mass of 250000kg.

Is the train in equilibrium or is there a net force? Use Newton’s second law to explain your answer in the space below.

|  |
| --- |

### Forces Exercise

In the space below use Newton’s second law to calculate the missing information. Each block is in equilibrium. Show all working.

| 159kg objecta | 9700g object |
| --- | --- |
| 735N acting on object a | 9800kN acting on object |

An office desk is rated to support a load 600N and an 85kg student sits on the desk. Will the desk support the student’s **weight** or will it collapse? Use Newton’s second law to explain your answer.

|  |
| --- |

## Resultant forces

We’ve explored what an object in equilibrium looks like and learned that a moving object can in fact be in equilibrium, but what happens when forces acting on an object are unbalanced.

Considering what you have learned about forces and Newton’s law, hypothesize what happens to an object when the forces acting upon it are unbalanced.

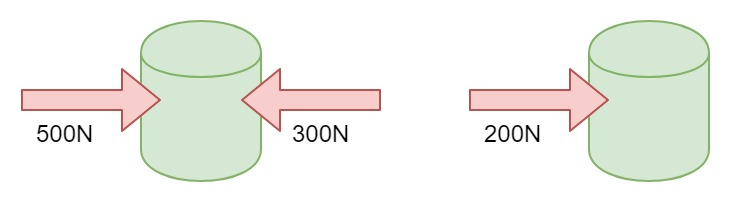
|  |
| --- |

If the forces acting on an object are unbalanced, and you add all of the forces together there will be a net force left over. This is called the **resultant**. The resultant is expressed as a single force, which can replace a group of forces acting on an object.

In the example below two forces are acting on a water tank (left). If we treat all forces travelling to the right or upwards as positive and all forces travelling to the left or downwards as negative, we can sum the forces and find the resultant.

In this case we have a 500N force travelling to the right so we will take it as a positive and a force of 300N travelling to the left so we will take it as a negative. This gives us the sum 500-300=200

As our sum has resulted in a positive number, the resultant force is therefore travelling to the right and has a magnitude of 200N



In this case we have been able to replace two opposing forces with a single force, however, it is possible to sum an infinite number of forces and replace them with a single resultant. This is called **vector** addition. A vector is a quantity that has both magnitude (300N) and direction (to the right).

### Vector addition

In the space below find the resultant of the forces acting on each object. Show working.

| C:\Users\asarina\Downloads\Untitled Diagram (2).jpg | 12000N - 25000N |
| --- | --- |
| 240N + 230N - 300N | 27kN - 25000N |
| 2.5kN - 2200N | 156kN + 27kN - 250kN |

### Practical Activity- Pasta Stress Test

In small groups of 2 or 3 you are going to test the way that fettucine responds to different loads. Using a vice and/or a clamp and some small weights load the fettucine in **tension**, **compression** and **shear** and record your results in the table below.

|  |  |  |
| --- | --- | --- |
| Load | Weight at failure | Observations |
| Tension |  |  |
| Compression |  |  |
| Shear |  |  |

In which type of loading did the fettucine withstand the most force applied, what does this tell us about the material?

|  |
| --- |

In which type of loading did the fettucine withstand the least force applied, what does this tell us about the material?

|  |
| --- |

Fettucine behaves similarly to steel and timber when under load. How will your observations of fettucine under load influence your ideas whilst designing you water tower?

|  |
| --- |

## Structure design

Use the table below to begin designing your water tower. You must complete a minimum of three varied designs. Use the large space to draw a scale model of the tower and the table below it to annotate your design ideas (lengths of members, joining methods, angles and so on.)

| **Design 1** |
| --- |

|  |  |  |
| --- | --- | --- |
| Notes | Notes | Notes |
| a |  |  |

### Structure design 2

|  |
| --- |

|  |  |  |
| --- | --- | --- |
| Notes | Notes | Notes |
| a |  |  |

### Structure design 3

|  |
| --- |

|  |  |  |
| --- | --- | --- |
| Notes | Notes | Notes |
| a |  |  |

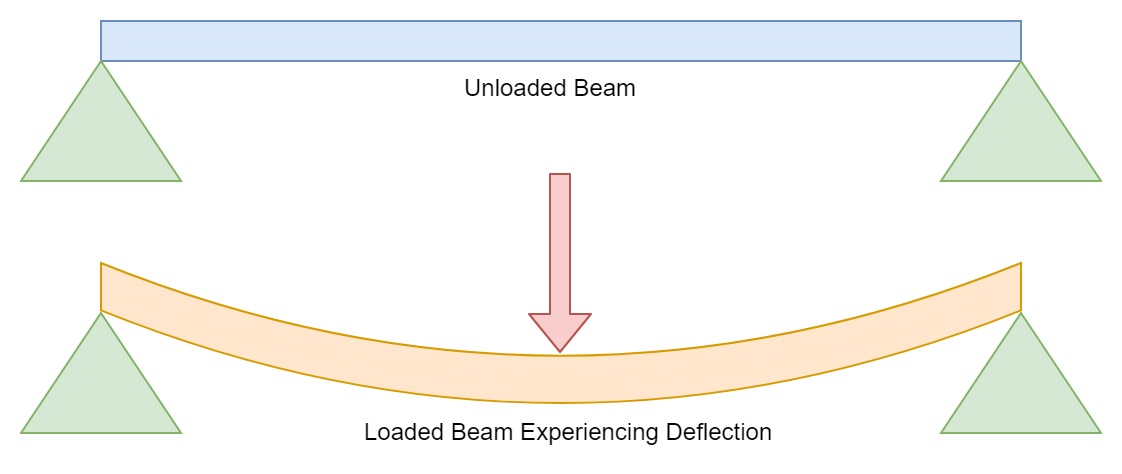
## Design analysis

Now that you have completed three truss designs and selected your best design, it is important to **prototype** and test your design so that any faults can be rectified before production of the final water tower.

### Practical activity- pasta prototype

Select the best design from your three. Once you have selected which design you are going to prototype use fettucine and hot glue to make a 1:1 scale prototype of your tower.

When you have finished constructing your prototype, begin to load the tower with weight. Slowly increase the weight and look for any noticeable deflections in the prototype. Deflection is a term which refers to how far a structural element is flexed or displaced under load. Members within the structure that exhibit large amounts of deflection are generally under the most load. You can use these observations to improve your design by making note of any deflections you notice on the previous corresponding design page.



Did any members of your tower exhibit noticeable deflection? What would you estimate to be the cause of the deflection (for example long unbraced member, improper use of triangles)?

|  |
| --- |

What design changes will you make in order to improve your structure?

|  |
| --- |

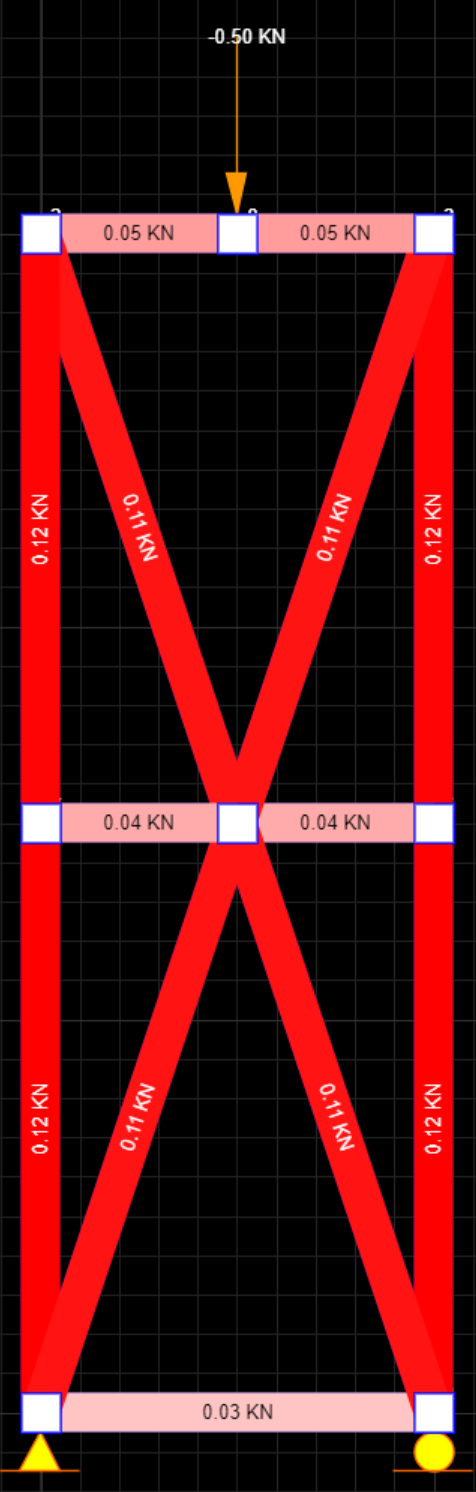
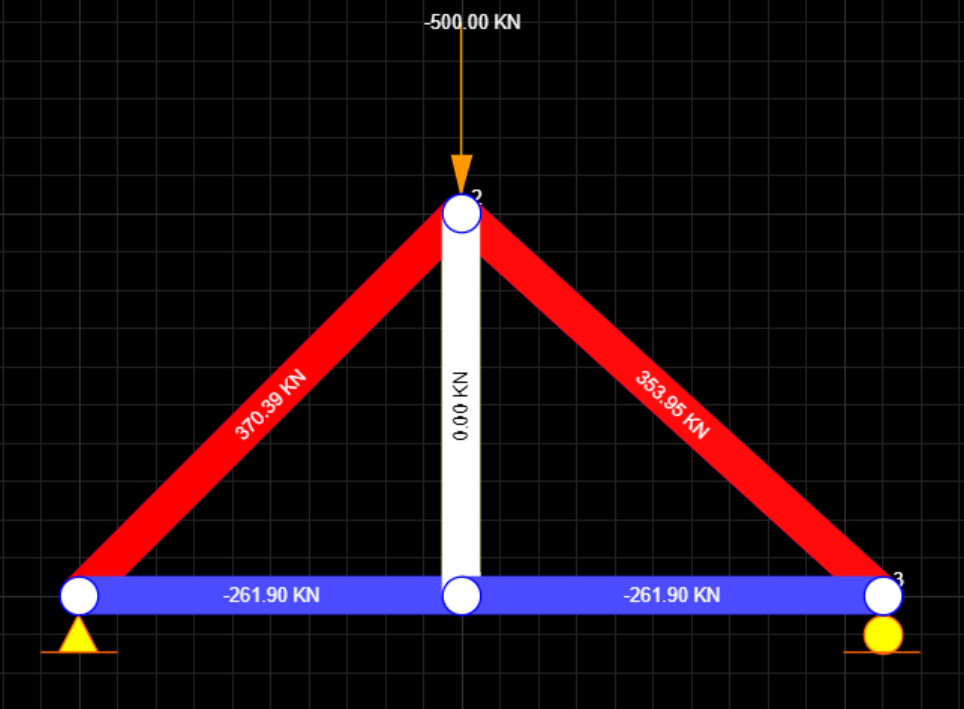
### Practical activity- computer prototype

Using a 2D truss simulation software such as [jfmatrix.com/Analysis](http://www.jfmatrix.com/Analysis), draw a replica of your frame in the software.

Once you have completed this add a pin joint to one side of the structure and a roller joint to the other. Finally add a load of 500N or 0.5kN in the centre of the frame at the top as shown below. Click the play button to run the simulation. While the simulation is running you have access to a lot of information about the frame, but if you select the ‘A’ at the top of the simulator you will be presented with an ‘axial diagram’ which will show you the forces present in each member.

A successful frame design should have relatively even distribution of forces throughout the members so that there is not a single member supporting unusually small or large loads.

You should also try to avoid zero force members (see the white member in the truss below). Redundant members support zero load and are only really adding weight to the structure. These are sometimes used in engineering for purely aesthetic purposes such as the example on the following page.

### Practical activity- computer prototype design

Once you have completed the simulation of your frame, draw a freehand sketch of it in the space below and label the force in each member of the frame. Once you have completed this answer the questions in the space provided.

|  |
| --- |

**Are there any members with outlying larger loads?**

|  |
| --- |

**Are there any members with outlying smaller loads?**

|  |
| --- |

**How can you modify your design so that the loads are evenly distributed throughout vertical members?**

|  |
| --- |

**Predict how your final design will fail when subject to loading.**

|  |
| --- |

## Joining Structures

When joining structures there are many things to consider including: the materials to be joined together, the service life of the joint, the strength of the joint and the application of the joint etc.

Generally joining methods can be classified into three categories: mechanical, adhesive and fusion. For each of these methods in the table below provide a description of each some examples and a list of advantages and disadvantages.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Joining methods | Description | Examples | Advantages | disadvantages |
| Mechanical |  |  |  |  |
| Adhesive |  |  |  |  |
| Fusion |  |  |  |  |

### Practical activity- joining methods

With your group create a small section of your frame, or a triangle using hoop pine with the same dimensions that you will use for your final project. Try using different joining methods including using screws, nails, PVA glue and hot glue to assist you in deciding which joining methods you will use in the production of your water tower.

Once your sample sections have had time to cure, test them under load to see which withstands the most load without failure.

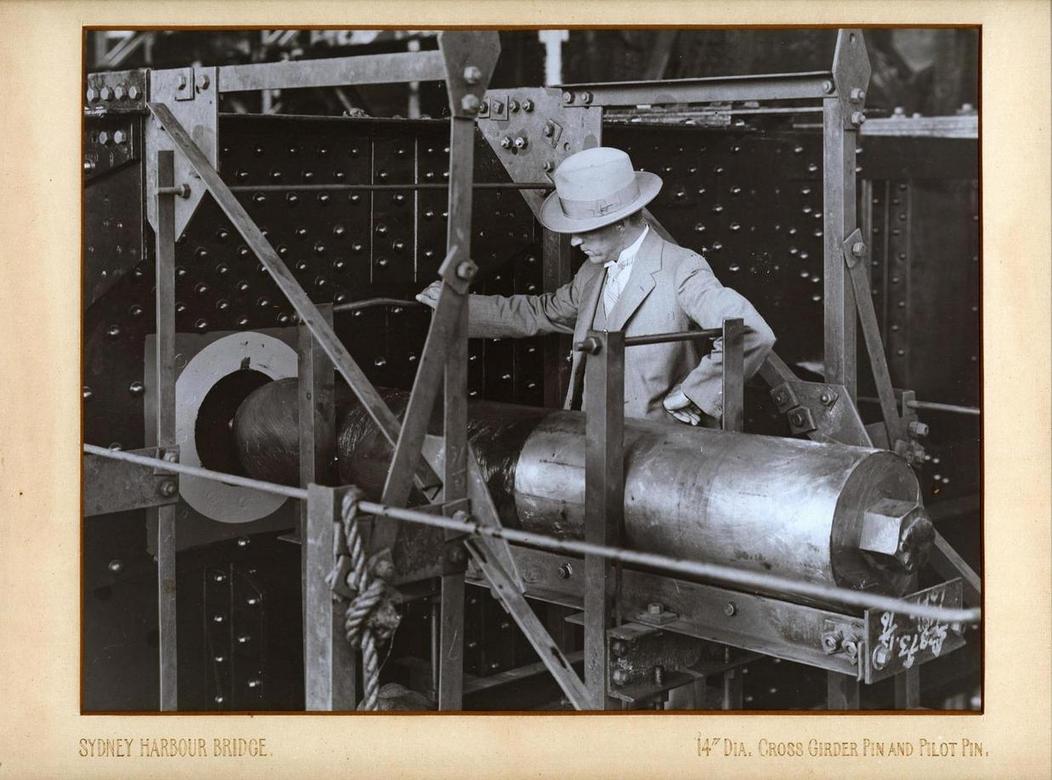


Figure 7 Cross Girder Pin Sydney Harbour Bridge retrieved from [bit.ly/2XDyVoO](https://bit.ly/2XDyVoO)

Answer the following questions in the space provided.

Which joining method withstood the most load? Why?

|  |
| --- |

Which joining method withstood the least load? Why?

|  |
| --- |

Which joining method/s will you apply in your final design?

|  |
| --- |

## Construction diary

Use the following pages as a diary to document the construction of your project. Make note of skills and knowledge gained, challenges faced and successes.

|  |  |
| --- | --- |
| Date | description |
| \_\_/\_\_/\_\_ |  |
| \_\_/\_\_/\_\_ |  |
| \_\_/\_\_/\_\_ |  |
| \_\_/\_\_/\_\_ |  |
| \_\_/\_\_/\_\_ |  |
| \_\_/\_\_/\_\_ |  |
| \_\_/\_\_/\_\_ |  |
| \_\_/\_\_/\_\_ |  |
| \_\_/\_\_/\_\_ |  |
| \_\_/\_\_/\_\_ |  |

## Skyscrapers

The Burj Khalifa is currently the world’s tallest building. However, it would not have been possible to build this giant without steady progressions in the fields of engineering and science. Some key inventions/innovations that have led to the construction of this structure are listed below. For each of the inventions find when it was first invented/implemented and the impact it had on skyscraper construction.

|  |  |
| --- | --- |
| Invention | Research |
| Safety elevator |  |
| Steel-skeleton construction (research the Home Insurance Building Chicago) |  |
| Air conditioning |  |
| Kangaroo crane (jumping crane) |  |
| Reinforced concrete |  |
| Bessemer process |  |

### The Burj Khalifa

Visit the Burj Khalifa’s official website [burjkhalifa.ae/en/](https://www.burjkhalifa.ae/en/)

Navigate the website to find information about the Burj Khalifa and complete the table below.

|  |  |
| --- | --- |
| The Burj Khalifa | Information |
| Height: |  |
| Number of stories: |  |
| Cubic metres of concrete used in foundation: |  |
| Cubic metres of concrete used total: |  |
| Total man hours for construction: |  |
| Record for vertical pumping of concrete: |  |
| Total weight of rebar used: |  |
| Time to construct excavation to opening: |  |
| Total number of glass panels used in cladding: |  |
| Water used per day: |  |
| Total number of elevators: |  |

## Landmark structure

You are required to research a landmark structure of your choice. You can choose whatever type of structure you want, but consider choosing something that relates to the project you have been working on.

You will need to identify what it is, where it is, the type and method of construction and the challenges that engineers may have faced at the time, as well as how they were able to overcome those challenges in order to complete the project. Include references of where you found the information.

|  |  |
| --- | --- |
| Name of structure | name |
| Location of structure |  |
| Type of structure |  |
| Image of the structure |  |
| History of the structure |  |
| Challenges faced during construction |  |
| Solutions used to overcome problems |  |
| Any other useful information |  |
| References |  |

## Structure stress test

Now that you have completed your final structure, it needs to be put to the ultimate test. Use the table below to record data and any observations during the stress test (for example at 75kg the frame was showing noticeable deflection).

Complete this table prior to stress testing your structure.

|  |  |
| --- | --- |
| Parameters | Value |
| Height (mm) |  |
| Weight (g) |  |
| Estimated weight at failure |  |
| Predicted method of failure |  |
| Improvements that could’ve been made prior to testing |  |

In the space below, record any observations during the stress test.

|  |
| --- |

Complete the table below once the stress test is completed.

|  |  |
| --- | --- |
| Observable | Observation |
| Weight at which deflection was noticeable |  |
| Ultimate weight supported before failure |  |
| Actual method of failure |  |

## Evaluation

Reflect on your final structure and answer the following questions in the space provided.

**Did your structure meet the design brief (was it under 50g, at least 300mm tall and held 50kg)?**

|  |
| --- |

**Did your structure perform as you had hypothesized? What differences were there between your hypothesis and actual performance?**

|  |
| --- |

**How could you improve the structure so that it would perform better?**

|  |
| --- |

**Do you think working collaboratively helped or hindered the development of the structure?**

|  |
| --- |

**What have you learnt through the completion of this project?**

|  |
| --- |