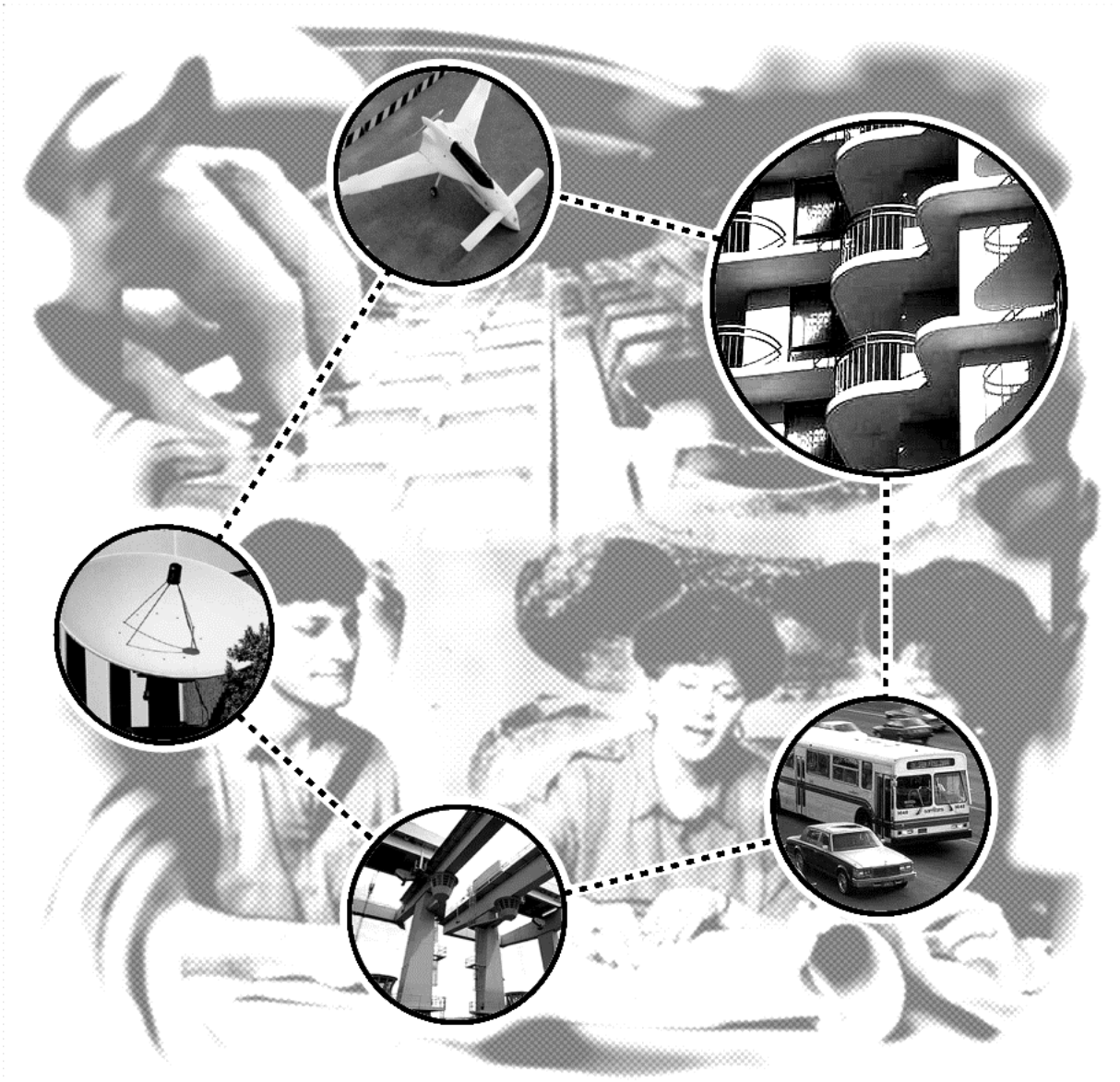
Engineering Studies
HSC Course
Stage 6

NEW SOUTH WALES DEPARTMENT OF EDUCATION AND TRAINING

TAFE NSW

OPEN TRAINING AND EDUCATION NETWORK - DISTANCE EDUCATION

Civil structures



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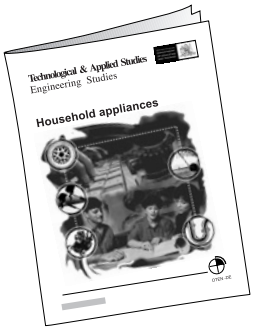
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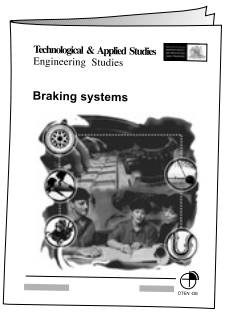
Engineering Studies Preliminary Course



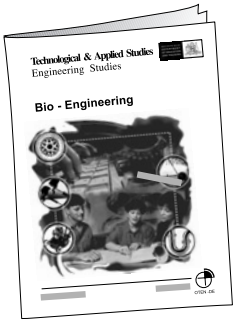
Household appliances examines common appliances found in the home. Simple appliances are analysed to identify materials and their applications. Electrical principles, researching methods and techniques to communicate technical information are introduced. The first student engineering report is completed undertaking an investigation of materials used in a household appliance.



Landscape products investigates engineering principles by focusing on common products, such as lawnmowers and clothes hoists. The historical development of these types of products demonstrates the effect materials development and technological advancements have on the design of products. Engineering techniques of force analysis are described. Orthogonal drawing methods are explained. An engineering report is completed that analyses lawnmower components.



Braking systems uses braking components and systems to describe engineering principles. The historical changes in materials and design are investigated. The relationship between the internal structure of iron and steel and the resulting engineering properties of those materials is detailed. Hydraulic principles are described and examples provided in braking systems. Orthogonal drawing techniques are further developed. An engineering report is completed that requires an analysis of a braking system component.



Bio-engineering looks at both engineering principles and also the scope of the bio-engineering profession. Careers and current issues in this field are explored. Engineers as managers and ethical issues confronted by the bio engineer are considered. An engineering report is completed that investigates a current bio-engineered product and describes the related issues that the bio-engineer would need to consider before, during and after this product development.

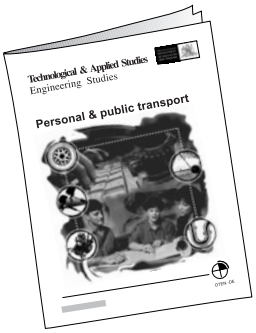


Irrigation systems is the elective topic for the preliminary modules. The historical development of irrigation systems is described and the impact of these systems on society discussed. Hydraulic analysis of irrigation systems is explained. The effect on irrigation product range that has occurred with the introduction of polymer is detailed. An engineering report on an irrigation system is completed.

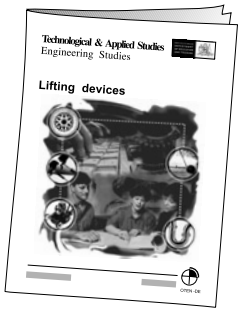
HSC Engineering Studies modules



Civil structures examines engineering principles as they relate to civil structures, such as bridges and buildings. The historical influences of engineering, the impact of engineering innovation, and environmental implications are discussed with reference to bridges. Mechanical analysis of bridges is used to introduce concepts of truss analysis and stress/strain. Material properties and application are explained with reference to a variety of civil structures. Technical communication skills described in this module include assembly drawing. The engineering report requires a comparison of two engineering solutions to solve the same engineering situation.



Personal and public transport uses bicycles, motor vehicles and trains as examples to explain engineering concepts. The historical development of cars is used to demonstrate the developing material list available for the engineer. The impact on society of these developments is discussed. The mechanical analysis of mechanisms involves the effect of friction. Energy and power relationships are explained. Methods of testing materials, and modifying material properties are examined. A series of industrial manufacturing processes is described. Electrical concepts such as power distribution and AC motors are detail in this module. Students are introduced to the use of freehand technical sketches.



Lifting devices investigates the social impact that devices ranging from complex cranes to simple car jacks, have had on our society. The mechanical concepts are explained, including the hydraulic concepts often used in lifting apparatus. The industrial processes used to form metals and the methods used to control physical properties are explained. Electrical requirements for many devices are detailed. The technical rules for sectioned orthogonal drawings are demonstrated. The engineering report is based on a comparison of two lifting devices.



Aeronautical engineering explores the scope of the aeronautical engineering profession. Career opportunities are considered, as well as ethical issues related to the profession. Technologies unique to this engineering field are described. Mechanical analysis includes aeronautical flight principles and fluid mechanics. Materials and material processes are discussed, concentrating on their application to aeronautics. The corrosion process is explained and preventative techniques listed. Communicating technical information using both freehand and computer-aided drawing is required. The engineering report is based on the aeronautical profession, current projects and issues.



Telecommunications engineering examines the history and impact on society of this field. Ethical issues and current technologies are described. The materials section concentrates on specialised testing, copper and its alloys, semiconductors and fibre optics. Electronic systems such as analogue and digital are explained and an overview of a variety of other technologies in this field is presented. Analysis, related to telecommunication products, is used to reinforce mechanical concepts. Communicating technical information using both freehand and computer-aided drawing is required. The engineering report is based on the telecommunication profession, current projects and issues.

Figure 0.1 Modules

Module overview

Look at the montage of civil structures below.



Figure 0.1 Civil structures

The term civil structure covers a wide variety of structures such as bridges, dams, roads and buildings like schools, hospitals, libraries, community centres and sporting facilities, as well as parkland structures including children's play equipment.

In this module you will learn about the history of technological changes associated with the design and construction of civil structures, particularly bridges. You will examine the significant impact civil structures have on society and the environment.

The materials used in civil structures must be chosen appropriately to match their properties with the application. The choice of manufacturing process also affects the properties of the material and therefore its performance in an engineered structure. Material properties, testing and manufacturing techniques are described in this module. You will learn that many engineering materials are prone to corrosion or deterioration of some sort.

The civil engineer will always need to examine the mechanics of how a structure works. Mathematical methods are used to solve such problems. You will be introduced to a few of these in this module. To communicate accurate and detailed engineering data, the engineer needs to be able to produce and interpret technical drawings. This module covers some of the rules for technical drawing as stated in the Australian drawing standards.

The engineering report, completed as the last part of this module, asks you to compare and contrast two solutions to an engineering problem.

You will need to do design analysis by using material investigation, mechanical calculations and communicate information using technical drawing. You will be asked to make conclusions based on the information collected.

Module components

Each module contains three components, the preliminary pages, the teaching/learning section and additional resources.

- The preliminary pages include:
  - module contents
  - subject overview
  - module overview
  - icons
  - glossary
  - directive terms.

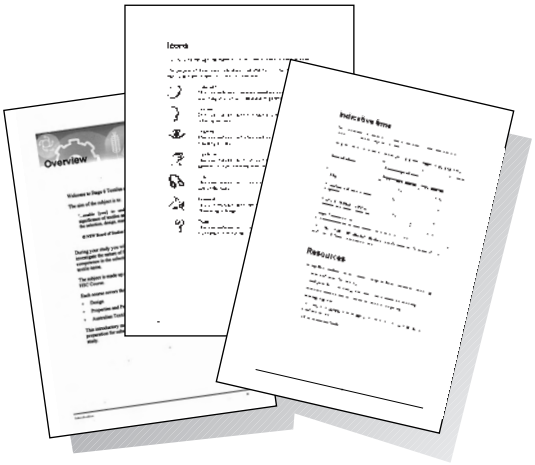


Figure 0.2 Preliminary pages

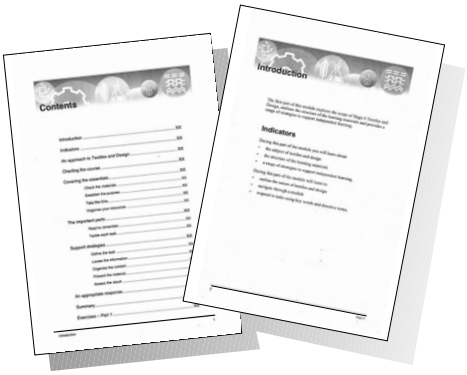


Figure 0.3 Teaching/learning section

- The teaching/learning parts may include:
  - part contents
  - introduction
  - teaching/learning text and tasks
  - exercises
  - check list.

- The additional information may include:
  - module appendix
  - bibliography
  - module evaluation.

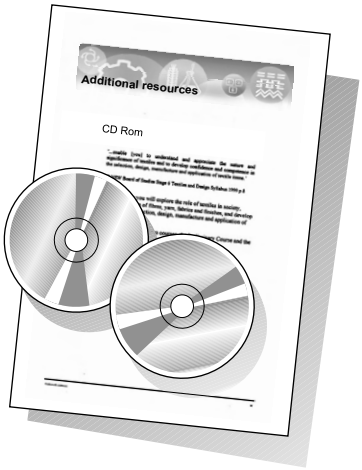


Figure 0.4 Additional materials

Support materials such as audiotapes, video cassettes and computer disks will sometimes accompany a module.

Module outcomes

At the end of this module, you should be working towards being able to:

- differentiate between properties of materials and justify the selection of materials, components and processes in engineering (H1.2)
- determine suitable properties, uses and applications of materials in engineering (H2.1)
- demonstrate proficiency in the use of mathematical, scientific and graphical methods to analyse and solve problems of engineering practice (H3.1)
- use appropriate written, oral and presentation skills in the preparation of detailed engineering reports (H3.2)
- develop and use specialised techniques in the application of graphics as a communication tool (H3.3)
- investigate the extent of technological change in engineering
- appreciate social, environmental and cultural implications of technological change in engineering and apply them to the analysis of specific problems (H4.1)
- work individually and in teams to solve specific engineering problems and in the preparation of engineering reports (H5.1)
- demonstrate skills in research and problem-solving related to engineering (H6.1)
- demonstrate skills in analysis, synthesis and experimentation related to engineering (H6.2).

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Refer to <http://www.boardofstudies.nsw.edu.au> for original and current documents.

Indicative time

The Preliminary course is 120 hours (indicative time) and the HSC course is 120 hours (indicative time).

The following table shows the approximate amount of time you should spend on this module.

Preliminary modules	**Percentage of time**	**Approximate number of hours**
Household appliances	20%	24 hr
Landscape products	20%	24 hr
Braking systems	20%	24 hr
Bio-engineering	20%	24 hr
Elective: Irrigation systems	20%	24 hr

HSC modules	**Percentage of time**	**Approximate number of hours**
Civil structures	20%	24 hr
Personal and public transport	20%	24 hr
Lifting devices	20%	24 hr
Aeronautical engineering	20%	24 hr
Telecommunications engineering	20%	24 hr

There are five parts in *Civil structures*. Each part will require about four to five hours of work. You should aim to complete the module within 20 to 25 hours.

Resource requirements

During this module you will need to access a range of resources including:

- technical drawing equipment
  - drawing board, tee square, set squares (30°–60°, 45°), protractor, pencils (0.5 mm mechanical pencil with B lead), eraser, pair of compasses, pair of dividers
- calculator
- four ice block sticks and four nails or tacks
- rule
- spring balance
- PVA glue
- recycled containers
- sand or rice
- a hammer
- an ice cube or two
- a soft lolly, for example a Fantail
- two identical moulds, for example fruit juice or UHT milk tetra briks
- two skewers or kebab sticks
- a casting medium
- elastic – either a few big bands that can be cut to make a length or continuous elastic normally used for dressmaking
- a pile of clay bricks or concrete blocks
- an empty egg carton
- a pair of scissors and a spike
- a length of elastic
- two paper clips or short lengths of kebab stick to act as anchors
- the washed lid from a food can
- a zinc-plated screw or nail
- a hacksaw or other hard cutting edge
- two plastic containers, such as icecream containers
- five unplated mild steel nails: bullet or flat heads, 50–100mm long
- one galvanized nail
- saltwater solution

- boiled water
- two pairs of pliers
- a length of wire, preferably copper or an unfolded paper clip
- six glass or plastic containers.

Icons

As you work through this module you will see symbols known as icons.

The purpose of these icons is to gain your attention and to indicate particular types of tasks you need to complete in this module.

The list below shows the icons and outlines the types of tasks for Stage 6 Engineering studies.



Computer
This icon indicates tasks such as researching using an electronic database or calculating using a spreadsheet.



Danger
This icon indicates tasks which may present a danger and to proceed with care.



Discuss
This icon indicates tasks such as discussing a point or debating an issue.



Examine
This icon indicates tasks such as reading an article or watching a video.



Hands on
This icon indicates tasks such as collecting data or conducting experiments.



Respond
This icon indicates the need to write a response or draw an object.



Think
This icon indicates tasks such as reflecting on your experience or picturing yourself in a situation.



Return
This icon indicates exercises for you to return to your teacher when you have completed the part. (OTEN OLP students will need to refer to their Learner's Guide for instructions on which exercises to return).



Glossary

As you work through the module you will encounter a range of terms that have specific meanings. The first time a term occurs in the text it will appear in bold.

The list below explains the terms you will encounter in this module.

abutments	parts of the bridge that resist the downward and outward forces of a bridge
alloy	a metal consisting of two or more constituents
amorphous	literally means without form and is used to describe substances that do not have a regular pattern within their atomic arrangement
annealing	heat treatment process to relieve the stresses in materials and which can be applied to metals and glasses
anode	positively-charged area where material is corroded away
arch bridge	a type of bridge that uses an arch as the main load bearing structure
asphalt	a semi-solid petroleum residue that is used for waterproofing and rolled with fine aggregate as a flexible paving surface
axial forces	forces that acts along the axis of the member
beam	simple structural member used in buildings and other civil structures; it is normally in a horizontal position and is comparatively long and slender
beam bridge	a type of bridge that relies on the bending strength of the superstructure to support the road surface
bearers	horizontal structures placed on piers
bending moment	internal reaction to the bending effect of external forces
bridge	a structure designed to provide safe passage across a gap

cable-stayed bridge	a modern bridging system using cables to provide additional support to the beam
cantilever	a type of bridge that relies on the main horizontal support beams balancing over towers
cast iron	an alloy of iron with approximately 2.5– 4.5% carbon
cathode	negatively-charged area where corrosion products collect
cellulose	fibres that are found in wood and other plant material
civil structure	usually government-funded structure of substantial size constructed for use by the general public
clay body	a mixture of clay minerals and non-plastic materials
cofferdam	a temporary dam built in a river to allow dredging for the construction of footings or piers in a dry environment
component	amount of force that is active in a particular direction; a force may be made up of two (or more) components
compressed-air caisson	a box-like structure filled with compressed air to keep it watertight so workers can excavate the riverbed prior to construction of the footings and piers
compression test	a gradual squashing force is applied to a specimen and the load and reduction in length are plotted
compressive stress	internal reaction to an externally applied force trying to shorten the material
concentrated load	a load that is applied at one point only
concrete	a composite of aggregate and an hydraulic cement binder
corrosion	the deterioration of material due to chemical changes brought about by its interaction with its surroundings
cross-sectional area	the area of the cut surface of a member, or component that is imagined cut perpendicularly to its long axis; for example the area of a circle with diameter equal to that of the cylinder
crystalline	a term used to describe materials that display a high degree of internal order at the atomic level
deck	the roadway structure of a bridge

development	the two-dimensional shape of an unfolded three-dimensional shape
devitrification	Changing of glass to its more stable crystalline state
double shear	when a component experiences shear along two separate shear planes, for example a bolt
ductility	the capacity of a material to undergo significant deformation or elongation under tensile load before fracture
ducting	a system of sheetmetal or polymer tubes or channels used in air conditioning to convey air throughout a building or structure; it is also used in extraction systems
elastic limit	the limit at which loaded material can return to its original length or shape without there being any permanent deformation
electrolyte	a liquid which will conduct electricity
equilibrant force	the one force that would balance an unbalanced force system
equilibrium	a state of rest or uniform motion; a system in balance is in equilibrium
extrusion	forming process where plastic material is forced through a suitably-shaped die
falsework	temporary scaffolding or formwork used to hold bridge components, or other structures, until they are secured or set in position
fissures	narrow openings, splits or minute cracks
float process	mass production technique used for making sheet glass
flux	a substance which helps bonding by improving flow characteristics and separating impurities
fold lines	lines on a pattern or development about which the sheetmetal is folded or bent to form the shape of the transition piece; represented on a drawing as thin dark lines
foundation	the earth or fill on which the footings or piers bear down
geotextiles	high strength sheet textiles used to reinforce under roadways, railways and retaining walls
generators	lines on edges from which a development can be produced

girder	a beam shaped to improve its resistance to bending
glass	an inorganic and amorphous product of fusion
glass fibre	fibres of glass either in short needles or continuous lengths
high tensile steel	an alloy steel that has a high tensile strength
hydraulic cements	cements that can continue to set under water
igneous rocks	geological materials that are formed when volcanic magma solidifies
joists	Parallel beams of timber, concrete or steel to which floor or ceiling materials are attached
laminated	when layers of similar or dissimilar materials are joined together
lignin	the organic cement that binds wood
members	structural parts of a frame or truss
metamorphic rocks	geological materials that have been formed by the application of heat and pressure
method of sections	commonly used method to analyse the internal forces in the members (not all the forces in all the members are required)
offset method	a method used in triangulation development to find the true lengths of lines; it uses the projected height of the line in front view, and the offset length of the line from the top view to determine the true length of a line
parallel development	a method of development used for sheetmetal objects that have parallel edges or generators such as a cube, prism or cylinder
piers	vertical columns on which the beams rest; in arch bridges it refers to the footings between the foundations and the arch
pin joint	the joints that lock the members of the truss into position, or holds the truss at the support; it does not allow any side to side movement but may allow some rotation; it may also be referred to as a hinge
pitch circle diameter	a method of indicating the position of holes in a round or circular shaped flange based on the distance from a central point
pitch circle radius	half of the pitch circle diameter
portland cement	a complex, hydraulic cement used extensively in the construction industry

positive bending	sign convention used when a beam deflects downward or sags as a load is placed on it
post-tensioning	tensioning of steel reinforcing used in concrete after casting into shape before it is put into service
pre-cast	a construction method of casting concrete components off-site
prestressed reinforced concrete	concrete where the steel reinforcing is placed in tension before the concrete is placed in service, may be pre-tensioned or post-tensioned
pre-tensioning	a method of prestressing reinforced concrete where the tensioning of the steel bars takes place before the concrete has been set into shape
proof stress	stress necessary to produce a certain amount of strain in the specimen
propagate	grow or extend
proportional limit	the position at the end of the straight-line section of the stress-strain diagram; signifies the limit at which stress is proportional to strain
radial development	a method of development used for sheetmetal objects that have edges or generators that meet at a point called the apex, such as pyramids or cones
radiographic examination	non-destructive tests that use x-rays or γ-rays to assess a weld or casting for internal flaws
redundant	extra to what is required; not providing any functional purpose
refractory	a material having the ability to retain its physical shape and chemical identity when subjected to high temperatures
reinforced concrete	concrete strengthened by the addition of steel bars or mesh
roller joint	allows unrestricted movement in one direction; the joint may be a smooth sliding joint or be placed on rollers; the reaction of the roller support is always at 90° to the flat surface
seasoned	process that removes moisture content from logged timber to improve its properties
second moment of area	a property of a shape that determines its resistance to bending; it is given either as a formula for a particular section or as a value supplied by the makers of the beams
sedimentary rocks	geological materials that are formed from the build up and consolidation of small rock particles in layers

shear area	the area of a section that is subject to shear stress this area is parallel to the applied force
shear force	a force that causes one part of a material to slide over the adjacent part of the material
shear stress	reaction to an external (shear) force applied at right angles to the axis
slump test	a test that is used to assess the workability of concrete
spalling	the flaking off of concrete caused by the corrosion of the reinforcing steel in reinforced concrete
span	the distance between piers or supports
steel	an alloy of iron and up to 1.5% carbon
strain	extension or compression per unit length; found by formula $\varepsilon = e / l$
stress	force per unit area $\sigma = L / A$; also the internal reaction to an externally applied force
stress raisers	parts within materials where any imperfection of surface finish, the external contour of the material or internal imperfection in the material interferes with the smooth 'flow' of stress lines; the deviation of these causes a higher concentration of stress at these positions which will often be the source of crack initiation and subsequent failure
structural members	supports used in the construction of engineered structures; made from steel sections, concrete, timber or other material
suspension bridge	a bridge system consisting of tensioned ropes or cables from which the roadway is suspended; the supporting columns for the cables are in compression
symmetry line	a thin dark chain line with two thin dark parallel lines on either end of the chain line: the symmetry line is used when only half of the pattern is drawn, and indicates that the remainder of the pattern is a mirror image of the first part
tensile stress	internal reaction to an externally applied force that is trying to stretch the material
toughness	ability of a material to absorb energy when being deformed and thus resist deformation and failure
transition piece	a sheetmetal member of a ducting system used to join different shaped or sized ducts
transverse beam testing	a type of destructive test that is used to assess the bending strength of a specimen

triangulation	a system of dividing a transition piece into triangular elements for the purpose of drawing the development of the transition piece
triangulation development	a method of development used for sheetmetal transition pieces that do not have a regular shape like a prism, pyramid, cylinder or cone
true length	the actual length of the line which must be used in all developments
truss	an engineered structure made up of smaller members formed into triangles
ultimate tensile stress	read from the stress-strain diagram, it is the maximum tensile stress a material can withstand without failure
ultra-sonic testing	a type of non-destructive test that uses high frequency vibrations to assess the internal features of welds and castings
uniformly distributed load	a constant load is spread out evenly over a length of the beam
voussoirs	small tapered blocks that form an arch
wrought iron	almost pure iron although it may contain non-metallic slag impurities which are rolled out; made by heating and forging
yield stress	the stress at which a marked increase in strain occurs without a corresponding increase in stress
Young's modulus	measure of the stiffness of the material; a relationship between stress and strain



Directive terms

The list below explains key words you will encounter in assessment tasks and examination questions.

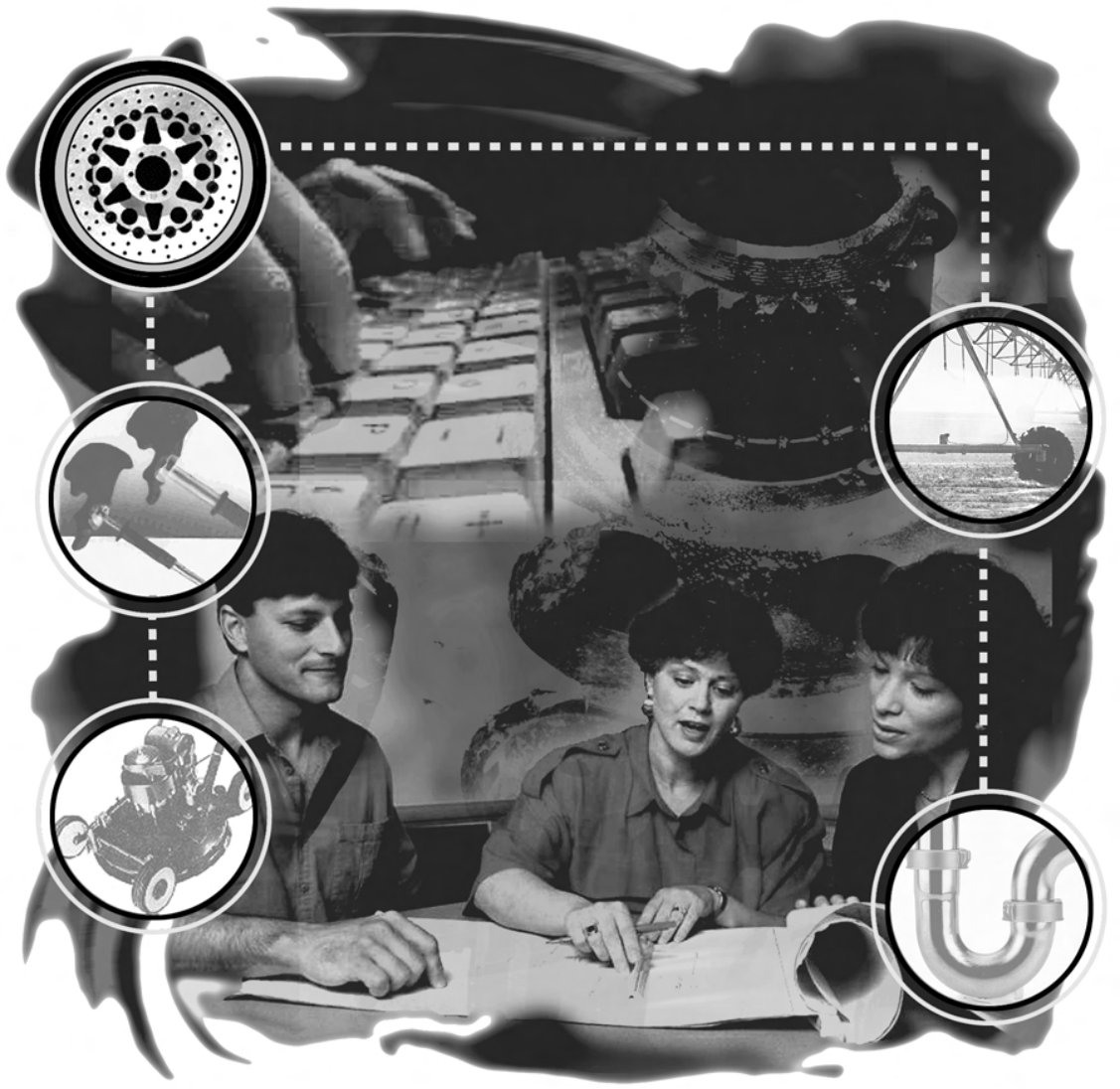
account	account for: state reasons for, report on; give an account of: narrate a series of events or transactions
analyse	identify components and the relationship between them, draw out and relate implications
apply	use, utilise, employ in a particular situation
appreciate	make a judgement about the value of
assess	make a judgement of value, quality, outcomes, results or size
calculate	ascertain/determine from given facts, figures or information
clarify	make clear or plain
classify	arrange or include in classes/categories
compare	show how things are similar or different
construct	make, build, put together items or arguments
contrast	show how things are different or opposite
critically (analyse/evaluate)	add a degree or level of accuracy, depth, knowledge and understanding, logic, questioning, reflection and quality to (analysis/evaluation)
deduce	draw conclusions
define	state meaning and identify essential qualities
demonstrate	show by example

describe	provide characteristics and features
discuss	identify issues and provide points for and/or against
distinguish	recognise or note/indicate as being distinct or different from; to note differences between
evaluate	make a judgement based on criteria; determine the value of
examine	inquire into
explain	relate cause and effect; make the relationships between things evident; provide why and/or how
extract	choose relevant and/or appropriate details
extrapolate	infer from what is known
identify	recognise and name
interpret	draw meaning from
investigate	plan, inquire into and draw conclusions about
justify	support an argument or conclusion
outline	sketch in general terms; indicate the main features of
predict	suggest what may happen based on available information
propose	put forward (for example a point of view, idea, argument, suggestion) for consideration or action
recall	present remembered ideas, facts or experiences
recommend	provide reasons in favour
recount	retell a series of events
summarise	express, concisely, the relevant details
synthesise	putting together various elements to make a whole

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Part 1: Civil structures – development





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Introduction

In this part you will trace the historical development of a common **civil structure** – the **bridge**. You will examine how bridge design has changed over time, reflecting the change in materials available and construction methods used by engineers.

As you investigate how bridges have changed in both shape and materials, keep in mind the following questions:

- Did a change in materials lead to a change in design?
- Was a new and innovative design developed using existing materials?
- What was the influence of new construction methods?
- How have these changes impacted on society and the environment?

What will you learn?

You will learn about:

- historical developments of civil structures
- engineering innovation in civil structures and their effect on people's lives
- construction and processing materials used in civil structures over time
- environmental implications from the use of materials in civil structures.

You will learn to:

- outline the history of technological change as applied to civil structures
- investigate the construction processes and materials used in civil structures from a historical point of view
- critically examine the impact of civil structures on society and the environment.

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Refer to <http://www.boardofstudies.nsw.edu.au> for original and current documents.

History of bridge design



a Name four civil structures in your local area.

b Outline the purpose of the structure.

c State the approximate date of construction.

d List the materials used in its construction.

1 Name _____

Purpose _____

Date _____

Materials _____

2 Name _____

Purpose _____

Date _____

Materials _____

3 Name _____

Purpose _____

Date _____

Materials _____

4 Name _____

Purpose _____

Date _____

Materials _____

Did you answer?

A common civil structure you may have included in your list is a bridge.

As an introduction to civil structures, this part will examine the development of a very common structure – the bridge. You will be able to apply the same types of analysis to other types of civil structures.

Bridges

Bridges are used to span gaps such as water (creeks, rivers, and harbours), roads and railway tracks. They are used by pedestrians, animals and vehicles. Bridges can make your journey safer, quicker or shorter.

Other terms associated with bridges are aqueducts, viaducts, causeways and overpasses.



How many of these terms do you recognise?

The first step in understanding the history of design development related to **bridges** is to analyse the forces that act on the structures. It is these forces that determine the suitability of various designs and the use of various materials.

The forces acting on bridges

From your work in mechanics you would be aware that forces can be applied in many different ways, each having a different effect on the body on which it is acting. Bridges may be loaded with:

- compressive forces
- tensile forces
- torsional forces
- shear forces.

These forces may cause the parts of the bridge to:

- squash
- stretch
- bend
- twist
- snap
- move in one direction.

The forces may be applied as:

- a dead load – like the weight-force of the bridge itself
- a live load – a load that frequently changes, like traffic
- an impact load – a load that is suddenly applied, like a ship crashing into a pylon
- a wind load – an important force to consider as it may push the bridge sideways or even try to lift the bridge up.

Temperature changes will also alter the loading of the bridge and many **members** will be placed under load conditions during construction which are different to the loads they will have to withstand when in service.

Different materials behave in different ways under different loadings. Some materials, like sandstone and concrete, are very good in compression but weak in tension. Thin parts tend to buckle under compressive forces. The properties of a material and the forces they will encounter need to be fully understood and carefully considered when designing a structure such as a bridge.

Bridge types

You will now examine different types of bridge systems as well as the different materials used over the years for each bridge type.

There are basically five types of bridge:

- basic beam
- cantilever – a modification of the beam
- truss
- arch
- suspension.

All of these bridge types have advantages when used in certain situations and all have limitations that must be considered. At different periods in time the popularity of each of the different bridge systems has been influenced by the materials commonly available and other technological influences of the time.

Basic beam bridge

The simplest type of bridge is the basic **beam bridge**, a plank-like **component** that spans a distance, without the aid of trusses. All you need is a beam long enough and strong enough to span the gap you want to cross and something on which to rest the ends and you have a bridge.

The earliest bridge was probably a tree trunk that had fallen across a creek. Unfortunately, relying on nature to drop a tree in just the right spot is rarely practical.



Figure 1.1 A basic beam bridge



Can you think why timber was used for the early beam bridges?

Timber is a natural material that is readily available in most parts of the world. It is easily cut, shaped and transported and is quite tough.

Why do you think simple timber beam bridges weren't more common in earlier times?

All bridges must be able to resist the load placed on them. Beam bridges are susceptible to failure through the bending of the beam.

Have you ever walked across a wooden plank set up between stepladders or trestles?

You probably noticed how much the plank sagged, especially when you walked in the middle.

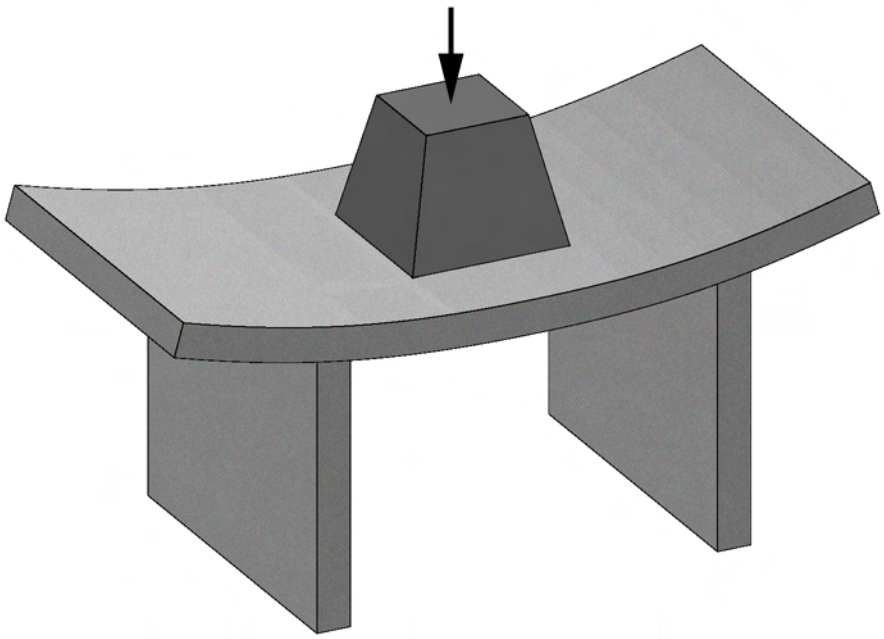


Figure 1.2 A beam under load

When the plank sags, you are placing the top surface in compression and the bottom surface in tension. The longer the **span**, the more the beam sags even under its own weight. Materials such as sandstone and concrete are not very good in tension, so unless the beam is very thick those materials by themselves are not good for beams.

Turning the plank onto its edge greatly reduces the amount it bends.



Test this concept by turning a thin flexible rule on its edge and trying to bend it.

Even a thin flexible rule that bends easily in one direction is very difficult to bend in the other direction. Turning the beam on its side is a way of improving its performance without changing the material.

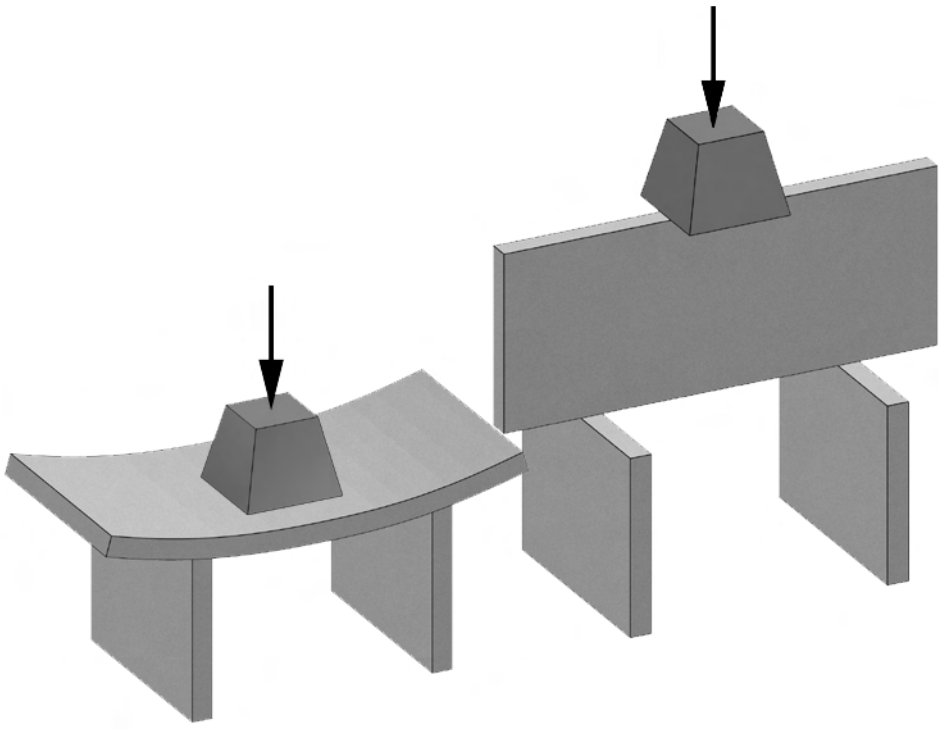


Figure 1.3 Comparison of load directions

Unfortunately, a thin beam placed on its edge may twist or fall over. To overcome this problem, two or more beams may be joined together to form a **girder**, a beam shaped to improve resistance to bending and twisting.

Common girder shapes include, the 'T', the 'I' and the box girder shown in figure 1.4.

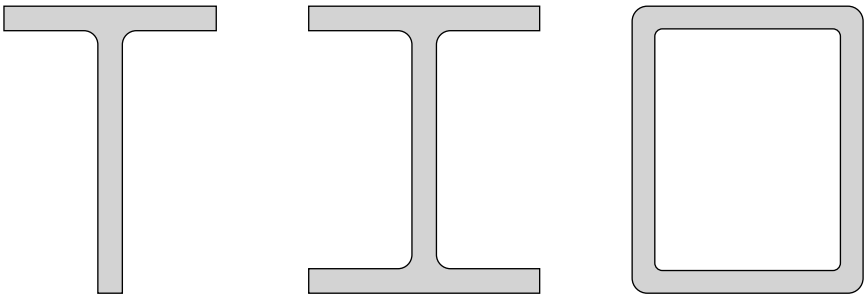


Figure 1.4 Common girder shapes – 'T', 'I' and box

The vertical sides of the girder resist bending from vertical forces.
The horizontal sides resist twisting and also make it easier to rest the beam on its supports or to fit a deck to the beam.

There are other disadvantages of timber beams. For example, the length of the span is limited by the length of the timber available. Also, timber is not very durable compared with other materials such as stone. It wears away easily, can be eaten by termites or fungus and burns readily. Timber needs to be **seasoned** before it can be used. Even after it is seasoned the timber continues to shrink and warp as it dries out, or expand if it gets too wet.

Timber was not the only material used to make early beam bridges.
Stone beams were suitable for small spans and loads where there was little chance of impact loading. They had the advantage of being weather and fire resistant, but their weight made construction difficult. While no ancient timber beam bridges are still standing, a primitive stone beam bridge still exists at Postbridge on Dartmoor in southern England. Figure 1.5 shows this bridge, believed to be more than two thousand years old. It crosses the East Dart River and consists of three large flat stones, each about four metres long supported on piles of stones.



Figure 1.5 Stone beam bridge at Postbridge

To overcome the limitations of the length of the beam, more spans can be added to make a multi-span beam bridge although this is not always possible. If the bridge is to span a deep gorge it is not always practical or safe to build **piers** or supports on which to rest the beams. The piers of a bridge across a river are a hindrance to smooth water flow under the bridge. Bridges with many small spans have many piers, which may lead to serious water flow problems.

Changes in the 19th century, such as the introduction of steam power and locomotion and the increasing availability of iron, had a significant influence on the design and construction of bridges at that time. There was now a need for bridges that could carry steam trains and cope with a dramatically increased loading.

The building up of solid materials into girders was employed in the design of the Britannia Rail Bridge across the Menai Straits in north-western Wales in

1850. This basic beam bridge was constructed of plates of wrought iron formed into two large box girders supported on smaller box girders. The trains traveled through the centre of the large box girders. Its central beam was 153 m long whereas the longest span of an iron beam bridge till then was only 10 m.

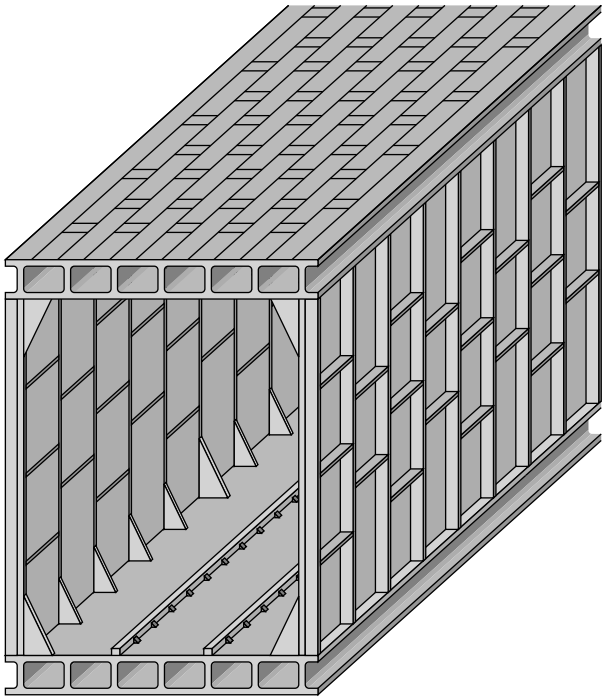


Figure 1.6 Details of the beam of the Britannia Rail Bridge

A disadvantage of this type of bridge is that because it is made from solid plates, it is extremely heavy. The supporting structure of the bridge is placed under considerable **stress** just from the weight of the bridge itself. Later, you will examine how trusses can be used to overcome this problem.

Basic beam bridges offer a simplicity of design that makes them appealing to civil engineers. The simple beam bridge has made a comeback over the past 40 years due to a change in materials and a change in construction methods. Spans of up to 40 m (the equivalent of a six-lane road with footpaths and median strip) are now readily achievable using a simple beam when using the composite material **pre-stressed reinforced concrete** as shown in figure 1.7. Concrete is excellent in compression while the steel reinforcement takes the tensile forces in the beam. Reinforced concrete beams can be cast into the shape of a girder to improve their resistance to bending.



Figure 1.7 Prestressed reinforced concrete beam bridge near Gosford

Pre-stressing increases the compressive forces in a concrete beam making it more resistant to tensile loadings. **Pre-tensioning** involves pre-stressing the steel reinforcement in the concrete before it is put into service. **Post-tensioning** involves passing steel cables through ducts in the concrete after the concrete has been cast into shape. The cables are then placed in tension and anchored to the concrete. Post-tensioning is used to join sections pre-cast off-site to minimise on-site construction time. This is an important consideration especially when bridging across a busy road or waterway. The Mooney Mooney Bridge near Gosford shown in figure 1.10 is an example of a post-tensioned, prestressed concrete bridge.

A recent development is the **cable-stayed bridge** which uses cables to support the beam. These bridges are part beam bridge and part suspension bridge, with some of the weight of the beam taken up by high tensile steel cables attached to a tower. This means the bridge can take a greater load, the span can be increased or the beam can be reduced in size, saving material and also reducing the size of the supporting piers.

Cable-stayed bridges, also known as tied beam bridges, have been used in a wide range of situations from small footbridges across roads to the ANZAC Bridge in Sydney shown in figure 1.8. A further advantage of the cable-stay design is that visually the bridge is lower and more slender than traditional arch designs such as the Sydney Harbour Bridge and the Gladesville Bridge, also in Sydney. The ANZAC Bridge does not block the view of the city from the west.

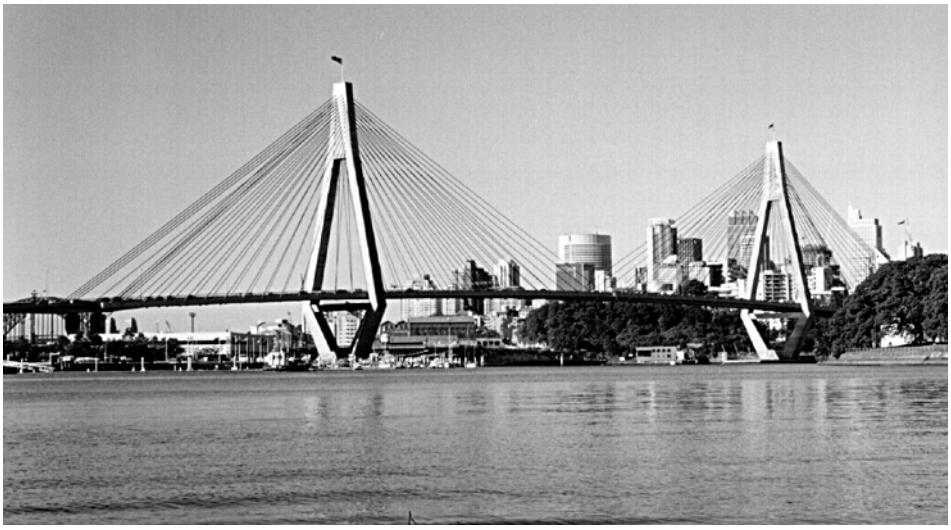


Figure 1.8 ANZAC Bridge in Sydney – a cable stayed bridge



Turn to the exercise section and complete exercise 1.1.

Cantilever bridge

A **cantilever** is a beam that is supported at one end only. To stop it from falling, the beam needs to be securely fixed to the support. In some cases the beam balances on top of the support, overhanging it on both sides. A shop awning, a streetlight attached to a telegraph pole and a diving board are all examples of cantilevers. One of the first known cantilever bridges was the Shogun Bridge, constructed between 500 and 600 AD in Nikko, Japan.

Types of cantilevers that can be used in constructing bridges include the true cantilever, simple beam with cantilever and a balanced cantilever with a suspended mid-span shown in figure 1.9.

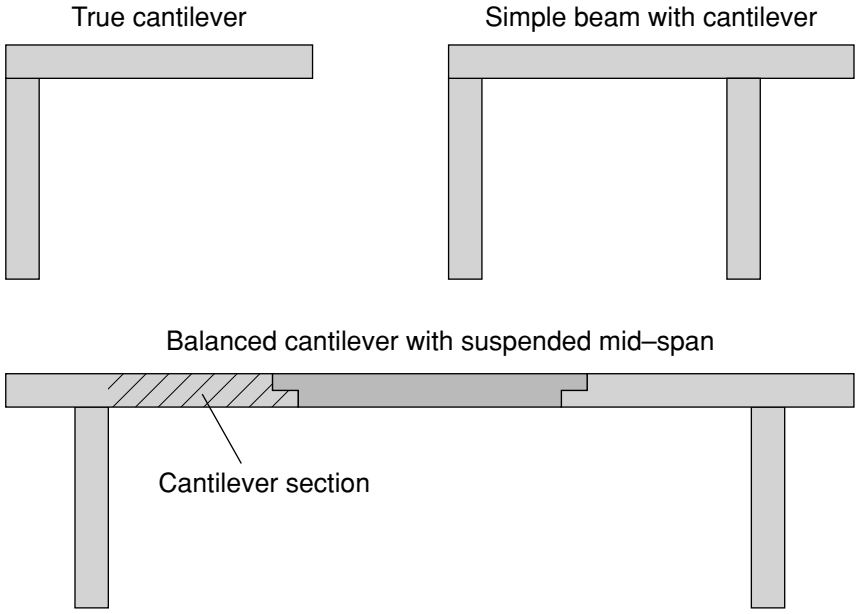


Figure 1.9 Types of cantilevers



What's the advantage of using the cantilever method?

On a basic beam bridge the beam is likely to break in the middle.
The thickness of the middle section can be increased to strengthen this part, but then it tends to sag under its own weight. With a cantilever bridge the cantilever is most likely to break at the supports. The weight of the middle of the bridge can be reduced with very little overall effect. The span of the cantilever can also be improved if it is combined with a suspended beam in the middle.

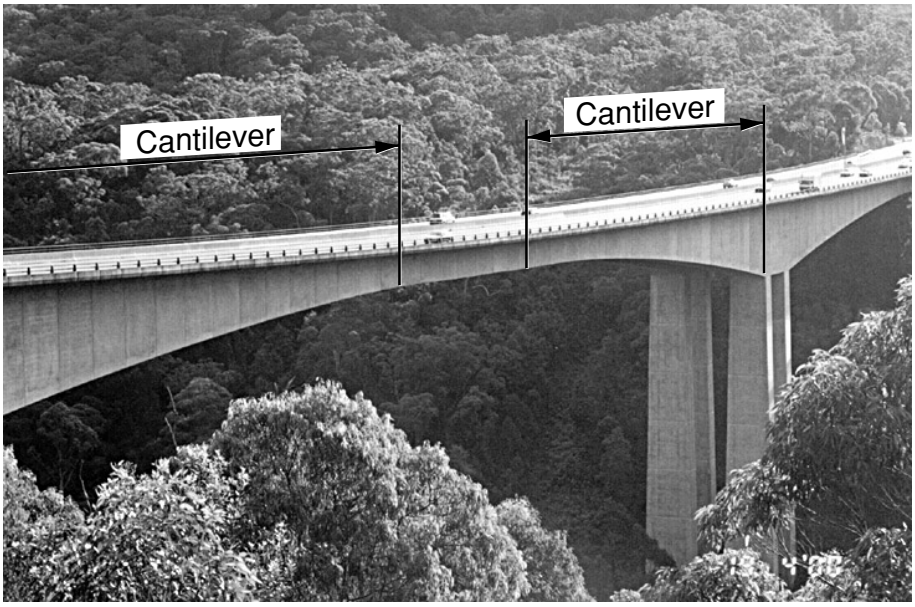


Figure 1.10 Mooney Mooney Bridge – a post-tensioned, pre-stressed concrete cantilevered bridge with a suspended mid-span

During construction the cantilever bridge can be built out from both sides. This greatly simplifies construction as little **falsework** (temporary scaffolding) is required to hold up the structure and there is less disruption to the traffic flow below. Figure 1.11 illustrates the arch of the Sydney Harbour Bridge when erected as two cantilevers. Temporary anchorage cables were required to strengthen the two halves until they were connected together.

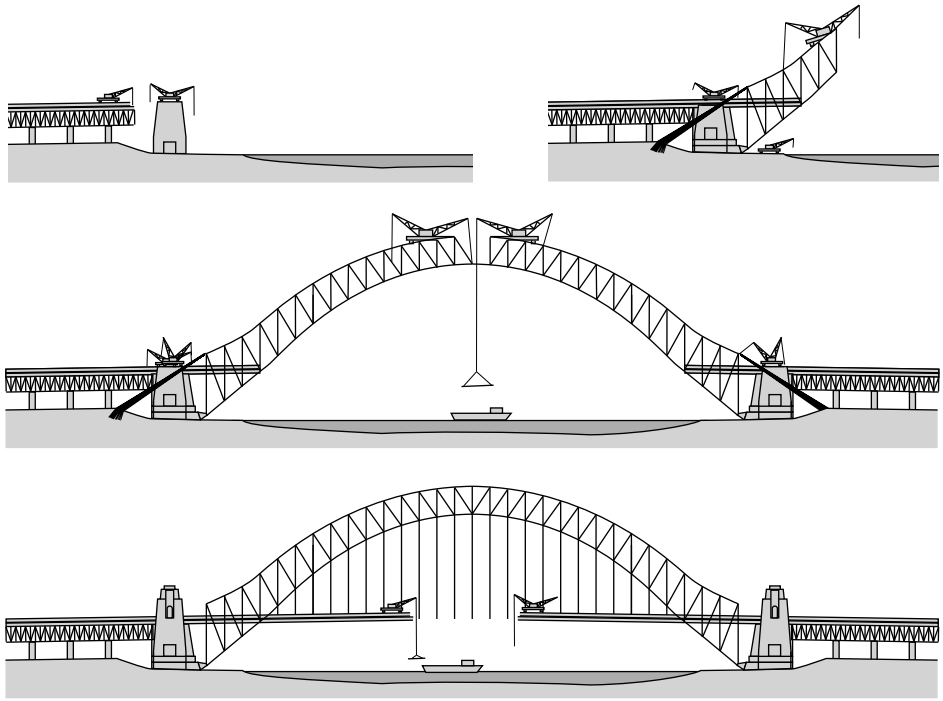


Figure 1.11 Erection of the arch of the Sydney Harbour Bridge

Truss bridges

In the 1750s the Grubenmann brothers from Switzerland constructed a different type of wooden bridge using long beams from smaller pieces of timber to form a **truss**. This design overcame a major shortcoming of simple timber beam bridges – the maximum span possible restricted by the maximum length of timber available.

The following activity illustrates the principle of the truss.



Join four ice block sticks to form a square using only one nail per join, as shown in figure 1.12.

Now push on one side of the structure.

You will notice that the structure is easily pushed out of shape.

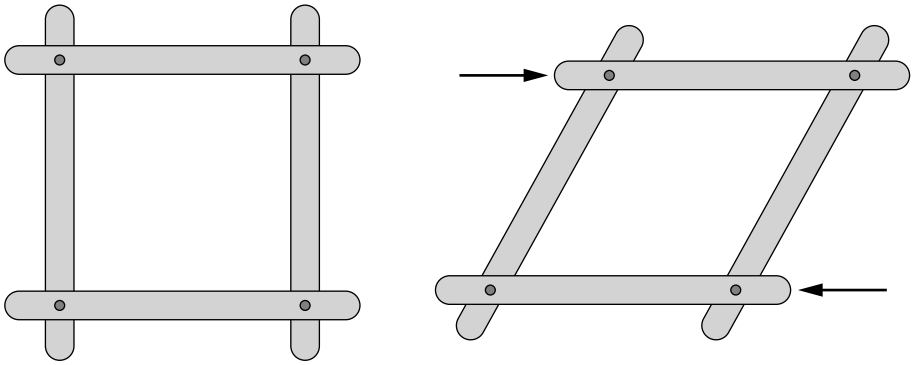


Figure 1.12 A square truss

An ice block stick joined diagonally across the structure would resist the distortion.

Construct another structure, this time using only three ice block sticks.



Could you push the triangle out of shape?

If you had more ice block sticks you could build up the truss into a longer, yet still rigid shape.

A truss removes much of the bending from a beam by transferring most of the force along the axis of the truss **member**. That is, truss members have to withstand **tensile stress** or **compressive stress** but not bending stress. It is possible to work out the magnitude and direction of the forces in a truss member and make the individual members different sizes depending on their location in the truss. To save weight, thin flexible cables can be used in place of solid members if the member will be in tension.



Why can't cables be used in compression?

Early truss builders designed different trusses to suit different situations. Some trusses have certain members in tension, others work to place certain members in compression. Common truss systems still carry the name of their designers, such as Warren, Pratt, Allan and Howe.

By the early 19 th century, timber truss bridges were being replaced by metal truss bridges in many parts of the world. The softwood timber used in early European truss bridges only had a working life of 10 to 15 years.

The availability of the more durable and stronger cast iron, wrought iron and finally steel, allowed truss members to be considerably longer, while the bridge had a much longer life and needed less maintenance. This change in materials allowed the same general design to be retained.

In Australia, especially down the east coast, the availability of strong, durable hardwoods and the lack of iron, especially in the 1800s, meant that timber bridges were constructed till a much later date. An Australian hardwood bridge would have a life span of about 50 years. Even as recently as 1950 it was common practice in New South Wales to make composite timber and steel trussed bridges. The bottom cords and the tensile members were constructed from steel. The timber members were in compression and required renewal about every 30 years.

In rural Australia it is still possible to find timber bridges in service, although most have had to be seriously reinforced to cope with timber degradation and with the demands of much greater traffic loads. The New South Wales Road and Traffic Authority (RTA) plans to replace 127 timber bridges between 1999 and 2003.

In solid box girders, like those used in the Britannia Rail Bridge, much of the material used provides little strength to the overall structure. You can think of a truss as a solid plate with much of the **redundant** material removed. Triangulated trusses use far less metal than solid plates. Less metal means less wind loading, less cost and less weight, further reducing the size of all the other components of the bridge. Trusses are simple to construct and may be prefabricated, that is built off-site to save construction time. Truss bridges are capable of spanning lengths up to about 300 m, although they are more suited to much smaller spans.



Figure 1.13 Iron Cove Bridge, Drummoyne Sydney – a steel truss bridge



Turn to the exercise section and complete exercise 1.2.

Trusses in bridges are now usually used in conjunction with other bridge systems where there is a need to stiffen part of the bridge to reduce bending. The arch of the Sydney Harbour Bridge shown in figure 1.14 is a 'trussed' arch with other trusses joining the two arches.
The approaches on either side of the Sydney Harbour Bridge are truss beam bridges.



Figure 1.14 Sydney Harbour Bridge

The Golden Gate Bridge in San Francisco was stiffened with an additional truss under the deck to counteract the rippling effects of crosswinds.

You will find trusses in a range of structures, not only in bridges. Rafters and **joists** have been replaced with pre-fabricated roof trusses in most new domestic buildings. The boom of a crane is a continuous truss.



List four examples where trusses are used to bridge a gap or strengthen a structure in your local community.

_____

_____

_____

_____

Did you answer?

Answers will vary but you may have listed:

- mobile telephone tower
- beam under the roof of a building
- electricity tower
- bridge
- exhibition centre.

Arch bridges

The first major long-lasting bridges were made by the Romans more than two thousand years ago when they pioneered the masonry **arch bridge** like the one shown in figure 1.15. Arches work by transferring the load through the arch to the supporting foundation via the **abutments**. As the load tries to straighten out the arch, the outward movement is resisted by the abutments and the downward force is transferred to the foundation.

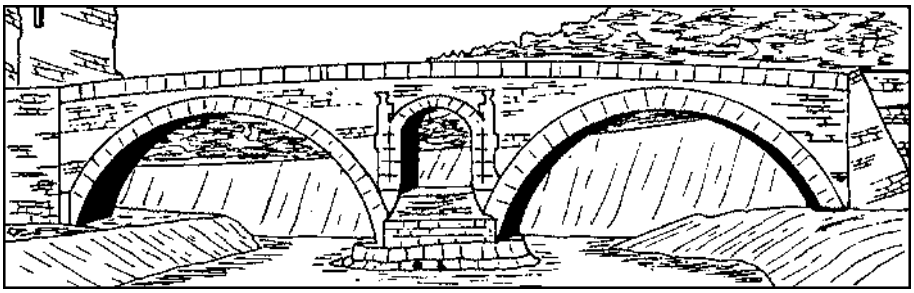


Figure 1.15 A Roman bridge

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A significant advantage of the masonry arch bridge is that the length of the span is not limited by the size of the individual components, as was the case with early beam bridges. The Romans produced a semi-circular arch that spanned 50 metres, a considerable span even by today's standards. By using stone the Romans avoided many of the shortcomings of timber. It had vastly superior weather resistance and wearing characteristics. It had excellent compressive strength and was fire resistant. Even the fact that it was a heavy material was an advantage in holding the arch together. Many Roman built arch bridges still stand today, testimony to the durability of the material and the skill of the bridge builders.

The main components of the Roman arch are **voussoirs**, tapered blocks of stone or brick masonry.

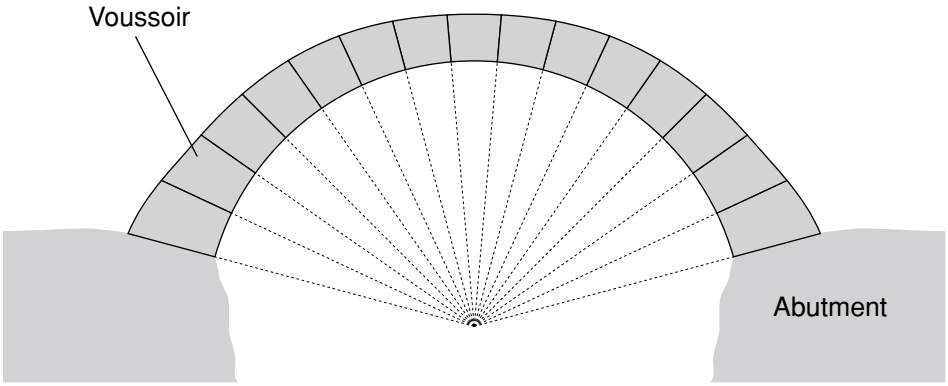


Figure 1.16 Parts of an arch bridge

The voussoirs were laid on top of each other to form the arch with the weight of each block bearing down on the previous block. A form of mortar was used to hold the blocks together, although this was not necessary for a well-constructed arch bridge as the weight of the bridge pushed the blocks together. In all arch bridges the components of the arch are in compression.

In an arch bridge, the longer the span the higher the arch, which presents a problem for traffic. The early solution to this problem was to make a number of smaller arches. However, this created other problems. Because the arch was made from masonry, the piers supporting the downward and outward forces had to be very large. The piers of a high Roman style arch were usually about one-third the size of the span and restricted the smooth flow of water below the bridge.

The designers of the original London Bridge, built across the Thames River in 1176, still had not overcome this problem. During times of high tidal flow there was a 1.5 m difference in water level on either side of the London Bridge due to the number and size of the piers.

Another drawback of the early arch bridge was that it couldn't be built out from two sides the way a cantilever bridge could. The arch needed to be fully supported during construction until it was ready to take its own weight. The Romans would construct a **cofferdam** (a temporary dam) to divert part of the river to allow the arch and its piers to be constructed one arch at a time.

Little changed in arch design until the latter stages of the European Renaissance in the 15th century. During the industrial revolution in the 18th century, techniques were developed that allowed the arch to be much flatter. An example is the Perronet arch, which uses slender piers and low arches, as shown in figure 1.17. This enabled greater bridge spans without an increase in height. Understanding the importance of building the piers on a **foundation** of solid rock and a greater knowledge of the outward forces produced by the arch enabled the piers to be reduced considerably in size to about one tenth of the span size.

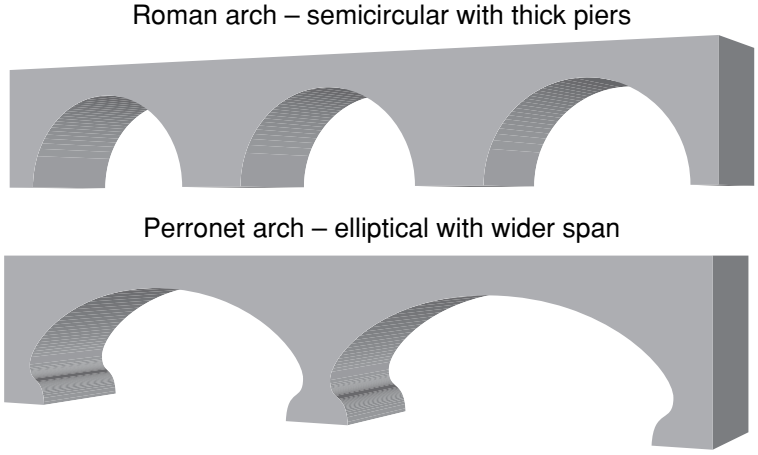


Figure 1.17 A Roman arch and Perronet arch

The late 18th century saw a significant development in bridge building. Figure 1.18 shows the first all-metal bridge – built over the River Severn at Coalbrookdale in England. This bridge had a 33 m **cast iron** span and was based on an arch design. Cast iron is an **alloy** of iron and carbon.



Why was cast iron suitable for an arch style of bridge?

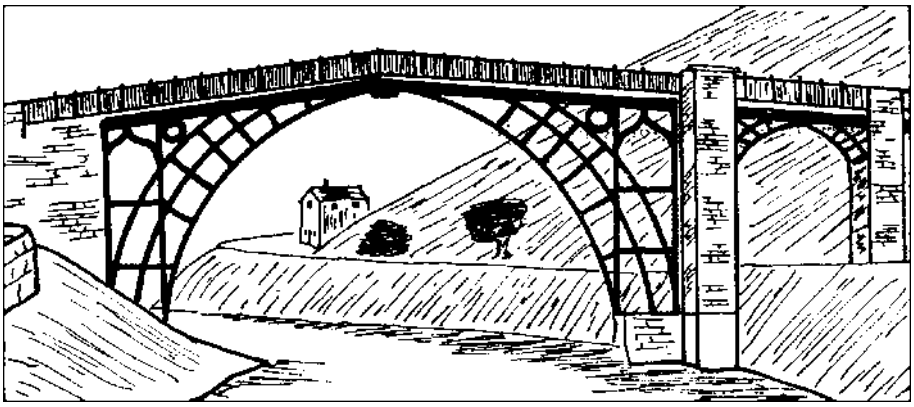


Figure 1.18 Coalbrookdale – the first all-metal bridge

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Cast iron was quickly superseded by **wrought iron** and later by **steel**. Wrought iron has three times the tensile strength of cast iron. This material development led many bridge builders away from the traditional arch towards other forms of bridge design.

The arch bridges that were built during the second half of the 19 th century were often constructed in a traditional manner but using **concrete** instead of stone. A small shallow arched bridge was built in 1869 in France. This pedestrian bridge had a span of only 13 m but is considered to be the first bridge to use **reinforced concrete**.

The arch is always in compression, whether you are using masonry materials, cast iron, more modern steel trusses or contemporary prestressed reinforced concrete to make the arch. This is also true whether the roadway hangs below the arch, as with the Sydney Harbour Bridge shown in figure 1.14, or on top pushing down on the arch, as with the predominantly concrete Gladesville Bridge shown in figure 1.19.



Figure 1.19 Gladesville Bridge across the Parramatta River Sydney – concrete arch

The principle of the arch is also seen in many other civil structures.
For example, the walls of most dams are arched (horizontally) to counteract the water pressure on the dam wall. Most simple beam bridges have a slight curve in them.

List other places where you have seen arches used in civil structures.

_____

_____

_____

_____

_____

Did you answer?

You may have listed doorways, windows and ceiling domes.

Turn to the exercise section and complete exercise 1.3.

Suspension bridges

A **suspension bridge** is very light and can span considerable distances. They are most suited to carrying light traffic loads. The suspension bridge, like the beam bridge, has its origins long before the substantial arch bridge of the Roman era. Early designs were constructed mainly in tropical areas using ropes made from vines, creepers, bamboo, leather or other natural rope-making materials. Quite long spans could be achieved, although these could be dangerous. The bridge typically consisted of three ropes – one for walking on and two others as handrails. This bridge was particularly unstable and was suitable for light foot traffic only.

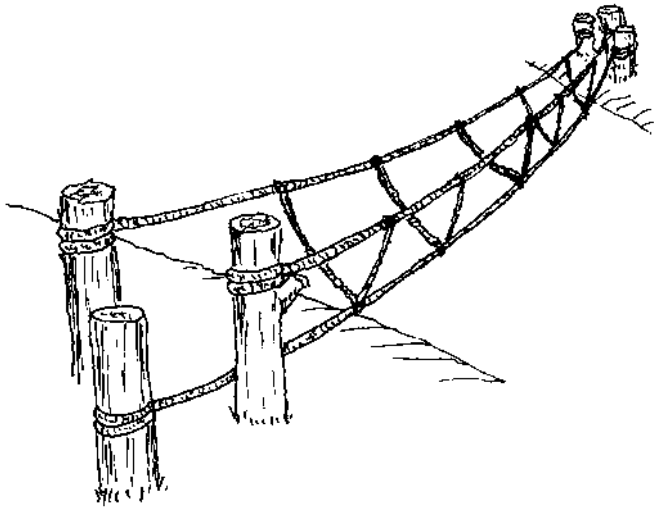


Figure 1.20 An early suspension bridge

An improvement to the basic design was to have two bottom ropes joined with a set of timber planks to form a pathway. Small suspension bridges of this type are often found in children's playgrounds. Even these small bridges demonstrate the inherent instability of the suspension bridge. Step on one end and that part will sag while the other parts of the bridge rise up. It is also easy to swing the bridge from side to side. The flexible cables, used because of their light weight and good tensile strength, cannot resist any of the compressive forces placed upon them. A reverse in loading due to the traffic moving across the bridge, suddenly applied loads or even the wind loading on the bridge will contribute to instability of the bridge.

The modern suspension bridge typically consists of cables fixed at their ends and draped over towers on either side of the span. The roadway structure, called the **deck**, is suspended from the cables. In some respects, the suspension bridge is the reverse of the arch in that the main components of the suspension bridge are placed in tension. The towers are the only main components in compression since they are being pulled down on by the cables.

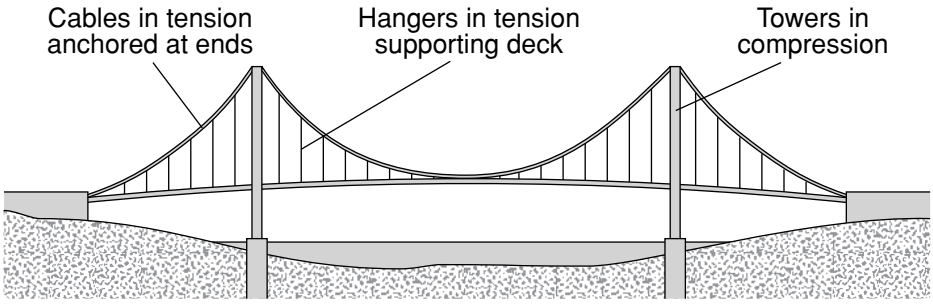


Figure 1.21 The components of a modern suspension bridge

The first appearance of the modern suspension bridge coincided with the introduction of wrought iron. A flat wrought iron chain similar to a bicycle chain was used to provide the tensile strength required. A notable bridge of this time was designed by Thomas Telford to cross the Menai Straits in Wales. This bridge, opened in 1826, had a central span of 193 m.

The popularity of suspension bridges ended abruptly with the collapse of a number of bridges and with an increasing need for bridges capable of carrying the heavier loads applied by the growing railway network.

The ability to span large distances with no central piers with a comparatively light structure meant that suspension bridges were always going to make a comeback. In the early 20 th century the development of **high tensile steel** cables and the ability to spin thin strands into thicker cables of long lengths led to the latest era of suspension bridge building. The growing popularity of the motorcar also contributed to the increased use of the suspension bridge. Modern suspension bridges, though considerably stronger than their predecessors, are generally not designed to carry railways.

The Golden Gate Bridge completed in 1937 deserves special mention because of its massive 1280 m central span. This bridge has become a symbol of San Francisco in much the same way the Sydney Harbour Bridge is a symbol of Sydney. Special architectural attention was paid during the design phase to ensure that the appearance of the bridge enhanced the beauty of the San Francisco bay.

Currently the longest bridge span in the world belongs to the Akashi-Kaikyo suspension bridge in Japan. It has a central span of 1991 m. The top twenty bridges with the longest spans are all suspension bridges.



Turn to the exercise section and complete exercise 1.4.

Bridge safety

Worker safety has not always had the importance that it does today. During construction of the massive Forth Bridge in the United Kingdom, 57 men were killed, most after falling from the bridge. Many of these deaths were simply listed as 'due to worker's carelessness'. During the building of the Sydney Harbour Bridge 17 men lost their lives.

In the late 19 th century a common method of digging silt from the riverbed to reach a solid foundation was to use a **compressed-air caisson**. This was a large wooden box with a closed top and open bottom with sides deep enough to reach from the riverbed to above the water level. Compressed air was pumped into the box to keep the box watertight. Workmen inside the caisson dug away the soil until they reached a firm foundation. The deepest caissons went to a depth of about 40 m. Unfortunately, at that time little was known of the effects of working in compressed air which meant that many workers died or became seriously ill with what is now known as the 'bends'.

You can learn much from past mistakes. There have been many famous and tragic incidents concerning bridge design and construction including bridge collapses, some of them fairly recent.

Tay Bridge

The Tay Bridge of Scotland was opened in 1878. It was constructed of brick and concrete piers and cast-iron columns with 84 large wrought iron trusses designed to carry the heavy steam trains of the time. Due to their immense weight, it was not considered necessary to tie the trusses to the columns.

During a violent storm on 28 December 1879, while the Edinburgh to Dundee mail train was crossing the bridge, 13 of the high middle spans were literally blown off their columns taking with them the columns and the mail train. All 75 people on board the train were killed. This tragedy demonstrated the power of the wind on a large structure like a bridge and led to immediate changes in the design of future bridges.

Tacoma Narrows Bridge

The Tacoma Narrows Bridge built in 1940 on the west coast of America was a long but unremarkable suspension bridge with a central span of 853 m. Its deck was only 13 m wide with the solid girders supporting the deck only 2.4 m deep with very little in the way of cross-bracing. Almost as soon as it was opened the deck swayed much more than expected. Four months later, on 7 November in a wind of only 68 km per hour the deck began to oscillate and sway violently. Within hours the bridge had shaken itself to pieces. You may have seen film footage of the final moments of the bridge as it collapsed into the water below.

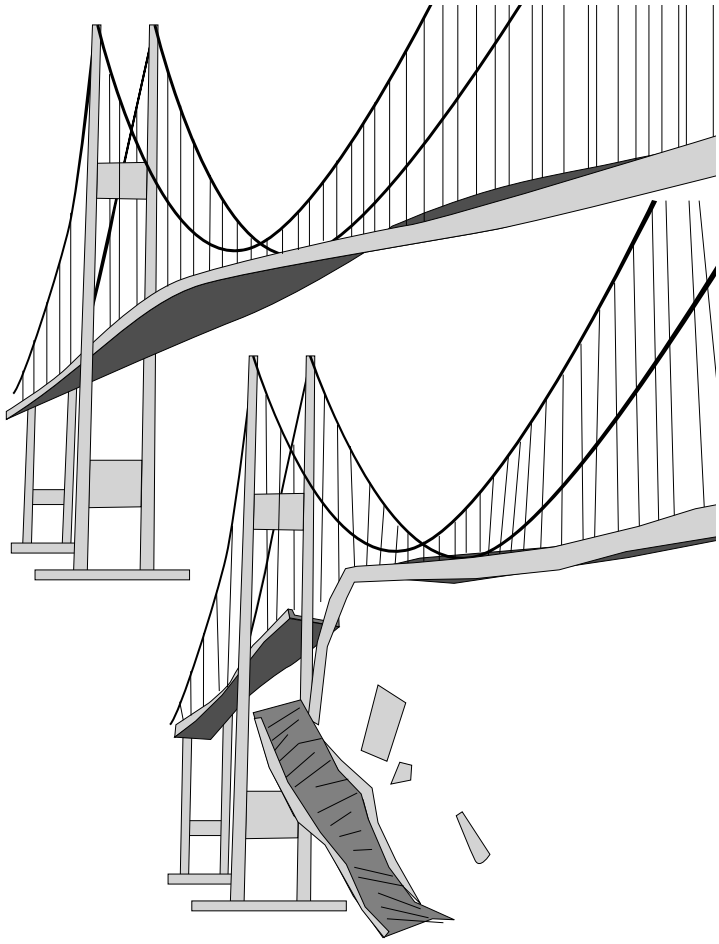


Figure 1.22 The Tacoma Narrows Bridge buckling

The tragedy of the Tacoma Narrows Bridge collapse was that bridge designers had not learnt from the previous suspension bridge failures a century earlier. During the mid 1800s, an alarming number of suspension bridges around the world fell or were blown down due to the instability of the road deck under fluctuating loads.

Following the Tacoma Narrows incident, the decks of many suspension bridges, including the Golden Gate Bridge in San Francisco, received additional strengthening. Models of modern suspension bridges now undergo rigorous testing in wind tunnels with the road deck often consisting of a streamlined box girder, as with the Severn Bridge in the United Kingdom, or large lattice truss girders, which do not trap the wind as a solid girder does. Some decks have been designed with slots to allow the wind to pass through.

West Gate Bridge

On 15 October 1970 the middle span of the West Gate Bridge over the Yarra River in Melbourne collapsed while under construction. A total of 35 men working either on or under the span at the time were killed.

Earlier in the year concerns were raised by the workmen who had noticed metal beams buckling and one of the spans sagging. Concern grew in June 1970 when a bridge in Wales collapsed while under construction. It had been designed by the same firm that designed the West Gate Bridge. An investigation was launched to report on the faults of the bridge design and construction. Construction continued during this investigation.

The span that collapsed was to be made from two halves bolted together in the middle. When the second half was lifted into position it was expected that it would line up neatly with the first. Unfortunately one side was 110 mm lower than the other. The high side was loaded up with 80 t of concrete to lower it into position. This worked, but a large buckle appeared at the end of the span. To allow the buckle to flatten out, the bolts at that end were removed. This also worked but meant that this half was now only supported by resting up against the face of the other half. Before the bolts could be replaced and the two halves bolted together the two sections collapsed.

The Royal Commission into the collapse of the West Gate Bridge was highly critical of almost every phase of the design and construction of the bridge. The workers were faced with correcting serious design faults during construction but did so without close supervision and without fully understanding the possible tragic results.

Tasman Bridge

The bridge across the Derwent River in Hobart consisted of a multi-span steel and concrete beam bridge. The central piers in the shipping lane were strengthened to withstand a collision from the large ships that used the river. Unfortunately, on the wet and windy night of 5 January 1975, the Lake Illawarra ship suffered steering problems on its voyage up the Derwent. It veered out of the normal shipping channel at full speed and crashed into one of the minor piers, bringing down one of the spans. Twelve people were killed in the accident, seven on board the Lake Illawarra and five motorists who were either on the span at the time or who drove straight over the gap into the Derwent River. Figure 1.23 shows the bridge with its missing span. Two cars can be seen with their front wheels over the end of the missing section. Note also the size of the base of the third and fourth piers in comparison to the other piers.



Figure 1.23 Tasman Bridge

© Photo courtesy of the Mercury

The investigation into the tragedy found that the ship's captain was to blame for the ship being off course, but some concern was also raised over the design of the minor piers. A lesson to be learnt from this collision is that it is important that engineers don't mistake events that shouldn't happen with events that won't happen – expect the unexpected.

Bridge building

Now that you have looked at the different types of bridge systems used over the years you should be able to determine 'what makes a good bridge' or 'what could make a good bridge better'?



List four criteria on which you could judge a bridge.

_____

_____

_____

_____

_____

Did you answer?

Factors you could take into account when evaluating a bridge include:

- length of span – can the length of the span of the bridge be increased? would that be an advantage?
- cost – can the bridge be built more cheaply without compromising other areas of performance? what will be the ongoing maintenance cost?
- strength – can the load-carrying capacity of the bridge be increased?
- appearance –does the bridge complement the surrounding environment? what sort of visual statement does it make?
- safety – are there safer ways in which the bridge can be constructed? can the bridge be made safer to use?
- adaptability – how will the bridge cope with future traffic patterns? can it be modified to accommodate more traffic or new types of traffic?
- life cycle – has the bridge been designed to be replaced within a certain period of time?
- environmental issues – did constructing or operating the bridge harm the local plants and animals or the overall environment?
- societal issues – has the bridge improved traffic flow in the area or has it created new problems? how has the bridge affected local businesses? how has the bridge affected people living nearby?



Keep these factors in mind as you look at different bridges in your local community. Could a better bridge be designed for each situation given the materials and technology available now?

The future in bridge building

To improve a bridge, the focus is often on how to increase the span. To increase the span of a bridge engineers can make the components stronger by making them bigger. But a bridge must be able to support its own weight. For most materials it is possible to accurately work out the maximum span achievable. To lengthen the span of a bridge in future years, increased use may be made of lighter composite materials such as Kevlar, a carbon fibre. Carbon fibre has a strength-to-weight ratio four times greater than that of high tensile steel. That would give it a theoretical limiting suspension span of twelve kilometres.



What developments might there be in building the types of bridges you see every day in your local community? Ask yourself the following questions.

- Will an increased use of pre-fabricated components allow bridges to be built more cheaply and faster than at present?
- Will 'hightech' materials find their way into common bridges?
- Will a particular bridge style such as the cable-stayed bridge dominate bridge designs in the future?
- Is it possible to reduce the environmental impact of the bridge?

It will be up to the civil engineers of the future to design a structure to meet the needs of the community using the materials and construction processes available at the time. Who knows – in many cases the best solution may be not to have a bridge at all.

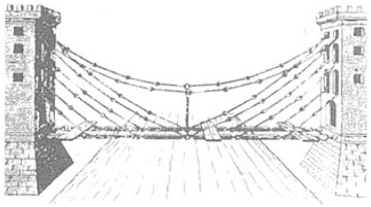


Turn to the exercises section and complete exercise 1.5.

Lifespan: Chronology of Bridge Building

Prehistory: The earliest bridges were formed when tree trunks were placed side by side over small streams and ravines. An advance on these simple beam bridges was the placing of stone slabs on rock supports to produce clappler bridges.

Many clapper bridges, such as the Tarr Steps over the River Barle in England, remain today but cannot be accurately dated.



© VSL

Sketch by Verantius, 1617

Another basic bridge form, the suspension bridge, has been used in China and South America for more than 2000 years. Forty thousand years ago, Neanderthal people burrowed underground at Bomvu Ridge in Swaziland. Using bare hands, bones and sharp stones they tunnelled searching for hematite, a stone used for decoration and burial rites.

3200 BC The construction of the arch is mastered by the Sumerians.

2650 BC Earliest recorded reference to a bridge. The material or design of the structure, across the Nile, is not known.

2000 BC Probably the earliest tunnel used for travel was a link under the Euphrates River. The tunnel between the main buildings of Babylon's Royal Palace was constructed by thousands of slaves using the cut and cover method. During the dry season, the river was diverted and a trench dug. After linning the trench with bricks and constructing an arched rood, the trench was then refilled.

850 BC Construction of the oldest surviving dateable bridge, a stone single-arch bridge over the River Meles in Smyrna (now Izmir), Turkey.

179 BC The Romans build the first stone bridge across the Tiber. One stone arch of the Pons Aemilius is all that remains, but there are many magnificient Roman bridges and aqueducts, such as the Pont du Gard, Nimes (AD 14), still standing.

6th Century AD The Shogun's Bridge in Nikko, Japan uses the principle of cantilevering.

1209 London Bridge is completed. Begun in 1176 by Benedictine monk Peter of Colechurch, it consisted of 20 narrow stone arches and was lined with shops and houses for almost it s entire length. It was replaced in 1831.

1335 The Ponte de Castel Vechio, a beautiful fortified bridge, is built in Verona. The importance of bridges as transport links meant that they have often been fortified and heavily defended during war. This bridge has omate battlements along its length and defensive towers at either end. The defences were of no use in World War II, but the bridge was still important enough to be destroyed. It has since been rebuilt.



© Barbara Gurney

Ponte Vecchio

1345 The Ponte Vecchio is built in Florence by Taddeo Gaddi. It is the most important surviving example of the pont-maison, the building-bridge of medieval times, where houses up to five storeys high were built on bridges.

1550 Sketches by Italian architect Andrea Palladio show a number of bridges using various forms of truss designs. There is not another example of trusses being used until 1758 when Ulric Grubenmann, a Swiss carpenter, builds a 50-metre wooden truss bridge over the Rhine.



© T Mannix

Bridge of Sighs

1595 Venice's Bridge of Sighs is built. Omate iron bars cover the windows of the bridge that linked the Doge's palace with his prison and torture chambers.

1617 The Venetian engineer Verantius sketches a bridge which is a combination of cable-stayed and suspension bridge using iron chains for support.

1779 The Iron Bridge over the Severn River, Coalbrookdale, England is designed by Abraham Darby III. This is the first major structure built of iron.

1794 The first recorded Australian bridge is built in Parramatta. Australia's first stone bridge was built across the Tank Stream in 1804.

1802 Albert Mathieu displays his plans for a tunnel under the English Channel. The proposal includes an artificial island midway where horses can be changed.

1810 Thomas Telford builds the 46-metre span cast iron arch of the Bonar Bridge over the Dormoch Firth in Scotland. Telford was the founding president of the world's first civil engineering society.

1824 The development of modern Portland Cement around this period is normally attributed to Aspdin.

1825 The oldest bridge still standing in Australia, the stone arched Richmond Bridge in Tasmania, is completed.



© David Stanley

Richmond Bridge

1826 Telsford's Menai Bridge over the Menai Straits in Wales has the world's then longest span at 177 metres. The wrought iron, chain-suspension bridge is the first to span an open stretch of ocean and reflects the emergence of the suspension bridge as a modern form capable of producing the longest spans.

1828 At the age of 22, Isambard Kingdom Brunel is seriously injured while working on the tunnel his father, Marc Isambard Brunel, is constructing under the

Thames. Marc Brunel had patented the Brunel Shield in 1818, a revolutionary system where a large iron collar was used to protect tunnellers working at the face of a tunnel in soft ground. The young Brunel is sent to Clifton near Bristol, to recuperate. In 1829 there is a competition to design a bridge to span the nearby Avon Gorge. Though Brunel had no bridge-building experience, his design for a suspension bridge is accepted in 1831, but his masterpiece is not completed until 1864, five years after his death.

1840 American Earl Trumble is credited with building the first iron truss bridge over the Erie Canal, New York State. Another American, Squire Whipple, used the first all-iron truss of "modern" form 13 years later. Iron and steel truss forms remain popular for short-span railway bridges until the development of 20th century concrete technology.

1850 Robert Stephenson's Britania Bridge is built over the Menai Straits in Wales. Like Brunel, Stephenson was the son of a famous engineer. George Stephenson had designed the world's first successful stream railway in 1825.

The Britannia Bridge is made of stiff square-section wrought iron tubes in two main spans of 140 metres each. It was originally planned to be a suspension bridge, but tests show that the tubes were strong enough to stand on their own.

1855 John Anderson Roebling spans the Niagara River with a 250-metre iron wire rope suspension bridge. It is the first major suspension bridge to carry a railroad for any extended period. Passengers have plenty of time to enjoy the view because trains are limited to 3 mph to reduce stresses.

1867 French gardener Joseph Monier patents the idea of strengthening thin concrete vessels by embedding iron wire mesh in the concrete. In 1879 another Frenchman, Francois Hennebique, fireproofs a metal-frame house he is building by covering the iron beams with concrete. These advances lead to the structural system where the metal carries tension-reinforced concrete. Hennebique goes on to build the longest spanning reinforced concrete bridge of the 19th century with a central arch of 50 metres.

1874 James B. Eads bridges the Mississippi at St. Louis with the first major structure made of steel. Its 150-metre arches were the longest in the world and provided a transport link the city needed to compete with Chicago for economic dominance of the midwest.

1877 Gustave Eiffel's Pia Maria Bridge over the Douro River, Oporto, Portugal, is opened. Its 160-metre crescent-shaped arch of wrought iron was both beautiful and economical, its cost being 31 per cent lower than the next bidder.

1883 The Brooklyn Bridge over the New York's East River is opened. By that time, its construction had claimed over 20 lives including that of its designer, John A Roebling.



© Alan Barnes

Brooklyn Bridge

1890 The Forth Bridge over the Firth of Forth, designed by Benjamin Baker, is opened. Its two steel cantilever truss spans are each 521 metres, the longest of their time. Originally the Firth was to be bridged by Thomas Bouch but the public lost confidence in him when his Firth of Tay bridge collapsed as a passenger train passed over it in 1879.



© Heather Luke

Forth Bridge

1911 Frenchman Eugene Freyssinet observes that the concrete arches of the Le Veudre Bridge he had built over the Allier river, near Vichy, France had begun to sag. Freyssinet inserts jacks into the crowns of the bridge's arches and forces the halves apart to raise the arches and filled the gaps with concrete- a form of prestressing. In 1928 he went on to patent a more general concept of prestressing, where steel cables force concrete into permanent compression. In 1946 he built the Luzancy bridge over the Marne River in France, first to show the possibilities of concrete-beam bridges when compressed by large forces induced by high-strength steel tendons within the structure.

1917 The Quebec Bridge over the St Lawrence River, Canada, opens. It still has the longest cantilever truss span in the world, 549 metres. Part of the bridge collapses during construction and by the time it opens, 87 workers are dead.

1930 The Salginatobel Bridge near Schiers, Switzerland is opened. Its designer, Robert Maillart, is considered by many to have produced the most innovative and beautiful bridges of the 20th century. The Salgintobel arch, with a 90-metre span, is far from the largest of its time but, like his later Schwanbach Bridge, its revolutionary form and economy of materials is acclaimed.

1931 Othmar Ammann's George Washington Bridge over the Hudson River of New York is opened. The 1070-metre span of this steel suspension bridge was almost twice the span of any existing bridge. By the 1930s road transportation has replaced rail as the dominant transport technology. Freed of the need to service a rail route, the designer of the George Washington Bridge is able to select a location where the geology best suits the design. The bridge could also carry the lighter "live load" of vehicular traffic rather than the massive weight of trains.

1932 Work begins on the Golden Gate Bridge spanning the entrance to San Francisco Harbour. On completion, its span of 1280 metres is the greatest in the world. Its spectacular location and the Art Deco elegance of its 230-metre towers make it one of the world's most admired structures, but it is not a true breakthrough in bridge design. In March, during the opening of the Sydney Harbour Bridge, Jack Lang, the Premier of NSW, is upstaged when a mounted member of the right-wing New Guard slashes the official ribbon with his sword.



© MAree Camilleri

Golden Gate Bridge

1940 The Tacoma Narrows suspension bridge in Washington State collapses. Winds caused undulations and four months after opening, a 40-knot gale turns the up-and-down dance into a wild twist. After the bridge collapses, many other bridges have their decks strengthened.

1950 The Lahn Bridge at Balduistein, West Germany, is the first prestressed concrete bridge to be made using free cantilevering method where the bridge is built out from its pylons without any temporary formwork as support. Free cantilevering had long been a popular method of building steel bridges but neither simple nor reinforced concrete had been well suited to the stresses that arise during this form of construction. It required a clear understanding of the qualities of prestressed concrete for this method to become a popular form of bridge construction.

1955 The Stromsund Bridge in Sweden is built. It is widely accepted as the first of the modern cable-stayed bridges made possible by the development of high-strength steel for the cables. Melbourne's Westgate and Sydney's Glebe Island bridge are developments on this theme.

1957 Bridge on the River Kwai which tells the story of PoWs being forced to build a bridge for the Japanese, wins seven Academy Awards.

1962 The first prestressed concrete bridge using the incremental launching method is built over the Rio Caroni in Venezuela.

1964 The Gladesville Bridge across the Parramatta River near Sydney is opened. Its concrete arch, spanning 304 metres, was for some time the largest in the world.

1969 The world's longest bridging, the Second Lake Pontchartrain Causeway, is completed near
New Orleans. The 38.4 kilometre long structure requires
no long spans and like the nearby first causeway,which sits on 2215 bents, its construction is more an achievement of the mass production of precast prestressed concrete than the bridge builder's art.

1970 Melbourne's Westgate Bridge collapses on October 15 during construction. Thirty-five people die. The collapse occurs during attempts to remove a buckle from a section of steel box-girder decking. The Royal Commission highlights "mistakes, miscalculations, errors of judgement, failure of communication and sheer inefficiency."

1975 On January 5, the freighter Illawarra slams into a pylon of the Tasman bridge in Hobart. The designers had planned for just such an impact, and only the section supported by that pillar collapses. But a concrete roadway section does crash, and the ship sinks with the loss of seven crew. Five bodies are recovered from cars that plunge into the river. Nine years later, the Bowen Bridge opens upstream, away from shipping lanes.



© David Stanley

Tasman Bridge

1977 New River Gorge Bridge, West Virginia, becomes the world's longest steel arch bridge, a record it still holds. Its span of 518 metres is 15 metres longer than the Sydney Harbour Bridge but its deck not as high.

1980 Christian Menn's Ganter Bridge in Switzerland on the Simplon road, above Brig is opened. The encasing of the cable-stays in concrete give it a striking new look, acclaimed by many as the most beautiful bridge built since World War II.



© Switzerland Tourism

Ganter Bridge

1981 The Queen opens the Humber Estuary Bridge. Its main span of 1410 metres is the world's longest. The bridge's 162-metre towers are 36 mm out of parallel to allow for the curvature of the earth. The Akashi-Kaikyo bridge linking the Honshu and Shikoku islands of Japan is to be completed in 1998. Its central span of 1990 metres will be the world's longest.

1986 The Gateway Bridge, Brisbane is opened. Its central span is 260 metres.

1988 Construction of the Sydney Harbour Tunnel begins.

1989 The California earthquake causes minor damage to San Francisco's Bay Bridge when one of its approach spans collapses, but there is no serious damage to the Golden Gate Bridge.

1991 French and English tunnellers have regular contact after a section of the Channel Tunnel's service tunnels meet.

© *Griff Clemens*

World's longest bridge spans



Look at the following tables which rank types of bridges according to their span.

Suspension bridges				
Ranking	**Bridge**	**Span (m)**	**Country**	**Year**
1	Akashi-Kaikyo	1991	Japan	1998
8	Golden Gate	1280	USA	1937
14	George Washington	1067	USA	1931
20	Severn	988	United Kingdom	1966
The only choice of bridge where very long spans are required.				

Cable-stayed bridges				
Ranking	**Bridge**	**Span (m)**	**Country**	**Year**
2	Tatara	890	Japan	1999
3	Pont de Normandie	856	France	1995
4	Second Nanjing	628	China	2001
Popular modern style of bridge suited to all but the widest spans. A simple way of increasing the span of basic beam bridges.				

Steel truss bridges				
Ranking	**Bridge**	**Span (m)**	**Country**	**Year**
1	Pont de Quebec	549	Canada	1917
2	Firth of Forth	521	United Kingdom	1890
3	Minato	510	Japan	1974
A very old method of building large bridges.				

Steel arch bridges				
Ranking	**Bridge**	**Span (m)**	**Country**	**Year**
1	New River Gorge	518	USA	1977
2	Bayonne	504	USA	1931
3	Sydney Harbour	503	Australia	1932
Another old style of constructing large bridges.				

Concrete arch bridges				
Ranking	**Bridge**	**Span (m)**	**Country**	**Year**
2	Wanxian	425	China	1997
3	Krk-1	390	Croatia	1980
4	Gladesville	305	Australia	1964
A modern alternative to the steel arch.				

Prestressed concrete beam bridges				
Ranking	**Bridge**	**Span (m)**	**Country**	**Year**
1	Stolmasundet	301	Norway	1998
5	Gateway	260	Australia	1986
22	Mooney Mooney	220	Australia	1986
A modern style of bridge suitable for small to medium spans				

Steel girder bridges				
Ranking	**Bridge**	**Span (m)**	**Country**	**Year**
1	Pont Costa e Silva	300	Brazil	1974
2	Neckartalbrucke-1	263	Germany	1978
3	Sava-1	261	Yugoslavia	1956
Similar in application to the prestressed concrete beam bridge.				

Adapted Juhani Virola, Helsinki University of Technology – Finland.



If you have access to the Internet, check out the latest figures by visiting <www.hut.fi/Units/Departments/R/Bridge/longspan.html> (accessed 7/7/02).



Turn to the exercise section and complete exercises 1.6 to 1.8.

Exercises

Exercise 1.1

a Examine the following illustration of a bridge.

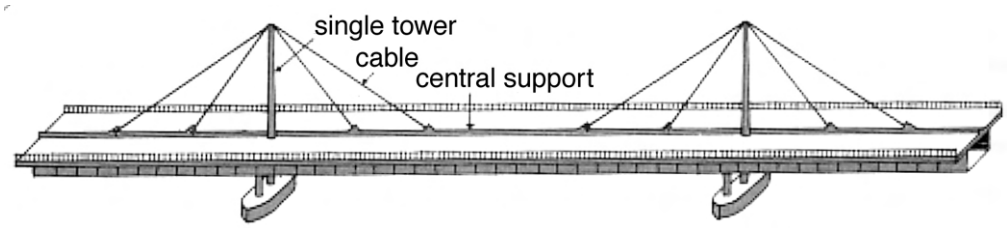


Figure 1.24 Bridge

© Kurth, H. 1975, p38.

b Name:

i the bridge type

_____

ii the stress type in the tower

_____

iii the stress type in the cables

_____

c List three advantages of the type of bridge shown in figure 1.32 over the simple beam bridge.

_____

_____

_____

Exercise 1.2

a Explain why timber truss bridges are able to span greater lengths than timber beam bridges.

_____

_____

_____

_____

_____

b List the advantages and disadvantages of sandstone as a building material.

Advantages	Disadvantages

c Explain the term ‘pre-fabricated construction’ as it applies to civil structures.

_____

_____

_____

_____

Exercise 1.3

The Sydney Harbour Bridge and the Gladesville Bridge both incorporate an arch in their design. Explain how the design of the components supporting the deck in each bridge was influenced by the properties of the materials used.



Figure 1.25 Sydney Harbour Bridge

a **Sydney Harbour Bridge**

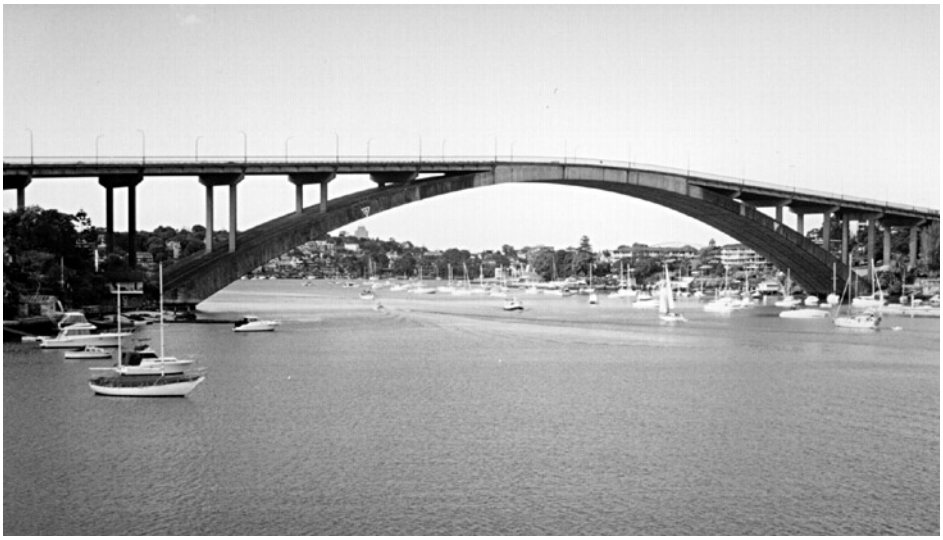


Figure 1.26 Gladesville Bridge

b **Gladesville Bridge**

Exercise 1.4

a Date the following events and sequence them on the time line below.

The first one has been completed for you.

- Reinforced concrete first used in a bridge
- Cable-stayed bridges increase in popularity
- Steel wire spun into thick cable
- Perronet arch replaces earlier arch designs
- Pre-stressed concrete widely used
- Wrought iron replaced cast iron
- Trussed timber bridge built in Switzerland
- Cast-iron first used in an arch bridge
- The first modern era of the suspension bridge begins

Date

1750 Perronet arch replaces earlier arch designs

- _____
- _____
- _____
- _____
- _____
- _____
- _____
- _____

b Explain the significance of three of the events from part a. Include how the new design was an improvement on past designs.

i _____

_____

_____

_____

_____

ii _____

_____

_____

_____

_____

iii _____

_____

_____

_____

_____

Exercise 1.5

Research what the job description of a civil engineer might be.

List four functions of the civil engineer.

i _____

ii _____

iii _____

iv _____

Exercise 1.6

a Label the following beam bridge components on the drawing below.

Foundation Deck Box Girder Pier Reinforcing

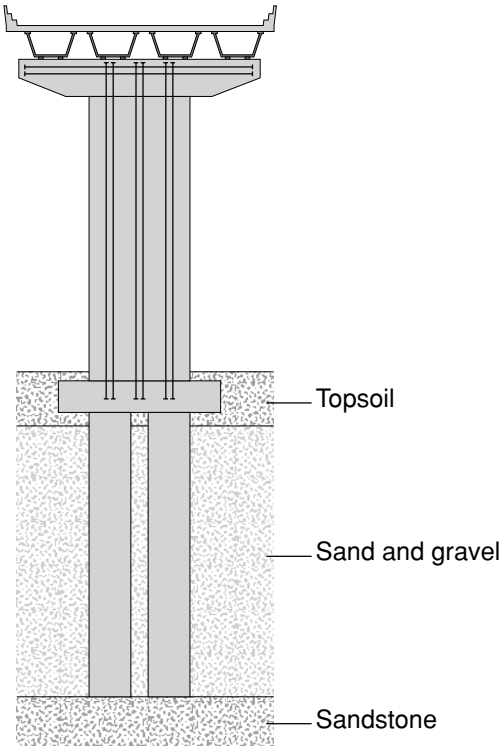


Figure 1.27 Beam bridge components

b List the advantages of using steel for a box girder rather than reinforced concrete.

_____

_____

_____

_____

Exercise 1.7

a List four examples of how engineers have become more conscious of the environment implications of their designs in recent times.

i _____

_____

_____

ii _____

_____

_____

iii _____

_____

_____

iv _____

_____

_____

b Name a bridge in your local area and outline the environmental and social impact on your local community if the bridge did not exist. (Consider the change in traffic patterns, the viability of local businesses and what might take its place).

_____

_____

_____

_____

_____

_____

_____

Exercise 1.8

Select the alternative a, b, c, or d, that best completes the statement. Circle the letter.

1 The main advantage of a beam bridge is:

a they are excellent for very long spans

b they are the simplest form of bridge to construct

c the beam can be very thin

d they can be made from Australian hardwood.

2 Timber road bridges were still constructed in rural New South Wales up till 1950 because:

a Australian softwood is very durable and inexpensive

b rural bridges weren't as important as city bridges

c steel was in short supply and Australian hardwood was very durable

d rural bridges are subjected to flooding and timber floats.

3 The most modern style of bridge is:

a the cable-stayed bridge

b the beam bridge

c the suspension bridge

d the pre-stressed reinforced concrete arch bridge.

4 The Tay Bridge fell down in a storm because:

a the columns were poorly constructed

b the bridge was overloaded

c the trusses were not tied to the columns

d a train derailed.

5 Safety has improved on construction sites because:

a unsafe work practices are no longer tolerated

b safety education is integrated into the training of the workforce

c there are large fines for companies and individuals who persist in unsafe work practices

d all of the above.

6 The best bridge is one that:

a has the longest span

b best meets the needs of its intended users

c is constructed on time and within budget

d causes the least amount of damage to the environment whilst under construction.

7 Cast iron is not used for cables in bridges because:

a it is too heavy

b it is too expensive

c it is only used for components that can be cast

d it is weak in tension.

8 Beam bridges usually fail when:

a the compressive stress is too great

b the bending stress is too great

c the tensile stress is too great

d the beam is too heavy.

9 The Perronet arch was an improvement over the Roman arch because:

a it was easier to construct using untrained labour

b it didn't need mortar to hold the voussoirs together

c it looked better because it was higher with thinner piers

d it was lower with thinner piers.

10 The cantilever bridge is:

a likely to break in the middle if overloaded

b often made thicker at the supports to improve its appearance

c combined with a suspended beam in the middle to increase its span

d less expensive than other forms of bridge.



Exercise cover sheet

Exercises 1.1 to 1.8 Name: _____

Check!

Have you have completed the following exercises?

- ❒ Exercise 1.1
- ❒ Exercise 1.2
- ❒ Exercise 1.3
- ❒ Exercise 1.4
- ❒ Exercise 1.5
- ❒ Exercise 1.6
- ❒ Exercise 1.7
- ❒ Exercise 1.8

Locate and complete any outstanding exercises then attach your responses to this sheet.

If you study Stage 6 Engineering Studies through a Distance Education Centre/School (DEC) you will need to return the exercise sheet and your responses as you complete each part of the module.

If you study Stage 6 Engineering Studies through the OTEN Open Learning Program (OLP) refer to the Learner's Guide to determine which exercises you need to return to your teacher along with the Mark Record Slip.

Progress check

In this part you traced the development of **bridges**, examining changes to design as a result of material availability and construction methods.



Take a few moments to reflect on your learning then tick the box which best represents your level of achievement.

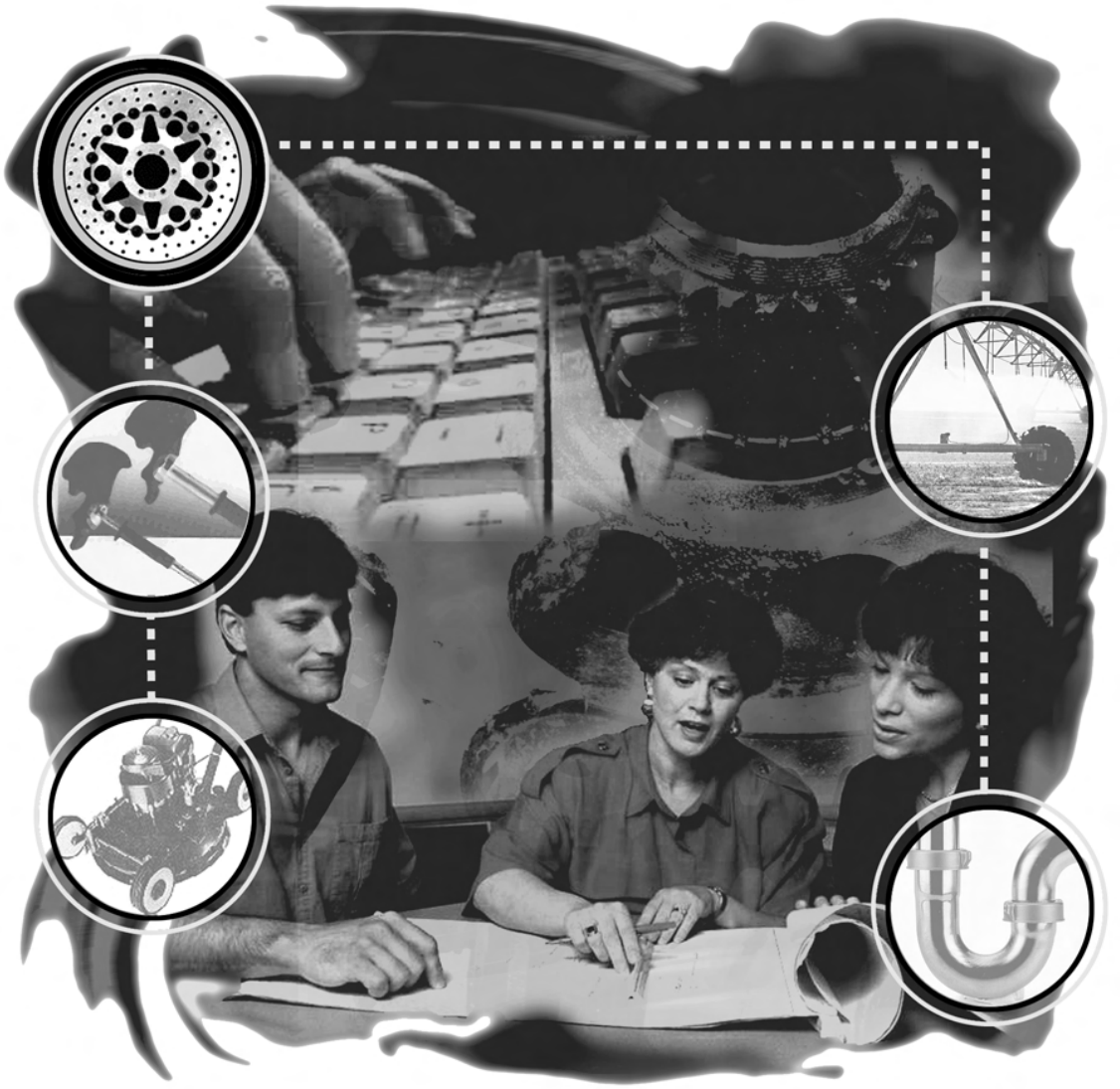
☑ **Agree – well done** ☑ **Disagree – revise your work** ☑ **Uncertain – contact your teacher**	**Agree**	**Disagree**	**Uncertain**
I have learnt about: • historical developments of civil structures • engineering innovation in civil structures and their effect on people's lives • construction and processing materials used in civil structures over time • environmental implications from the use of materials in civil structures.			
I have learnt to: • outline the history of technological change as applied to civil structures • investigate the construction processes and materials used in civil structures from a historical point of view • critically examine the impact of civil structures on society and the environment.			

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In the next pat you will examine mathematical and graphical methods used to solve problems relating to the engineering of civil structures.

Part 2: Civil structures – mechanics and hydraulics





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Introduction

Civil structures need to be engineered to ensure that they can withstand stresses and strains due to normal service loads as well as from forces such as earthquakes, cyclones, floods, fires, collisions, overloading and wind loads.

This part examines mathematical and graphical methods used to solve problems relating to the engineering of civil structures.

What will you learn?

You will learn about:

- Engineering mechanics and hydraulics as applied to civil structures:
  - stress and strain, truss analysis, bending stress induced by point loads only, uniformly distributed loads, crack theory, crack formation and growth.

You will learn to:

- apply mathematical and/or graphical methods to solve problems related to the design of civil structures
- evaluate the importance of the stress/strain diagram in understanding the properties of materials
- calculate the bending stress on simply supported beams involving vertical point loads only
- describe the effect of uniformly distributed loads on a simple beam, without calculations
- examine how failure due to cracking can be repaired or eliminated.

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Mechanical analysis

It is important for the civil engineer to be able to predict the reaction of various materials to different loads. The properties of various materials can be tested and the results plotted graphically. A significant consideration in designing civil structures is the stress and strain that structural members will be subjected to.

Stress and strain

Stress

Stress is the body's internal reaction to an externally applied force.

It may be a tensile, compressive or shear stress. Tensile and compressive stresses are axial stresses because the external force (either tension or compression) is applied along the axis of the member. A shear stress is a reaction to an external (shear) force applied at right angles to the axis.

Stress is calculated by dividing the external force (or load) by the area.

$$\text{Stress} = \frac{\text{load}}{\text{area}}$$

$$\sigma = \frac{L}{A}$$

While the calculation is relatively straightforward, a common error is for the incorrect area to be used. This was discussed in the module on Braking Systems. Refer back to your notes if you would like some revision on selecting the correct area.

For both tensile and compressive stresses, it is always the area that is at right angles to the force. As the force is axial, then the area is perpendicular to the axis. This is commonly called the **cross-sectional area** (CSA).

For **shear stress**, the area is always measured parallel to the applied force. This is known as the **shear area**, which is the area that needs to break if the component is to fail.

Shear stresses act along planes inside the material. These will be parallel to the applied force and the **shear force** will cause one section to slide over an adjacent section. If the member fails along two separate parallel planes, this is known as **double shear**.

The basic units used in stress calculations are:

Stress – Pascal (Pa)

Force – Newton (N)

Area – square metre (m^2)

$1\ Pa = 1\ N / m^2$

However, the unit of a pascal is very small (approximately the weight of 0.1 kg spread over a square metre). Also most engineering application areas will be expressed in millimeters squared (squared mm), rather than metres squared (squared m).

More realistic units are MPa (10^6 Pa) for stress and mm^2 for areas. These units will generally not require conversion to basic units.

$1MPa = 1\ N / mm^2$

Strain



Can you recall the definition of strain?

You should recall from earlier work that **strain** (ε) is defined as the extension divided by the original length.

This is represented by the formula $\varepsilon = \frac{e}{l}$

Strain is an important property to the engineer as it indicates to how much the material will deform (either stretch or compress) under a load.

This is particularly important in civil structures as too much deformation may produce a buckling of the structural member which could ultimately lead to failure.

Tension test

The tension test involves the application of a load to a material sample. It is from this test that a load-extension graph is produced. From this diagram, the engineer can establish some of the properties of the material and can predict the behaviour of components made from this material under this type of load.

In this test, a steadily increasing axial tensile load is applied to a small specimen until it breaks. During the test, the applied load is plotted against the extension of the material.



The following diagram illustrates a typical load-extension graph for a low-carbon steel (commonly used for **structural members** in civil structures).

A load-extension graph will have exactly the same shape as a stress-strain diagram. This is because stress is found by dividing the applied force by the original cross-sectional area (a constant) and strain is found by dividing the extension by the original length (also a constant).

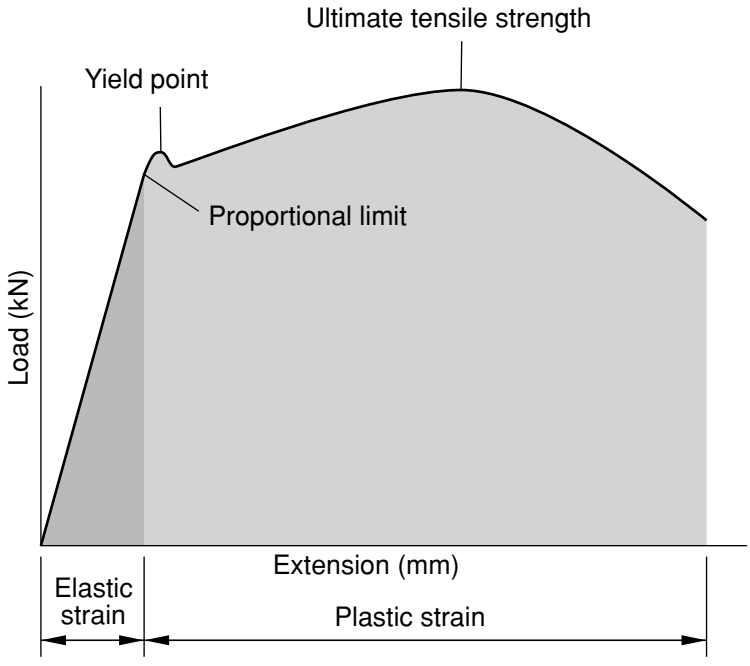


Figure 2.1 Load-extension graph for a low-carbon steel

From the load/extension graph, created during the tension test, a stress/strain diagram can be derived. From the stress/strain data the engineer can determine significant information such as:

- proportional limit stress
- yield stress
- proof stress
- ultimate tensile stress
- Young's Modulus (stiffness)
- breaking point.

Proportional limit stress is the stress at the end of the straight-line section of the stress-strain diagram. This is also sometimes called the **elastic limit**.

Yield stress is the stress at which a marked increase in strain occurs without a corresponding increase in stress. This is shown on the graph by the flattening out of the curve. Steels generally exhibit a well-defined yield point, whereas many metals and other materials do not exhibit a definite yield point. When this happens, the yield continues after the proportional limit, and the yield stress can only be determined by another method. This 'off-set' method is known as the proof stress.

Proof stress is the stress necessary to produce a certain amount of strain in the material. Depending on the service, an 'offset' percentage of strain is requested by the engineer. Common values for strain are 0.1% and 0.2%. The 'offset' method involves drawing a line parallel to the straight-line section, from the percentage required, until it intersects with the curve. This approximates the yield stress.



Look at the following diagram which illustrates the 'offset' method to approximate yield stress.

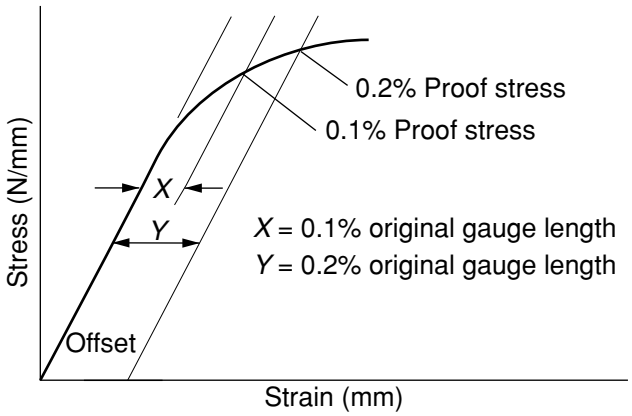


Figure 2.2 Stress-strain graph for proof stress

Ultimate tensile stress (UTS) is the maximum stress a material can withstand before it fails but not necessarily breaks. This is read from the top of the graphed line. UTS values are sometimes used in design work. Because the material has deformed plastically, it is necessary to compensate for this by applying a factor of safety into design calculations.

A factor of safety is a multiplier by which the calculated value is increased. For example, it is calculated that two bolts are sufficient to support a given load, but a safety factor of '4' is required on the specifications, then '4 x 2 = 8' bolts will be used to support the load.

The factors of safety multiplier will depend on the application.

Young's modulus is a measure of the stiffness of the material. This is shown on a stress-strain diagram by the slope of the straight-line section up to the proportional limit. The steeper the slope, the stiffer the material, the higher the value of Young's modulus and the smaller the deformation. It is calculated by dividing stress (σ) by the strain (ε).

Common values of Young's Modulus (E) include steel (210 GPa), copper (120 GPa), aluminium (70 GPa) and timber (10 GPa).

> Note: the units are the same as stress, but normally measured in gigapascals (GPa).
>
> 1 GPa = 10^9 Pa or 10^3 MPa

Toughness can also be determined from the stress-strain diagram. It is represented by the area under the graph, from the initial point to the point of fracture. Fracture is indicated by where the graph ends. Toughness is an important property in structural members as it is the ability of a material to absorb energy when being deformed and therefore to resist deformation and failure.

Breaking point is also known as the fracture point. This is where the material breaks or fails under a tensile loading. It is normally less than the ultimate strength, as many materials undergo some stretching before failure. This demonstrates the **ductility** of the material. Because the material has increased in length, there must be a corresponding decrease in cross-sectional area. Because this area has been reduced, a smaller force is necessary to continue to elongate the material.

Examine the following stress-strain calculation for a 30 mm by 50 mm rectangular bar subjected to a 6 kN axial compressive force as shown in figure 2.3.

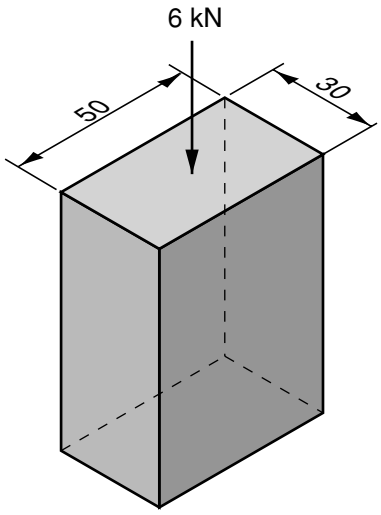


Figure 2.3 Axial compressive load

To determine the stress on the bar you first need to calculate the cross-sectional area.

$$A = 30 \times 50$$

$$= 1\,500 \text{ mm}^2$$

Also, because you are using 1 MPa = 1N/mm^2, you also have to convert the kN to N, that is, 6 kN = 6 x 10^3 N.

$$\sigma = \frac{F}{A}$$

$$= \frac{6 \times 10^3}{1500} \quad \frac{N}{mm^2}$$

$$= 4 \text{ MPa}$$

Examine the following stress-strain calculation for a 20 mm diameter punch which supplies a force of 40 kN. This is sufficient to punch a hole in a 15 mm thick metal plate as shown in figure 2.4.

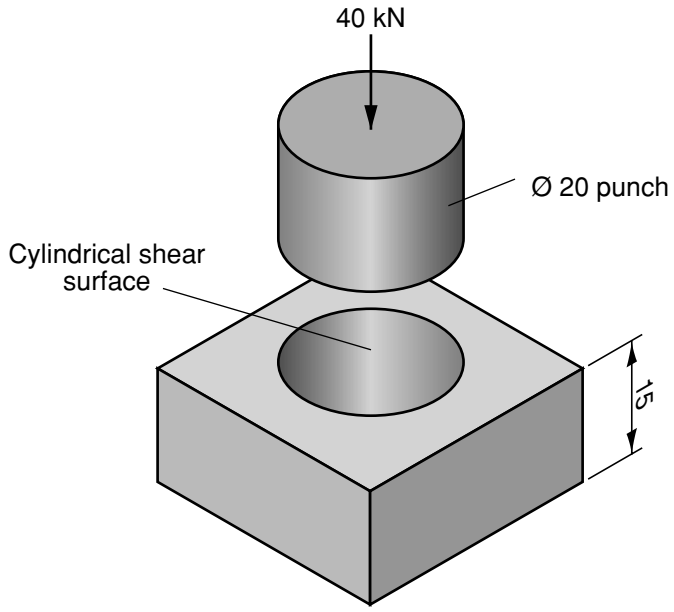


Figure 2.4 Shear stress

There will be two different stresses set up: a compressive stress in the punch and a shear stress in the plate.

The compressive stress is set up by the 40 kN force spread over the cross sectional area.

$$\text{Area of a circle} = \frac{\pi d^2}{4}$$

$$= \frac{\pi(20)^2}{4}$$

$$= 314.2 \text{ mm}^2$$

$$\sigma_c = \frac{F}{A}$$

$$= \frac{40 \times 10^3 \text{N}}{314.2 \text{ mm}^2}$$

$$= 127.3 \text{ MPa}$$

The shear stress in the plate uses the same force, but the area that will fail is parallel to the applied force. This is calculated by multiplying the perimeter (πd for a circle) with the thickness of the plate (t).

$$\text{Equation} = \pi\, d \times t$$

$$= \pi \times 20 \times 15$$

$$= 942.25 \text{ mm}^2$$

$$\sigma_s = \frac{E}{A}$$

$$= \frac{40 \times 10^3}{942.25} \frac{N}{mm^2}$$

$$= 42.4 \text{ MPa}$$



Examine the following stress-strain calculation for a 25 mm bolt which connects a plate to a bracket as shown in figure 2.5.

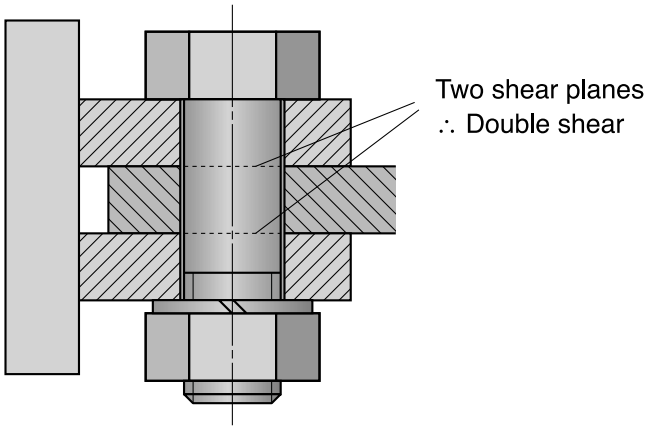


Figure 2.5 Double shear

Given that the factor of safety is 5, calculate the maximum value of the force (F) if the allowable shear stress in the bolt is 60 MPa.

It should be noted that for the bolt to fail, it would have to be sheared along two separate shear planes. This is called 'double shear' and the shear area will be twice the cross-sectional area of the bolt.

$$\text{Shear area} = 2 \times \frac{\pi d^2}{4}$$

$$= \frac{2 \times \pi (25)^2}{4}$$

$$= 981.7 \text{ mm}^2$$

$$\sigma = \frac{F}{A}$$

$$= \sigma \times A$$

$$= 60 \times 981.7$$

$$58902 \text{ N}$$

$$= 58.9 \text{ kN}$$

Factor of safety = (the calculated value is divided by the factor of safety)

$$F = 11.8 \text{ kN}$$



Turn to the exercise section and complete exercise 2.1.



Examine the following stress-strain diagram which demonstrates several properties of various materials.

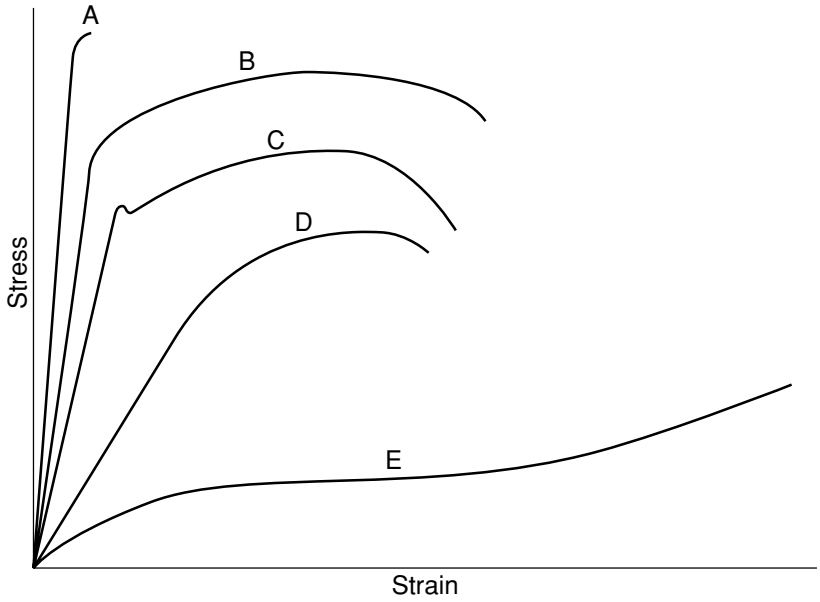


Figure 2.6 Stress-strain diagram for different materials

Complete the following table:

a evaluate the properties of the materials shown in figure 2.6 by placing A, B, C or D in the appropriate row

b explain the reason for your answer in the space provided.

Property	**Material**	**Reason**
Stiffest		
Strongest in tension		
Toughest		
Most ductile		
Most brittle		
Most likely to be a low Carbon steel		
Does not obey Hooke's Law		
Most likely to be a non-ferrous metal		
Most likely to be an organic polymer		

Did you answer?

Stiffest material: A – steepest slope.

Strongest material in tension: A – highest point on the diagram.

Toughest material: B – greatest area under the curve.

Most ductile material: B – longest line after yield.

Most brittle material: A – no elongation.

Material most likely to be low Carbon steel: C – shows a distinct yield point.

Material that does not obey Hooke's Law: E – no straight line section.

Material most likely to be a non-ferrous metal: D – no distinct yield point.

Material most likely to be an organic polymer: E – an elastic curve.

Turn to the exercise section and complete exercise 2.2.

Truss analysis

As you discovered in the previous part, truss design is critical in civil engineering as trusses are often used to support and strengthen structures such as buildings and bridges.

> A truss is a structural frame used in engineering. A truss consists of straight bars known as members, that are connected at each end using a joint. The members are arranged in a triangulated pattern.

Truss analysis is essential in order to calculate the stress and strain that the members in the structure will need to withstand.



Why is it necessary to arrange the members of a truss in a triangulated pattern?

Think back to the activity in part one where you compared the stability of two structures; a square and a triangle.

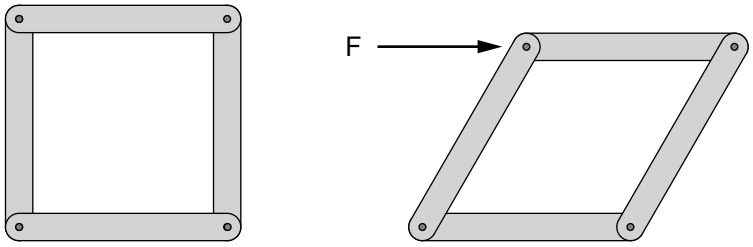


Figure 2.7 Unstable structure shape

A structure of any other configuration other than a triangle can be pushed out of shape, without changing any of the member's lengths.

Triangulated shapes retain their shape. This is why rectangular frames, commonly found in buildings as well as bridges, are always braced with another member to form a triangle.

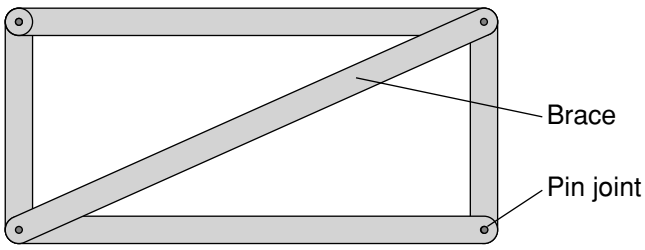


Figure 2.8 Rectangular frame with brace

The members of most trusses used in civil structures, such as bridges and large span roofs, are made from rolled steel sections. Lighter trusses in smaller buildings may be made from solid steel rods, and if weight is a critical factor, then tubular stock may be used.

Trusses are used because they are capable of taking a much greater load than a beam, as well as spanning a much greater distance.

When spanning a distance, the truss must be supported at each end. As the truss will exert a force on these supports, it is necessary that the supports balance this force with a reaction at the support.

Reactions at supports

There are two different types of supports generally found in supporting civil structures:

- pin joint
- roller support.

Pin joint

The **pin joint** locks the truss in position. It does not allow any sideways movement, but may allow some rotation. It may also be referred to as a hinge.

The pin joint is represented by the following graphic.

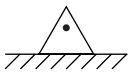


Figure 2.9 Pin joint representation

The reaction at this joint is to balance any vertical loading and any horizontal loading on the truss. The reaction will have an unknown magnitude and direction. This is represented by a wriggly arrow.

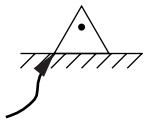


Figure 2.10 Vector with unknown magnitude and direction

For easier calculations, it is generally more convenient to represent this reaction as two components: one vertical and one horizontal. By doing this, you still have two unknowns, but now the unknowns are two magnitudes instead of a magnitude and a direction.

Roller support

The roller support joint is essential in most civil structures, particularly those made from steel, as it is necessary to counteract any expansion or contraction due to temperature changes. It allows unrestricted movement in one direction. The joint may be a smooth-sliding joint or be placed on rollers. The roller support is represented by a graphic shown in figure 2.11.

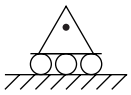


Figure 2.11 Roller joint representation

The reaction is a vector that acts perpendicular to the roller's surface.

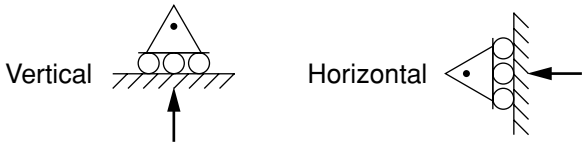


Figure 2.12 Reaction direction at a roller joint



Examine the method used to determine the reactions at the supports for a simple beam to be used to support a walkway leading on to a bridge or connect buildings together shown in figure 2.13.

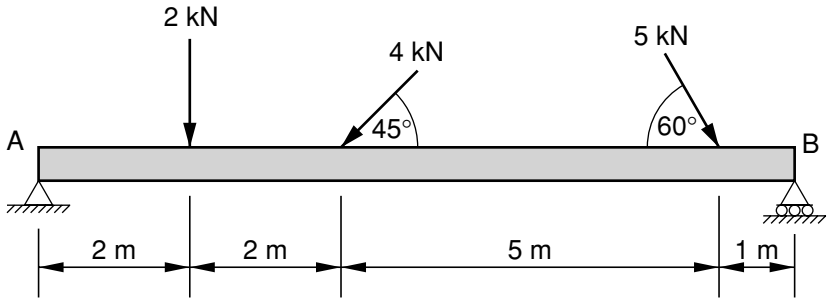


Figure 2.13 Reactions of supports for a simple beam

The first step in solving this problem is to draw a free body diagram of all the forces that are acting on the beam. This should also indicate the reactions at the supports. At the pin joint A, the reaction is shown as a horizontal and a vertical component. At the roller joint B, the reaction will be vertical, as the roller surface is horizontal. The directions (or senses) of the reactions are assumed and may not be correct. These may be corrected during the calculations of the problem.

It is also a good idea to convert any inclined loadings into their horizontal and vertical components.

There are three unknowns (two at the pin joint and one at the roller), so it is necessary to have three equations in order to be able to solve the problem.

From Landscape products, you should recall that there are three equations of equilibrium:

$$\Sigma H = 0$$

$$\Sigma V = 0$$

$$\Sigma M = 0$$

All three equations are used to solve the reactions at the supports.

You would start by taking moments (ΣM) about the pin joint. Two of the unknowns can be eliminated, R_{AH} and R_{AV} because both the components pass through the pin, so they create no moment.

Remember, the moment of a force is found by multiplying the force by the perpendicular distance away from the point to the line of action of the force ($M = F \times d$).

For R_{AH} and $R_{AV,}$ $d = 0$, so the moments created by these forces are also $= 0$.

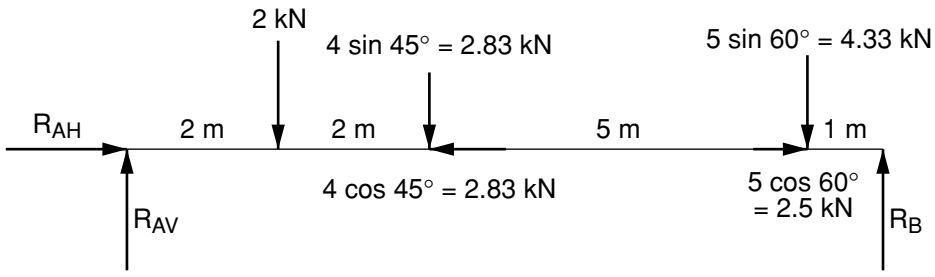


Figure 2.14 Free body diagram of forces acting on beam

For equilibrium

$$\sum M_A = 0$$

$$(R_B \times 10) - (4.33 \times 9) - (2.83 \times 4) - (2 \times 2) = 0$$

$$10R_B = 39 + 11.32 + 4$$

$$R_B = 5.43\text{kN} \uparrow$$

To find the horizontal component at A, R_{AH}

$$+\rightarrow \sum H = 0$$

$$R_{AH} - 2.83 + 2.5 = 0$$

$$\therefore R_{AV} = 0.33 \text{ kN} \rightarrow$$

To find the vertical component at A, R_{AV}

$$+\uparrow \sum V = 0$$

$$R_{AV} - 2 - 2.83 - 4.33 + 5.4 = 0$$

$$\therefore R_{AV} = 3.73 \text{ kN} \uparrow$$

Now the components are converted back to a single force.

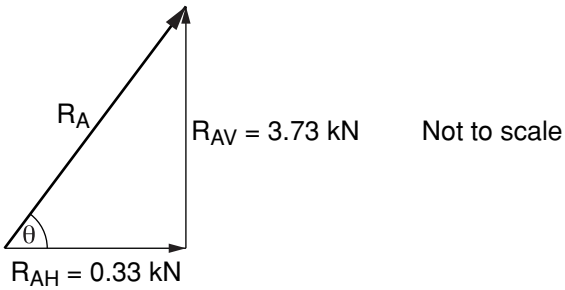


Figure 2.15 Force diagram for reaction at A

$$R_A^2 = (3.73)^2 + (0.33)^2$$

$$R_A = \sqrt{14}$$

$$= 3.7 \text{ kN}$$

$$\text{Tan } \theta = 3.73/\ 0.33$$

$$\theta = \tan^{-1} 11.30$$

$$= 85°$$

$$\text{Reaction A} = 3.7 \text{ kN} \angle 85°$$

$$\text{Reaction B} = 5.4 \text{ kN} \uparrow$$

Internal forces (stresses)

Any loading placed on a truss is transferred to the supports via the members of the truss. This will induce internal forces, called stresses, in these members.

If the loading is placed at the joints of the truss, then the forces in the members will be **axial forces**. These will either be tensile (if they are trying to stretch or extend the member) or compressive (if they are trying to shorten or compress the member). It is important for the engineer to know the magnitude of these forces so they can design a suitably-sized member to withstand these forces.

Tensile stress

If the external force tends to stretch the member, the force is called a tensile force and the member is said to be in tension.

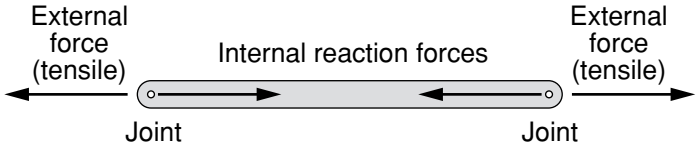


Figure 2.16 Tensile stress

The internal force is a reaction force and is equal and opposite to the external force in order to balance it. Note that it tends to act away from the joint.

Compressive stress

If the external force tends to shorten the member, the force is called a compressive force and the member is said to be in compression.

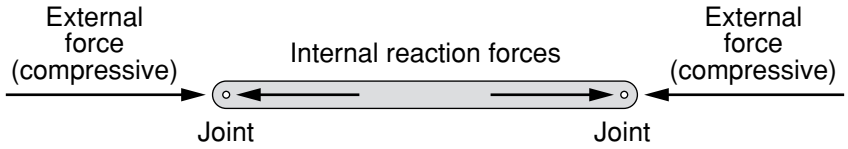


Figure 2.17 Compressive stress

The internal force is a reaction force, and is equal and opposite to the external force in order to balance it. Note that it tends to act towards the joint.

Method of joints

A convenient method to analyse the forces in the members of a truss, is to investigate each joint separately. If the whole truss is in **equilibrium**, then each joint will also be in equilibrium.

As all the forces (both internal and external) act through the joint, the force-system can be considered as a concurrent system. The **equilibrant force** or forces can be found by using a graphical representation of equilibrium. You should recall this from your work in Landscape products.



Examine the method used to determine the magnitude and nature of the forces in each of the members in a **roller joint** of a truss with a vertical reaction of 40 kN acting vertically upwards as shown in figure 2.18.

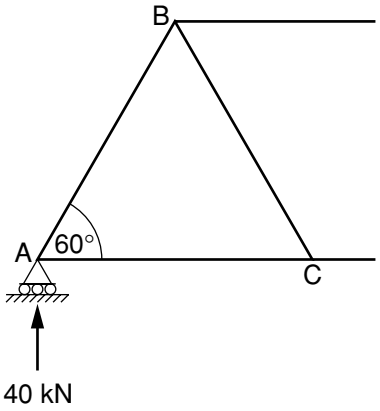


Figure 2.18 Roller joint of a truss

Consider joint A.

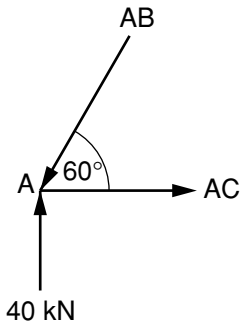


Figure 2.19 Free body diagram joint A

Since the forces act along the member axes, we can represent all the forces at the joint by drawing them with the same relationship as the members (figure 2.19). Therefore, the force AC acts horizontally and at right angles to the support reaction, and the force AB acts at 60°to AC. AC is likely to be a tensile force because it is at the bottom of the truss. AB must have a component acting downwards to balance the reaction force acting upwards.

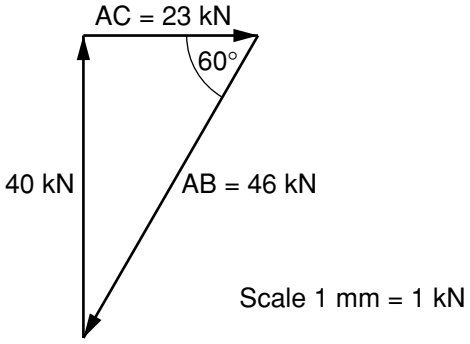


Figure 2.20 Force diagram

If we rearrange the forces keeping, their directions the same, but placing them one after the other, 'head to tail', then we can determine the two unknown forces either graphically (by drawing to a scale) or mathematically.

Mathematical solution to force diagram:

$$\tan 60° = \frac{40}{AC}$$

$$\therefore \ AC = \frac{40}{\tan 60°}$$

$$= 23 \text{ kN}$$

$$\sin 60° = \frac{40}{AB}$$

$$AB = \frac{40}{\sin 60°}$$

$$= 46 \text{ kN}$$

When the arrows are transferred back to the joint, AC is acting away from the joint, so is considered to be in tension. In contrast AB is acting towards the joint, so is considered to be in compression.

Examine the method used to determine the forces acting in each of the members when a typically configured Warren truss used in the construction of a bridge is loaded as shown in figure 2.21.

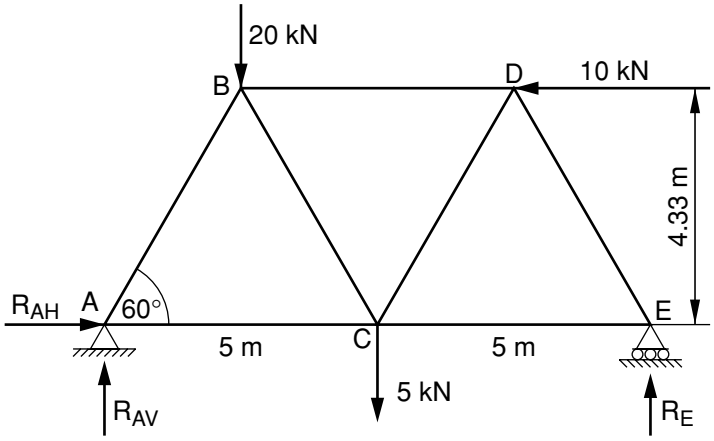


Figure 2.21 Warren truss

The reactions at the supports would be found first.

Why is it generally more convenient to add a vertical component and a horizontal component for the reaction at the pin joint when a mathematical solution is attempted?

Because moment calculations require a perpendicular distance.

For equilibrium:

$$\circlearrowleft^{+}\Sigma M_A = 0$$

$$(R_E \times 10) + (10 \times 4.33) - (20 \times 2.5) - (5 \times 5) = 0$$

$$10\,R_E = 50 + 25 - 43.3$$

$$R_E = \frac{31.7}{10}$$

$$= 3.17 \text{ kN} \uparrow$$

$$^{+}\uparrow \Sigma V = 0$$

$$R_{AV} - 20 - 5 + 3.17 = 0$$

$$R_{AV} = 21.83 \text{ kN} \uparrow$$

$$^{+}\rightarrow \Sigma H = 0$$

$$R_{AH} - 10 = 0$$

$$R_{AH} = 10 \text{ kN} \rightarrow$$

Joint A

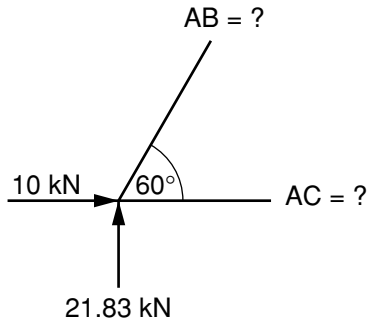
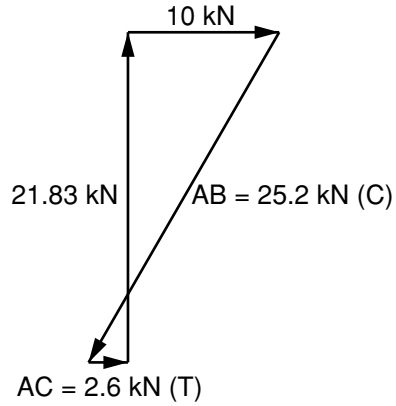


Figure 2.22 Free body diagram joint A

Graphical solution:

Force diagram drawn to scale 1 mm = 0.5 kN



Remember, draw each force, one after the other, 'head to tail,' with the right directions and to scale, and you will be able to measure off the two unknown forces.

Figure 2.23 Force diagram joint A

Analytical solution:

$$^{+}\uparrow \Sigma V = 0$$

$$- AB \sin 60° + 21.83 = 0$$

$$AB = \frac{21.83}{\sin 60°}$$

$$= 25.2 \text{ kN (C)}$$

$$^{+}\rightarrow \Sigma H = 0$$

$$10 - 25.2 \cos 60° + AC = 0$$

$$AC = 12.6 - 10$$

$$= 2.6 \text{ kN (T)}$$

Joint B

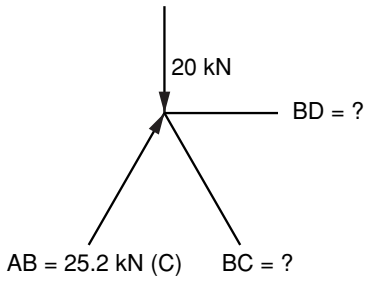
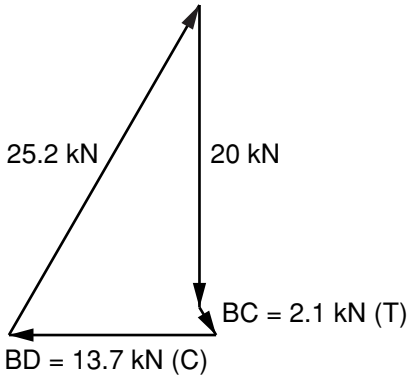


Figure 2.24 Free body diagram joint B

The next joint that is analysed can only have two unknowns. From joint A, it was found that AB = 25.2 kN in compression. This force is now applied to joint B. Note that the arrowhead aims in the opposite direction compare to joint A.

As the member is in compression, the internal force must act in the direction of the joint being considered.

Force diagram:



(Scale 1 mm = 0.5 kN)

Figure 2.25 Force diagram joint B

BC and BD are scaled from this diagram, or can be determined mathematically.

The next joint that is analysed can only have two unknowns. This will be joint C.

Joint C

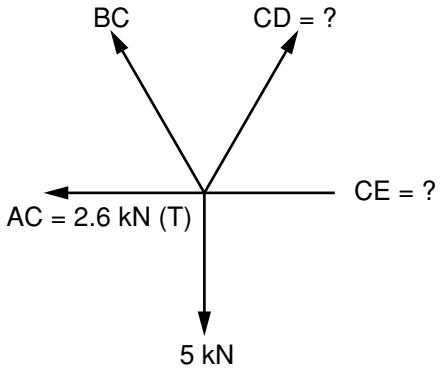
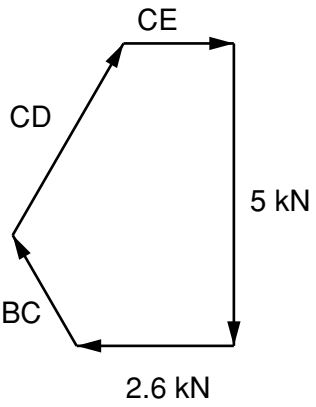


Figure 2.26 Free body diagram joint C

Force diagram:



(Scale 4 mm = 0.5 kN)

Figure 2.27 Force diagram joint C

CE and CD are scaled from this diagram.

The next joint that is analysed can only have two unknowns. This will be joint D.

Joint D

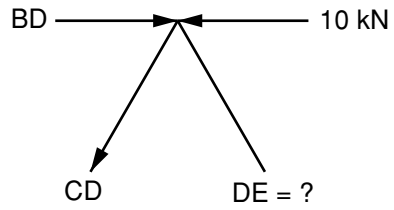


Figure 2.28 Free body diagram joint D

Force diagram:

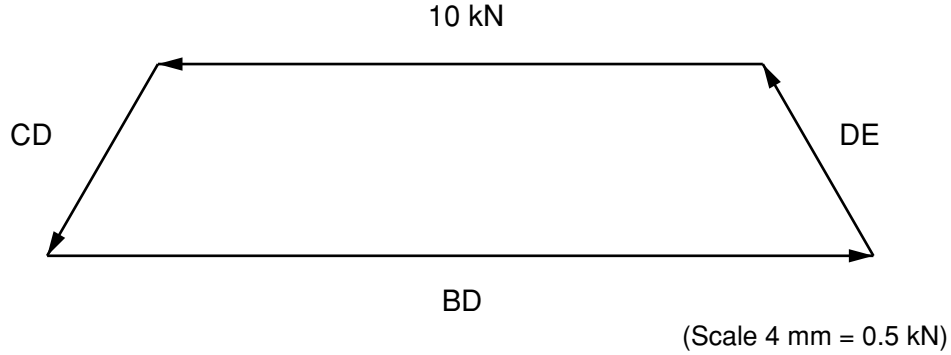


Figure 2.29 Force diagram joint D

DE is scaled from this diagram.

Turn to the exercise section and complete exercise 2.3.

Method of sections

The **method of sections** is another method of analysing the internal forces in a truss. This method is used when not all the internal forces in the members are required. You do not have to analyse the whole truss, just the particular member required.

A Howe truss shown in figure 2.30 is commonly used as a roofing truss.

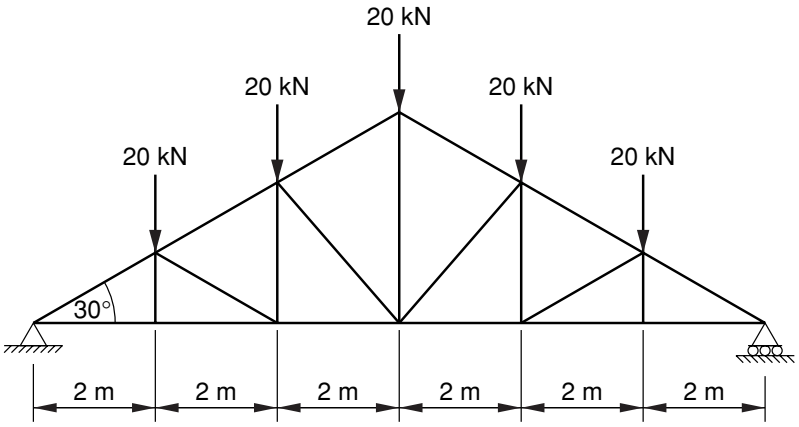


Figure 2.30 Howe roofing truss

The method of sections uses a cutting plane that passes through three members of the truss. One of these members must be the member being analysed. The reactions at the supports are calculated if required.

Only one part of the truss is now considered. For this part of the truss to remain in equilibrium, it is necessary to apply three forces (X, Y and Z) to the three cut members. These forces will act along the axes of the members and are normally assumed to be tensile forces.

To find the magnitude of the force in a cut member, take moments about the point where the other two cut members intersect. This will eliminate these two members from the calculation, as both pass through the point, so have no turning effect about that point. Only external forces acting on the section of the truss being considered are used in the calculations.



The loading of the roof truss in the above example is symmetric.

State how this affects the reactions.

Did you answer?

The reactions will be equal.



Examine the Howe truss with cutting plane drawn in, joints numbered, assumed nature of cut members and reactions as shown in figure 2.31.

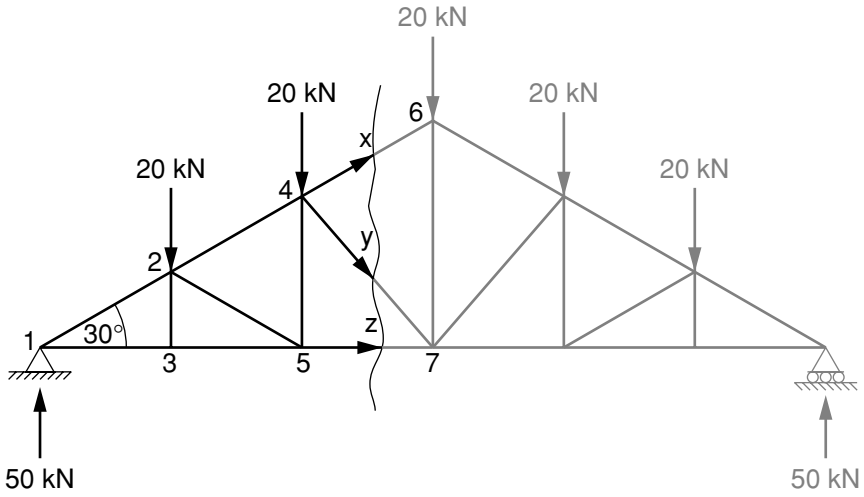


Figure 2.31 Howe truss

By symmetry, the reactions at each support will equal 50 kN ↑

Consider the left hand side of the cutting plane.

To find X

Take moments where Y and Z intersect (joint 7)

$$\oplus \Sigma M_7 = 0$$

$$(20 \times 2) + (20 \times 4) - (X \sin 30° \times 6) - (50 \times 6) = 0$$

$$\therefore X = \frac{-300 + 40 + 80}{6 \sin 30°}$$

$$= -60 \text{ kN}$$

A negative answer means the assumption of tension was incorrect = –60 kN (compression)

Note: The force X is resolved into two components as shown in figure 2.32.

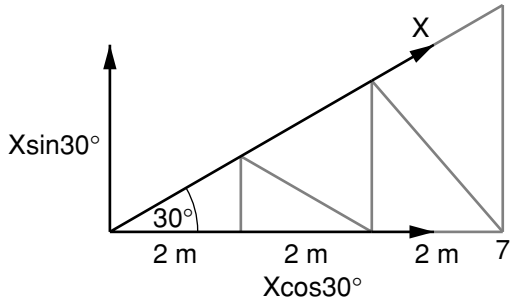


Figure 2.32 The components of force X

The Xcos30° component passes through joint 7 and therefore does not produce a moment. However, the Xsin30° component acts at d = 6 m from joint 7, hence Xsin30° x 6.

To find Y

Take moments where X and Z intersect (joint 1)

$$\circlearrowleft \Sigma M_1 = 0$$

$$-(Y \sin 49° \times 6) - (20 \times 4) - (20 \times 2) = 0$$

$$Y = \frac{-80 - 40}{6 \sin 49°}$$

A negative indicates that the original assumption of tension was incorrect, = -26.5 kN

$\therefore$ Y will be in compression = 26.5 kN (compression)

Note: You will need to calculate some angles to determine the Y components. See figure 2.33.

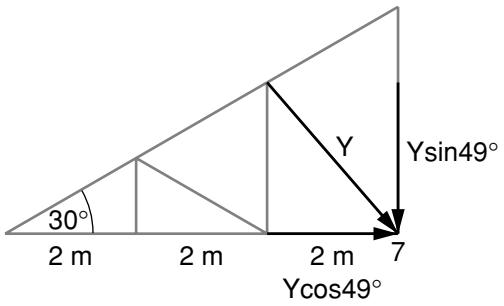


Figure 2.33 The components of force Y

Since the line of the Ycos49° component force passes through joint 1, it produces no moment about joint 1. However, the component Ysin49° acts at 6 m from joint 1, hence Ysin49° x 6.

To find Z

Take moments where X and Y intersect (joint 4)

$$\circlearrowleft \Sigma M_4 = 0$$

$$(Z \times 2.3) + (20 \times 2) - (50 \times 4) = 0$$

$$Z = \frac{200 - 40}{2.3}$$

A positive indicates that the original assumption of tension was correct. = 6967 kN (tension)

Examine the method used to find the force in the top member 2, 4 and the inclined member 3, 4 for a particular loading where the reaction at the roller support was 150 kN as shown in figure 2.32.

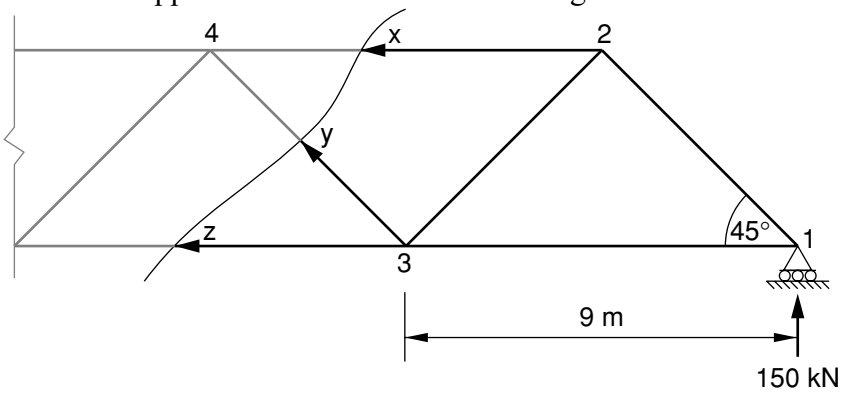


Figure 2.34 Parallel truss with cutting plane in position

To find X (top member 2, 4)

$$\begin{aligned} \oplus \Sigma M_3 &= 0 \\ (X \times 4.5) + (150 \times 9) &= 0 \\ \therefore X &= \frac{-150 \times 9}{4.5} \\ &= -300 \text{ kN} \\ &= 300 \text{ kN (compression)} \end{aligned}$$

To find Y (sloping member 3, 4)

As X and Z are parallel, they do not intersect. To solve this you can take moments anywhere along the bottom of the truss (to eliminate Z) other than joint 3. The previously calculated value of X must be used in this calculation.

A better method is to calculate the sum of the vertical forces. This will eliminate both X and Z as they have no vertical components.

$$\begin{aligned} {}^{+}\uparrow \Sigma V &= 0 \\ Y \sin 45° + 150 &= 0 \\ Y &= \frac{-150}{\sin 45°} \\ &= -212 \text{ kN} \\ &= 212 \text{ kN (compression)} \end{aligned}$$

Turn to the exercise section and complete exercise 2.4.

Beams

Shear force

The forces investigated so far have been axial forces. These forces can either extend (if it's a tensile force) or shorten the member (if it's a compressive force). Some buckling could also occur if the member is a long, slender member.

If the force is not an axial force (it acts at an angle to the axis), then the force may tend to break the member by a shearing action. This will be particularly important to civil structures as the loading will more than likely be at an angle to the axis. This could be anything from the beam's self weight, to the load it has been designed to carry.

A shear force causes one part of a material to slide over the adjacent part of the material.



Picture a pair of scissors cutting paper. This is done by a shearing action where the blade of the scissors causes one part of the paper to slide over another part of the paper. If the paper is not strong enough to resist this action, it is said to fail in shear.

The shear force at any particular point is calculated by adding all the force components acting perpendicular to the member's axis to one side of that point. This is similar to the method of sections where you considered one side or the other.

If the right side tends to move down relative to the left side, it is considered to have positive shear. Figure 2.35 illustrates the sign convention used in constructing shear force diagrams.

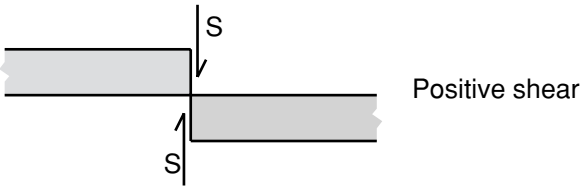


Figure 2.35 Diagrammatic representation of positive shear force

A shear force diagram is constructed by plotting the shear force values for all points along the beam.

Examine the method used to draw a shear force diagram for a simple 10 m beam loaded with a 10 kN force and a 20 kN force, each 3 m from either end of the beam, as shown in figure 2.34.

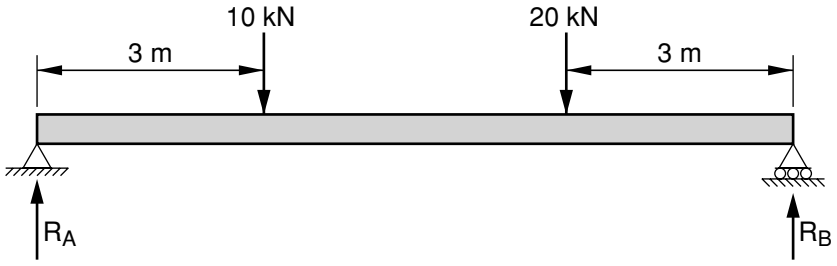


Figure 2.36 Simple beam loaded with shear forces

First, you would find the reactions.

$$\oplus \Sigma M_A = 0$$

$$(R_B \times 10) - (10 \times 3) - (20 \times 7) = 0$$

$$\therefore R_B = \frac{30 + 140}{10}$$

$$= 17 \text{ kN} \uparrow$$

$$+\uparrow \Sigma V = 0$$

$$R_A - 10 - 20 + 17 = 0$$

$$R_A = 13 \text{ kN} \uparrow$$

To find the shear force just to the right of A, consider just the very left part of the beam as shown in figure 2.35, and calculate the sum of the vertical forces.



Figure 2.37 Shear force at A

$$+\uparrow \Sigma V = 0$$

$$13 - S = 0$$

$$\therefore S = 13 \text{ kN}$$

Now consider a 3 m length of the beam from the left support to just beyond the 10 kN force, as shown in figure 2.36

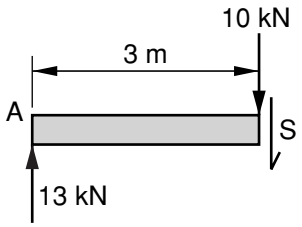


Figure 2.38 Shear force just to the right of 10 kN force

Taking the sum of the vertical forces,

$$+\uparrow \Sigma V = 0$$

$$13 - 10 - S = 0$$

$$\therefore S = 3 \text{ kN}$$

Moving across to the 20 kN load, we have:

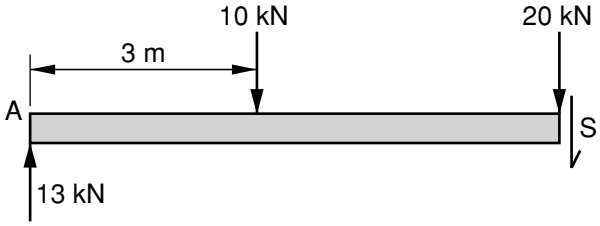


Figure 2.39 Shear force just to the right of 20 kN force

$$+\uparrow \Sigma V = 0$$

$$13 - 10 - 20 - S = 0$$

$$\therefore S = -17 \text{ kN}$$

The shear force diagram (SFD) for the beam is now drawn to scale. From the diagram a value for the shear force can be determined at any point along the beam.

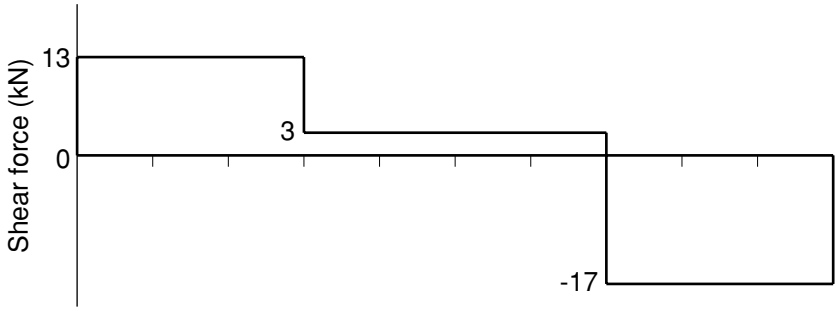


Figure 2.40 Shear force diagram for the beam

Note that the shear force does not change between concentrated point loads, and this is represented by a horizontal line.

An easy method to construct a shear force diagram is called ‘follow the force rule’. The shear force will remain constant until it reaches a concentrated point load. It will then change by the amount of the force in the same direction as the force.



Examine the method used to determine the distribution of shear forces and bending moments along **bearers** which sits on piers, neglecting the mass of the bearer, for an elevated timber floor supported by joists.

The floor is supported by floor joists which run at right angles across the bearers and are placed so that their centres are 450 mm apart. Floor loads are transmitted via these joists to the bearer.

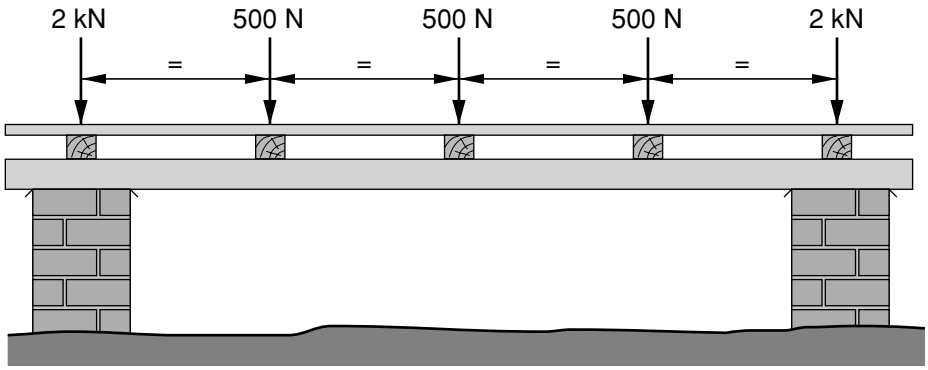


Figure 2.41 Cross-section of an elevated timber floor

It is necessary to find the reactions at the pier supports.

By symmetry the reactions will be equal, and share the load equally, that is, 2.75 kN each, vertically up.

The shear force diagram is most easily constructed by using the 'follow the force rule'. For a **concentrated load**, no changes occur between these loads. When a load is reached, the shear force diagram will change by the same amount as the load in the direction of the load.

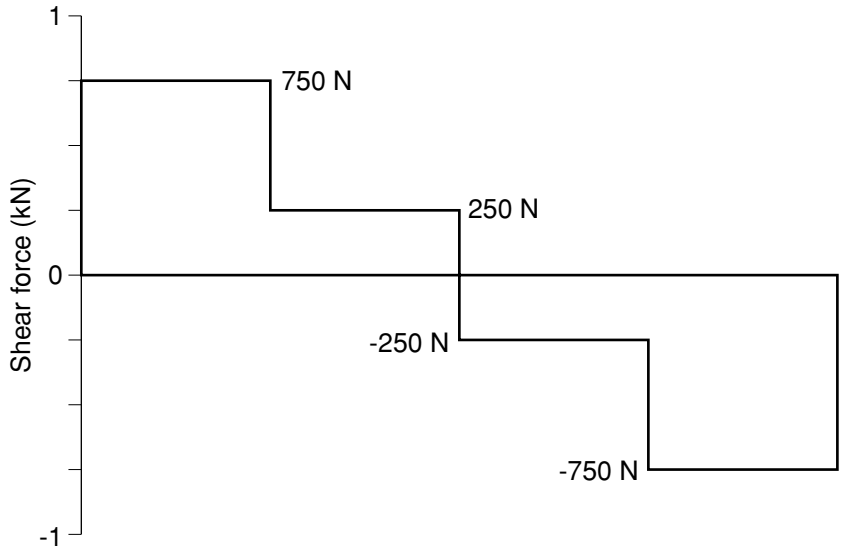


Figure 2.42 Shear force diagram for elevated floor

Note at each pier (end support) there is a 2 kN force down and a 2.75 kN (reaction) force up. This results in a 0.75 kN up force.

Bending moment

Beams are commonly used in buildings to support loads over a variety of spans in preference to a triangulated truss. Trusses tend to use up too much space.

Obviously if the beam is a structural member, the engineer doesn't want it to fail due to shear forces. The beam will have been designed so as not to fail due to shear. However, the loads will also induce some bending of the beam over the span. The beam will have to be designed by the engineer to withstand any **bending moment**. The maximum working load would be determined, generally with a factor of safety built in, and the beam would have to be strong enough so as not to fail due to bending.

As with shear forces, the bending moment is calculated by adding all the bending moments to one side of any particular point. It is the amount of moment that needs to be added to the beam to balance all the bending moments to one side. This is similar to the method of sections used in truss analysis.

As with shear forces, a sign convention is used for bending moments. A beam that bends down in the middle when a load is applied is regarded as being in **positive bending**.

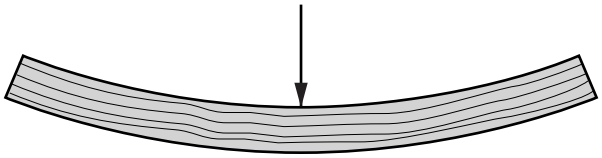


Figure 2.43 Positive moment convention – concave upwards



Examine the method used to draw the bending moment diagram for a simple 10 metre beam loaded with a 10 kN force and a 20 kN force, 3 metres from each end of the beam, as shown in figure 2.42.

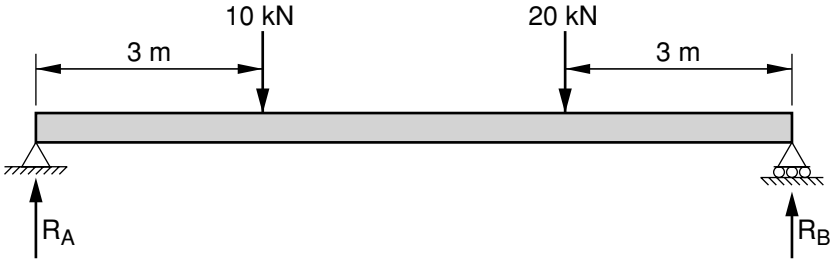


Figure 2.44 Simple beam loaded with forces creating bending

First, you would find the reactions.

$$\begin{aligned} \oplus \Sigma M_A &= 0 \\ (R_B \times 10) - (10 \times 3) - (20 \times 7) &= 0 \\ \therefore R_B &= \frac{30 + 140}{10} \\ &= 17 \text{ kN} \uparrow \\ +\uparrow \Sigma V &= 0 \\ R_A - 10 - 20 + 17 &= 0 \\ R_A &= 13 \text{ kN} \uparrow \end{aligned}$$

Bending moment just to the right of A to 10 kN force.

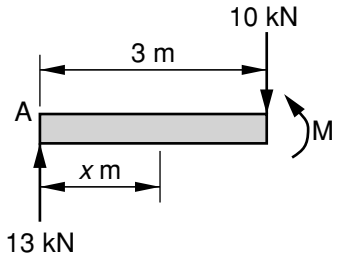


Figure 2.45 Bending moment between A and 10 kN force

$0 < x < 3$ m

Take moments about the cut point at x.

$$\oplus \Sigma M_x = 0$$

$$-(13 \times x) + M = 0$$

$$\therefore M = 13x \text{ kNm}$$

This is the equation of a straight line of the form $y = mx + b$. It has a slope of 13 and a y intercept of 0.

At $x = 3$

$$BM = 13 \times 3$$

$$= 39 \text{ kNm}$$

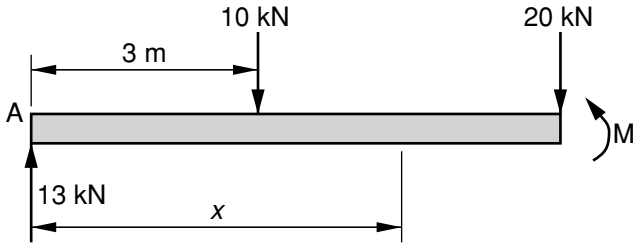


Figure 2.46 Bending moment between 10 kN and 20 kN force

$3 < x < 7$ m

Take moments about the cut point, x.

$$\circlearrowleft \Sigma M_x = 0$$

$$-(13 \times x) + (10 \times (x - 3)) + M = 0$$

$$\therefore M = 13x - 10x + 30$$

$$= 3x + 30$$

At $x = 7$

$$M = 21 + 30$$

$$= 51 \text{ kNm}$$

The bending moment diagram for the beam is now drawn to scale. From the diagram a value for the bending moment can be determined at any point along the beam.

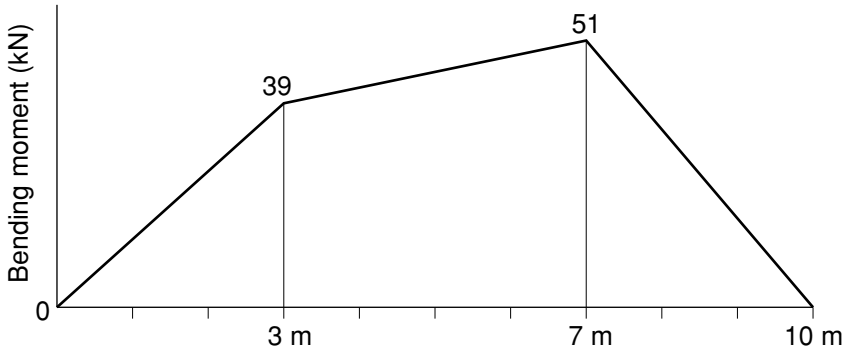


Figure 2.47 Bending moment diagram for the beam

The bending moments between concentrated point loads are represented by an inclined line.

It is only necessary to calculate values at the point loads, then join them with a straight line.

Alternative method

An alternate method to find the values is to calculate the values of the areas from the shear force diagram.

Using the shear force diagram in figure 2.38, the shear force area up to 3 metres is equal to 13 x 3 = 39 kNm. This is the same as the value calculated by first principles.

The total area up to 7 metres is equal to (13 x 3) + (3 x 4) = 51 kNm.

The positive shear will produce a positive bending moment.

Uniformly distributed loads

When constructing shear force and bending moment diagrams, the engineer should also consider the self-weight of the beam.

This is generally regarded as a **uniformly distributed load** if the beam has a uniform cross-sectional area.

The uniformly distributed loads will have the effect of continually changing the shear force, along the length of the beam. Similarly, the bending moment diagram will be affected by the corresponding moment supplied by the shear force.

A uniformly distributed load can be represented by a load per unit length (N/m), as shown graphically in figure 2.46.

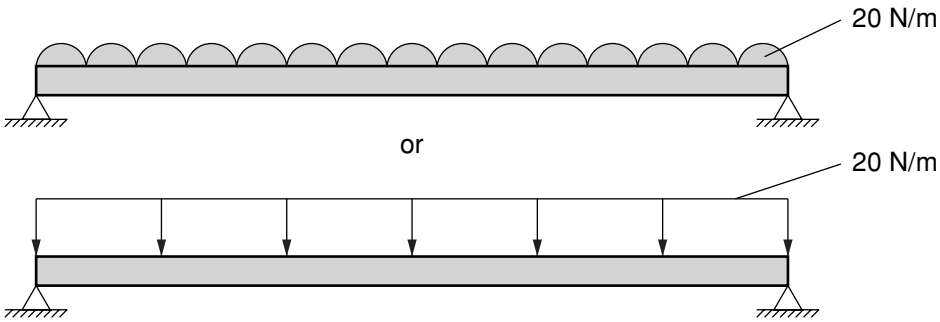


Figure 2.48 Alternate ways of representing uniformly distributed loads

To develop a shear force and bending moment diagram for uniformly loaded beams, the same principles are applied.

The beam is cut at a series of points and the shear force and bending moments are calculated.

Consider the beam in figure 2.48. If the beam was 10 m long, with a distributed load of 20 N/m, the total load on the beam would be 200 N.

$$20 \times 10 = 200\ \text{N}\downarrow$$

Therefore the reactive forces at the supports would be 100 N↑

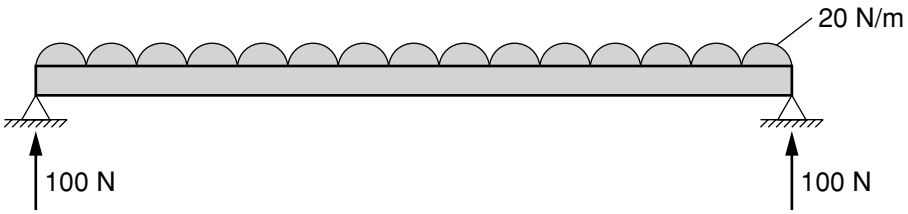


Figure 2.49 Beam with a distributed load

To calculate the shear force and bending moment at any point, the beam is sectioned.

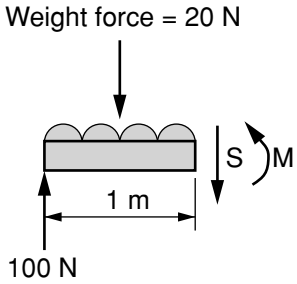


Figure 2.50 Section 1

$$\text{weight force} = 1 \times 20$$
$$= 20\ \text{N}$$

Shear Force

$$+\uparrow\uparrow\Sigma Fv = 0$$
$$100 - 20 - S = 0$$
$$S = 80\ \text{N}\downarrow\downarrow$$

Bending Moment

$$+\circlearrowleft\Sigma M = 0$$
$$-100 \times 1 + 20 \text{ x } 0.5 + M = 0$$
$$-100 + 10 + M = 0$$
$$M = 90\ \text{Nm}$$

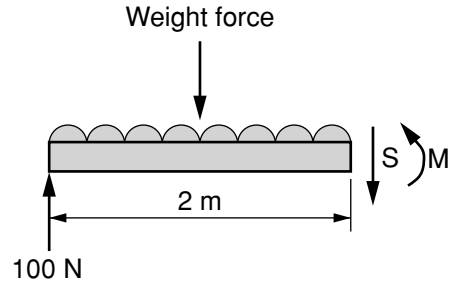


Figure 2.51 Section 2

$$\text{weight force} = 2 \times 20$$

$$= 40\ \text{N}\downarrow$$

Shear Force

$$+\uparrow \Sigma Fv = 0$$

$$100 - 40 - S =$$

$$S = 60\ \text{N}\downarrow$$

Bending Moment

$$+\circlearrowleft \Sigma M = 0$$

$$-100 \times 2 + 40 \times 1 + M = 0$$

$$-200 + 40 + M =$$

$$M = 160\ \text{Nm}$$

As you can see as we move across the beam (as the beam sections get larger). The shear force decreases and the bending moment increases. This trend will continue for the shear force calculations. However, this will not be observed when calculating the bending moments.



Determine where the bending moment will be maximised.

_____

Did you answer?

The maximum bending will occur in the middle of the beam.

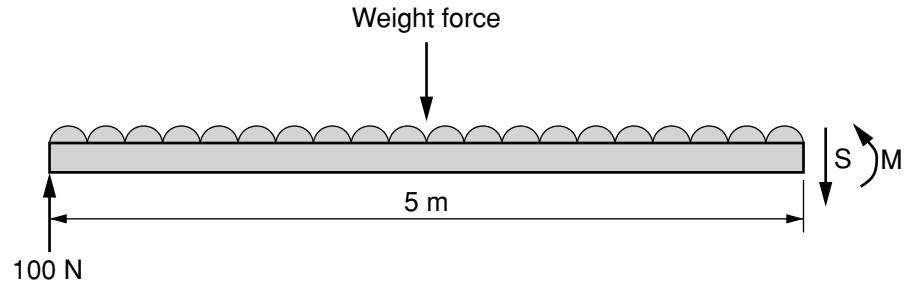


Figure 2.52 Section 3

$$\text{weight force} = 5 \times 20$$

$$= 100\ \text{N}\downarrow$$

$$+\circlearrowleft \Sigma M = 0$$

$$-100 \times 5 + 100 \text{ x } 2.5 + M =$$

$$-500 + 250 + M =$$

$$M = 250\ \text{Nm}$$

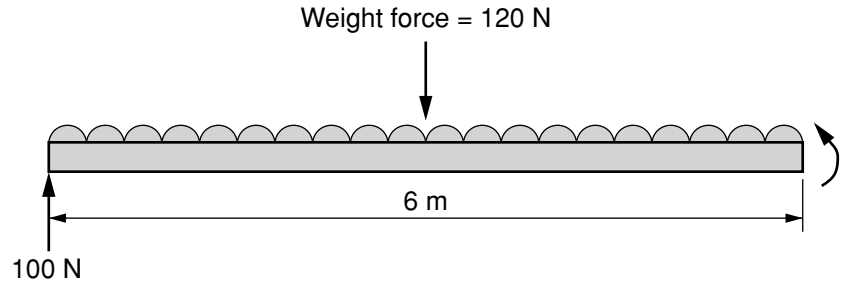


Figure 2.53 Section 4

$$\text{weight force} = 5 \times 20$$

$$= 100\ \text{N}\downarrow$$

$$+\circlearrowleft \Sigma M = 0$$

$$-100 \times 6 + 120 \text{ x } 3 + M = 0$$

$$-600 + 360 + M =$$

$$M = 240\ \text{Nm}$$

Draw the shear force and bending moment diagrams for the beam shown in figure 2.48.

Did you answer?

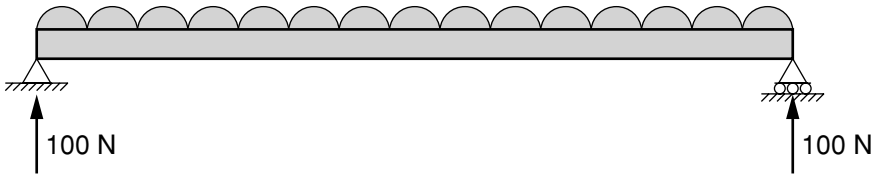


Figure 2.54 Shear force diagram

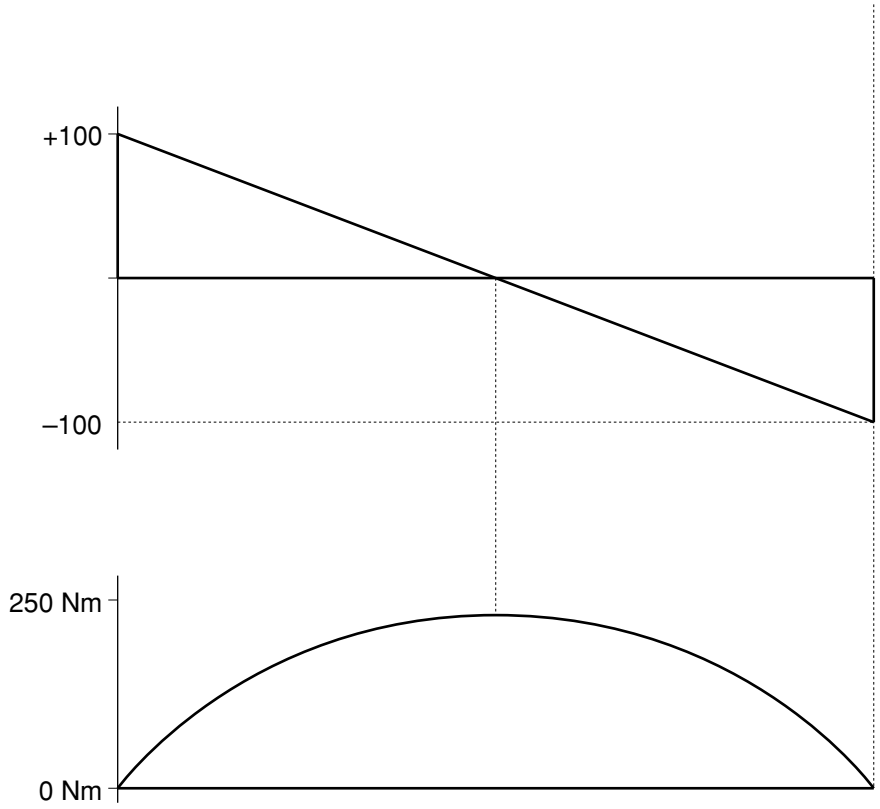


Figure 2.55 Bending diagram

Turn to the exercise section and complete exercise 2.5.

Bending stress

When a beam bends, it experiences both shear forces and bending moments within. These internal stresses balance the external shear forces and bending moments in a similar way as tensile and compressive stresses balance tensile and compressive external axial forces.

As the beam bends, the concave side of the beam will compress, and therefore compressive stresses will be set up within that part of the beam. Similarly, the convex side of the beam will stretch, so tensile stresses will be set up within that part of the beam. These stresses will be greatest on the outer fibres of the beam.

Somewhere in between there exists a plane where the internal fibres are not subjected to either tensile or compressive stresses, that is zero stress. This plane is called the neutral axis.

To calculate the bending stress at any section in a beam, the following equation can be used.

$$\sigma = \frac{My}{I}$$

Where σ = bending stress (either tensile or compressive) (MPa)

M = bending moment at the fibre being considered (Nmm)

y = distance from the neutral axis (mm)

I = **second moment of area** of the cross section (mm^4)

The second moment of area (I) will be given as either a formula for a given cross section or as numerical value.

To find the maximum value of bending stress, the bending moment (M) must be a maximum, and the distance from the neutral axis (y) must also be a maximum. The maximum bending moment occurs when the shear force is equal to zero. This can be read from the shear force diagram.

If the beam is loaded such that the shear force is equal to zero for a part length of the beam, then pure bending will exist.

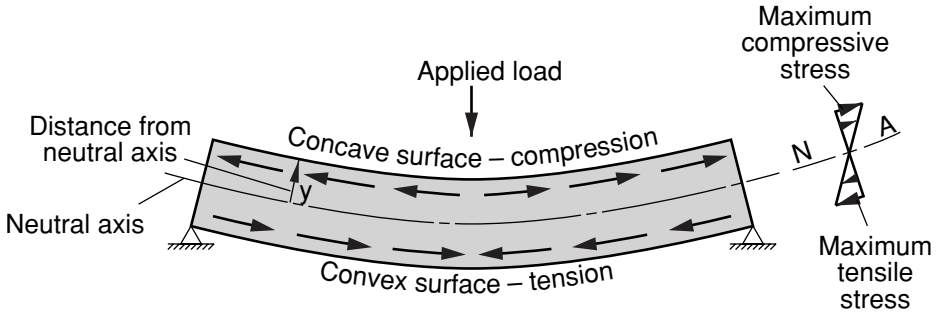


Figure 2.56 Bending stresses in a beam

Examine the method used to determine the maximum bending stress in a beam.

The beam, 50 mm x 75 mm, is supported at each end. Two 2 kN loads act at a point 2 metres from each end.

A shear force diagram, is used to determine the maximum bending moment and the position on the beam where this exists.

Determine the maximum bending stress in the beam given that the second moment of area (I) for the beam positioned on its edge is 1.76×10^6 mm^4.

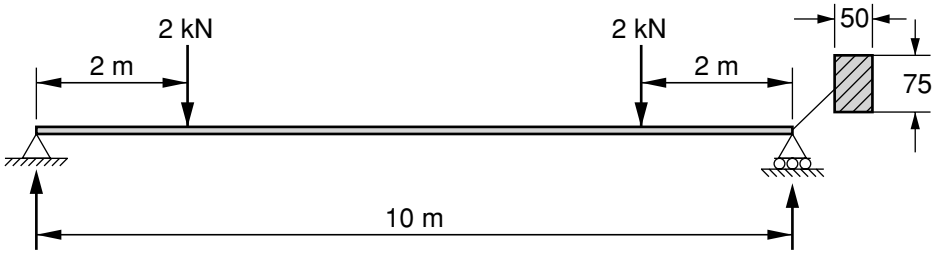


Figure 2.57 Rectangular beam loaded symmetrically

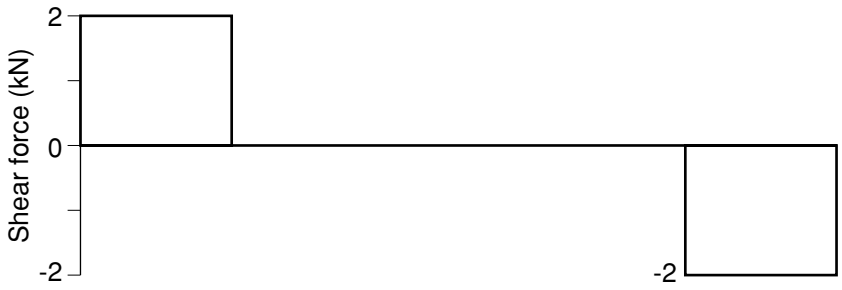


Figure 2.58 Shear force diagram

The maximum bending will occur when the shear force = 0.

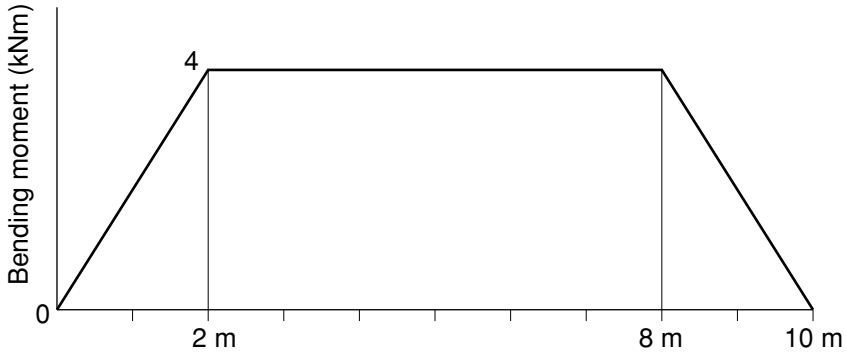


Figure 2.59 Bending moment diagram

The middle of the beam experiences pure bending (which is a maximum when the shear force is equal to zero).

Maximum bending stress occurs when the bending moment is a maximum.

$$\sigma = \frac{My}{I}$$

$$= \frac{4 \times 10^6 \times 37.5}{1.76 \times 10^6}$$

$$= 85.2 \text{ MPa}$$

$M = 4$ kNm

$= 4 \times 10^3 \times 10^3$ Nmm

$y = \frac{75}{2}$ mm

$= 37.5$ mm

$I = 1.76 \times 10^6$ mm^4

Turn to the exercise section and complete exercises 2.6 and 2.7.

Crack theory

Metals have a theoretical strength based on the knowledge of inter-atomic forces. The real strength is only a fraction of the theoretical strength. This is similar for non-metallic materials. The reason for this is explained by the presence of imperfections in the materials.

In 1920, A.A.Griffiths advanced the theory that in any brittle non-metallic material such as **glass**, ceramics etc, minute cracks or **fissures** present. These will act as **stress raisers** by concentrating stresses at the tips of the crack. Once an applied stress reaches a certain value, the cracks will **propagate**.

For small elliptical cracks (of length 2c) the stress applied perpendicular to the major axis of the crack can be found from:

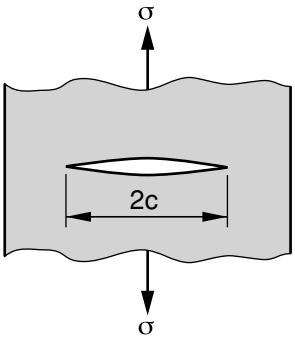


Figure 2.60 Stress on a small elliptical crack

$$\sigma^2 = \frac{2\gamma E}{\pi c}$$

where E = Young's modulus for the material

γ = surface energy per unit area

c = half the length of the longest axis

The surface area possesses energy in the form of surface tension. This can be seen in mercury which tends to become spherical because a sphere contains the maximum volume with a minimum surface area. This minimizes the surface energy. To produce a new crack, new free surfaces must be generated and energy must be supplied to achieve this.



A good example to illustrate this concept is a balloon. When the balloon is deflated and a pin is stuck into the balloon, a hole is produced. It does not result in the propagation of a crack. However, if the balloon is inflated, it will explode with a bang. This is because the released energy is greater than that required to create new surfaces of the small crack.

A common method used in engineering to eliminate failure due to cracking is to drill a hole at the tip of the crack, or just in front of an advancing crack as occurs in plate-glass windows. This increases the surface area of the crack and would then require greater energy to open up the crack any further. It also takes away the stress concentrator at the end of the crack.

Metals have greater crack toughness than the more brittle ceramics because being more ductile, plastic deformation is more likely to occur at the tip of the crack. For plastic deformation to occur, energy is required, and thus a much higher energy is required to propagate cracks in ductile materials as compared to brittle materials.



Turn to the exercise section and complete exercise 2.8.

This part has investigated several mechanical analysis techniques.

You have examined tension testing and the plotting of a load/extension graph. This data is converted into a stress/strain diagram. From this diagram, the engineer can derive many engineering properties of the materials.

You have examined truss analysis, the engineer's way of investigating the internal forces created in the structural members of a truss. You have explored ways of analysing shear forces and bending moments. And finally, you have learned how the real strength of materials is reduced by the presence of surface imperfections such as cracks, and how the propagation of cracks can be prevented.

Exercises

Exercise 2.1

A bolt is used to connect two members of a bridge structure. The shear stress in the bolt is not to exceed 160 MPa and the maximum axial load to be applied to the rod coupling is 30 kN.

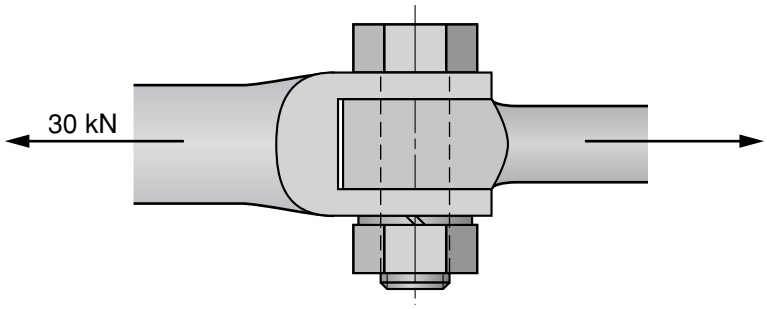


Figure 2.61 Bolt connecting two members

a Mathematically calculate the minimum diameter of the bolt.

b State the diameter of the bolt that should be used if it is necessary to include a factor of safety of 4 in the calculations.

Exercise 2.2

Tensile stress-strain curves for four different materials A, B, C and D are shown below. They demonstrate several properties of the different materials.

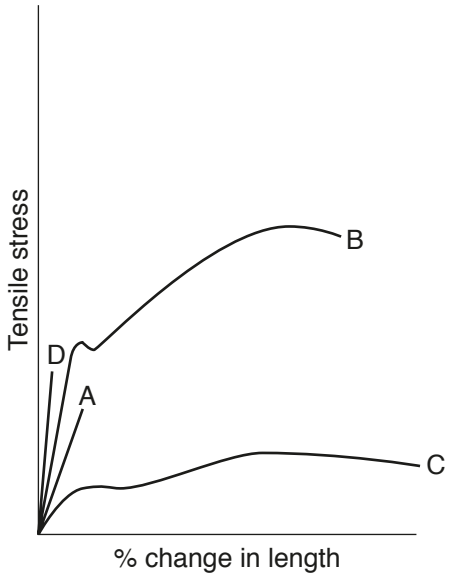


Figure 2.62 Tensile stress-strain diagrams

Evaluate the importance of understanding the properties of materials by using the information from the stress-strain diagram given.

With reference to the above results, answer the following questions by placing A, B, C or D in the appropriate spaces. Justify your answer with a reason for your choice.

Stiffest material _____

Toughest material _____

Most ductile material _____

Most brittle material _____

Most likely to be cast iron _____

Most likely to be a ceramic _____

Exercise 2.3

A small truss is often used in buildings to support the roof.

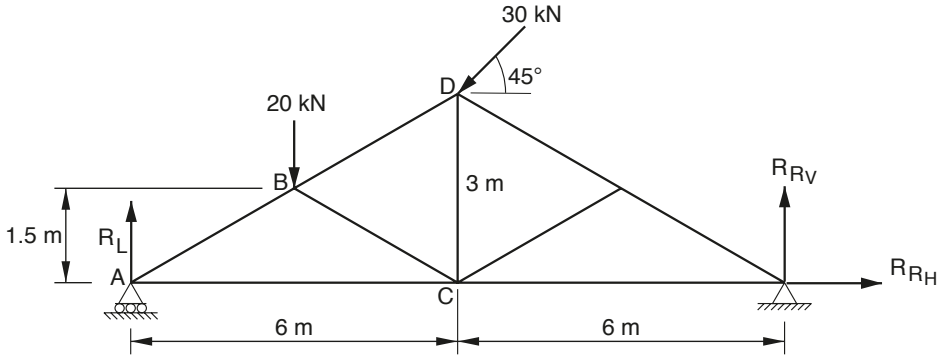


Figure 2.63 Small truss with various loads

a Find the reactions at the supports (Reaction Left R_L, Reaction Right Horizontal R_{RH} and Reaction Right Vertical R_{RV}).

b Determine the internal forces in members AB and AC using a mathematical technique.

c Verify your answers by applying a graphical method to solve the internal forces in members AB and AC.

d In the design of the truss, it is necessary to calculate the size of each of the members depending on the size of the forces in these members.

Determine the minimum cross-sectional area (CSA) for bar AB if the allowable stress in compression is 120 MPa.

Exercise 2.4

Small steel bridges are often constructed using a Warren truss. The truss may be above or below the roadway. It is necessary to calculate the internal forces in all members for different loadings so that the engineer can use the correct cross-sectional area to carry these stresses.

Using the mathematical method of sections, determine the magnitude (size) and nature (tension or compression) of the force in members CE and DE.

The truss is loaded, as shown in figure 2.57.

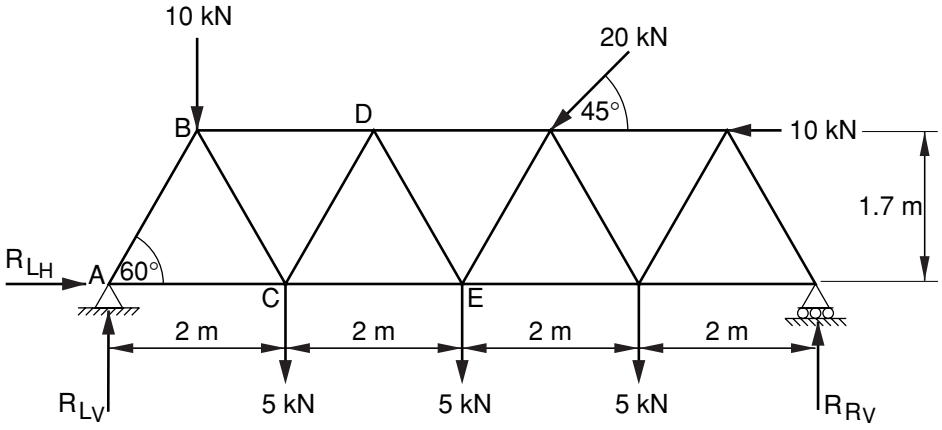


Figure 2.64 Warren truss with various loads

a calculate the reactions

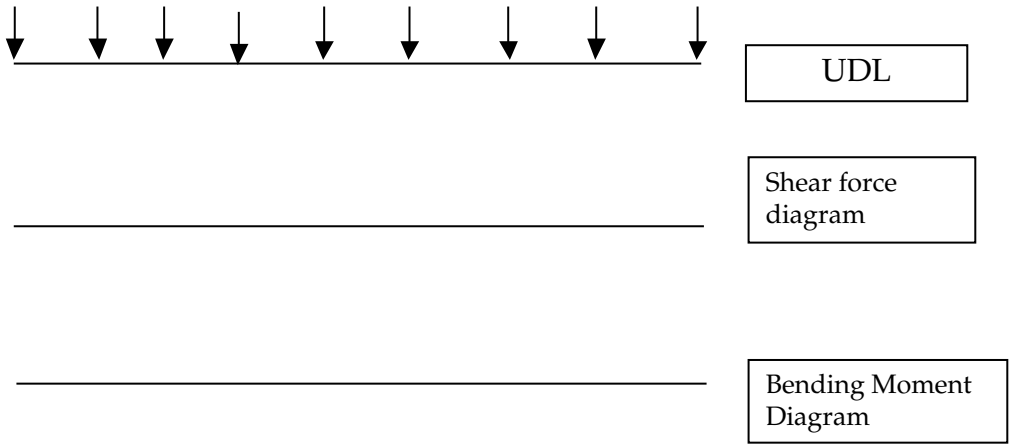
b force in CE and DE

Exercise 2.5

In the design of beams, it is necessary to include in the calculations the self-weight of the beam.

For a simple beam of the same dimensions over its entire length, draw a typical shear force diagram and a typical bending moment diagram. Do not include calculations in your description.

Indicate the convention used to show a uniformly distributed load.



Exercise 2.6

A rectangular concrete beam could be used as support for walls in a building. These walls will transmit loads (possibly from the roof or the floors above the walls) into the beam.

The concrete beam has a cross-section of 500 mm x 150 mm and is placed on its edge on two supports. It is subjected to loads from the walls as shown.

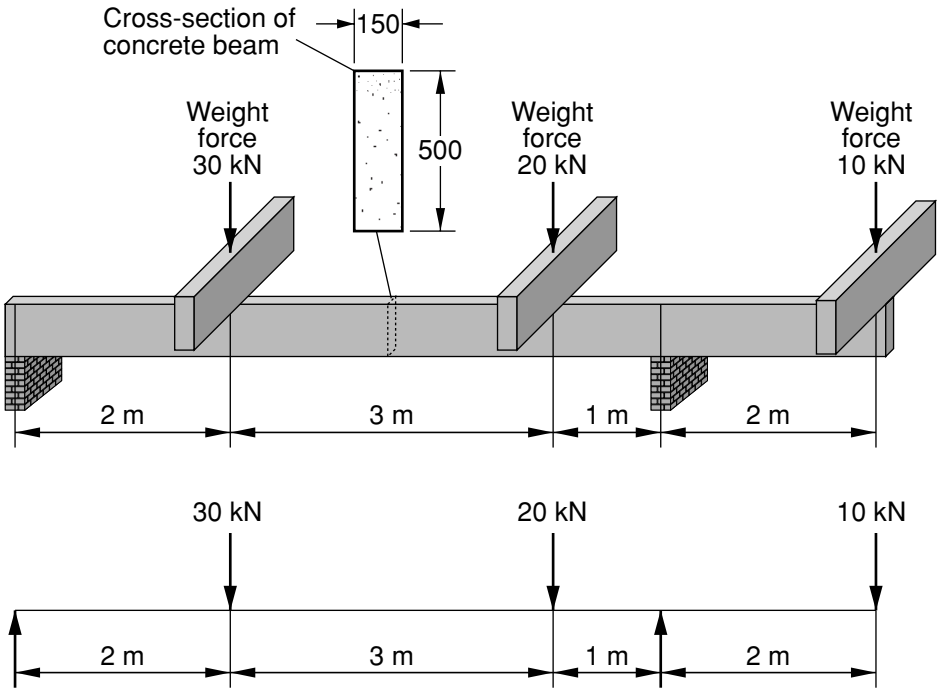


Figure 2.65 Simply supported concrete beam and free body diagram

Using the information:

a determine the reaction at each of the supports

b draw the shear force diagram

c draw the bending moment diagram

d determine the maximum bending stress in the beam if the second moment of area, $I = 1.56 \times 10^9$ mm^4.

Exercise 2.6 cont.

Exercise 2.7

During the construction of a civil structure, a plank supported as a simply-supported beam is used to provide access by builders over an excavation. The plank is 5 m x 300 mm x 50 mm and two builders of masses 90 kg and 100 kg stand on the plank as shown.

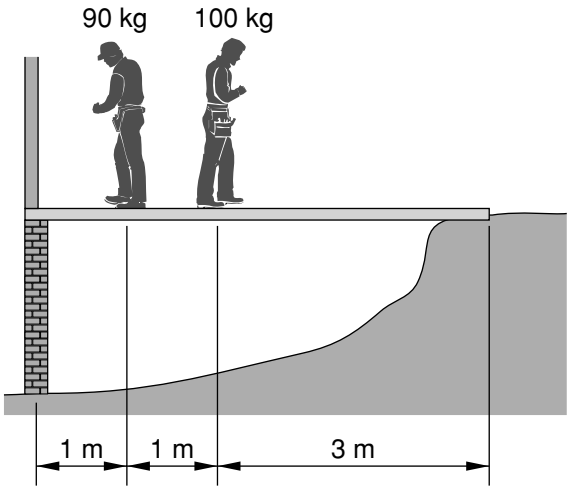


Figure 2.66 Workmen on a plank

Using the information:

a determine the reaction at each of the supports

b draw the shear force diagram

c draw the bending moment diagram

d determine the maximum bending stress in the plank if the second moment of area, $I = 3.125 \times 10^6$ mm^4.

Exercise 2.7 cont.

Exercise 2.8

Select the alternative a, b, c, or d, that best completes the statement.
Circle the letter.

1 A steel structural member of a bridge has a cross-section as shown in the diagram.

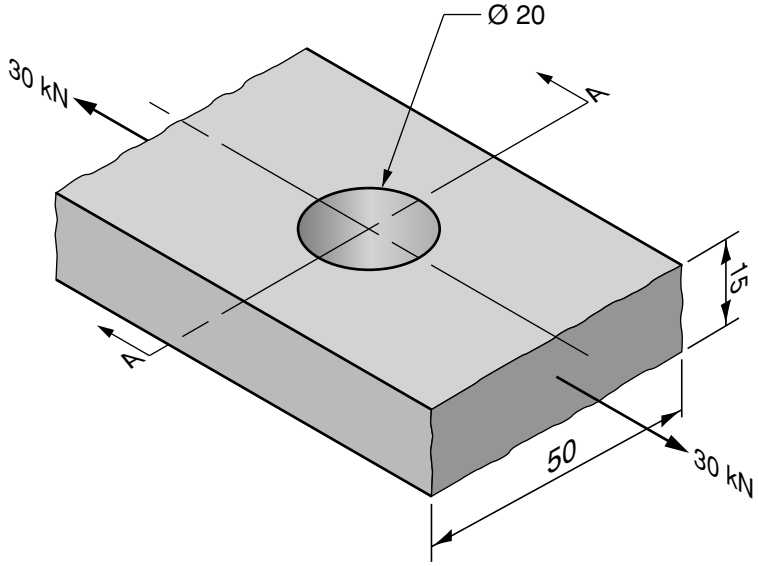


Figure 2.67 Tensile load applied to a steel section

A tensile load is applied along the axis of the member. To determine the stress in the member at section AA, the area used in the calculations will be:

a $50 \times 15\ mm^2$

b $30 \times 15\ mm^2$

c $20 \times 15\ mm^2$

d $\pi(20)^2 \div 4\ mm^2$.

2 The joint shown has a reaction force of 50 kN acting vertically upwards.

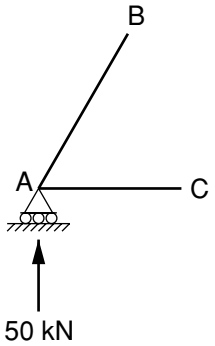


Figure 2.68 Pin joint with a reaction produces stress in the members

The members AB and AC would have some stresses (internal forces).

These stresses would be:

a AB and AC – both tensile stresses

b AB and AC – both compressive stresses

c AB – tensile stress, AC – compressive stress

d AB – compressive stress, AC – tensile stress.

3 The proof stress is:

a used to prove that a material won't fail for a particular loading.

b used only on elastic materials that will demonstrate Hooke's Law

c the stress necessary to produce some previously specified amount of permanent set (common measures being 0.1% or 0.2% of the original gauge length)

d a non–destructive test that demonstrates the material's strength.

4 One of the following statements about Young's modulus is incorrect. Circle the letter of the statement that is incorrect.

a Young's modulus is also known as the Modulus of Elasticity and is a measure of the slope of the straight-line portion of a stress-strain diagram up to the proportional limit.

b Young's modulus is also known as the Modulus of Stiffness and is a measure of the stiffness of a material.

c Young's modulus can be calculated by dividing any value of stress less than the proportional limit by the corresponding value of strain in the material.

d Young's modulus is a measure of the area under a stress-strain diagram up to the proportional limit.

5 The following stress-strain diagram shows the graph for some different materials.

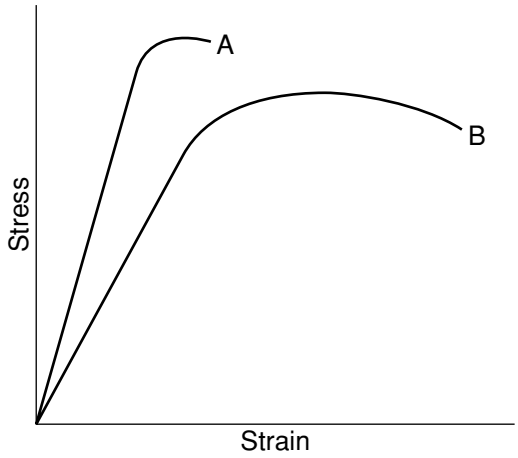


Figure 2.69 Stress – strain diagram for different materials

a material A is stiffer, stronger and tougher than material B

b material B is stiffer, stronger and tougher than material A

c material A is stiffer, stronger but not as tough as material B

d material A is stiffer, tougher but not as strong as material B.

6 The method of Sections is:

a used to examine the cross sectional shapes of members in a truss

b used to determine the true shapes and angles of an inclined member of a truss

c a method of truss analysis where a section is passed through a truss and both sides of the section are analysed to check for balance

d a method of truss analysis to determine internal forces in a particular member.

7 Shear Force and Bending Moments:

a are equal to the reactions of a beam at the supports

b are internal reactions to external forces applied along a structural member

c change along the length of the beam

d are connected by the relationship that when the bending moment is zero, the shear force will be a maximum.

8 Point loads on a beam induce bending stresses in the beam:

a the maximum compressive stress and the maximum tensile stress are of equal magnitude and are on the outer surfaces of the beam

b the cross sectional shape of the beam has no bearing on the magnitude of the bending stresses

c there are no bending stresses on the neutral axis, even though the beam is curved under the loading

d the bending stress in the beam is calculated by dividing the point load by the cross sectional area.

9 A Uniformly Distributed Load (UDL):

a will produce the same shape Shear Force and Bending Moment diagrams as several concentrated point loads placed along the beam

b can change in magnitude uniformly along the beam

c has no effect on calculations on a simple beam

d has the same magnitude acting at all points along the beam.



Exercise cover sheet

Exercises 2.1 to 2.8 Name: _____

Check!

Have you have completed the following exercises?

- ❒ Exercise 2.1
- ❒ Exercise 2.2
- ❒ Exercise 2.3
- ❒ Exercise 2.4
- ❒ Exercise 2.5
- ❒ Exercise 2.6
- ❒ Exercise 2.7
- ❒ Exercise 2.8

Locate and complete any outstanding exercises then attach your responses to this sheet.

If you study Stage 6 Engineering Studies through a Distance Education Centre/School (DEC) you will need to return the exercise sheet and your responses as you complete each part of the module.

If you study Stage 6 Engineering Studies through the OTEN Open Learning Program (OLP) refer to the Learner's Guide to determine which exercises you need to return to your teacher along with the Mark Record Slip.

Progress check

In this part you examined mathematical and graphical methods used to solve engineering problems relating to civil structures.



Take a few moments to reflect on your learning then tick the box which best represents your level of achievement.

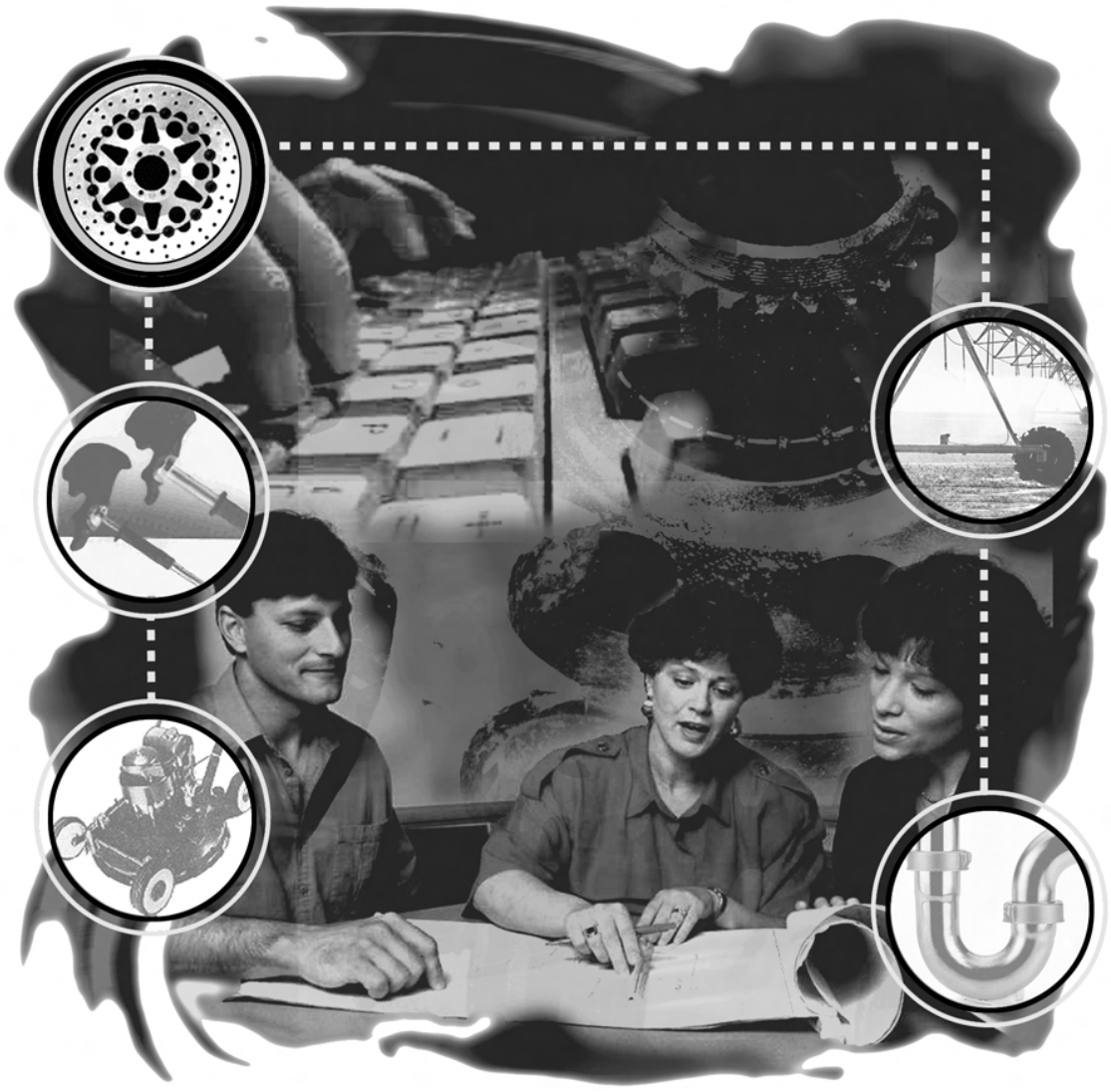
☑ **Agree – well done** ☑ **Disagree – revise your work** ☑ **Uncertain – contact your teacher**	**Agree**	**Disagree**	**Uncertain**
I have learnt about: • Engineering mechanics and hydraulics as applied to civil structures: – stress and strain, truss analysis, bending stress induced by point loads only, uniformly distributed loads, crack theory, crack formation and growth.			
I have learnt to: • apply mathematical and/or graphical methods to solve problems related to the design of civil structures • evaluate the importance of the stress/strain diagram in understanding the properties of materials • calculate the bending stress on simply supported beams involving vertical point loads only • describe the effect of uniformly distributed loads on a simple beam, without calculations • examine how failure due to cracking can be repaired or eliminated.			

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Refer to <http://www.boardofstudies.nsw.edu.au> for original and current documents.

In the next part you will examine the materials and structure/property relationships and preservation issues as they relate to civil structures.

Part 3: Civil structures – materials





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Introduction

Engineers are particularly interested in the development, properties and availability of materials and how this affects the design of civil structures. In this part you will examine specific materials, investigate structure/property relationships, conduct simple experiments and outline preservation issues as they relate to civil structures.

What will you learn?

You will learn about:

- specialised testing of engineering materials and/or systems
- the structure/property relationships and applications of different ceramic materials
- different composite materials
- the mechanism of corrosion and how it affects different materials
- the recyclability of materials.

You will learn to:

- describe basic testing conducted on civil structures
- examine the structure, properties, uses and appropriateness of materials used in civil structures
- make appropriate choices of materials and processes for use in civil structures
- explain the special properties of composite materials
- experiment with simple pre-tensioned and post-tensioned structures
- evaluate the significance of corrosion problems in civil structures
- describe methods for recycling materials when civil structures are replaced.

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Refer to <http//www.boardofstudies.nsw.edu.au> for original and current documents.

Materials analysis

In this section you will examine a number of engineering materials with special emphasis on testing, corrosion and recycling as they relate to the construction and support of civil structures, specifically bridges.

Case study – bridge design in NSW

Bridge design in NSW reflects the changes in materials and construction in the field of civil engineering. The following case study examines the features and materials in prominent bridges around the state. All of the bridges featured are still in use.

Arch bridges

Stone – Stone Quarry Bridge

The Stone Quarry Bridge at Picton was built in 1860 from sandstone quarried 200 m downstream. This stone arch bridge still carries the main rail line between Sydney and Melbourne.

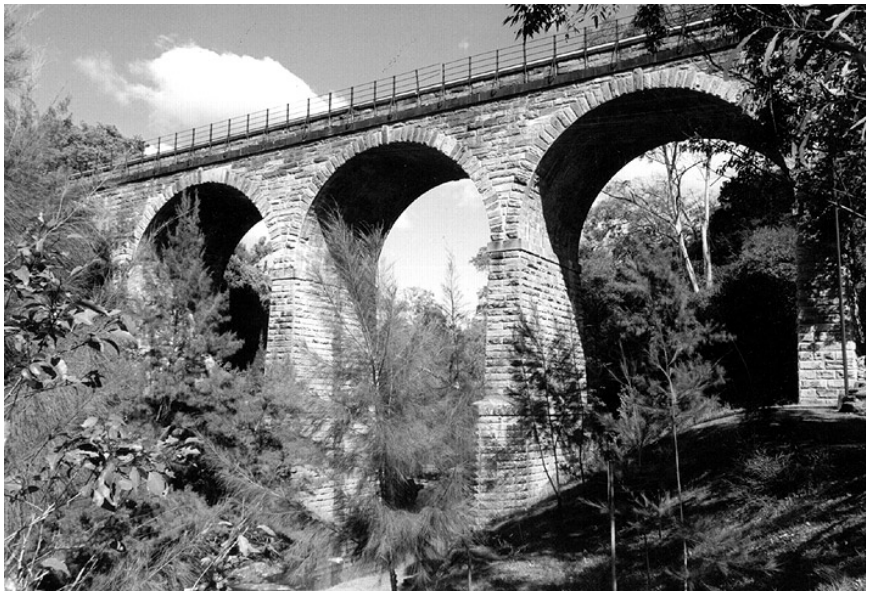


Figure 3.1 Sandstone arch bridge

Steel – Sydney Harbour Bridge

The Sydney Harbour Bridge was opened in 1932. This engineering masterpiece contains 52 800 t of steel in the arch and approach spans, held together by around six million rivets. The arch is supported on four steel bearing pins each 4.2 m long and 368 mm in diameter.
The pylons, which are decorative, contain 17 000 cubic metres of granite. A total of 95 000 cubic metres of concrete was used in the bridge.



Figure 3.2 Steel arch bridge

Reinforced concrete – Gladesville Bridge

The Gladesville Bridge was built during the 1960s. This bridge supports the roadway on a concrete arch. This arch was built from pre-cast segments that were assembled on supports, or falsework, and post-tensioned into place. The bridge deck or roadway was formed up and cast in position.

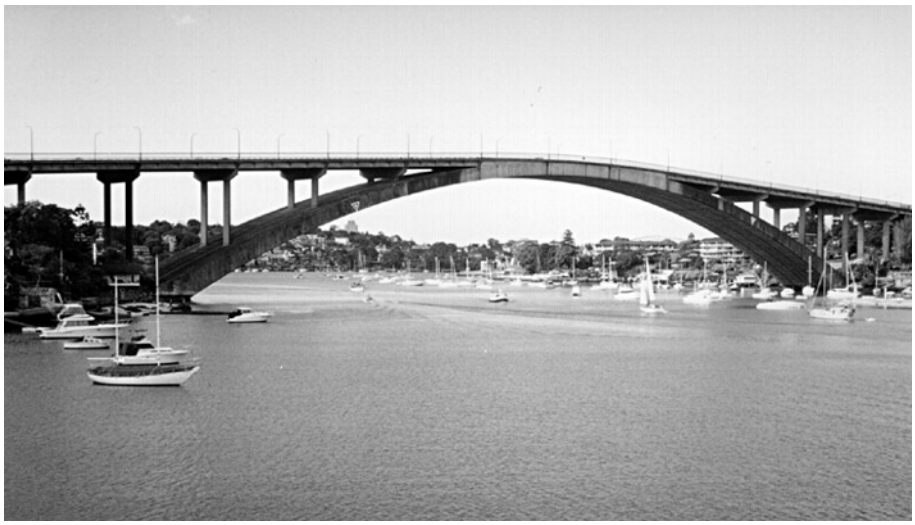


Figure 3.3 Concrete arch bridge

Truss bridges

Timber – Victoria Bridge

Built in 1897, the Victoria Bridge at Picton uses sandstone blocks for foundations and local Australian hardwood for the piers and truss. The structure is a McDonald truss assembled with steel plates and bolts. Long steel bolts, in tension, are used to hang the roadway from the top of the trusses.

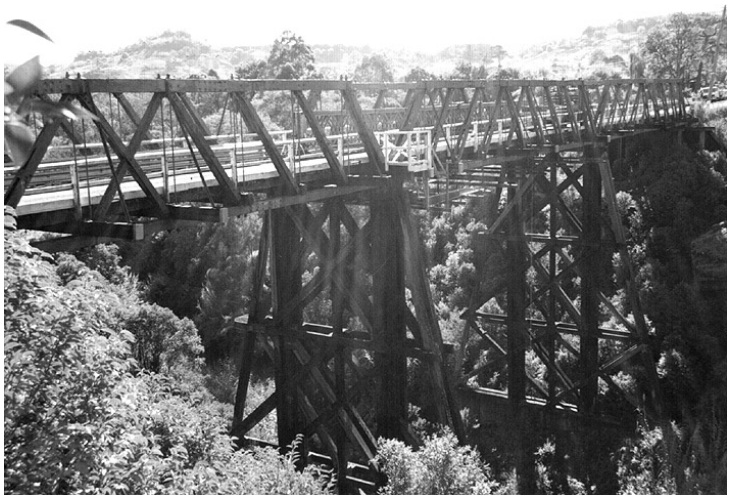


Figure 3.4 Timber trussed bridge

Steel – Georges River Bridge

The Georges River Bridge, at Tom's Ugly Point is a steel truss bridge fabricated from hot-rolled plate steel riveted together and supported on concrete piers. The spans are longer than for the Victoria Bridge due to the greater strength of steel. Because of the position of the roadway, this is known as a through truss.



Figure 3.5 Steel truss bridge

Similar bridges, such as the Ryde bridge across the Parramatta River, incorporate a centre lift section to allow tall ships to pass.

Suspension bridges

Timber and steel – Maldon Bridge

Built in 1903, the original timber structure of the Maldon Bridge was severely damaged by fire in 1939. The cables were not damaged but there was some distortion to the steel trusses. Steel towers, supported on the original concrete abutments, were built to replace the timber towers. The cables in this bridge anchor up in the sandstone cliffs instead of down under the roadway as is usually the case.

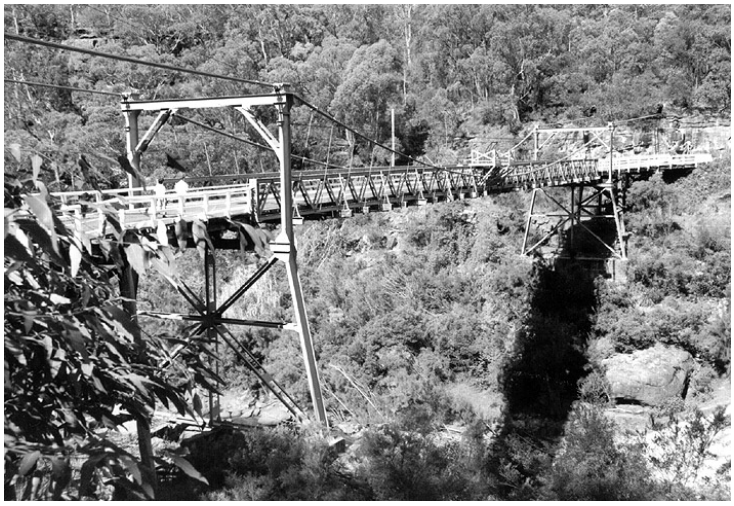


Figure 3.6 Timber and steel suspension bridge

Concrete and steel – Anzac Bridge

The Anzac Bridge was completed in the early 1990s. This cable-stayed bridge utilises the tensile strength of steel and the compressive strength of concrete. The steel cables that suspend the roadway are under tension as are the stressing tendons that compress the reinforced concrete deck. The 120 m high reinforced concrete towers are under compressive loads induced by the dead load of the bridge together with the live load of the traffic.

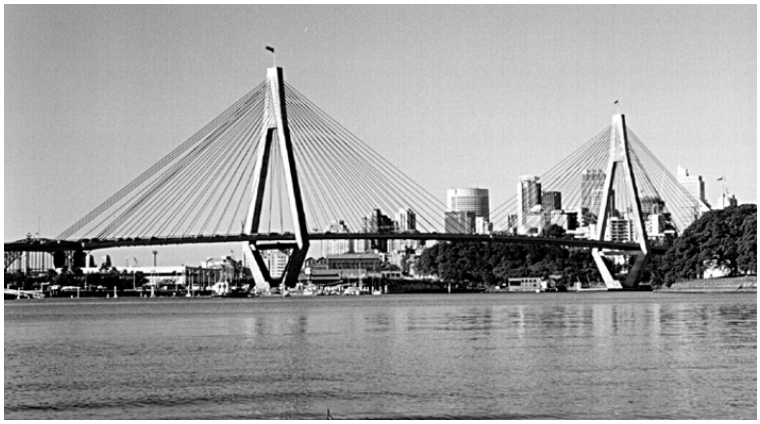


Figure 3.7 Concrete and steel cable-stayed bridge

Beam bridges

Timber – The Old Northern Road Bridge

The bridge on the Old Northern Road was built in the early 1830s. This bridge has Australian hardwood piers buried in the ground, logs as beams and cut hardwood as the road deck and railing. All these sections are bolted together. The original bolts have square heads.



Figure 3.8 Timber beam bridge

Steel – New Bridge at Tom Ugly's point

Built in the 1980s to duplicate the original steel truss bridge, the concrete pier spacing and height are designed to fit in with the existing structure.
The roadway is supported on three painted steel box girders that were manufactured off-site in transportable lengths. Each new piece was delivered to the southern bank where it was welded to the end of the 'growing' beam. The total length was then pushed out across the river onto the piers to make way for the next section to arrive. The roadway was cast in position in reinforced concrete and the galvanised steel railings were added.



Figure 3.9 Steel beam bridge

Reinforced concrete – Captain Cook Bridge

The Captain Cook Bridge, completed in the early 1960s, is curved to allow passage for tall watercraft. Built on a series of long reinforced concrete piers, this bridge has three beams to support the roadway. These beams are made from precast reinforced concrete sections that are post-tensioned together. The roadway was cast in position.

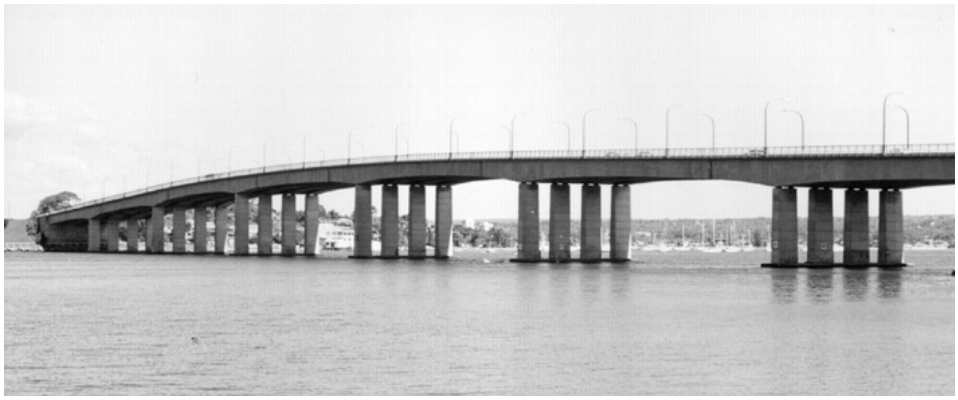


Figure 3.10 Reinforced concrete beam bridge

Cantilever bridges

Reinforced concrete – Mooney Mooney Bridges

Completed in the early 1980s, the Mooney Mooney Bridges are twin cantilever bridges, almost half a kilometre long. The design attempts to balance each half of the bridge on its pier. This relies on the compressive and bending strength of the piers that are built onto the solid sandstone footings. The main structure is made from precast concrete box girder sections. Each new section is 'attached' to the prestressing cables that pass back through the 'growing' bridge. A closing 'drop in' span finally joins the two sides.



Figure 3.11 Reinforced concrete cantilever bridge



Turn to the exercise section and complete exercise 3.1.

Testing of materials

Testing is critical to the engineer at all stages in the design and construction of civil structures as it provides a sound understanding of:

a the properties of materials

b the effects of forming processes

c the suitability of the design of structures.

Radiographic examination



List some of the objects in your immediate environment that you would need to dissect in order to examine the internal structure.

_____

_____

Did you answer?

Your list could include objects such as a wall, your body and the wooden leg of a chair.

In industry X-rays and γ-radiation are used to conduct **radiographic examination** of the internal detail of materials. Both methods use radiation to penetrate the item tested and then register on either a photographic film or a fluorescent screen. Any internal void allows the rays to pass through more easily, resulting in a dark area on the film.

γ-rays are able to penetrate thicker structures and are effective in the radiography of steel. The equipment needed for γ-radiation is simpler than that used for X-rays.

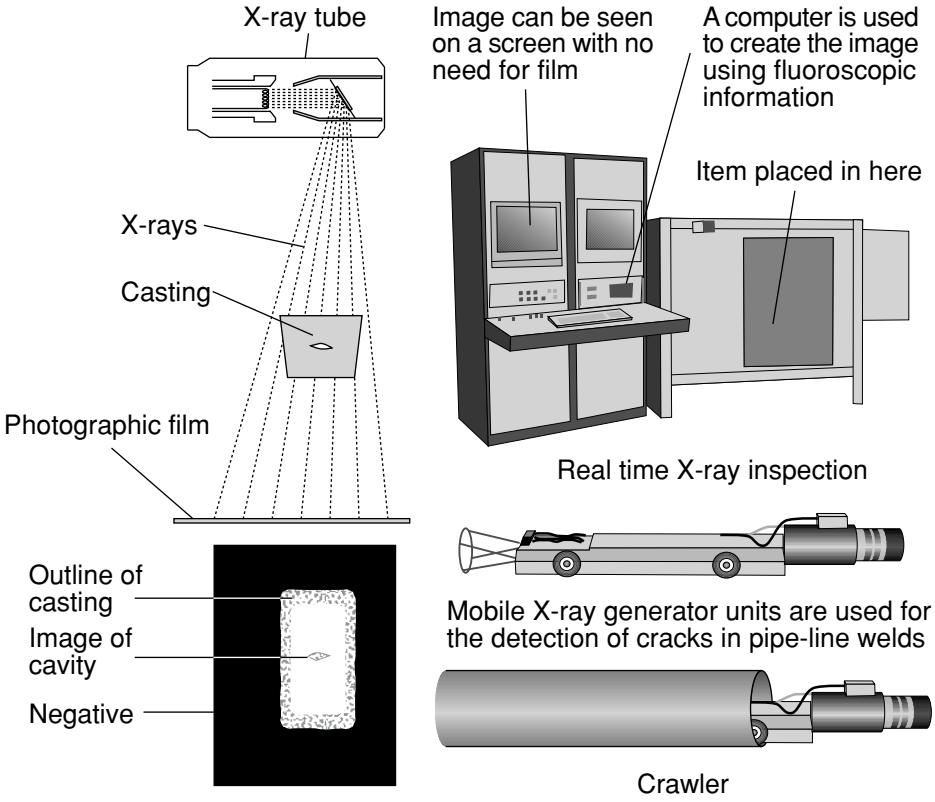


Figure 3.12 X-ray testing

Welding is the major joining method used in steel-framed civil structures. Radiation examination is used to inspect the quality of any weld so repairs can be carried out before the structure is put into service.

Ultrasonic testing

In **ultrasonic testing** a probe transmits high frequency vibrations as it passes over the surface of a component. Under normal conditions, the vibrations will be reflected from the bottom inside surface back to the probe. Any voids cause the vibrations to be reflected without travelling to the bottom of the object. This appears as an irregularity on the cathode ray tube.

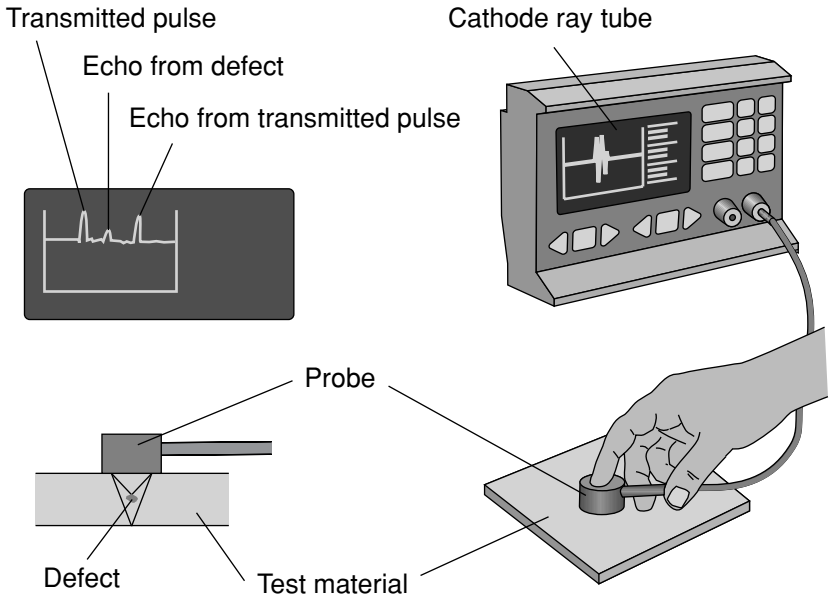


Figure 3.13 Ultrasonic testing

Useful for testing sheet materials more than 6 mm thick, the equipment can also be used for testing welds.

Tensile testing



Is medium carbon steel stronger after it has been annealed, normalised or cold drawn? Which is the most suitable material for use as cables on a suspension bridge?

Steel cables, tendons and hangers are all subject to direct tensile loads when used in civil structures. By comparing the results of tensile tests conducted on a variety of materials in different conditions, an engineer is able to best determine the most suitable material for each application. For example, tensile tests provide information on the elasticity, proof stress, toughness and ductility of the materials tested.

Compression testing

Materials used in civil structures are often subject to compressive forces. Comparison of the performance of different concrete mixes, bricks fired at different temperatures or different species of timber are all useful in determining the most suitable material to be used in any given application.



The following experiment demonstrates the difference between brittle and ductile materials.

You will need:

- a hammer
- 1–2 ice cubes
- a soft lolly, such as a Fantail
- a concrete path.

Carry out the following steps.

1 Place the ice cube on the path and gently hit it with the hammer. If you crush the first ice cube, use the second ice cube and hit it a little more gently.

2 Before the ice melts, gently hit the lolly with the same impact.

3 Compare the ice cube with the lolly.

4 Record your results below.



_____

_____

You should be able to see breaks along the planes of the ice cube. This indicates the failure of the material.

In contrast, the lolly should bulge slightly, unless it was a really cold day. There was no definite failure point under the load.

This is the difference between brittle and ductile or malleable materials.

> Note: True compressive tests use a gradually applied load not an impact as in this activity.

Brittle materials, such as stone and concrete, commonly fail along a diagonal plane or in a conical shape, sometimes called an hourglass failure. Due to the sudden failure of brittle materials, the ultimate compressive stress of the material is simply the value when it breaks. This is not the case with ductile materials which undergo a lot of deformation and may never actually break, but just get flatten and flatten

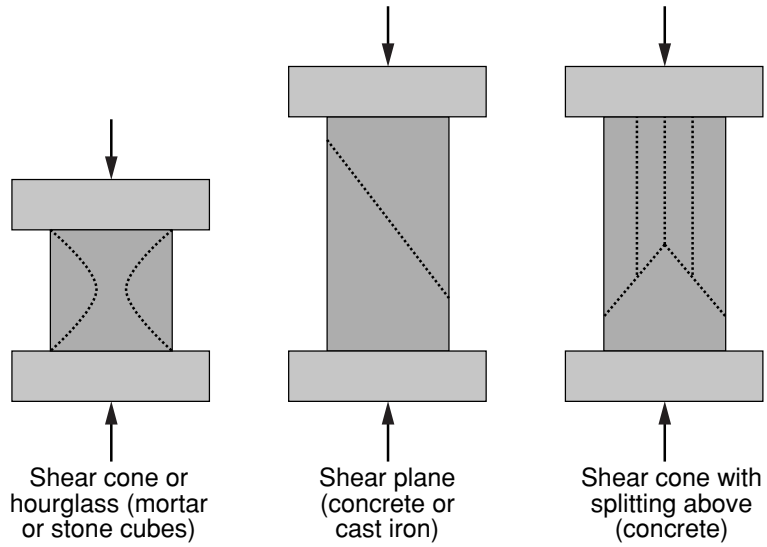


Figure 3.14 Compression failures of brittle materials

Transverse beam testing

Many materials used in civil structures are not solely in tension or in compression but are subject to both at the same time. They are used in such a way that they are exposed to bending stresses.

Transverse beam testing involves placing a test piece between two supports and then gradually applying a load. The deflection of the test piece is recorded and a load-deflection graph is produced. These results can be compared to other tests from identically sized test pieces or if the test is being used to check quality control, comparisons can be made to known values.

Timber is normally tested using a central point loading while concrete is tested using the centre-thirds method.

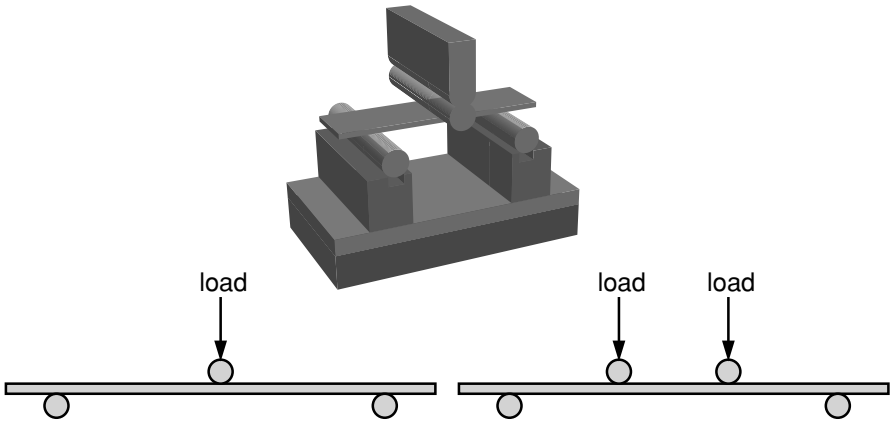


Figure 3.15 Centre third and central point loaded transverse beam tests



Suggest why construction timber, usually radiata pine, often has coloured stripes along one face.

Did you answer?

It is related to the stress grade of the timber.

Building timber is passed through an Australian-developed, grading machine that subjects the timber to a predetermined load. The machine senses the amount of deflection and squirts coloured dyes onto the timber to indicate the stress grading. Each colour represents a standard grade. A common grade of timber used for beams and truss chords is F7. This code indicates that the basic working stress in bending should not exceed 7 MPa.

Concrete testing

The water-to-cement ratio in concrete affects the workability of the mix and also the final strength of the concrete. Workability refers to how easily the wet concrete slurry can fill a mould or cavity. Trapped air pockets caused by poor workability reduce the strength of the concrete structure.

The **slump test** is a test that is used to give a measure of workability. Wet concrete is placed into a mould with a shape as shown in figure 3.16. The mould is 300 mm high. When the mould is removed, the concrete slumps.

A dry mix will subside, or slump, to between 0–25 mm and a sloppy mix will slump between 175–250 mm.

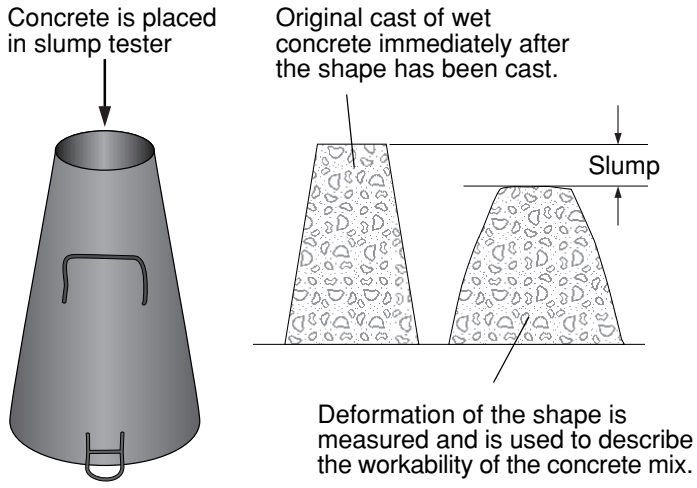


Figure 3.16 Concrete slump test

Figure 3.17 shoes how concrete strength decreases as the water-cement ratio increases. A higher water-to-cement ratio also causes more shrinkage during the curing process.

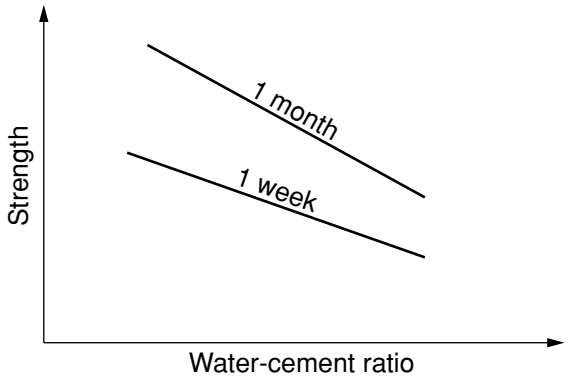


Figure 3.17 Relationship between water and strength in concrete

A compromise must be made between strength and workability depending on the application. For example, a stiff mix is used for large open foundations, while a medium wet mix is used for large structural members.

The strength of the concrete is generally measured after 28 days, as in this time it normally doubles the strength that it attains after one day. Test mouldings should be made at the time of the pour and retained for a**compression test** after the specified time periods.

Modelling

An important part of the design and development of civil structures involves making accurate scale models that can be used to expose the design to a range of conditions. Models of buildings can be placed in a wind tunnel to assess the wind loads that the walls are likely to experience. The flow of air over and through a bridge design can also be assessed in a wind tunnel. It is important that the model is exposed to conditions that closely resemble the actual service conditions of the finished structure.

The model of Botany Bay that assessed the changes to current and wave patterns caused by the runways of Kingsford Smith Airport at Mascot in Sydney was an engineering feat in itself.

A 1:175 scale model of the Anzac Bridge and its surrounds was used to test the response of the deck to high wind loads.

Computer programs are now able to simulate many of the loading conditions that act on civil structures. This has greatly simplified this phase of the engineering process.



Turn to the exercise section and complete exercise 3.2.

Ceramics

The Romans were prolific builders, constructing many community buildings such as the Colosseum and the many viaducts and bridges that still exist throughout Europe. From the design of these early structures it is clear the Romans appreciated and understood the properties of ceramic materials.

How does the design of the bridge shown in figure 3.18 reflect an understanding of the properties of ceramic materials?

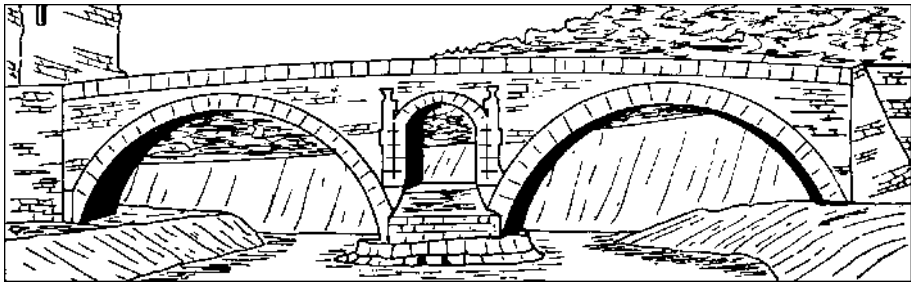


Figure 3.18 Early stone bridge

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This bridge contains a series of arches while many modern bridges use horizontal beams as their main structural members.

The only construction materials available for the first structures of the NSW colony were local timber and stone, so many of the early structures show the typical arch design used with stone.



Figure 3.19 Convict built culvert circa 1832

You have investigated the structure/property relationship of a number of materials, including ceramics, and also considered the use of ceramics in a variety of household appliances. In this part, you will explore ceramic materials in more detail.

Of all the materials available to the modern engineer, ceramics are the largest and most diverse group in terms of properties, uses and composition.

Within civil structures, the uses of ceramics range from:

- bricks in walls to computer chips in control units
- decorative landscaping to reinforced concrete beams in bridges
- window glass to cement
- delicate floor tiles to massive foundations.

Ceramics can be defined as materials containing phases that are compounds of metals and non-metals. Generally, though not in the case of glasses or cements, they develop hardness and chemical resistance with the application of various amounts of heat. Ceramics may have crystalline or non-crystalline structures, may be glass-bonded or may be cements.

The bonds between the atoms in ceramics are ionic and/or covalent. These ionic and covalent bonds provide ceramics with high melting points and as there are no free electrons, they are insulators. They are hard and brittle and have good resistance to weathering and chemical attack.

Natural ceramics

Rocks form much of the earth's crust and are made up of a combination of minerals, ores and organic non-mineral materials. Rocks are normally classified by the processes that formed them. These naturally occurring ceramics have good compressive strength and because of their brittleness can be shaped by chipping and cleaving into sections.

Igneous rocks

Igneous rocks form when molten volcanic material, magma, solidifies. If magma is molten when reaching the surface it is known as lava and reactions occur in the rapidly cooling matter to produce fine-grained, often glassy-looking rock. These include obsidian (volcanic glass), bluestone and basalt. Basalt is commonly crushed and used as aggregate in the manufacture of concrete, **asphalt** and road bases.

Granite forms when magma solidifies before reaching the surface. It typically is large grained and soft and is often polished and used for hard-wearing decorative surfaces in community buildings. For example, the facing on the piers and pylons of the Sydney Harbour Bridge was made from eighteen thousand cubic metres of granite quarried near Moruya on the south coast of NSW. Each individual stone was cut to size and finished at the quarry then numbered for fitting at the bridge site. Wastage from the quarry was crushed and used in the concrete for the bridge.

Both types of igneous rocks weather when exposed to the atmosphere and moisture. This process breaks the rock into small particles that can be transported by wind and water to new locations.

Sedimentary rocks

Sedimentary rocks form when particles of weathered rock are deposited in layers on sea or lake beds and consolidate under pressure from the weight of successive layers. Movement of the earth's crust raises and tilts these masses, exposing the layers of different particles as part of the land mass. Shales and sandstones are formed in this way.

Limestone can be formed when shells and other plant and animal matter are consolidated in this way under extreme heat and pressure. Limestone, along with shale, is used to make **portland cement**.

Sandstone was used extensively in early NSW. Stone for the oldest bridge on mainland Australia, the Lennox Bridge constructed in 1833 on the Mitchell Pass at the foot of the Blue Mountains was quarried only 500 m away. The Landsdowne Bridge constructed in 1836, that still carries traffic on the busy Hume Highway today, was built from stone quarried 10 km downstream on the bank of the Georges River.

Many early community buildings and monuments were also constructed from local sedimentary and igneous rocks. Large community buildings like the Sydney Town Hall and the NSW Parliament House are fine examples of the use of local sandstone in early colonial constructions.

The church shown in figure 3.20, was built in the early 1800s in a small town close to Sydney. It is typical of many of the more permanent community buildings of the time. The sandstone memorial shown in figure 3.21 is also similar to those found in suburbs and towns throughout Australia.

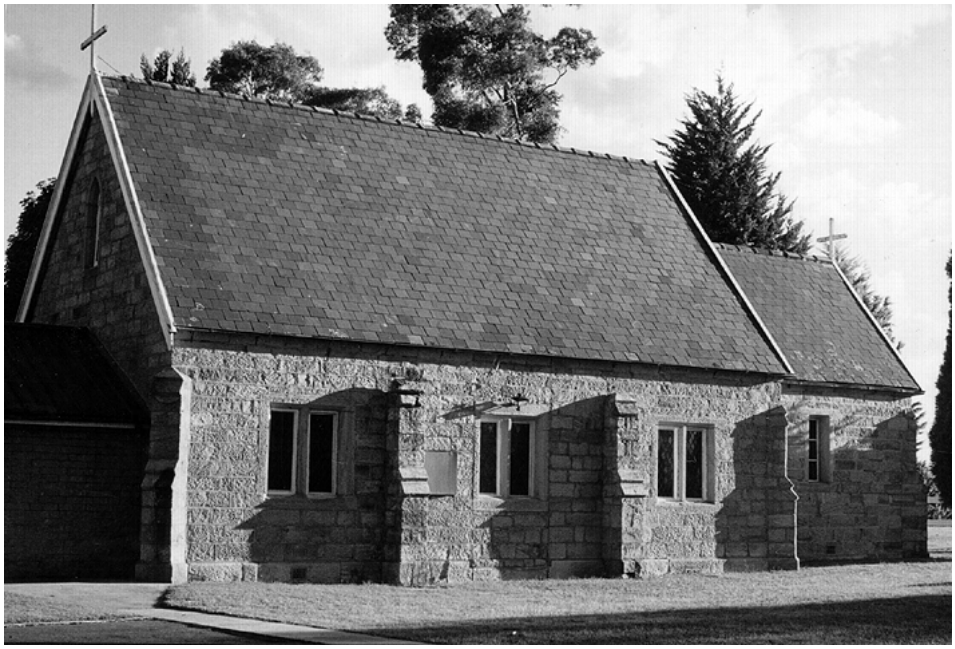


Figure 3.20 Sandstone church



Figure 3.21 Sandstone war memorial

Metamorphic rocks

If igneous or sedimentary rocks are subjected to intense heat and/or pressure their properties are changed, for example, their density increases.

The best way to indicate this change is to compare **metamorphic rocks** with the sedimentary rocks from which they were formed.

Slate ⇨ from shale

Marble ⇨ from limestone

Quartzite ⇨ from sandstone

Anthracite ⇨ from coal

Slate has historically been used for roofing and damp courses and is often used today as a flooring material. Early buildings in NSW were often roofed in slate transported from the British Isles in sailing ships. These 'export grade' slates were often much thinner than those used locally and the load of thinner slates would cover a lot more roof area.

Silicates

Silicates form a large and important group of ceramic materials. Silica (SiO_2) is well known as an engineering ceramic and many ceramics used in construction industries contain silicate phases. The basic structural unit of silicates is the silicon-oxygen tetrahedron.

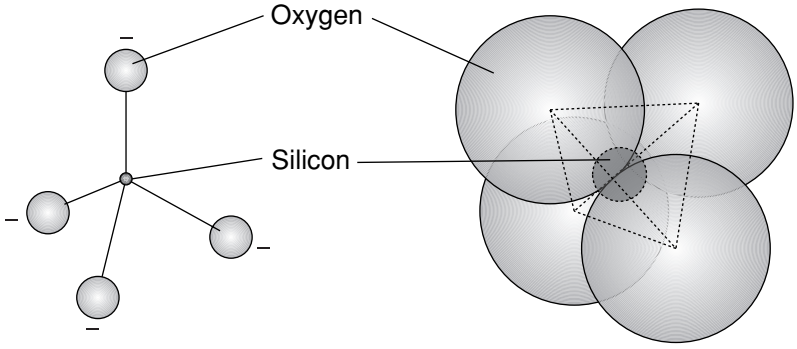


Figure 3.22 Simple silica tetrahedron

The silica tetrahedron contains a silicon atom surrounded by four oxygen atoms. The silicon atom shares one of its four valance electrons with each oxygen atom in the molecule, leaving each oxygen looking for another electron to fill its outer electron shell. This unit is therefore a negative ion and is represented by the formula SiO_4^{-4}. The silica tetrahedron gains the four electrons to fill the outer shells in a number of different ways and this will result in the formation of a variety of different structures.

Simple units

Orthosilicates are formed when two metal atoms donate two electrons each and an ionic bond is formed between the metals and the silica tetrahedron.

Pyrosilicates are formed when oxygen atoms share electron pairs with two silicon atoms forming a covalent bond. As all the outer shells are not complete electrons from metal atoms must be captured to form ionic bonds with the two silica tetrahedra.

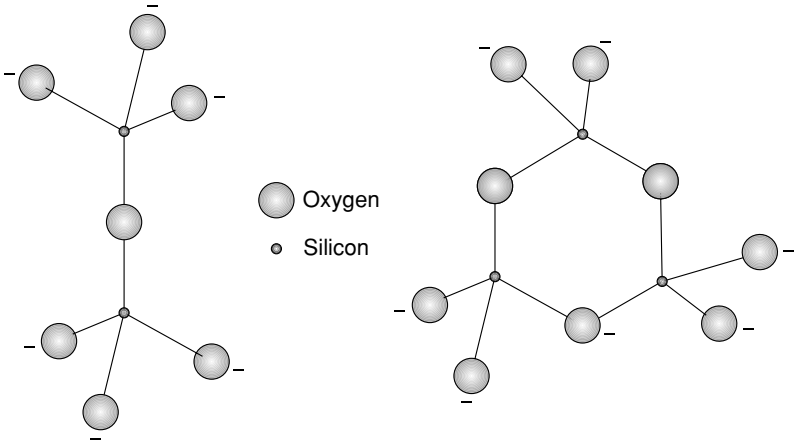


Figure 3.23 Simple structures

Chain structures

Single chains (pyroxenes) and double chains (amphiboles) are formed when oxygen atoms are shared by adjacent tetrahedra. While primary bonds hold the units along the chains, adjacent chains are held together by weak Van der Waals forces.

Asbestos is an example of an amphibole and exhibits good tensile strength along the fibres. This explains why asbestos fibres were once used to reinforce cement sheeting (fibro) that was used for wall cladding and external ceilings and soffit linings. Unfortunately this lack of strong bonds in three dimensions allows the fibre to split into very fine needles that can be inhaled and may lead to respiratory disease.

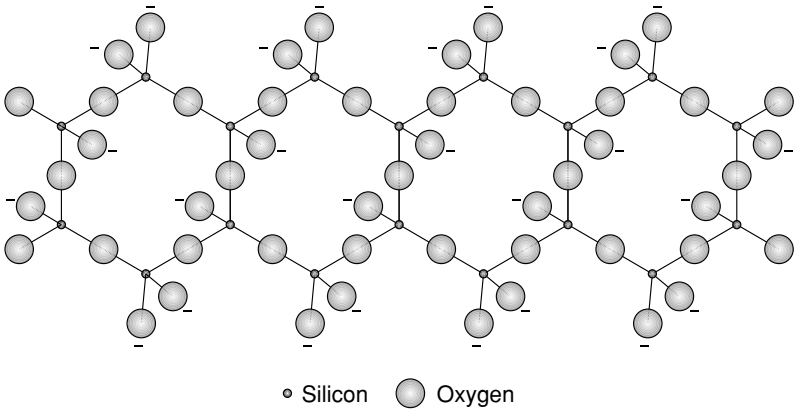


Figure 3.24 Chain structure

Sheet structures

If three oxygens of each tetrahedra are jointly shared with other tetrahedra a layer or sheet structure results. This forms a negatively charged layer composed of the silicate tetrahedra ions ($Si_2O_5^{-2}$). These may be interleaved with positively charged layers composed of metal hydroxides. Each layer is held together by strong primary bonds while the opposite charges of the adjacent layers attract in weak Van der Waals forces.

This accounts for the properties of these materials. They are soft, easily split between but not across sheets and feel soapy to touch. Mica, talc and clays (kaolinite) are all examples of sheet structures.

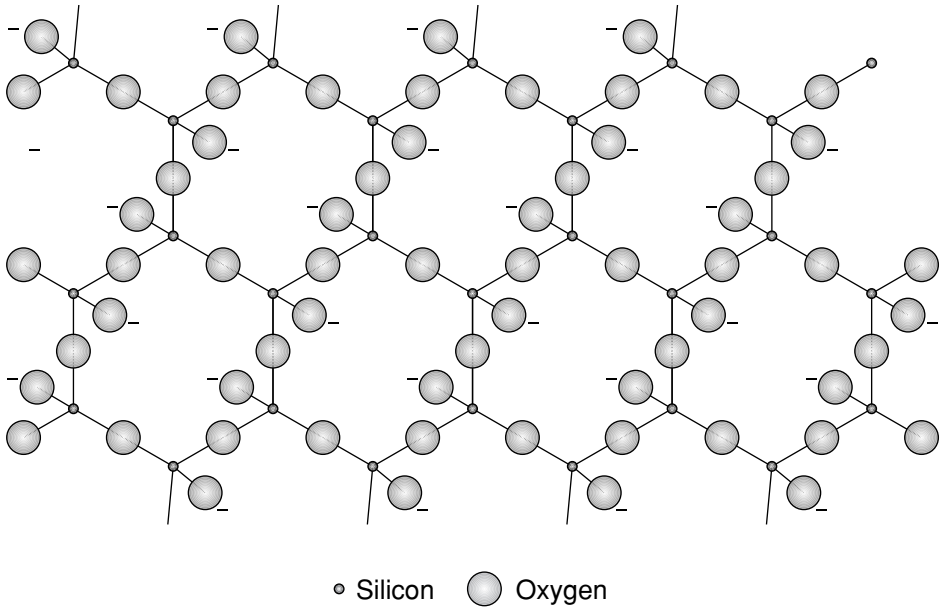


Figure 3.25 Sheet structures

Framework structures

Framework structures are formed when each oxygen is shared by two tetrahedra linking adjacent units into a three-dimensional framework. The strong covalent bonding in this structure results in pure silica (SiO_2) having a melting point of 1710°C and is a useful **refractory** material.

A common form of silica is quartz, the main material found in sand. Feldspar ($KAl\ Si_3O_8$) is another common framework.

Most commercial glasses are silicates, based on SiO_2 molecules, but are **amorphous** not crystalline like the structures described above.

Clays

Clays are the bases for one of the largest groups of ceramics. Clay-based bricks, pavers, tiles and sanitary ware are often found in community buildings.

Clays are the result of the breakdown of certain rocks due to weathering. Clay-mineral crystals are sheet structures, as previously described, in which negative silicate structures are interleaved with hydrated metal ions. Hydrated aluminium silicate ($Al_2O_3.2SiO_2.2H_2O$), called kaolinite, is a common example of this structure. Clays also contain small amounts of some or all of the following: quartz, mica, residual feldspar, metal oxides and organic matter. These impurities provide colour, bind or lubricate the structure and give mechanical strength during forming. They also act as **flux** and minimise shrinkage during firing.

Clays typically:

- have extremely small plate-like particles
- are plastic when wet
- become rigid when dry but will regain plasticity when re-wetted
- become permanently hard and strong when fired.

Plasticity

The water within the clay mineral is part of the structure and should not be confused with the water that is added to increase the plasticity of the clay.

Due to the varying sizes of ions and similarly charged ions repelling each other, slip and distortion between the layers within sheets is difficult to achieve. Figure 3.26 shows the random arrangement of sheet clay crystals in dry clay and illustrates how additional water acts as a lubricating film allowing the particles to be arranged in roughly parallel rows.

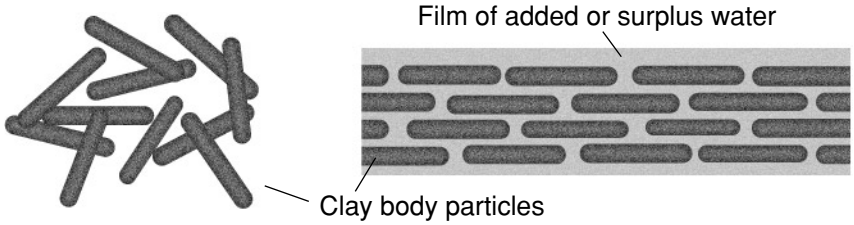


Figure 3.26 The effect of excess water on clay

When the water added is sufficient to just form a film around the sheet crystals, through secondary bonding, the clay becomes plastic but still has sufficient strength to support its own weight after forming and prior to drying and firing.

Firing

Once fired, the clay product is transformed to its permanent, rigid condition and can never be returned to clay. The following table summarises the main stages of the drying and firing of clay.

Stage	Range	Effects
Drying	Up to 150°C	Water causing plasticity is dried off, leaving the clay rigid but with little strength.
Dehydration	150°–650°C	The water within the clay crystals is removed, leaving alumina and silica. Heating must proceed slowly to allow the water to move out of the structure or the product may explode.
Oxidation	550°–900°C	Any metal compounds present oxidise and remaining organic materials are burnt off.
Vitrification	900° upwards	Vitrification occurs with a glassy phase flowing in the structure binding the unmelted particles together. Severe shrinkage occurs during this stage reducing the porosity of the structure.

Clay bodies

Pure clay is rarely used and normally a **clay body** is made by combining clay with non-plastics such as crushed quartz, feldspar or grog (finely crushed, previously fired, clay materials). These additional components alter the plasticity of the clay, act as fluxes, cause better flow of the glassy phase (vitrification) and reduce shrinkage.

Earthenware is a relatively soft and porous clay body used in construction materials such as bricks, and wall and floor tiles. It has quite high apparent porosity, usually around 8%. Earthenware is fired at the relatively low temperature range of 800°– 950°C.

Stoneware is dense, hard, has good chemical resistance, high vitrification, and good colour range and is used for items such as roofing tiles. It has apparent porosity between 1–2% and is fired at temperatures greater than 1250°C.

Porcelain is much finer than stoneware and is dense, hard, with excellent chemical resistance, a good light colour range and is used for items such as sanitary ware and electrical insulators. It has an apparent porosity less than 1% and is fired between 1300–1450°C.

When it is necessary to reduce the actual porosity of ceramic items, such as roof tiles, wall and floor tiles and sanitary ware, they are glazed. This involves coating the surface of the item with a glass 'paint' which leaves a glass residue on the surface when fired.

Forming processes

Clay bodies may be formed dry, as a soft plastic mass, or as a suspension in water. All items are fired once shaping has been completed.

Pressing

In the pressing process the dry clay is powdered and pressed into a mould of the desired shape. Density can be controlled by the amount of pressure used. This process is used to make some bricks (with 'frogs' not holes), wall tiles and electrical insulators.

Isostatic pressing

In the isostatic pressing process, the dry powder is placed in a flexible polymer mould within a moulding box. High pressure liquid or gas is forced into the moulding box providing more uniform packing of intricate shapes. This process can be used to manufacture small complex shapes, such as spark plug insulators.

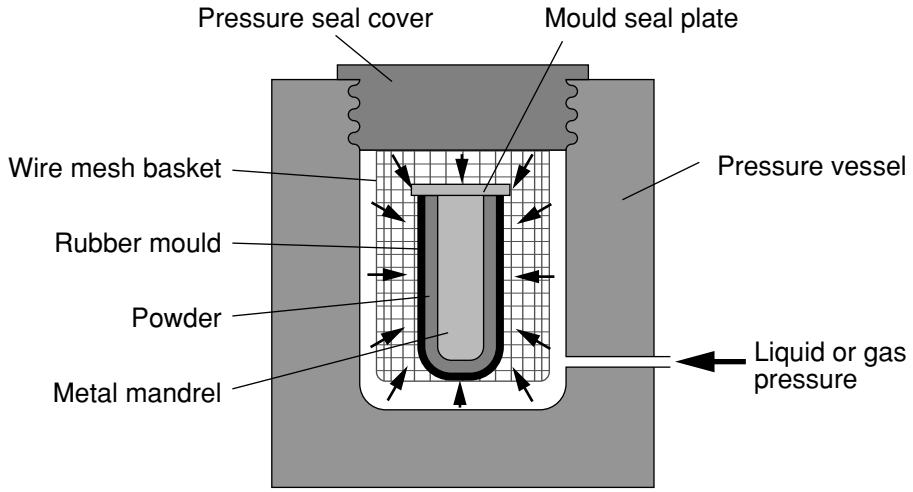


Figure 3.27 Isostatic pressing

Hand throwing

Hand throwing is an ancient process, still used by artist potters.
The plastic clay is pushed and pulled by hand as it spins slowly on the potter's wheel. Jiggering is a mechanised throwing process where a plastic internal mould sits on top of the wheel and a profile tool is lowered onto a disc of plastic clay as it rotates. This process is used to make items such as tableware.

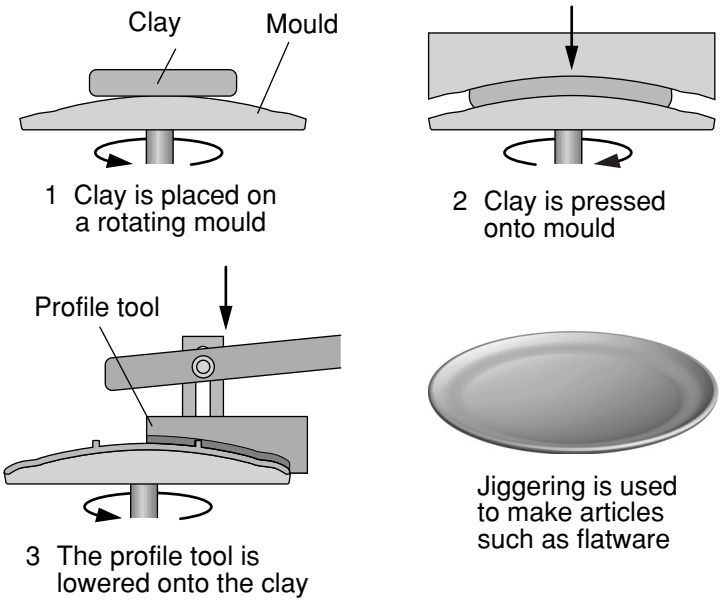


Figure 3.28 Jiggering

Extrusion

During **extrusion**, a plastic mixture of clay body is forced through a suitably shaped orifice. Density can be controlled by die shape and the pressures used. Some bricks (those with holes through them), pipes and hollow tiles are made using this process.

Slip casting

Slip casting involves preparing the clay body as a creamy suspension of clay in water, called slip, and pouring it into a Plaster of Paris mould. A layer or skin of clay will build up inside the wall of the mould as water is absorbed into the plaster mould. Once the desired shell thickness has been achieved, excess slip is poured from the mould leaving a hollow moulding. This method is suitable for complex, non-concentric shapes with a variety of wall thicknesses including sanitary ware and kitchenware.

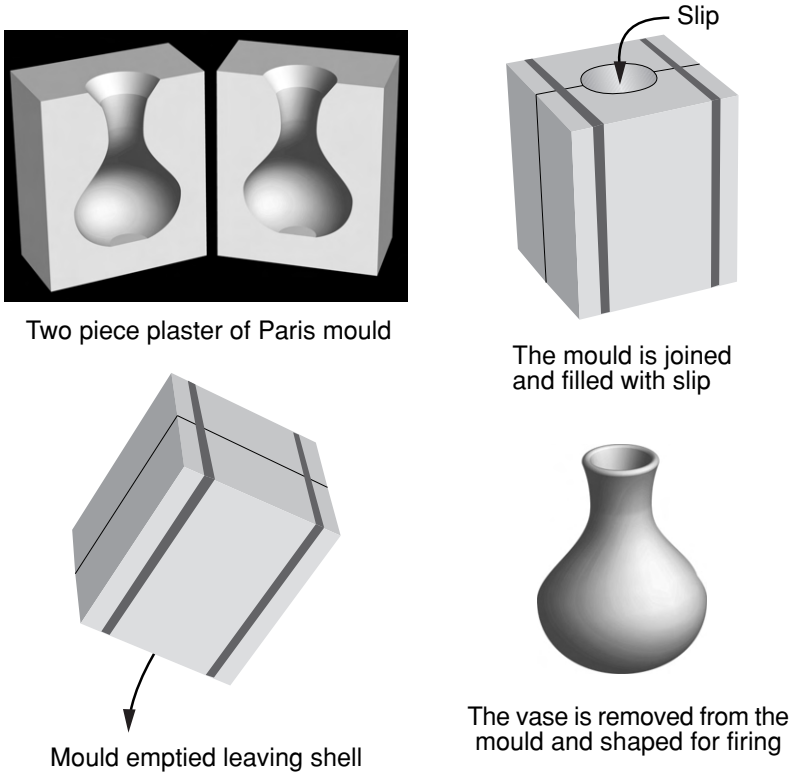


Figure 3.29 Stages of slip casting

Bricks

Manufactured bricks provided a viable alternative as a building material to stone.

Bricks as a building tool have been used for thousands of years. Early brick buildings may have been somewhat unstable as the clay material (clay brick) was not fired they would have been damaged by extreme weather conditions.

Recently there has been a resurgence in mud brick building.

The intrinsic properties of clay make it a very useful material for construction purposes – when moist it is highly plastic and rigid when dry, thus retaining its shape until rewet. In order to fix the clay body into a permanent shape the brick needs to be fired. This process removes all of the water from the structure and is non-reversible so that the brick material cannot be rehydrated and plasticised.

The notion of firing is quite old. Fired ceramics have been found as paving in ancient Sumer, 65 Centuries ago and high quality bricks were used to construct the Ishtar Gate of Babylon in the 17 Century BC. The spread of brick making through Europe was attributed to the influence of the Romans.

Manfacturing techniques

The first process required for the manufacture of bricks is the digging of the clay, usually done with mechanical excavators. The clay is then transported to storage areas where the larger fragments are crushed, ground and sieved. This produces a product that is free of contaminants and is of a suitable consistency, or particle size.

Pressing

The simplest forming process is the compacting of the clay base material into a mould of a particular size and shape. Initially the material would have been stamped down to compact it and force the clay into the corners of the mould. This method is still used and is particularly suited to the manufacture of solid bricks and pavers.

Solid bricks have an indentation in the top of them, known as a frog.

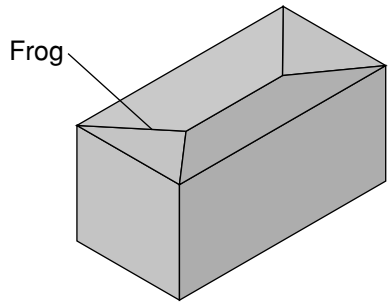


Figure 3.30 Solid Brick



Why is the frog put in the top of the brick?

Did you answer?

The frog in the top of the brick results from the method used to compact the clay material into the mould. The mould is filled with the clay and a ram is lowered from the top of the mould, thus compressing and forcing the clay into the corners of the mould.

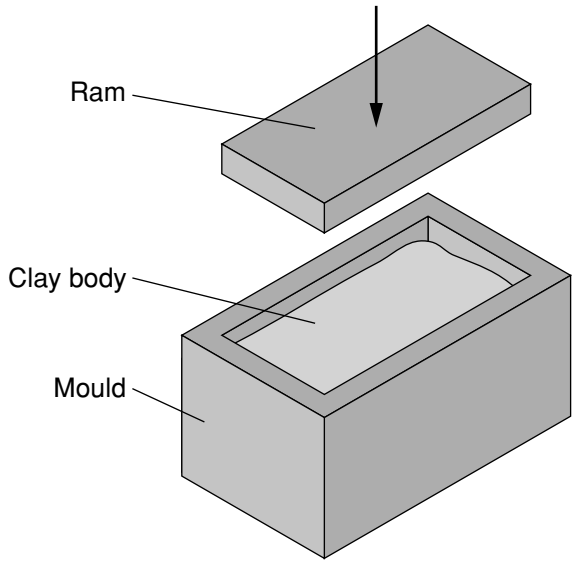


Figure 3.31 Pressing a solid brick

Extruded Bricks

To produce extruded bricks the clay body is mixed with sufficient water to produce the required amount of plasticity. The clay enters an extruder, commonly known as a pug mill where it is further mixed and kneaded by a series of knife like blades. In the pug mill it is possible for air bubbles to become trapped which could explode in firing. It is for this reason a vacuum chamber is attached to the pug mill to remove the air. The de-aired clay then moves into the last part of the mill where it is compressed by a helictical shaft and forced through a die at the head of the extruder.

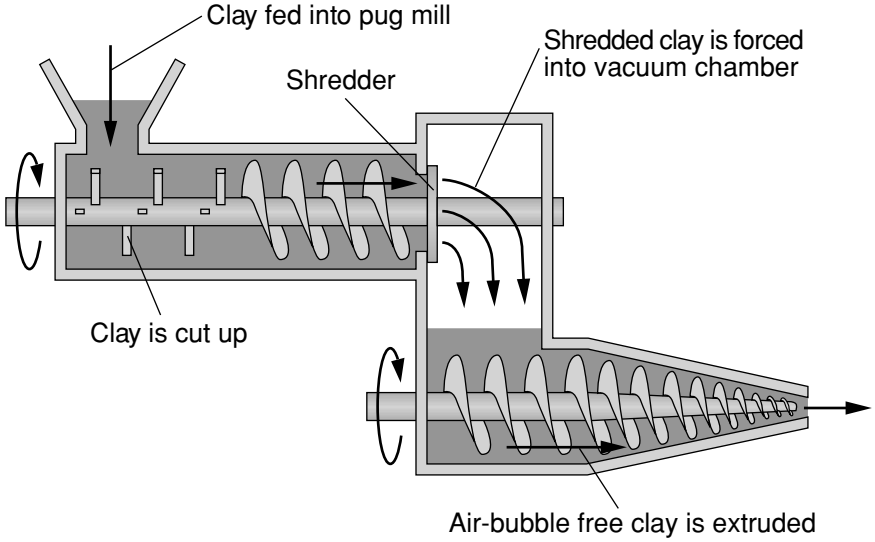


Figure 3.32 Extruder

This process is very similar to squeezing a tube of tooth paste. The die at the head of the extruder can be a variety of shapes so as to produce bricks of various sizes, shapes, textures or even hollow sections.

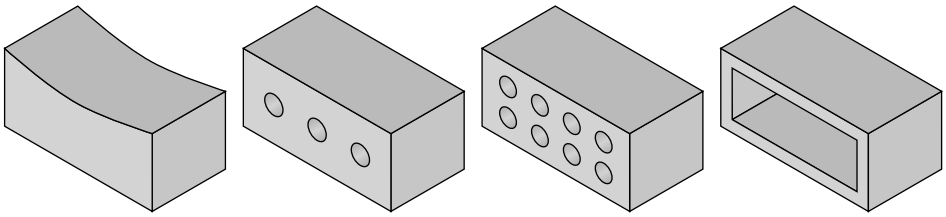


Figure 3.33 Extruded shapes

The size of the clay column that is so produced is usually slightly larger than the finish size of the brick. This column is then sliced into lengths by a wire to produce brick sized parts.

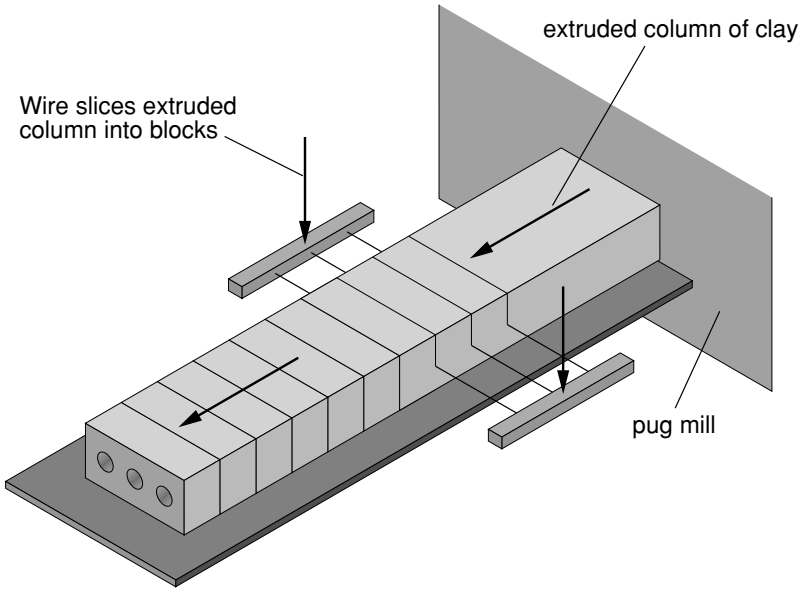


Figure 3.34 Slicing of the bricks



Why would the bricks be made larger than the desired finish size?

Did you answer?

This is to allow for the shrinkage of the clay in the drying and firing process

The bricks are subsequently allowed to dry and are then fired so that they retain their shape and size.



Turn to the exercise section and complete exercise 3.3.

Glasses

Glass is the result of fusion of inorganic materials that have been subsequently cooled to rigidity without crystallisation.

Glasses rarely exist naturally, the exception being near volcanoes where the conditions for rapidly cooling molten rock can occur.

The earliest examples of manufactured glass are probably in Mesopotamia where glass beads and other decorative ornaments around 4500 years old have been discovered. Artisans were casting, extruding and colouring glass to form quite fine and decorative samples at the height of the Roman Empire.

Flat or sheet glass for windows and stained glass for church decoration developed from the 6th century AD but it wasn't until the 14th century AD that glass making became an organised craft with skills being handed down from master to apprentice. Since the 14th century there have been steady improvements in method, composition and properties to develop glass into the important material it is today. Whereas much early glass was coloured, as seen in old bottles and windows, the majority of glass used today is clear.

Glass used in the early colony of NSW was imported. It came in small panels which, depending on the size of the window opening were assembled within timber frames with timber mouldings separating the panels. This gave rise to the colonial style of window that has been copied in recent years as part of residential housing fashion.

Properties

Glass is transparent, making it useful for windows and lenses. It is brittle and shatters under impact, breaking in tension. It is, however, very strong in compression. Theoretically it should also be strong in tension but, as in clay bodies, minute surface cracks and internal irregularities cause stress concentrations greatly reducing the actual strength.

Structure

The structure of glass is amorphous which allows it to be transparent. Glass can be crystallised to become tougher and less brittle but its optical clarity is greatly reduced.

Glass formers

The majority of glasses are based on silicon dioxide (SiO_2) which occurs extensively in nature in such crystalline forms as quartz and crystobalite (beach sand). Because SiO_2 can be fused and cooled without crystallizing it is called a glass former. Other oxides such as boron oxide (B_2O_3), germanium dioxide (GeO_2) and phosphorus pentoxide (P_2O_5), are also glass formers, under suitable conditions.

The melting point of SiO_2 is 1700°C but the addition of certain metal oxides (modifiers) to SiO_2 will lower this temperature to more practical levels (under 1000°C).

Intermediates and modifiers

Intermediates are metal oxides which, when added to a glass former, increase the bond strengths within the structure by serving as directional links in the glass network.

Oxides of aluminium, zinc, lead, titanium and cadmium act as intermediates.

Modifiers are metal oxides which, as well as lowering the melting point and viscosity of the glass former, contribute required physical, chemical and optical properties to the final product. They are not linked to the structure.

Oxides of sodium, calcium, magnesium and potassium all act as modifiers.

> Note: The lists of oxides classified as intermediates and modifiers are general. There are other oxides not included in these lists which will perform special tasks. An oxide listed as a modifier may act as an intermediate in a different type of glass and vice versa.

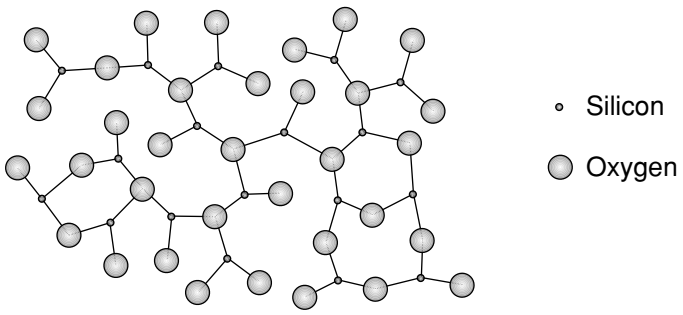


Figure 3.35 The amorphous structure of vitreous silica

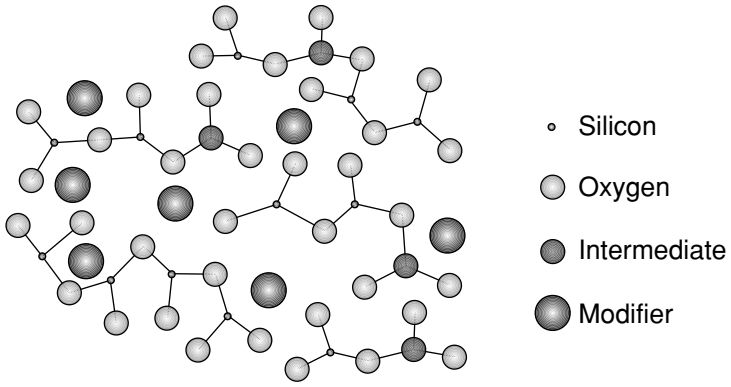


Figure 3.36 Silica glass including modifiers and intermediates

Glass manufacture

Glass is manufactured by melting the glass former together with suitable intermediates and modifiers in a furnace operating at temperatures of between 1100°C and 1500°C depending on the ingredients used.

Quantities of broken glass known as cullet can also be included for recycling purposes.

The furnace operation is continuous: the molten glass that emerges from one end of the furnace is followed by raw materials added at the other end.

Devitrification

Some contaminate particles, if introduced to the glass melt, will act to develop and propagate local crystalline growth during cooling. The development of crystalline areas in the amorphous glass structure is called **devitrification** and local areas of crystallisation in the amorphous glass are referred to as 'stones'.

Stones represent very weak and brittle areas in the glass and, as well as adversely affecting the strength properties, render that part of the glass opaque.

Recrystallisation

If devitrification is deliberately controlled to form a polycrystalline glass, a glass ceramic is produced. The individual crystals are very small and uniformly distributed, occupying from 70–100% of the mass.

Commercial glass types

All commercial glasses use SiO_2 as the main constituent along with varying amounts of other metal oxides.

Soda lime glasses

Soda lime glasses are the most common glasses. They contain significant amounts of soda (Na_2O) and lime (CaO). While the presence of soda will prevent devitrification, it also produces a glass that is water-soluble. The addition of lime overcomes the water solubility and hence the name soda lime glass.

Soda lime glasses soften at about 850°C, are low cost, won't recrystallize, are water-resistant and easily hot-formed to shape.
They are used for window and plate glass, bottles, tableware and light bulbs.

Borosilicate glasses

Borosilicate glasses contain up to 20% boron oxide (B_2O_3), have low thermal expansion and provide good resistance to fracture at elevated temperatures. Known by the trade name 'Pyrex', these glasses are used for electrical insulation, laboratory ware and ovenware.

High silica glasses

Borosilicate glass is formed to the required product shape then reheated to 1200°C to remove most of the Boron Oxide to produce high silica glasses. These glasses have excellent resistance to thermal shock and are used in situations of continuous high temperature (800°C) such as missile nose cones and space vehicle windows.

Lead glasses

Lead glasses, as the name suggests, contain a high proportion of lead, which lowers the softening temperature to well below the 850°C of soda lime glass. They have a high refractive index and are used extensively for optical glass. They are also used for neon sign tubes, thermometer tubes and the tableware known as 'crystal'.

Glass production

Viscosity and the shaping of glass

Viscosity is defined as the resistance of a fluid to flow due to internal friction. More simply, the relative viscosity of a fluid can be described by how 'runny' it appears to be. Water has low viscosity while honey and treacle have high viscosity. The viscosity of most fluids decreases with temperature, therefore warm honey is more runny (low viscosity) than cold honey (high viscosity).

Because glass can be conveniently heated to various levels of viscosity there are many ways available for shaping it. In its lowest viscous state (molten) it can be cast in a mould. Slightly higher levels of viscosity allow the material to be pressed, vacuum forced or extruded using dies. Other shaping methods include blowing by air pressure, rolling, twisting, drawing, bending and stretching. Because of its viscous properties it can also be 'welded'.

Sheet glass

The revolutionary **float process** was developed in the 1950s and replaced the traditional method of drawing viscous glass through vertical rollers. Raw glassmaking ingredients are fed into a gas-fired furnace where glass is formed at temperatures up to 1550°C. A continuous ribbon of glass is floated over a bath of molten tin. Gravity flattens the glass which is fire-polished as it spreads over the tin. As the glass exits this bath it is at 600°C and can be carried by rollers through another furnace, the annealing lehr. It gradually cools and as it exits, it is cut and stacked. Figure 3.37 illustrates the process of manufacturing sheet glass.

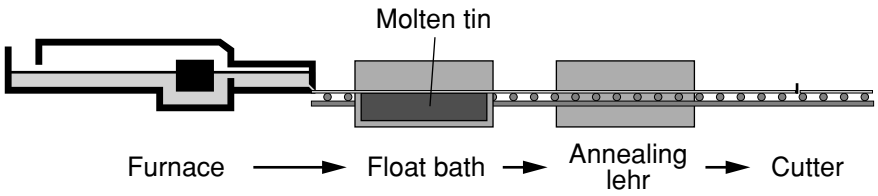


Figure 3.37 The float glass process

Glass containers

Glass for containers is made in a furnace as for sheet glass. A molten glass ‘gob’, a mass equal to the amount needed for a container, is dropped into a mould. It is then shaped by a series of compressed air ‘blows’. The continuous process delivers the containers into an annealing lehr where they are cooled. Figure 3.38 illustrates this process.

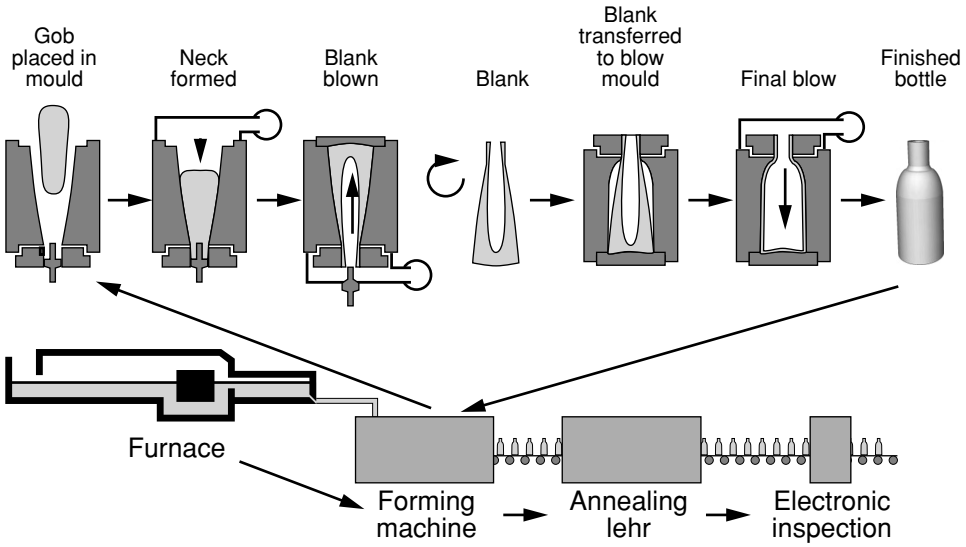


Figure 3.38 Container glass production

Glass fibre

It is generally accepted that in low tensile strength materials, fracture is caused by small surface defects and flaws which tend to concentrate stresses at particular points.

Glass is classed as a brittle material. The tensile strength of glass depends upon:

- the surface condition (the fewer minute cracks, scratches and flaws, the stronger it will be)
- the surface area or size (the smaller the surface area, the less opportunity for cracks and flaws).

Glass in fibre form has very little surface area and therefore virtually no surface flaws. **Glass fibre** can be as much as 100 times as strong under tensile load as a piece of window glass. This makes it much stronger than steel.

This feature along with the other desirable properties of glass (non-corrosive, ease of manufacture, unlimited supply of raw materials) makes glass fibre an ideal strengthener or reinforcement for weaker materials. Glass reinforced polymers are a good example of its use.

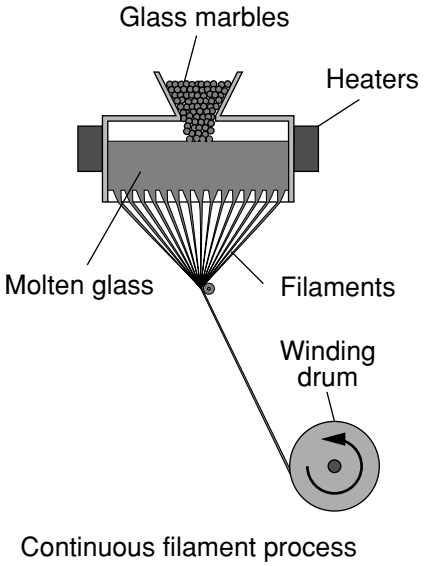
Manufacture

There are two main methods for the manufacture of glass fibre:

- continuous filament process
- crown process.

Continuous filament process

In this process, a continuous supply of glass, in marble form to ensure even viscosity, is fed into an electrically - heated reservoir. The bottom of the reservoir is a ceramic bush containing between 140 and 500 tiny holes through which the molten glass is drawn as a filament. The individual filaments are seized and collected to hold them together. The single strand made up of the fine filaments is then wound onto winding drums that are stored for curing and future spinning into matting or tape. This process is used to make reinforcing fibres.

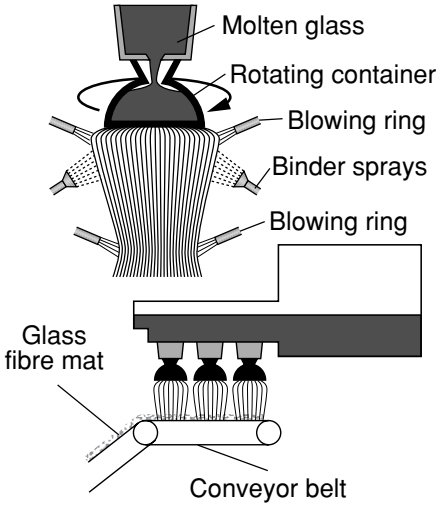


Continuous filament process

Figure 3.39 Glass fibre production

The crown process

In this process, molten glass is fed into a rapidly rotating container with hundreds of tiny holes spaced around its bottom edge. Centrifugal forces cause the molten glass to be squeezed through the holes in the form of individual fibres about 0.007 mm in diameter. The fibres are then air cooled before being sprayed with a binding agent. To ensure maximum entanglement, the fibre mass is again subjected to compressed air blowing before being laid in mat form on a conveyor belt for transportation to curing, pressing and trimming. This process is used to make glass wool, used for insulation.



The Crown process

Figure 3.40 Glass fibre production

Improving glass properties

Any rapid drop in temperature develops stresses that adversely affect the physical properties of glass.

Annealing

To relieve glass of the thermal stresses developed during manufacture, it is reheated and soaked at the **annealing** temperature range, then allowed to cool slowly to room temperature.

As a general rule, the larger the size of the glass body, the slower the cooling rate should be. Correct annealing will provide a slightly denser product completely free from internal stresses and strains.

Tempering (toughening)

As glass is not strong in tension but quite strong in compression, the tempering of glass is designed to place the outside surfaces in compression. This reduces the possibility of failure due to tensile stresses, while leaving the interior in tension to maintain the strength properties.

The tempering process involves heating the glass to its annealing range and rapidly cooling the outside surfaces by air blasting. This provides a rigid skin which encloses a still viscous interior. As the glass mass cools to room temperature it contracts to develop compressive stresses in the skin and tensile stresses in the interior as shown in figure 3.36.

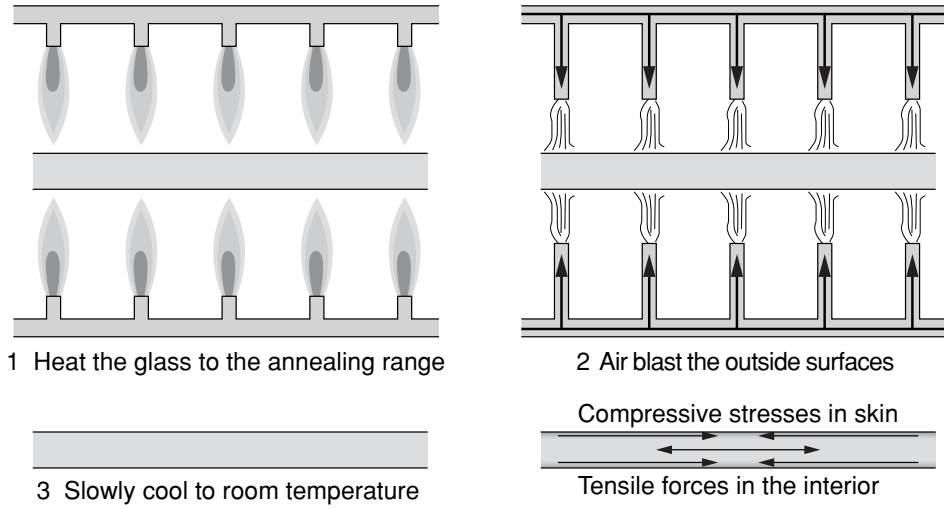


Figure 3.41 Tempering of glass

Tempered glass is four to five times as strong as annealed glass. It has a high degree of impact resistance and retains the same level of transparency as the original glass.

Any machining such as cutting or grinding must be carried out prior to tempering.

Laminated safety glass

Laminated safety glass is a 'sandwich' consisting of two sheets of annealed glass bonded together by a thin sheet of transparent polymer (polyvinyl-buterate). The assembly is conducted in an environment of low humidity and low temperature (below 16°C). Once assembled, the laminate is passed through a series of heaters and rubber rollers to achieve

preliminary adhesion after which it is subjected to much higher pressure and temperatures (above 100°C) to develop final adhesion and even thickness (0.4 mm) of the polymer interleaf. The laminate is then slowly cooled to prevent cracking.

If the laminate is fractured, the polymer absorbs some of the energy of impact preventing the inside glass layer from cracking. It also holds the shattered glass pieces together, preventing damage to property and injury to persons. When used as window glass, the polymer interleaf also serves to insulate noise levels by up to 15%. It is used for motor vehicle windscreens and window glass in high risk locations.

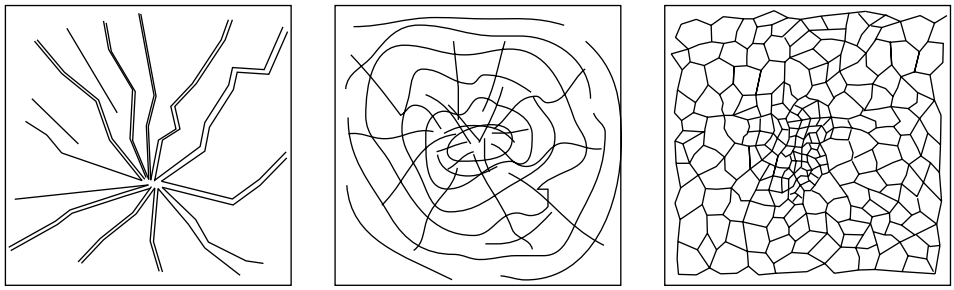


Figure 3.42 Fracture patterns of glass

Mechanical properties of ceramics

The use of ceramics in engineering reveals that stone, brick, cement and glass are stronger in compression than in tension.

Crystalline ceramics

Plastic deformation of **crystalline** materials occurs when adjacent parts of a crystal slide over each other. This process of slip occurs along well-defined planes within the crystal structure. This occurs readily in most metals but is restricted in ceramics. Reasons for this include:

- significant size differences between the atoms or ions combined to form ceramics – slip is consequently mechanically restricted because of the uneven surfaces along the slip planes
- ionic bonds in some ceramics which restrict slip if similarly-charged particles are forced together
- low symmetry of ceramic crystals which reduces the number of planes along which slip could occur.

These restrictions to slip give ceramics their characteristic high compressive strength. In theory, tensile strength should also be high but small cracks and flaws in the structure act as stress concentrators. Cracks will propagate at these points often leading to failure in tension by cleavage.

Non-crystalline ceramics

As glass is a non-crystalline material it does not deform along slip planes but by the process of viscous flow. A localised stress will break some of the bonds allowing the atoms to move and resulting in some permanent deformation. The structure of glass, the amount of applied stress and the temperature all influence the rate of viscous flow.

Viscous flow in glass at room temperature is very low and it is more likely to fail in a brittle manner when hit by an impact load. Over time, glass may flow under its own weight and old, large plate glass windows are often thicker at the bottom due to this phenomenon. This is known as creep.



Turn to the exercise section and complete exercise 3.4.

Cements

Hydraulic cements

Hydraulic cements include Portland cement and Pozzolanas.

Portland cement

Portland cement is the most important and widely-used cement in the construction industries. When it dries, it resembles a natural stone quarried near Portland in England that was used for the construction of civil structures such as the Nottingham University.

The stages in the production of Portland cement are:

Mixing and grinding crushed limestone and shale

⇩

Fusing the mix to '**clinker**' in a kiln at temperatures up to 1480°C

⇩

Mixing up to 2% gypsum with the cooled clinker

⇩

Grinding the mix to fine powder ready for use

This cement is a mixture of a number of minerals based on the oxides of calcium, silicon, iron and aluminium. The amount of gypsum (hydrated calcium sulphate) added determines the rate at which cement sets.

When Portland cement is mixed with the required amount of water, a series of hydration reactions occur to form a silicate gel and various hydrates. This silicate gel represents about half the mass of the set cement, binding the hydrates together and providing strength to the set cement. Once the water is added to this mix the reactions will proceed even if the cement mass is completely submerged.



List some situations where a cement/concrete mass may be submerged while it is setting.

_____

_____

Did you answer?

You might have suggested a boat ramp or pier or something similar.

Pozzolana concrete

Pozzolana concrete was developed in Roman times and sets in the same way as Portland cement. Natural pozzolana is volcanic in origin and contains silica, alumina and iron oxide. Synthetic pozzolana can be made from certain clays, slag from iron manufacturing, fly-ash and diatomaceous earth.

When pozzolana is mixed with lime and water, hydrated silicates and aluminates are formed. These are reheated and ground to form cement powder which is mixed with aggregate and water to form a strong, fire-resistant concrete.

Non-hydraulic cements

Non-hydraulic cements set and harden in air and cannot be used under water.

Lime

Lime is produced by:

- grinding limestone, mixing it with silica, alumina and iron and firing it at around 1000°C – this produces calcium oxide (CaO)
- adding water to the CaO to produce $Ca(OH)_2$ – a white powder known as slaked or hydrated lime.

Mixing hydrated lime with sand or clay and water makes lime mortar. This was once used extensively in brick buildings. A little Portland cement added to the mortar will increase both strength and water-resistant properties.

Gypsum

Heating hydrated calcium sulphate produces:

- the semi-hydrate $CaSO_4.H_2O$ (Plaster of Paris) at 180°C
- the anhydrate $CaSO_4$ (Keene's cement) at 540°C.

In both cases, the crystals produced are ground to a powder which set and harden when mixed with water.

Plaster of Paris is porous, soft and soluble in water. When **laminated** between two paper sheets it is used extensively as plasterboard sheeting that is used as a lining material in many modern buildings.

ene's cement is hard and strong. It is not soluble in water and can be used in exposed areas such as wall and floors and also as an imitation marble.



Explain why it is easier to reuse bricks that were laid with lime mortar compared with those laid with cement mortar.

_____

_____

Did you answer?

The lime mortar is softer than cement mortar and so chips off more easily.

Composite materials

A composite material consists of two or more materials joined to give a combination of properties that could not be obtained from any one of the materials.

Classifying composites

Composites can be divided into three groups:

- particulate, that is, composed of particles
- laminar, that is, composed of layers
- fibre, that is, textile type materials.

Particulate composites

Particulate composites are made up of particles which have been joined together to produce unusual combinations of properties rather than to improve strength. Concrete is a particulate composite.

Laminar composites

Laminate or laminar generally means that the parts are physically joined face-to-face not edge-to-edge. Similar laminates, such as plywood, and dissimilar laminates, like vinyl fabric, are joined to take advantage of the combination of properties.

Fibre composites

In fibre composited, the properties of a base material, or matrix, are improved by incorporating strong, stiff or brittle fibres into the structure. This makes it a single structure with no part of the matrix isolated from the rest as the fibres might be. The matrix acts to bond the fibres together.

The matrix material transmits the force to the fibres and provides bulk and toughness, while the fibres carry most of the applied force.

Fibres also help to prevent the movement of cracks through a fibre composite by ‘bluntening’ the end of the crack.

Fibre composites have been used for centuries. Straw was used by Ancient Egyptians and Greeks to strengthen mud bricks. This process is still used today to make mud bricks.

The fibres may be in the form of a continuous fabric, like the welded steel mesh used to reinforce concrete slabs, or in individual fibres, as in mud bricks.

Concrete

More than 2000 years ago the Romans developed concrete based on crushed volcanic rock (pozzolan) and used it in conjunction with brick and masonry in many of their civil structures. After the fall of the Roman Empire, the use of concrete was not revived till the 19th century. Since that time, concrete has been used more than any other construction material – there would be few civil structures built today that don't incorporate concrete in their design.

Concrete is a particulate composite which is a mass of inert filler (an aggregate of sand and crushed rock) held together by a matrix of binder, a cement-water paste. The properties of both the newly-mixed and set concrete depend on the relative proportions of each of the components.

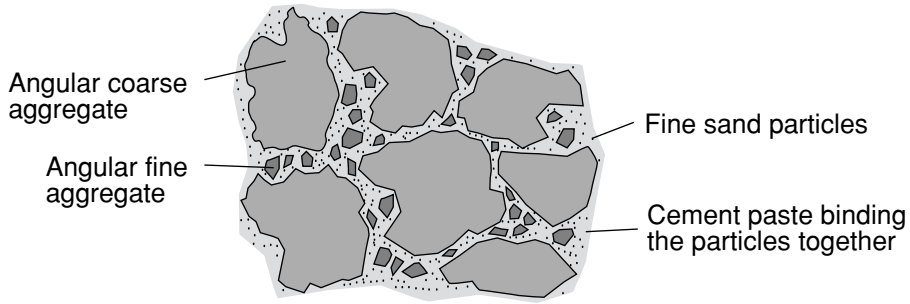


Figure 3.43 Macrostructure of concrete

The role of the aggregate is to:

- provide a filler for the cementing material to bind
- provide particles that resist the applied loads and abrasion
- reduce volume changes that occur when the cement paste dries and sets.

The role of the cement-water paste is to:

- lubricate the mixed, wet concrete
- fill the voids between the aggregate, making the mass watertight
- strengthen the set concrete.

Mixing concrete

A common concrete mix consists of four-parts aggregate, two-parts sand and one-part cement. The aggregate and sand should be:

- as strong and durable as the cement (crushed igneous rock is often used for aggregate)
- sharp-cornered and angular to improve the mechanical interlocking and the overall strength
- graded or of different sizes so the smaller pieces pack into the voids between the larger pieces.

When water is added to the dry mix, the cement paste should coat all sand and aggregate particles and fill the voids between aggregate particles. The cement paste sets through a series of chemical reactions and binds the mass together. Remember, it is important to use just the right amount of water in the mix. Too little and the reactions don't occur, too much and the strength is reduced.

Lightweight concrete

Lightweight concrete is sometimes used where compressive strength is not important but the dead load of the concrete is critical. It is produced using either lightweight aggregates, such as vermiculite (an expanded shale product), or by aerating the concrete chemically to form tiny bubbles through the matrix.

Additions to concrete

Other materials may be added to the mix to modify one or more of the properties of concrete.

The table below lists some examples and the resulting characteristics.

Materials	**Types**	**Characteristics**
$CaCl_2$	Accelerators	Give early strength and curing
Fused alumina particles	Surface hardeners	Produce abrasion resistant surfaces
Various salts	Retardants	Retard curing
Inorganic pigments	Colouring agents	Provide colour
Fine iron particles plus chloride	Bonding admixtures	Bond fresh to hardened concrete

Curing concrete

Concrete starts to set as the water that makes the mix plastic, dries out. At this stage it is said to be 'green'. It is important to keep the concrete moist at this stage. Premature drying may prevent the required chemical reactions, reducing the strength of the concrete.

A normal concrete mix, cured in air, will have a compressive strength of 3.8MPa after a day, 10MPa after a week, 16.7MPa after 28 days and 38MPa after a year. It is rated on its strength after 28 days.



a List different ways that concrete is used in civil structures.

_____

_____

_____

b Explain how concrete stays in the barrel of the concrete truck while the truck is moving and pours out when it arrives at the site.

_____

_____

_____

Did you answer?

a Inside the barrel is a large helix or Archimedean spiral, a large screw thread.

b When the barrel turns in one direction the concrete moves towards the bottom and when it turns in the opposite direction it moves to the top.



Turn to the exercise section and complete exercise 3.5

Reinforced concrete

As the tensile strength of concrete is only one tenth of its compressive strength, reinforcement is commonly used. This combines the tensile strength of the reinforcement, usually mild steel, with the compressive strength and casting ability of concrete. Civil structures often use reinforced concrete, as careful positioning of the reinforcement will allows for tensile stresses resulting from bending, shear and torsional loads.

In 1867 the Frenchman Monier patented the use of steel wire mesh in garden pots. Today, the commonly used reinforcing materials are mild steel rods, bars or mesh. To increase the bond strength between the steel and the concrete, the steel may be given a patterned surface and the bars may be bent or deformed. This reinforcement is carefully embedded in the concrete and takes the tensile forces while the concrete resists the compressive forces. Without this reinforcement, concrete beams would crack and eventually fail on the face that is in tension.

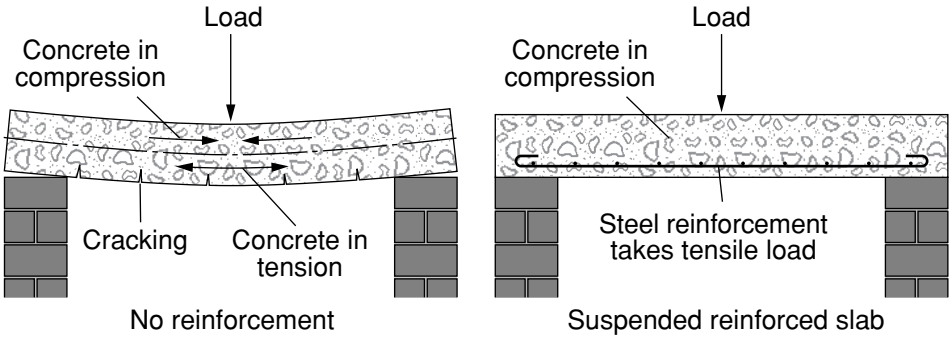


Figure 3.44 Reinforcement in a suspended slab

The effect of reinforcement



Think about what happens when a truck drives over a concrete slab.

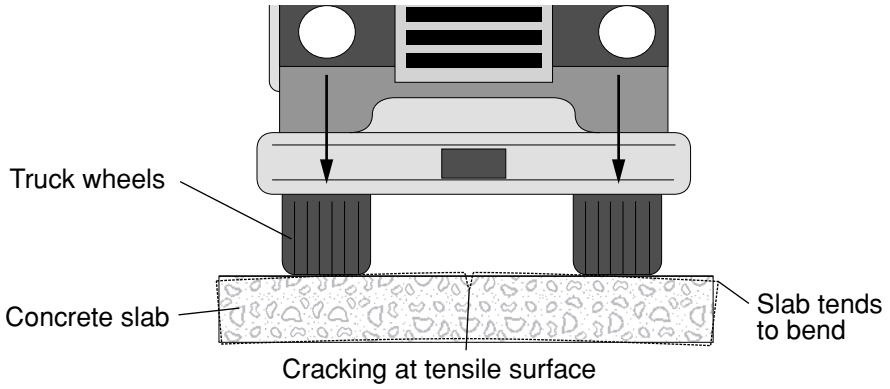


Figure 3.45 Truck on a plain concrete slab

The weight of the truck, acting at the wheels, will tend to bend the slab. Concrete is weak in tension, so the surface that is in tension will crack.



Think about what happens when a truck drives over a reinforced concrete slab.

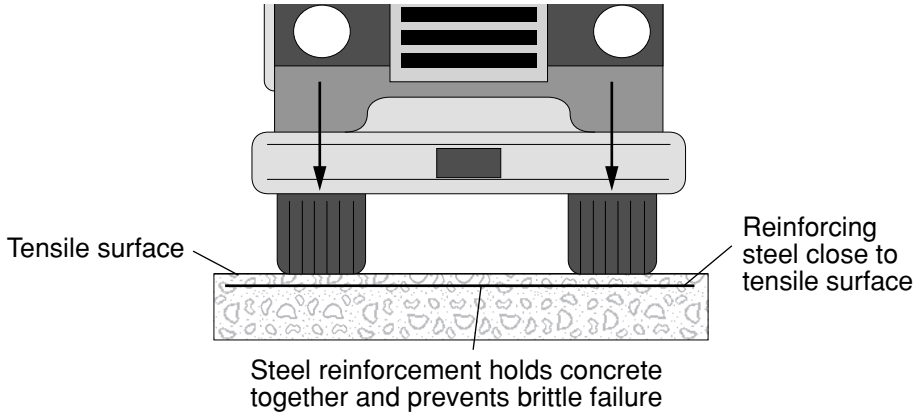


Figure 3.46 Truck on a reinforced concrete slab

If the concrete has steel reinforcing bars, the tensile load is taken by the steel (which has a high tensile strength) holding the concrete together and preventing cracking.



Look at civil structures that are under construction. Many will be cast in position from reinforced concrete. Check out the amount of steel that is used. Notice that sometimes the steel reinforcement is bent before delivery. Look at the position of the steel and note its position near the top, middle, or bottom.

Reinforced concrete construction

In situ

Reinforced concrete construction can be done in situ. This term derives from the words *in sit*uation. In this process an on-site mould is prepared into which the steel and plastic concrete is placed. The mould may simply be a hole in the ground, as for footings or a pool, or may be a complex arrangement of supports and special waterproof plywood, as seen in the upper floors of a community building.

When looking at civil structures, you may have seen fabric reinforcement used in floors, roadways and bridge decks. You may notice deformed bars, often wired together, in stairs, footings, foundations, columns, retaining walls, beams and swimming pools.

Pre-cast

When multiples of the one shape are required, a steel, concrete, polymer or composite mould is made and the components are made off-site, that is they are pre-cast. The overall size and weight of the components is limited by transport and lifting capabilities. Lifting eyes, to aid with transportation, and ducts or tubes, to take tensioning tendons, are normally cast in sections.

Pre-cast items used in civil structures may include simple bridge culvert sections, columns, beams, stair sections, suspended slabs and wall slabs. It is common to see a skeletal frame built in either steel or reinforced concrete that is then clad in large pre-cast slabs. These hang from the frame and may be cast with special pre-finished surfaces.

Prestressed

A disadvantage of ordinary reinforced concrete is the great weight and bulk of concrete needed to provide adequate strength. The concrete in the part of the beam in tension does little except enclose reinforcing steel.

In prestressed concrete, strong steel bars or cables are placed in high tension. When this tension is released, the composite structure is placed in compression. Prestressing can also cause the beam to bend up in the middle but some of this is lost when the beam is loaded. The compressive force induced is designed to be greater than the expected tensile load. In this way, the concrete will never be placed under tension.

Prestressing is of two types:

- pre-tensioned
- post-tensioned.

Pre-tensioned

Concrete is cast around tendons that are already in tension. These tendons are in addition to the normal steel reinforcement used in the structure. Once the concrete has set, the external tensile force is removed and the structure is placed in compression due to the bond between the concrete and the surface of the steel tendons.

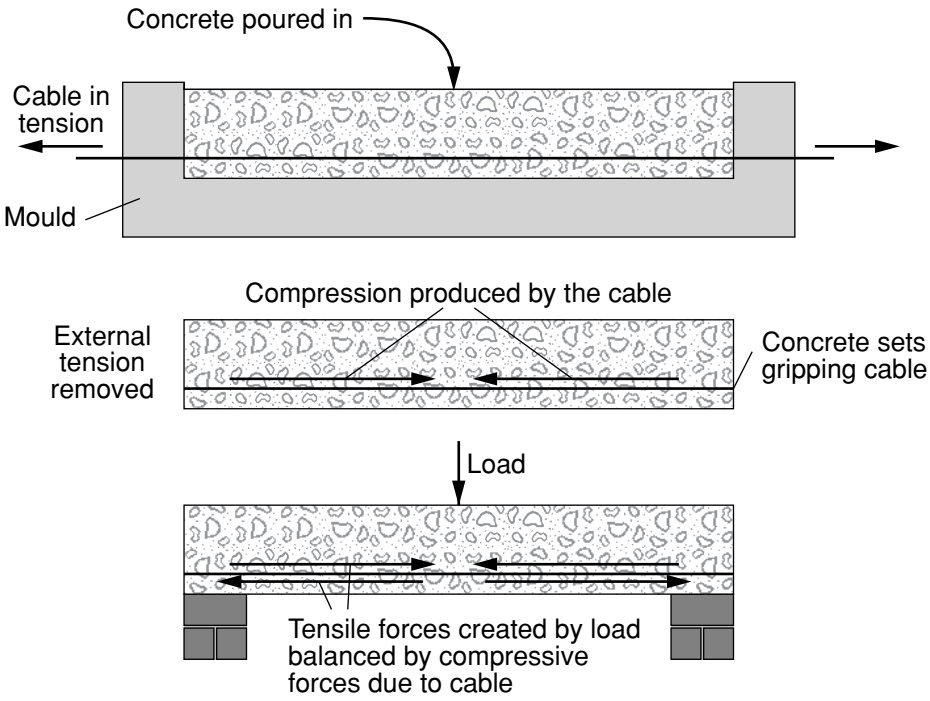


Figure 3.47 The principle of pre-tensioned concrete

Pre-tensioning closes cracks that occur during curing of the concrete and greatly increases the waterproofing qualities of the structure. Load bearing qualities are also improved allowing a reduction in the size of sections required. Prestressed items are normally pre-cast and may include structural beams used in bridges and in floor beams in buildings.



The following experiment demonstrates the effects of pre-tensioning on structures.

You will need:

- two identical moulds, for example fruit juice or UHT milk containers
- two skewers or kebab sticks
- a casting medium, for example a mixture of sand and PVA glue or any brittle casting medium such as plaster or ice
- elastic – either a few big bands that can be cut to make a length or continuous elastic normally used for dressmaking
- a pile of clay bricks.

Carry out the following steps.

1 Reseal the end of the used tetra briks then cut one of the large faces out to provide access to the moulds.

2 Put one mould aside, and mark a line 6 mm up from the bottom on each end of the other mould.

3 Make four or five equally-spaced small slits along these lines. (The number of slits will depend on the width of the mould and the size of the cross-section of the elastic).

4 Mark 20 mm up from the bottom on the inside of each mould.

5 Cut the elastic into four or five pieces, one for each slit.

6 Tie one end of each piece of elastic to a skewer kebab stick. (This will just help to spread the load).

7 Thread the elastic pieces through the slits at one end then stretch them along the mould and feed them through the corresponding hole. Tie the elastic pieces in a stretched condition (really stretched), to the other stick.

8 If you are using a dry casting medium you may wish to fill the mould up to the slits before inserting the elastic. If you are using a wet casting medium, stretch the elastic before filling the mould.

9 Fill both moulds up to the 20 mm mark and allow them to set (they must both be the same thickness).

10 When the casting medium has started setting, cut the knots on the end of the elastic and let the setting continue.

11 Once the moulds are set, cut the mould away from each.

Testing:

- Support the beam on top of two bricks.
- Gently place bricks across the centre of the moulding/beam, one at a time.
- Compare the number of bricks required to cause failure in each moulding.

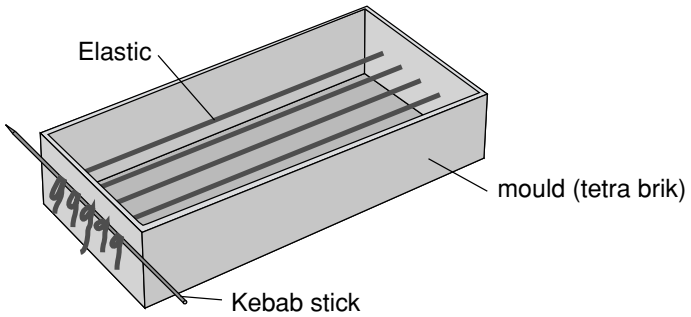


Figure 3.48 Pre-tensioning mould

Post-tensioning

Concrete is cast, either as a complete member or in pre-cast segments, with longitudinal holes or ducts left where tendons can be placed. The tendons are anchored at one end and stretched by hydraulic jacks at the other end. Before the jacks are removed, the stretched steel tendons are locked into position at the jacking end.

The compression force from the stretching of the wires is transferred to the concrete. The gap between the wires and the duct is filled with mortar injected under pressure.

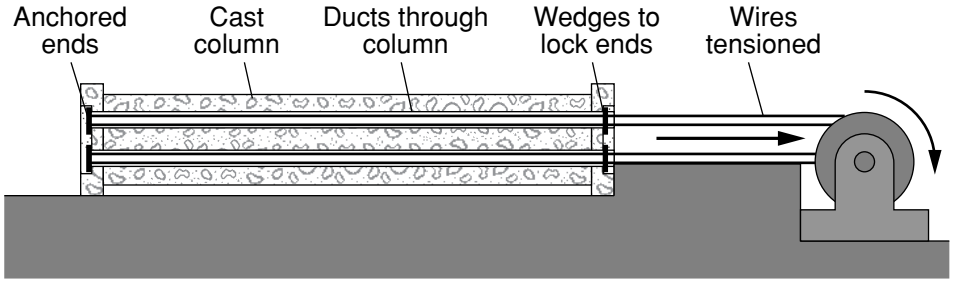


Figure 3.49 Post-tensioned concrete

This method is useful for assembling pre-cast segments that are made off-site and assembled on supports before post-tensioning into a single cohesive structure.



The following experiment demonstrates the pre-casting of a structure in segments.

The separated cells from an egg carton could never be individually used to bridge a wide gap. If a tendon is used to connect the cells, a type of post-tensioned beam can be constructed.

You will need:

- an egg carton.
- scissors
- length of elastic
- two paper-clips or short lengths of a kebab stick to act as anchors.

Carry out the following steps.

1 Separate the lid from the egg carton

2 Cut between each cell on the base of the carton.

3 Make a hole in the bottom of each of the egg cells using the scissors.

4 Tie one end of the elastic around one of the anchors. Thread the other end through the holes in the bottom of the cells. The cells must be arranged face-to-face then base-to-base.

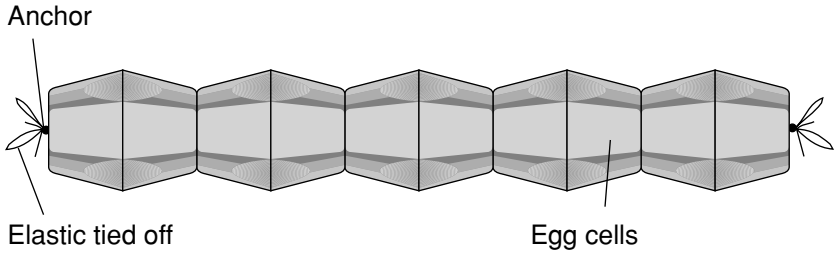


Figure 3.50 Post-tensioning experiment

5 Once the elastic is threaded through all the cells, stretch it as tight as possible. Tie it around the other anchor.

You should now have a beam that will span two supports. The more you tension the elastic, the more rigid the beam will become.

Explain the effect of moving the elastic closer to the lower surface of the composite beam.

_____

_____

Did you answer?

When the elastic is moved towards the bottom, it should be more difficult to bend the beam when it is loaded on the top surface.

Slip forming

Concrete cast in situ can be cast in a continuous set of forms. Originally developed for the casting of wheat silos, it has been used with success for casting stairwells and lift shafts in high rise buildings. A continuous slip forming system is also used for casting concrete kerbs on roadways.

Tilt up

In the tilt up process the concrete floor slab is used as the casting bed. Wall sections are then cast, with no horizontal joints. After they have cured, these load-bearing panels are lifted into position by crane and anchored to reinforcing rods left protruding from the floor.

Turn to the exercise section and complete exercise 3.6.

Glass reinforced concrete

Glass fibre reinforcement can be used with standard concrete mixes. This composite is non-corrosive, light in weight, is easy to form, cut and shape and is non-combustible.

Wood

The term wood applies to the composition of wood elements in its natural state, while timber refers to the solid wood sawn for construction purposes.

Structure

Wood is a naturally occurring composite material composed mainly of:

- **cellulose** 60%
- lignin 28%
- sugars 12%

The **lignin** is organic cement that binds the cellulose fibres together. Because the fibres are aligned along the grain, timber has a much greater strength along than across the grain.

The cross-section of a tree reveals a number of common features with two obvious components, the heartwood and the sapwood. The heartwood at the centre is composed of dead cells that are relatively resistant to decay and insect attack. The sapwood is not as dense or resistant as the heartwood but generally has similar strength.

There are two classes of woods that are grouped by structure rather than mechanical properties. Hardwoods normally have broad, flat leaves, irregular branch patterns and a complex cell structure including very large cells known as vessels or pores. Eucalypts are hardwoods. Softwoods generally have needle-like leaves, regular branch arrangement and a simpler, single type of cells known as trachieds. Pines are softwoods.

Properties

Wood is easy to handle, work and join. It has an excellent strength-to-weight ratio and a high modulus of elasticity. While it is a good thermal insulator it softens under heat allowing it to be bent and shaped. Most importantly wood is a renewable resource that, as it grows, consumes carbon dioxide (CO_2), a bi-product of our energy-dependent world.

Wood is combustible and as an organic product will revert to its components through fungal and insect attack. Its strength is variable due to imperfections, so large sections must be used and it will shrink and swell due to changes in the moisture content of the environment.

For centuries timber has been used as a basic construction material for civil structures. The simple beam bridge shown in figure 3.51 was built in the 1830s and is still in use on the Old Northern Road between Central Mangrove and Wollombi. The simple construction technique can be clearly seen.

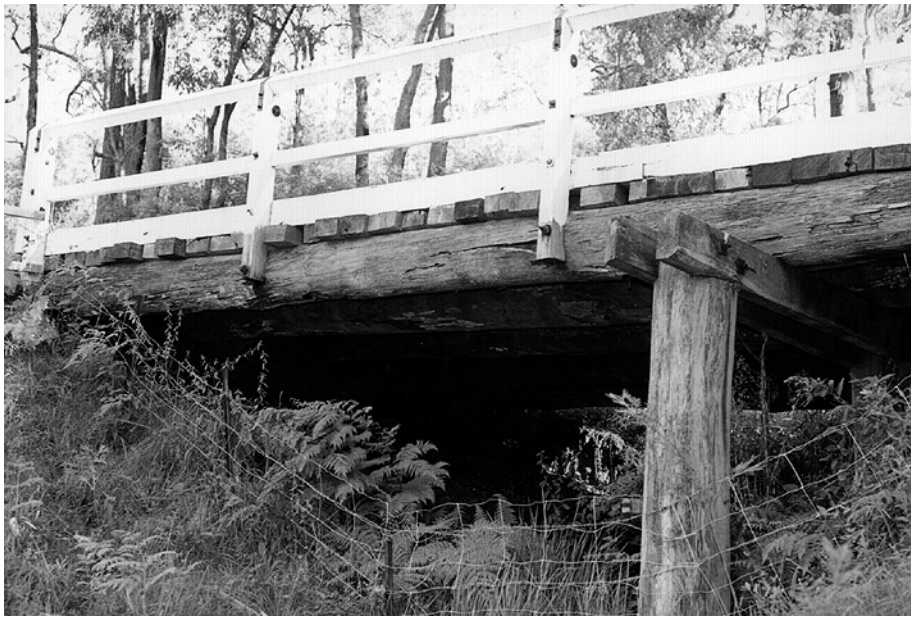


Figure 3.51 Simple timber beam bridge

Due to the strength limitations of wood, truss bridges were also common. This allowed greater distance between pylons. When iron and steel became available in limited quantities, composite trusses were built with the metal used for the tension members and large sections of timber for the short members under compression. Theoretically, timber is stronger in tension than compression but the presence of knots and other irregularities greatly reduces its strength.

The Roads and Traffic Authority still services many timber beam and truss bridges on public roads throughout NSW. It is still considered economically viable to maintain these structures rather than replace them with new concrete bridges.

Timber community buildings were also commonplace in the early colony. The church shown in figure 3.52 was built in 1832 near Camden and is still in use. It is clad in vertical, hand-cut slabs of local eucalypt.

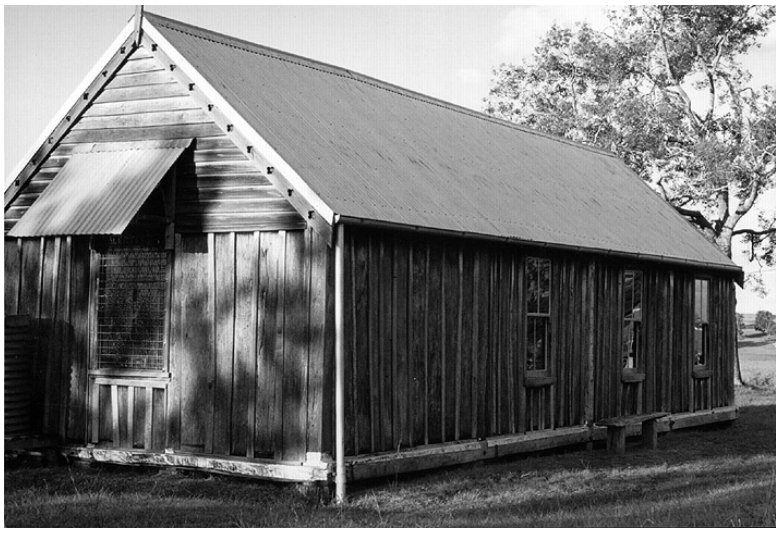


Figure 3.52 Early timber church

Timber is still used in many new civil structures both as a component of interior design and as a construction material. For example, Parliament House in Canberra uses many different timbers and timber products to create a warm and rich interior in a large and spacious building.

List the ways in which timbers and timber products are used in local community buildings as part of the interior design. This could include exposed beams and panelling.

_____

_____

Did you answer?

In simpler community buildings, timber is still commonly used for floor and wall frames, beams, flooring, lining and roof trusses.

Previously much of the construction timber used in Australia was cut from the native pine forests of Canada and the USA. Currently, much of the timber used is milled from plantations in Australia and New Zealand. As the large sections of timber that once came from mature trees are in short supply, composite beams made from timber, metal, or combinations of timbers and metals have been developed.

There is very little timber used in bridges today but solid timber formwork and plywood are used to form moulds into which concrete is cast.

Composites of timber

Laminated beams

Laminated beams are thin boards or planks that are glued face-to-face with strong glues binding them. Knots and other defects are removed from the raw materials and care is taken that butt joints in long beams are supported by adjacent laminates.

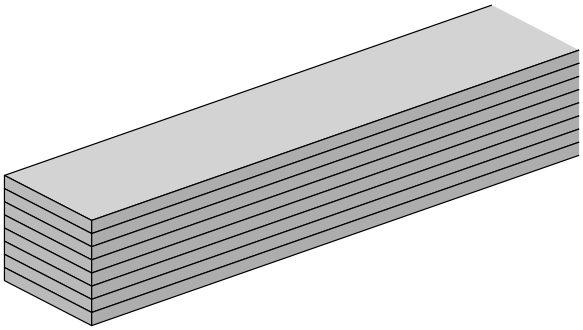


Figure 3.53 Laminated beam

The beams can be made as thick and as long as needed and can be made in arched shapes to support the roofs of large halls and stadiums. Two metre thick beams, 100 m in length are common. Transportation to the construction site is the only limitation on size.

Plywood

Plywood is made from an odd number of wood veneers, that is, thin slices of timber about 1–2 mm thick, that are glued so that the grain is at right angles in each alternating ply.

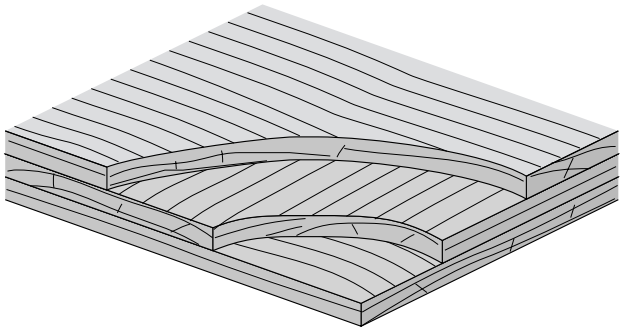


Figure 3.54 Plywood structure

This overcomes the inherent weakness due to the directional properties in timber and therefore is stronger than timber of the same dimension.
It can be bent, cut and joined easily and expensive face veneers can be used over basic cores. Large sheets can be made and with appropriate glues and surface coatings it can be made waterproof.

Plywood is used extensively for formwork when casting concrete bridge sections and for flooring, bracing and lining in community buildings. For example, the halls and pavilions at the Sydney showgrounds use laminated beams, composite timber/metal beams and plywood panelling. Some of this ply panelling has a special surface treatment to improve its sound dampening qualities.

Particle board

Particle board is made when a mass of softwood woodchips, from coarse sawdust to flat shavings, is bound with resin into flat sheets under heat and pressure. The board produced has no directional properties and is generally unsuitable as a structural material. It may be used as a core for timber veneers or plastic laminates for fitting-out buildings and is often used as a flooring material.

Fibreboard

Fibreboard is made from woodchips which are ground or exploded into a fibrous pulp, which is then pressed, with a thermosetting resin, into sheets. It is denser than particle board and therefore stronger and not as easily affected by moisture. It is also used as a core for other laminates but is used in its raw state for wall linings and trimmings. It can be shaped into ornate profiles and used as architraves and skirting boards.

Asphalt

Asphalt is a semi-solid, black/brown residue from the evaporation of some petroleums. It occurs naturally and has been used for waterproofing for thousands of years. Natural asphalts are rock-like and must be heated before use but the asphalts or bitumens used today are mostly refined from oil.

This plastic substance is a powerful cement, readily adhesive, highly waterproof and durable. It forms a flexible composite with stone aggregates and is unaffected by most acids, alkalies and salts. It may be liquified by the application of heat or the addition of solvents.

In civil structures it is coated on metals (aluminium) and fabrics and used as a waterproofing membrane or dampcourse. Asphalt mixes readily with gravels and sands to make flexible paving surfaces that are waterproof and make ideal roads and pavements. These asphalt pavements have excellent adhesion to many surfaces and can be laid without joints. As the material is not as rigid as concrete, the characteristics of the subgrades of the road influence the service behaviour of the pavement.

Geotextiles

Geotextiles are textiles that provide drainage, filtration, reinforcement and separation of soils in construction and civil engineering applications. Within the broad field of civil engineering, geotextiles are used to stabilise slopes and earth walls, to reinforce and stabilise subgrades on construction sites, to reinforce and reduce rutting on roads, provide a stable base under railway lines and to cap and contain land fill sites. Large geotextile bags filled with sand were used to construct an artificial reef at the Gold Coast.

Polymers such as polypropylene, PVC, high-density polyethylene and polyester are used extensively in the production of geotextiles. These thermosoftening polymers, are tough, resist corrosion, have suitable tensile strength and, when woven into a fabric, feature high tensile strengths at low elongation. The polymer is extruded or slitted into fibres that may be rolled into a mat or woven into a continuous fabric depending on the application.

A typical road construction technique involves building up the roadway on a base of compressed gravel (aggregate base) that is then overlaid with some form of paving. A common cause of road failure is the contamination of the aggregate base from the soil of the subgrade. In time, traffic and vibration force the aggregate base into the soil and allow silt and clay to move up into the aggregate. The effect in wet areas or areas with poor subgrade is even worse and the use of geotextiles in these situations greatly improves the performance of these structures.

Geotextiles are often laid in large sheets directly onto the subsoil over which a road, railway or paved surface is to be laid. The aggregate base and final surface is then prepared in the traditional way as shown in figure 3.55.

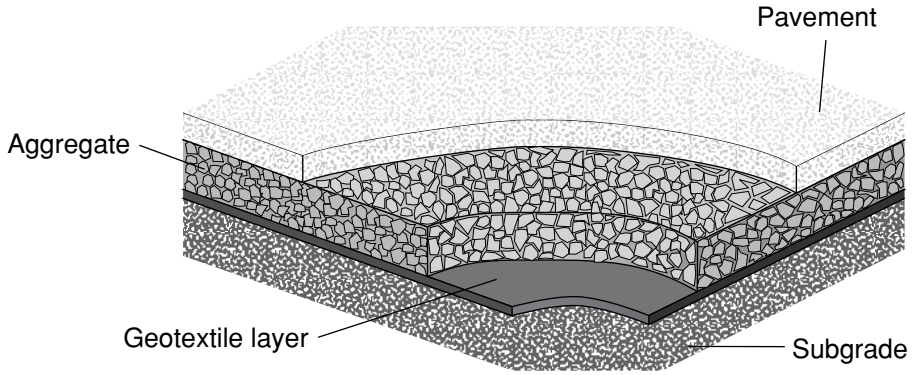


Figure 3.55 Cross-section through a sealed roadway

There are a number of applications of geotextiles in the development and construction of bridges. Today, bridges are rigid structures that commonly have an asphalt pavement laid over a concrete deck. These bridge structures move little under normal traffic load but it is common to find that the roadway on the approach to the bridge is potholed and has sometimes dropped. To help prevent this, the approach is often built up and geotextiles are used to retain the built-up soil and to provide subsurface drainage.

The retaining geotextile, shown in figure 3.56, allows and encourages the regrowth of vegetation to further consolidate the slope. The special textile used for drainage allows the movement of water while stopping adjacent soil from clogging the system.

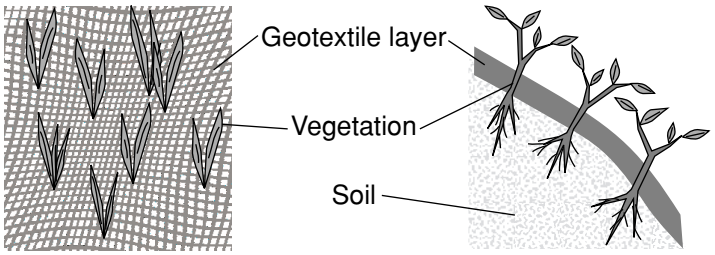


Figure 3.56 Fabric soil retaining system

Recycling

Disposal of waste materials is strongly discouraged and many materials are now reused or recycled. All civil structures have a limited life and many of the traditional construction materials can be cleaned and reused.

Used bricks and dimension stone may need to have the mortar removed but can be successfully reused either as a face material or as the base for a rendered finish. Roofing materials such as traditional slates and contemporary clay and concrete tiles can also be reused and are often in demand to repair buildings that have been damaged in storms. Clay-bodied materials such as bricks and tiles are also crushed and used in landscaping.

Timber can also be reused. The care required in removing the timber and the labour involved in extracting nails often means it is only cost-effective to recycle rare timbers in demand for reproduction and recycled furniture. While there is a ready supply of construction grade timber, as is currently available from the plantation pine forests of Australia and New Zealand, it is unlikely that standard construction timber will be widely recycled or reused.

Sheet glass can be reused in its original condition, however, it is more likely to be crushed and used as raw material in the manufacture of new glass products. Solid wastes including tyres, mixed plastics, wood flour and even sewerage sludge can be mixed with resins and then cast, moulded or extruded into new construction products. The material produced by this process is hard and tough yet light-weight and stable.
It resists corrosion and attack by insects, is easily machined and holds screws and nails just like timber.

Most metals are either reused or recycled. Steel beams are often reused in a new application and other steel items such as roofing and railings are recycled to make new steel products. Other recycled metals used in civil structures include lead and zinc (flashings), copper (electrical and plumbing) and aluminium (window and door frames).

Although neither asphalt nor concrete can be reused, they can be recycled. A large industry exists in recycling both these materials with both fixed and transportable plants crushing both materials into smaller pieces. This crushed material is reused as aggregate base in new road constructions and in other applications where aggregate is used.



a Describe a method that could be used to remove steel reinforcement from the crushed concrete.

_____

_____

_____

_____

b List construction materials that could be recycled or reused in a community building in your local area.

_____

_____

_____

Did you answer?

a Long lengths of reinforcement would probably be cut away from large pieces of concrete and removed manually. As the concrete was crushed into smaller pieces, the smaller lengths of reinforcement could be sorted from the concrete using large magnets.

b Some of the following materials could be recycled or reused in a building:

- timber flooring, timber footing, roof trusses
- joinery (windows and door frames)
- bricks
- slate, tile or iron roofing
- some finishes, such as granite or resin finishes
- concrete used in footings and in the main structure
- structural steel framing.



Turn to the exercise section and complete exercise 3.7.

Corrosion

Corrosion is the deterioration of material due to chemical changes caused by interaction with its surroundings. While it typically refers to the conversion of a metal to its oxide or other compound, the action of the atmosphere on other materials such as stone, glass, concrete and timber can also be called corrosion.

Civil structures are situated in a range of environments where the potential for corrosion differs. To minimise potential corrosion, individual situations are assessed and the most effective solutions introduced.

This may involve the use of special materials, the surface protection of different components and the appropriate design for each situation.

The fitting of a metal roof to a large timber-framed community hall is an example of a simple design choice to combat corrosion. Timber battens are attached to trusses and the sheet metal roof is screwed to these battens. The steel screws used to hold down the roofing sheets are exposed to the elements and therefore must be plated and/or painted. The nails used to attach the battens to the trusses are made from unplated mild steel as most of the nail is protected by the timber surrounding it and the heads are only exposed to the dry, non-corrosive atmosphere of the roof cavity.

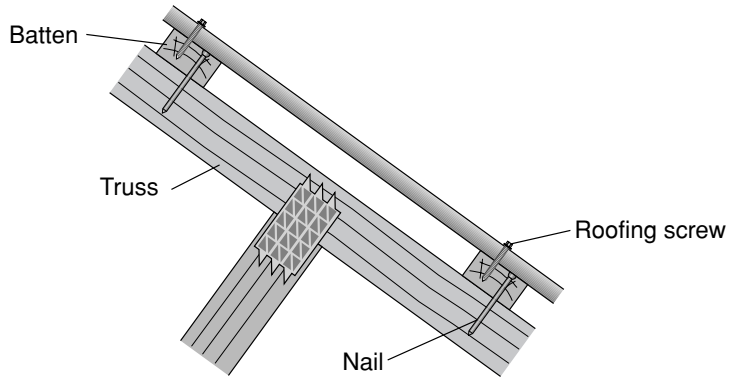


Figure 3.57 Section through a roof structure

Another simple example may be found in the metal lintels used to support the bricks over windows and doors in brick buildings. Traditionally, arches were used as supports. An arch places all the bricks under compression and provides sufficient strength for the brickwork to be continued above the opening. An increasing appreciation for the tensile strength of steel resulted in the use of painted mild steel bars or angles. In certain environments, these bars corroded so badly that the rust caused the bar to swell and in some cases caused cracking of the brickwork at the top corners of the openings. The only way to remedy this problem is to remove the affected bricks and to replace the bar.

Metal lintels used today are still made from steel but are galvanised (coated in zinc). If you were building a new surf clubhouse you would probably choose stainless steel (alloy steel) lintels. While these are more expensive, they are less likely to corrode in the salt-filled environment.

Traditional bridge building materials such as timber, stone, steel and concrete are all subject to corrosion under different environmental conditions. You might consider the corrosion of exposed timber and steel to be a problem without a solution, but even the massive steel Sydney Harbour Bridge has an indefinite life given the right treatment. The 485 000 square metres of steel in the bridge takes around 3 000 litres of paint per coat and due to the maintenance program none of the 6 000 000 rivets in the bridge have needed to be replaced since it was built in 1932.

Some imagine that the increasing use of reinforced concrete for structural members virtually removes the problem of corrosion. While this is true to some extent, figure 3.58 clearly shows the problem of **spalling** that occurs when the reinforcing steel corrodes. The products of the corrosion of steel can occupy up to seven times the volume of the parent steel, so the swelling of the corroding steel reinforcement will eventually cause the top layer of the brittle concrete to split off.



Figure 3.58 Spalling in a reinforced concrete post

Failure to treat this situation will lead to a substantial lowering of the strength properties of the reinforced concrete structures.

Principles of corrosion

To better understand the role that corrosion plays in the design, development and maintenance of civil structures, it is important to consider some of the basic principles related to corrosion.

There are two basic types of corrosion which attack metals:

- chemical corrosion
- electrolytic corrosion.

Chemical corrosion

Simple chemical corrosion typically occurs in a dry environment. Metals can react with a variety of chemicals to produce new substances that do not have the structural properties of the metal. Chemical corrosion occurs when the metal reacts directly with substances with which it comes in contact.

The most common form of chemical corrosion occurs when oxygen in the atmosphere combines with the metal to form a film of metal oxide on the surface. This metal oxide film is normally an ionically bonded ceramic. If this film is porous it will allow water and more oxygen to pass through so that the corrosion can penetrate deep into the metal.
If the oxide film rubs off easily, the process of oxidation will continue more rapidly and the metal will eventually corrode away.

The overall reaction of iron corrosion is represented by the following equation.

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$



Complete the equation below which represents the oxidation of aluminium.

$$Al + O_2 \rightarrow Al_2O_3$$

Did you answer?

$$4Al + 3O_2 \rightarrow 2Al_2O_3$$

Aluminium and stainless steel oxidise easily but the oxide film resulting from corrosion is dense and bonds tightly to the surface. As a result, the film acts as a protective layer for the metal beneath, as shown in figure 3.59.

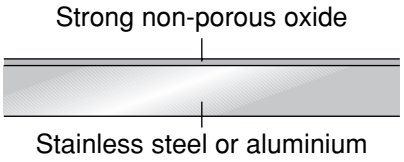


Figure 3.59 A protective oxide layer

In contrast, mild steel has a weak, porous oxide film (rust) which flakes off easily. This allows corrosion to continue deep below the visible surface, as shown in figure 3.60.

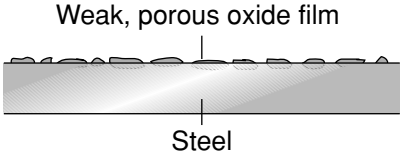


Figure 3.60 Porous rust layer on steel

Pure metals such as gold, silver and copper remain unoxidised due to their low chemical reactivity as well as their purity.

Electrolytic corrosion

Electrolytic corrosion is a complex form of chemical corrosion that normally occurs in a wet environment.

To understand this you can examine the process in a simple electrolytic cell, shown in figure 3.61. An electrolytic cell is made up of two dissimilar metals that are connected by a conductor, with both metals immersed in the **electrolyte**. The most reactive metal is called the **anode** and least reactive the **cathode**. The ions will move from the anode to the cathode.

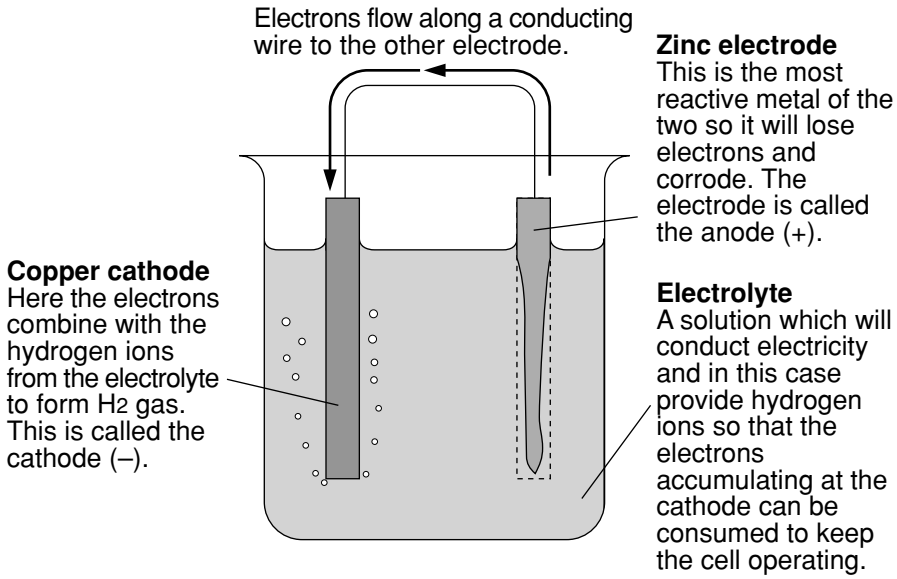


Figure 3.61 A simple electrolytic cell

If the electrons keep moving, the anode will corrode. The electrons can only flow if the electrolyte is present and the connection between the electrodes is maintained. This represents a closed loop through which the electrons can travel. This is known as a circuit**.**

In the previous example, the electrodes used are made of copper and zinc and the zinc electrode is corroded. This will occur whenever zinc and copper are coupled in this way due to the difference in electrode potential between the two metals. The reactivity of metals, relative to a standard hydrogen electrode, is represented on the Standard Reactivity Series and the voltages associated with this series allows the engineer to anticipate the rate and vigour of reactions that will occur between metals in contact.

Standard Reactivity Series
Potassium (most reactive)
Magnesium
Aluminium
Manganese
Zinc
Chromium
Iron
Cadmium
Nickel
Tin
Lead
Hydrogen
Copper
Silver
Platinum
Gold (least reactive)

This table can be used to predict how certain metals and combinations of metals will corrode. It is fair to assume that metals grouped close together will be safe to use together. However, other factors such as the sizes of anodes and cathodes and any changes to the environment may alter the expected results.

An example of electrolytic corrosion is the rusting of unprotected steel building components. These components rust quickly in coastal locations due to the presence of salt in the moist air. The salty, moist air acts as an electrolyte. In the hot, dry outback, building components do not rust as quickly. This is because there is no electrolyte present.



The following experiment demonstrates the effect of corrosion on zinc-plated steel and tin-plated steel.

You will need:

- the washed lid from a food can
- a zinc-plated nail or screw
- a saltwater solution
- a hacksaw or other hard-cutting edged tool
- two plastic containers, such as ice-cream containers.

Carry out the following steps.

1 Scratch through the tin coating across the diameter of the lid using the hacksaw.

2 Scratch through the zinc coating on the nail or screw.

3 Place each individual component in a container and cover it with the saltwater solution.

4 Leave the containers in the sun and regularly agitate the container.

5 Observe what happens at the scratch marks on the lid and the screw or nail over the next week.

6 Record the results

Object	**Observations**
Lid	
Nail/screw	

Repeat the experiment using boiled tap water instead of the saltwater solution. Compare the results of the two experiments.

Did you answer?

You should have found that the steel in the screw didn't appear to corrode at all while rust appeared on the scratch mark on the lid. This is because zinc is above iron on the reactivity series so the zinc corrodes in preference to the steel. However, iron is above tin on the series so the lid will corrode. You should have found that corrosion was slower in the boiled water. This is because the solution isn't a good electrolyte and doesn't let the circuit flow as easily.

The corrosion of mild steel involves both chemical and electrolytic attack. The oxide of iron is porous and weak and so will flake off to expose the surface below. This results in further oxidation. Electrolytic corrosion also occurs in mild steel due to the different phases (ferrite and cementite) as shown in figure 3.62.

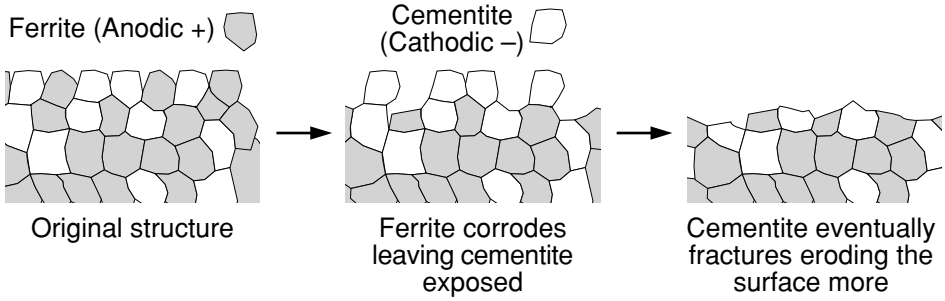


Figure 3.62 Intergranular corrosion in pearlite

Ferrite is anodic to cementite, therefore the ferrite will corrode away leaving cementite exposed. Cementite is brittle, so the exposed layers will break away, eroding the surface of the metal.

As both aluminium and stainless steel are single-phase solid solutions, they are protected by the oxide film, as well as the lack of dissimilar phases within the metals. This prevents the formation of the microscopic electrolytic cells which form in multi-phase materials.

Stress corrosion

Stress corrosion can occur in both dry and wet environments in any situation where there is a variation in the stresses in a component. For example, folded or bent areas of cold worked metals become anodic and readily corrode. Welded joints are also subject to this form of corrosion. The stresses induced due to the uneven cooling of the weld will cause corrosion on the edges of the joint.

At the simplest level, the grain boundaries in metals are more highly stressed than other areas of the grain and corrosion will more readily occur at these anodic areas of the metal's structure. This process is known as intergranular corrosion.



The following experiment demonstrates the effect stress has on corrosion.

You will need:

- five unplated mild steel nails (bullet or flat heads) 50–100 mm long.
- one galvanized nail – the same size as the unplated steel nails
- saltwater solution
- boiled water
- two pairs of pliers
- a length of wire, preferably copper or an unfolded paperclip
- six glass or plastic containers
- abrasive paper or steel wool.

Carry out the following steps.

1 Clean the unplated nails with steel wool, a scourer or abrasive paper.

2 Immerse one nail in a container of saltwater solution.

3 Immerse one nail in a container of boiled water.

4 Stand one nail in a container and half cover with saltwater solution.

5 Bend one nail in half, to induce stress at the bend, then cover with saltwater solution.

6 Twitch (twist with a pair of pliers) a short piece of wire around a steel nail and the other end around a similar-sized galvanized nail.

7 Cover both with solution, agitate and heat the containers to accelerate the reactions and observe any changes that take place over the period of a week.

8 Record your results.

Specimen	**Observations**
Specimen 1	
Specimen 2	
Specimen 3	
Specimen 4	
Specimen 5	
Specimen 6	

You have probably observed that:

The saltwater environment promoted corrosion, while little corrosion occurred in the boiled water due to the purity of the water.

The half-covered nail was like a steel pier on a wharf.



Have you noticed how corrosion of steel piers occurs more readily at the water line?

Stress points like the bend in the nail and the cold-formed head corroded more readily.

When the two nails were coupled together, the zinc corroded first and protected the steel.

Minimizing corrosion

Surface coatings include paints, oxide films and metallic and ceramic coatings. Most of these attempt to isolate the metals from the electrolyte, that is, provide a physical barrier. Some will provide both chemical and physical protection, for example, zinc sprayed onto iron.

Paints

Paints require regular maintenance. If the film is broken for example by scratching or flaking, the area will corrode much more rapidly than if the whole surface was left exposed.

Oxides and other films

One well-known corrosion-resisting oxide film is anodising on aluminium. Anodising is produced by electrolysis. The aluminium is connected to an electric source which causes the aluminium to oxidise at a faster than normal rate. Colourful pigments are then used in the Al_2O_3 layer to decorate the item. Examples of anodised aluminium can be seen in window and door frames.

Phosphoric acid is also used as a dip to remove rust from iron and steel. This leaves a thin, insoluble corrosion-resistant film of iron phosphate in preparation for coating the steel with paint.

Metallic coatings

Metal coatings can be applied using a number of techniques.

Hot Dipping

In this process the metal to be coated is cleaned in an acid pickle bath and then dipped into a molten metal such as zinc, tin, cadmium, lead or aluminium.

Electroplating

This is an expensive process in which metals such as gold, silver, nickel, chromium, copper, cadmium, tin and zinc are electrolytically deposited onto the article. The item coated is the cathode in the cell, while the metal being deposited is the anode. This method has the advantage that the item is not heated so previously heat-treated components are left unaltered.

Cladding

In this process, one metal is sandwiched between sheets of the coating material and the sandwich is then rolled to the required thickness. This rolling welds the metals together. The best known example is 'Alclad'. It is made up of corrosion-resistant aluminium clad to strong but reactive duralumin.

Sherardising

In this process the item to be coated is heated to around 370°C. Zinc powder is then deposited on the surface of the heated component.

This process is used for coating parts such as nuts, bolts and threaded components which would otherwise become clogged during normal hot-dip galvanizing.

Spraying

This process involves the coating of parts with a wide range of molten metals. Zinc is the metal most often used.

An arc of electricity melts zinc electrodes and the molten zinc is then blasted by air onto the surface to be coated.

This process is used for large structures such as bridges and building frames.

Galvanic protection (cathodic protection)

This method places the metal to be protected in close (electrical) contact with a metal that is far more reactive.

The more reactive metal corrodes and protects the metal. The reactive metal that is being eaten away is known as a sacrificial anode.

The galvanisation of mild steel is the best example of this method. Zinc, the most reactive metal of the two, forms the anode. Electrons move from the zinc to the scratch via the mild steel and combine with hydrogen ions near the scratch to form bubbles of hydrogen gas. Remember, the electrolyte completes the circuit.

The hulls of ships, underground pipelines and steel pylons on bridges are often protected in this way. If you see a metal hull boat on a slipway, look for the small ingots of zinc securely fixed to the hull near the propeller shaft. These are the sacrificial anodes that protect the hull from corrosion.

Ceramic coatings

Ceramic coatings are applied to the surface in powder form and then fused onto the metal base by baking at high temperatures. This provides a smooth, colourful, non-porous and highly protective coating for metals.

Used in glass-lined hot water tanks, enamel for stoves, washing machines, saucepans and bath tubs.

Impressed voltage

Another method of protecting metal from corrosion is by impressed voltage. This is achieved by connecting a battery in such a way that it causes electrons to flow into the material requiring protection. This replaces the electrons that would otherwise be lost by the metal during corrosion. The metal remains intact and does not form other compounds such as rust.

Corrosion common in civil structures

Uniform attack

Steel contains the two phases ferrite and cementite. Electrolytic action between these two phases can produce corrosion over the surface of sheet steel. Coating the surface of the steel will exclude the electrolyte from the surface and prevent corrosion.

In the past, steel trusses of large civil structures, such as bridges, were protected with lead-based paints. The hazards associated with the removal and disposal of lead-based paints, including health threats to workers and the leaching of waste lead materials, has caused the engineering community to look for new coating systems. Many different systems are currently in use and their effectiveness is constantly evaluated.

Concentration cells

When a single piece of metal, or joined pieces of similar metals, are exposed to an electrolyte that varies in its composition the area near the more dilute electrolyte will corrode. This can also produce pits on the surface of a metal.

Water seeping under a surface finish or into a crack or seam will inevitably contain less dissolved oxygen than the water exposed to the atmosphere and a concentration cell and subsequent corrosion will occur.

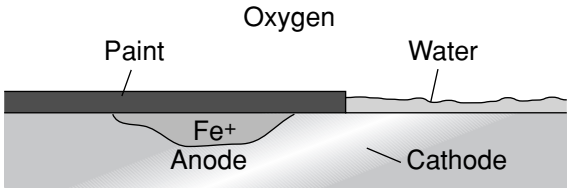


Figure 3.63 Painted metal

Looking at figure 3.63, it appears important that the painters on the Harbour Bridge clean off all flaking paint so that the new coating sticks well to the metal surface and doesn't provide voids that could hold water.

Figure 3.64 shows crevice corrosion that can occur on any civil structure where two plates are joined. If possible, this joint should be welded with a continuous weld or at the very least a sealant or coating used to prevent the entry of water.

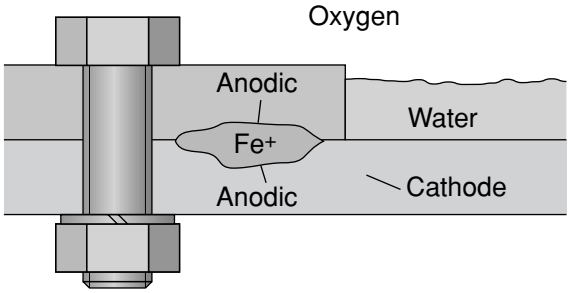


Figure 3.64 Overlapping plates

Differential aeration

Differential aeration will occur on the steel pylons of bridges. As the oxygen level is lowest under the water where the pylon enters the bed of the river this area will become the anode and a ring of rust will accumulate near the water line as shown in figure 3.65. A sacrificial anode at the lower end of the pylon will slow this process. However, the use of reinforced concrete or stone pylons is a better design solution.

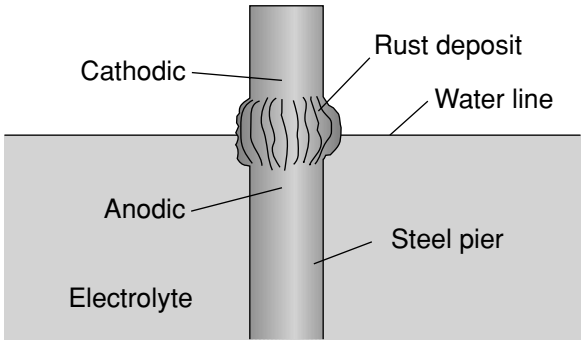


Figure 3.65 Corrosion on a steel pier

Composition cells

Corrosion can occur between any two dissimilar metals and composition cells can be used to protect a component, as in the case of a sacrificial anode. Unfortunately, poor practice sometimes means this type of corrosion causes damage to civil structures.

For example, lead flashing is inappropriate for a steel roof with an alloy coating of zinc and aluminium as it causes corrosion. Zinc is a better material for this situation.

As engineers are conscious of the effect of this type of corrosion, it is unusual for cells of this type to occur in the design of civil structures. It is often a temporary fitting, repair or poor construction technique that causes corrosion of this type.

Corrosion in concrete

A combination of factors produces deterioration in concrete, often resulting in a spalling effect. Electrolytic corrosion occurs when the steel reinforcing or tendons become the anode and chlorides in water act as the electrolyte.

A number of initiatives may be taken in new constructions to prevent this process. Probably the most important is ensuring the steel is embedded deeply enough so the chemicals from the surface can't reach it. Other effective strategies to prevent corrosion include keeping the cement/water ratio below 0.4, having a high cement content, careful design to prevent cracking and the use of chemical additives.

Research into the protection of existing reinforced concrete structures is ongoing. Successful techniques include:

- using induced voltage to provide cathodic protection for the steel reinforcement
- sealing the surface to prevent water entering the structure
- electrolytic removal of the chloride ions from the concrete through the use of a DC current.

Advances in this type of technology have enabled bridges to be constructed from different fibres and polymers.

Weathering of stone

Although stone does not corrode in the same way as steel, any exposed material will eventually weather and break down into its components. Fortunately, under normal environmental conditions, this is an extremely slow process, so most civil structures have a long life expectancy.

Of course, there are differences between the properties of stones. Some of the sandstones used in civil structures in early NSW have not weathered as well as others. This may be due to the make-up of the stone or because of adverse conditions such as wind and rain or wear, for example wear in the middle of stone steps. Polluted rain containing a cocktail of chemicals can also accelerate the weathering of stone structures.

Society values the engineering feats from our recent past and a thriving industry has developed around the restoration of stone structures. This has seen a resurgence in the age-old craft of the stonemason and has seen restoration of many of the early community buildings that can be found throughout our major cities and towns.

Breakdown of timber

If a tree were to fall in the bush, it would be reduced to its original chemical ingredients through the action of living scavengers such as boring insects, fungi and bacteria. When timber is used for construction, these scavengers are regarded as pests.

Pests

The most common insect pests in Australia are termites or white ants. These pests go to great lengths to find timber to eat and are known to build a long maze of tunnels from their nests, to provide a ready source of food. Chemicals sprayed into the ground were once widely used to prevent attack from termites, but as the residual effects of these chemicals have become apparent, alternative solutions have been developed. Mechanical barriers such as ant caps have long been used, but crushed granite, stainless steel mesh and traps are all newer devices that are used.

Native timbers, like Jarrah and Brush Box, are known to resist termites and other borers, though Turpentine is the preferred timber for wharf piers and is used with the bark.

Fungi

The best known effects of attack by fungi and mould are dry-rot and wet-rot. The fungus responsible for dry-rot lives in damp, poorly ventilated conditions and appears as a dark furry mass with branching tendrils. Affected timber becomes discoloured and appears dry and shrunken.

Wet-rot occurs in very wet conditions. A pale green scum first appears that soon turns brown and eventually black.

Preserving timber

Some Australian timbers, such as cypress pine, are known to resist attack by termites. When the correct insect-resistant hardwood is used, piers for bridges or wharves can be sunk straight into the ground with no concern of attack.

Common types of preservatives include the application of:

- tar/oil derivatives, such as creosote
  - this inexpensive treatment against fungi, some insects and marine borers is useful for protecting piers and marine pylons
- water-borne solutions, such as copper/chromium/arsenic
  - this protects against insects such as termites and fungal attack and is useful for landscape fencing and power poles.



Turn to the exercise section and complete exercises 3.8 and 3.9.



Exercises

Exercise 3.1

a Complete the table by suggesting a service property, suitable material and manufacturing method for each of the components listed.

Component	Service property	Suitable material	Manufacturing method
Bridge deck			Post Tensioned
Ground cover to reduce erosion			Woven
Long roof beam			
Roofing tiles	Water resistant		
Concrete formwork		plywood	
Bridge roadway surface	Suitable friction properties		

b With reference to the forces in the towers, cables and bridge deck, suggest suitable materials for each of these components of a suspension or cable stay bridge.

Towers

_____

_____

Cables

_____

_____

Bridge deck

_____

_____

Exercise 3.2

a Sketch the normal failure pattern of concrete that has undergone a compression test.

b With the aid of a sketch, describe how an X-ray test is used to find a void in a welded joint.

_____

_____

_____

_____

c Name tests that may be carried out on a scale model of a civil structure.

_____

_____

d Describe a transverse beam test that could be applied to a timber sample and support your answer with a sketch.

Exercise 3.3

a List five different components of bridges or community buildings that are made of ceramics.

i _____

ii _____

iii _____

iv _____

v _____

b Extruded bricks are very common materials used in community buildings.

i Suggest a clay body that would be suitable for manufacturing these bricks.

_____

ii Describe the extrusion process.

_____

_____

_____

_____

iii Explain what occurs at the different stages in the firing of the bricks.

Drying

_____

_____

_____

Dehydration

_____

_____

_____

Oxidation

_____

_____

_____

Vitrification

_____

_____

_____

Exercise 3.4

a List two reasons why dried ceramic materials are hard and brittle.

i _____

_____

ii _____

_____

b Explain, why glass fibres have high tensile strength.

_____

_____

_____

_____

_____

_____

c Explain, with the aid of a sketch, the float process used for the production of sheet glass.

d Define the term viscosity.

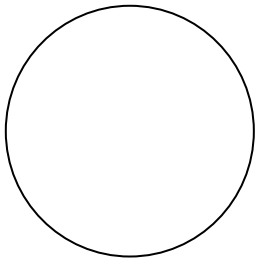
Exercise 3.5

a Explain the differences between hydraulic and non-hydraulic cements.

b List three characteristics of the aggregate that is used in concrete.

Exercise 3.6

a Sketch and label the macrostructure of reinforced concrete showing each of the four constituents.



b Explain why it is important to keep cements wet during the curing process.

_____

_____

c Describe the effect that a high water-to-cement ratio will have on the strength and setting of concrete.

_____

_____

_____

Exercise 3.7

a Define a composite material.

_____

_____

b Explain the process of pretensioning concrete.

_____

_____

_____

c Sketch and label the cross-section of a roadway that has a geotextile layer separating the aggregate from the subgrade.

d State whether the following materials can be recycled and/or reused and suggest one problem associated with the recycling or reusing of each.

i Clay bricks _____

Problem: _____

ii Reinforced concrete _____

Problem: _____

iii Construction timber _____

Problem: _____

iv Glass _____

Problem: _____

Exercise 3.8

a Timber, steel and reinforced concrete have all been used in the construction of bridges. Without repeating an answer, suggest an advantage and disadvantage of each material in this application.

Material	Advantages	Disadvantages
Timber		
Reinforced Concrete		
Steel		

b Corrosion is a consideration in the design of civil structures. Without repeating an answer, suggest one suitable method of protection for each of the components listed.

Component	Protection method
Steel to be used for roofing	
Reinforcing steel in concrete	
Aluminium for window frames	
Steel pylons in salt water	
Timber posts to be put in the ground	
External timber wall cladding	

Exercise 3.9

Select the alternative a, b, c, or d that best completes the statement. Circle the letter.

1 Tensile tests provide an indication of tensile strength and other properties such as:

a toughness, impact strength and ductility

b resilience, compressive strength and ductility

c toughness, proof stress and ductility

d hardness, compressive strength and elasticity.

2 Non-destructive tests commonly carried out on welds include:

a tensile and penetrant

b ultra-sonic and impact

c x-ray and compression

d x-ray and γ-ray.

3 The rating strength of concrete is normally measured after:

a 28 days

b seven days

c one month

d one year.

4 Arches featured prominently in the design of stone bridges and buildings. This was mainly due to:

a the relatively poor tensile strength of natural stone

b the unavailability of cements to bind the stone together

c the pleasing aesthetic lines of the arch

d the unavailability of large pieces of stone to bridge gaps.

5 Plastic clay bodies are examples of silicate structures that are in the form of :

a a framework

b a sheet

c a simple unit

d a double chain.

6 The main reason that clay roof tiles are glazed is to:

a improve the compressive strength

b provide a slippery surface

c prevent shrinkage

d reduce the surface porosity.

7 Glasses are clear because they:

a have an amorphous structure

b are covalently bonded

c are ionically bonded

d contain very small particles.

8 Softwoods are typified by the following features:

a broad, flat leaves and thin bark

b complex cells and needle-like leaves

c soft heartwood and well defined growth rings

d simple cells and needle-like leaves.

9 One major advantage of plywood over solid timber is:

a it is available in large sheets

b it is more waterproof

c expensive veneers can be put on the inside layers

d it can be bent and curved to any shape.

10 The process where zinc powder is coated on the surface of heated components such as bolts is known as:

a electroplating

b sherardising

c dipping

d cladding.



Exercise cover sheet

Exercises 3.1 to 3.9 Name: _____

Check!

Have you have completed the following exercises?

- ❒ Exercise 3.1
- ❒ Exercise 3.2
- ❒ Exercise 3.3
- ❒ Exercise 3.4
- ❒ Exercise 3.5
- ❒ Exercise 3.6
- ❒ Exercise 3.7
- ❒ Exercise 3.8
- ❒ Exercise 3.9

Locate and complete any outstanding exercises then attach your responses to this sheet.

If you study Stage 6 Engineering Studies through a Distance Education Centre/School (DEC) you will need to return the exercise sheet and your responses as you complete each part of the module.

If you study Stage 6 Engineering Studies through the OTEN Open Learning Program (OLP) refer to the Learner's Guide to determine which exercises you need to return to your teacher along with the Mark Record Slip.

Progress check

In this part you examined the materials and structure/property relationships and preservation issues as they relate to civil structures.



Take a few moments to reflect on your learning then tick the box which best represents your level of achievement.

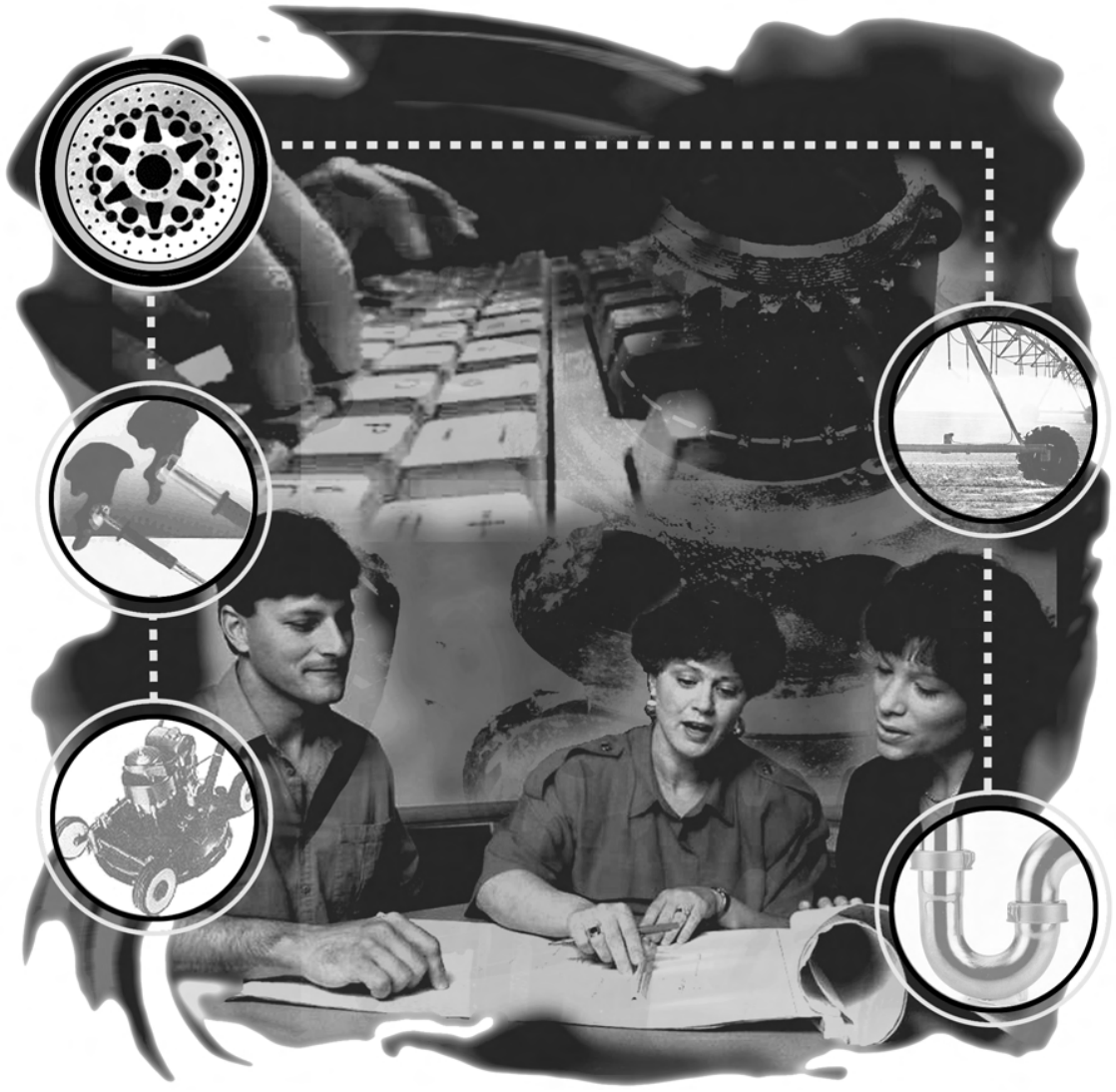
☑ **Agree – well done** ☑ **Disagree – revise your work** ☑ **Uncertain – contact your teacher**	**Agree**	**Disagree**	**Uncertain**
I have learnt about: • specialised testing of engineering materials and/or systems • the structure/property relationships and applications of different ceramic materials • different composite materials • the mechanism of corrosion and how it affects different materials • the recyclability of materials.			
I have learnt to: • describe basic testing conducted on civil structures • examine the structure, properties, uses and appropriateness of materials used in civil structures • make appropriate choices of materials and processes for use in civil structures • explain the special properties of composite materials • experiment with simple pre-tensioned and post-tensioned structures • evaluate the significance of corrosion problems in civil structures • describe methods for recycling materials when civil structures are replaced.			

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In the next part you will produce technical drawings applying appropriate AS 1100 Standards to communicate engineering concepts relating to civil structures.

Part 4: Civil structures – communications





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Introduction

In this part you will examine technical drawing techniques regarding developments of transition pieces. You will learn to construct developments of non-circular transition pieces used to join ducting in civil structures.

You will also apply Australian Standards (AS 1100) to orthogonal assembly drawings. You will draw fasteners, supports and brackets used in civil structures, applying the appropriate standards.

What will you learn?

You will learn about:

- Australian Standards (AS 1100)
- orthogonal assembly drawings
- development
  - development of transition pieces
  - computer graphics.

You will learn to:

- produce orthogonal drawings applying appropriate Australian Standards (AS 1100)
- construct the development of non-circular transition pieces
- apply graphical methods to the solution of relevant problems.

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Technical drawing

Developments



Are you familiar with the term ‘net’?

In mathematics, a net is a pattern used to make a cube, a pyramid, a cone or a cylinder from cardboard.

In engineering, a sheetmetal object is usually set out on a flat surface before it is folded or bent into shape. The pattern used to set out the shape of the sheetmetal object on a flat surface or sheet of metal is called a **development**.

Parallel development of a cube and a cylinder

Sheetmetal objects that have edges or **generators** that are parallel may be developed using parallel development.

Another way to consider a development is to imagine the shape formed when a sheetmetal object is unfolded to form a flat surface. Figure 4.01 shows a cube and a cylinder being unfolded.

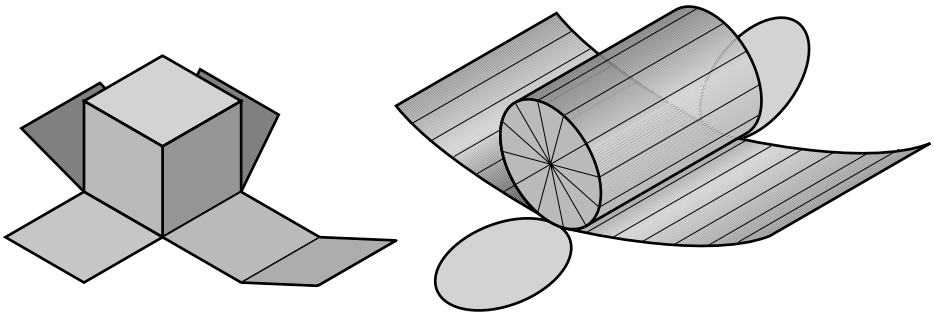


Figure 4.01 Unfolding a cube and a cylinder

Figures 4.02 and 4.03 show the developments of a cube and a cylinder. You should be able to see why the development method used is called **parallel development** – the sides of the object are developed as squares or rectangles (opposite sides are parallel).

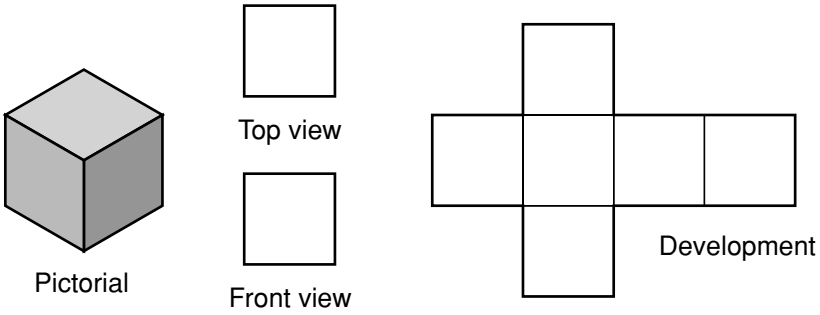


Figure 4.02 Development of a cube

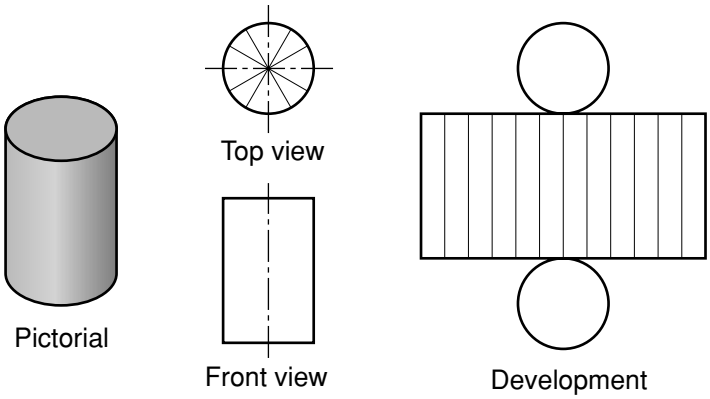


Figure 4.03 Development of a cylinder



Draw the development of a cube and a cylinder using cardboard or drawing paper then form the cube and cylinder by folding the pattern at the **fold lines**.

The use of true length

If an object or structure is to be made to a predetermined size then the development must be made to produce that size. To produce an object to a predetermined size, all sizes used in the development must be **true length**, that is, the actual length required for that object.

It is easy to determine the true lengths to use in the development of a 20 mm cube. All the edges used to form the cube are 20 mm in length, therefore, the true lengths must be 20 mm.

In your Preliminary module on Irrigation Systems you learnt two methods for determining the true length of a line:

- the rotation method
- the auxiliary plane method.

These methods may be applied to the construction of a development. The rotation method is used in figure 4.05 to find the true length of the long edge of the pyramid side. However, for more difficult developments such as transition pieces, there is a third method – the **offset method**. This method is described later in this part.

Radial development of a pyramid and a cone

Sheetmetal objects that have edges or generators that are not parallel, but meet at a point called the apex, may be developed using **radial development**.

Figure 4.04 shows a pyramid and a cone being unfolded

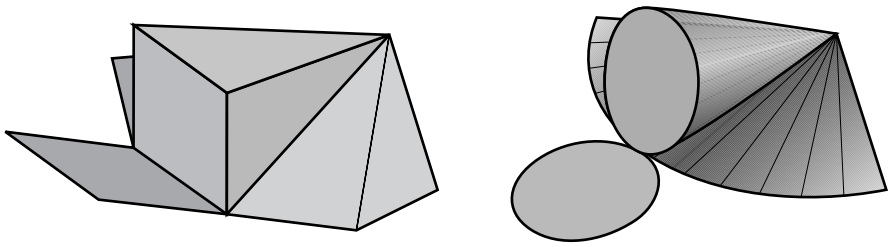


Figure 4.04 Unfolding a pyramid and a cone

Figures 4.05 and 4.06 show the development of a pyramid and a cone. You should be able to see why the development method used is called radial development – the development of the sides of the shape are centred at one point, and the length of the side edges or generators are scribed from that point.

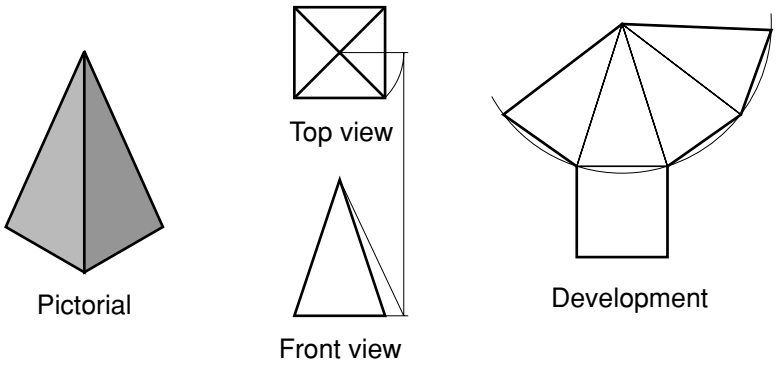


Figure 4.05 Development of a pyramid

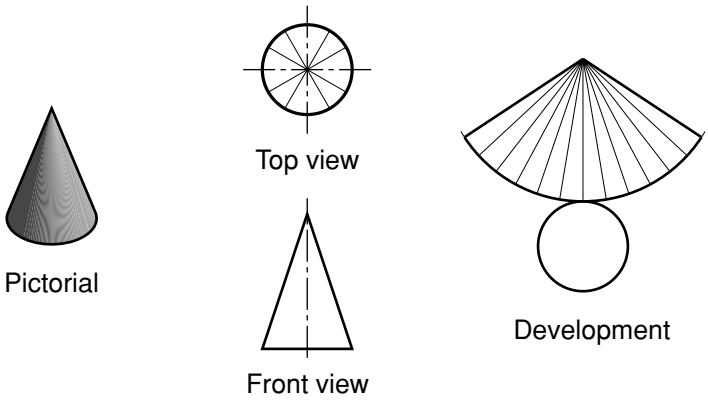


Figure 4.06 Development of a cone



Draw the development of a pyramid and of a cone using cardboard or drawing paper then form the pyramid and cone by folding the pattern at the fold lines.

Transition pieces

Civil structures such as high-rise buildings, tunnels, community halls and shopping centres all use air-conditioning. The cooled or heated air is directed throughout the structure using **ducting** to transfer the air from the air conditioner. You may have seen this type of ducting in the underground parking areas of shopping centres.

Ducting is also used in extraction systems to remove contaminated fumes or stale air from buildings. This type of ducting is visible above the cooking areas in fish and chip or hamburger shops. Many homes use ducting in stove hoods to remove cooking fumes.

Ducts are usually made from sheetmetal, usually from low-carbon steel sheets coated with zinc, zincalum, enamel or paint.

When two ducts of different size and/or shape are to be joined to form a ducting system, the sheetmetal member used to join the ducts is called a **transition piece**. Figure 4.07 illustrates the use of transition pieces in ducting.

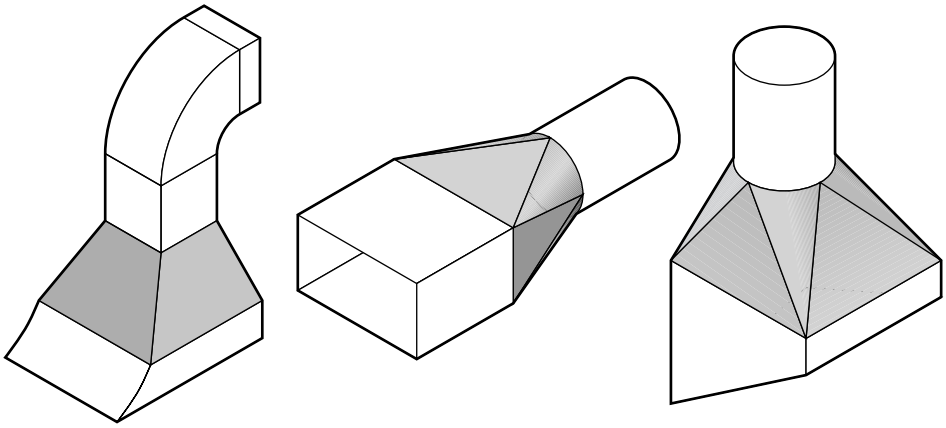


Figure 4.07 Examples of ducting systems that use transition pieces

Developing transition pieces

Transition pieces are made from the same type of sheetmetal as the other ducts in the ducting system. As with all sheetmetal components they are designed and set out as a development on a flat sheet. The development is then cut from the sheetmetal and folded or bent into shape to form the transition piece.

As with all developed shapes, true length lines must be used when constructing the development to ensure the correct shape and size of the transition piece. During the design drawing stage, all drawing sizes are measured to a suitable scale. These scaled drawings can then be used to mark out full-sized shapes on the sheet metal.

Triangulation and development of irregular shape transition pieces

Sheetmetal objects that have irregular shapes, for example, prisms or pyramids, may be developed using **triangulation development**.

Figure 4.08 shows a simple transition piece used to join a large rectangular-shaped duct to a smaller square-shaped duct. Triangulation development requires the shape to be triangulated, that is, divided into triangles, then the development of each of these triangles can be made, determining true length of each line as required.

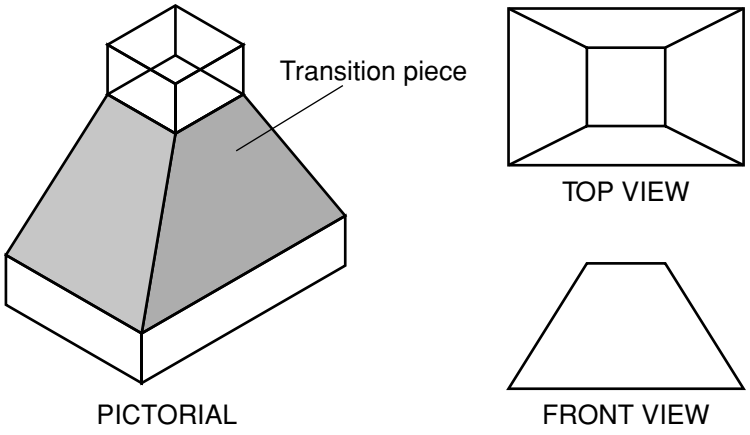


Figure 4.08 Development using triangulation method

Method of triangulating

Producing a triangulation development for a transition piece involves a series of steps.

The steps for triangulating are:

1. Draw the top and front views using orthogonal projection.
2. Define the position of the seam, the part where the development will start – it is usual for the seam to be the shortest edge.
3. Label the larger square, the base, starting at the seam and then the corners with the letters (a, b, c ...) using lower case, lettering is in an anti-clockwise direction.
4. Label the smaller square, the top, starting at the seam and then the corners with the numbers (1, 2, 3 …) using lower case, lettering in an anti-clockwise direction
5. In the top view, the seam line a1 is lightly drawn then the line b1 is drawn. Thus forming the triangle *a 1 b*
6. Lightly draw the line *b 2*, thus forming the triangle *b 1 2.*
7. Lightly draw the line *b 3*, forming the triangle *b 2 3.*

8 Continue to triangulate the remaining part of the top view, this will form triangles *b 3 c, c 3 d, d 3 4, d 4 e, e 4 5, e 5 1,* and *e 1 a.*

9 The transition piece has now been triangulated in preparation for the development.

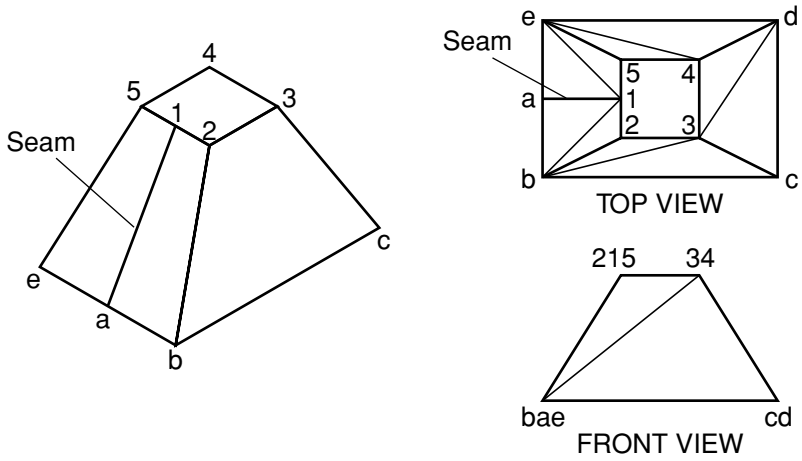


Figure 4.09 Lettering and triangulating the transition piece

The transition piece is now ready for development by drawing the first triangle, *a 1 b* Remember, only the true length of each line can be used in any development of a true shape.

The first line that is drawn is the line *a 1*.



Is it true length in either the top view or the front view?

To be true length, the line must be parallel to one of the planes, or shown as a point in one of the planes, it will then be shown as true length in the other view. That is, you must be looking at the line at right angles to see its true length. (The line *a 1* is seen as true length as it is parallel in the top view therefore it is true length in the other. The line b *1* is not parallel in either view so it is not true length in either view. Therefore the true length needs to be determined. The rotation or the auxiliary view method can be used. The offset method uses an auxiliary view to determine true lengths.

The offset method of determining true length – creating a 'true length' diagram

Determining the true length involves a series of steps.



Look at figure 4.10. The following steps describe the offset method used to determine the true length of the lines in this transition piece.

A true length diagram was created by:

1 The heights in front view.

From the front view:

i a very light construction line was used to project the height across from the top of the transition piece

ii a very light construction line was used to project the height across from the base of the transition piece

iii a very light construction line was used to draw a vertical line just to the right of the front view, crossing these two projected lines

iv the point *a* is labelled where the vertical line crosses the lower projected line. This point can also be used as the point *b, c, d, e* as all of these points lay on the same height

2 From the top view:

i dividers or a compass were set to the length *b 1* in the top view

ii this distance was marked along the top projected line from the previously projected vertical line

iii this point is labelled 1.

3 The true length:

i a light construction line was used to join the points *1* and *b*.

ii this line is the true length of *b 1*

This procedure can then be repeated to find the true lengths of all of the inclined lines

4 Steps 2–3 are repeated to determine the true lengths of lines b 2, b 3, c 3 ….

i dividers or a compass are set to the length *b 2* in the top view

ii this distance is marked along the top projected line from the previously projected vertical line

iii this point is labelled *2*.

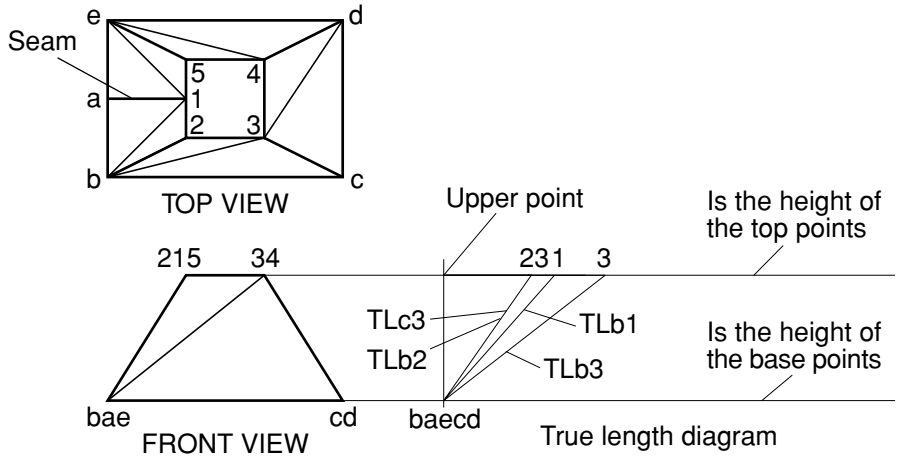


Figure 4.10 Determining true length using the offset method

The development

As the true length of the lines is determined, the development of the shape can commence.

Look at the method for producing the development, shown in figure 4.11 to 4.18.

1 To draw line *a 1*:

- i at a convenient position, or from the given starting position if appropriate, a light construction line was drawn
- ii a point is labelled *1* on this line
- iii the true length distance of *a 1* was marked off from point *1* along the construction line using dividers. The true length of *a 1* can be found directly in the front view as the line *a 1* is horizontal in the top view
- iv this point is labelled *a.*

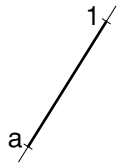


Figure 4.11

The first side of triangle *a 1 b* has now been drawn. This is the first line of the development.

2 To draw line *a b:*

- i the line *a b* was shown as a point in the front view therefore it must be true length in the other view, the top view. A compass was set to the distance *a b* from the top view.

ii with centre *a* and radius *a b ,* a very light arc is drawn.

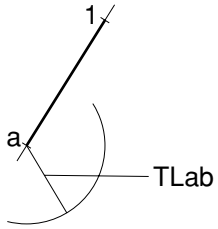


Figure 4.12

3 To draw line *b 1*

i The true length of *b 1* has been be determined using the offset method, described earlier and was found in the true length diagram

ii a compass was set to the true length distance *b 1*

vi with centre *1* and radius *b 1*, a very light arc was drawn to cut the previous arc

vii this intersection is the position of *b*.

The shape of the first triangle in the development is now complete.

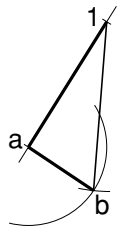


Figure 4.13

The next triangle, *1 b 2*, was drawn using the line *b 1*, and true lengths of *1 2* and of *b 2.*

The length *1 2* was shown as true length in the top view and the true length of *b 2* was found from the true height diagram.

With the compass set at the true length of *1 2* an arc was drawn from point *1*, and a second arc was drawn from *b* with the compass set at the true length *b 2.* At the point of intersection of the two arcs was the point

2. Draw the triangle 1 b 2.

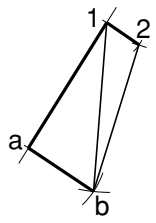


Figure 4.14

The same method was used to determine the location of point *3* so as to complete the triangle *2 b 3*.

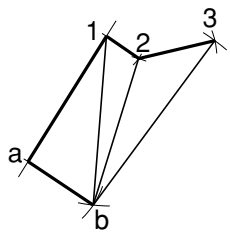


Figure 4.15

The next triangle to be developed was *b 3 c*. The true length of *b c* can be measured from either the top or front views as the line is horizontal in both views. The length of the line *c 3* can be found from the true length diagram. The location of *c* is then determined using the compass method and the triangle b 3 c is completed.

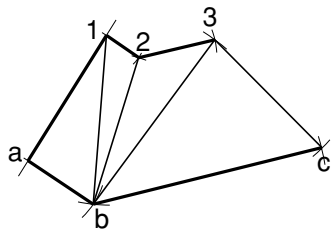


Figure 4.16

This technique is used to find the location for each of the points to complete the development.

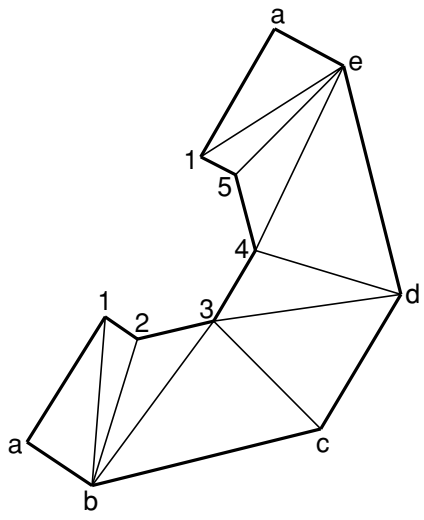


Figure 4.17 Full Development of the transition piece

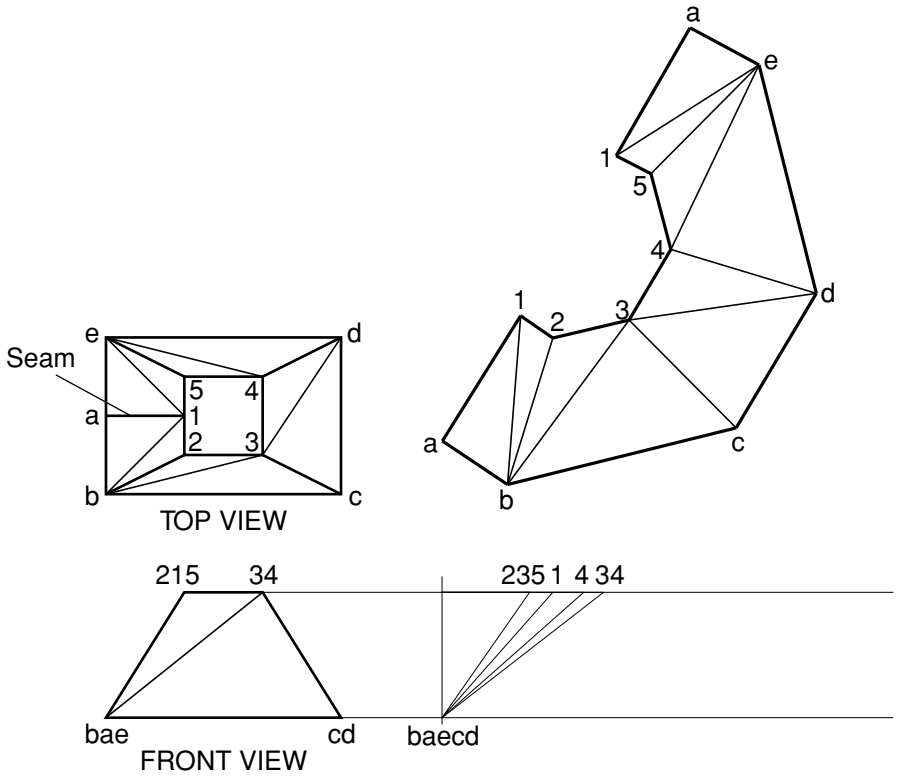


Figure 4.18 Completed drawing

In many instances, only a half development is produced where there is a line of symmetry. This can be seen in figure 4.18 but it is important to note that the layout of the initial triangulation reflects that only a half pattern is to be produced.

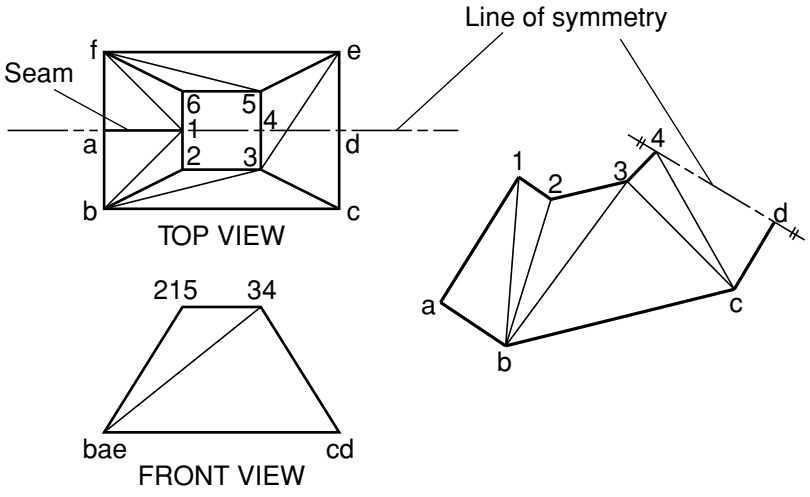


Figure 4.19 Development of a half pattern

Linework: outlines, fold lines, construction lines and symmetry lines

So far only light construction lines have been used in constructing the development. Now outlines, fold lines and symmetry lines are required. The remaining lines stay as construction lines.

Outlines The lines on the outside of the pattern are the outlines. These lines are represented, using AS 1100 standards, as thick dark lines. On A4 size paper, the thickness of outlines is 0.5 mm.

Fold lines The lines on the pattern about which the sheetmetal is to be folded or bent to form the duct, are fold lines. These lines are represented, using AS 1100 standards, as thin dark lines. On A4 size paper, the thickness of fold lines is 0.25 mm.

Construction lines All other lines remain as construction lines. Be careful that the triangulation lines on the flat surfaces, that are not fold lines, remain as light construction lines. The line *a 2* on the flat surface *a b 2 1* is a construction line, not a fold line.

Symmetry line If a development is symmetrical, it is acceptable to draw only one half of the development. However, to indicate that you have drawn only half of the required development, a **symmetry line** should be used.

The symmetry line is a thin dark chain line with double parallel lines crossing at each end.



Turn to the exercise section and complete exercises 4.1 and 4.2. For the first exercise, you may like to refer to the steps for producing a triangulation development. Try to complete the second exercise without reference to the notes.

The offset method extended

Some transition pieces involve more than two heights to project across. Figure 4.20 illustrates a transition piece with a sloping base. There are three heights in the front view to project across for the true length diagram.

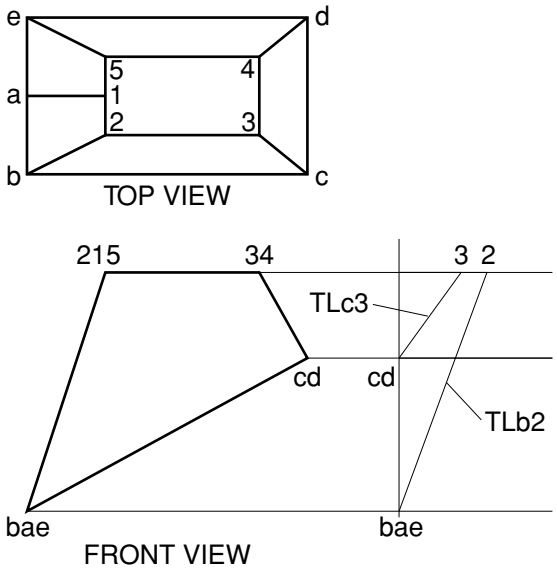


Figure 4.20 Using the offset method

Care must be taken to use the correct heights to determine the true length of each line.

Turn to the exercise section for this part and complete 4.3. Remember to carefully determine the true lengths.

You have now examined the method for constructing transition pieces with flat surfaces only. These transition pieces are used to join ducts that involve shapes having only flat surfaces, for example square-to-rectangular, square-to-square and square-to-hexagonal transition pieces – the next section will describe techniques that can be used when the transition pieces incorporate a circular end.

Transition pieces involving circular ducts

Many ducts are circular in shape. That is, they are cylinders. The transition piece used to join a square shape to a circular shape involves both flat and curved surfaces.

Developing non-circular transition pieces, that join a polygonal-shaped duct to a circular shaped duct, requires additional steps.

As the circular shape does not have any edges to letter or number, you have to create points on the circle by dividing the circular end into a number of equal parts, as shown in figure 4.20. It is convenient and sufficiently accurate to divide the circular end into twelve equal parts.

The following procedure is used for dividing the circle into twelve equal parts. In any orthogonal view, where the true shape of the circular end can be seen, very light construction lines are drawn through the centre of the circle:

- a vertical line
- a horizontal line
- two 60° lines
- two 30° lines

using your tee square and 60°–30° set square.

The circle can now be considered a 12-sided polygon, rather than a circle.

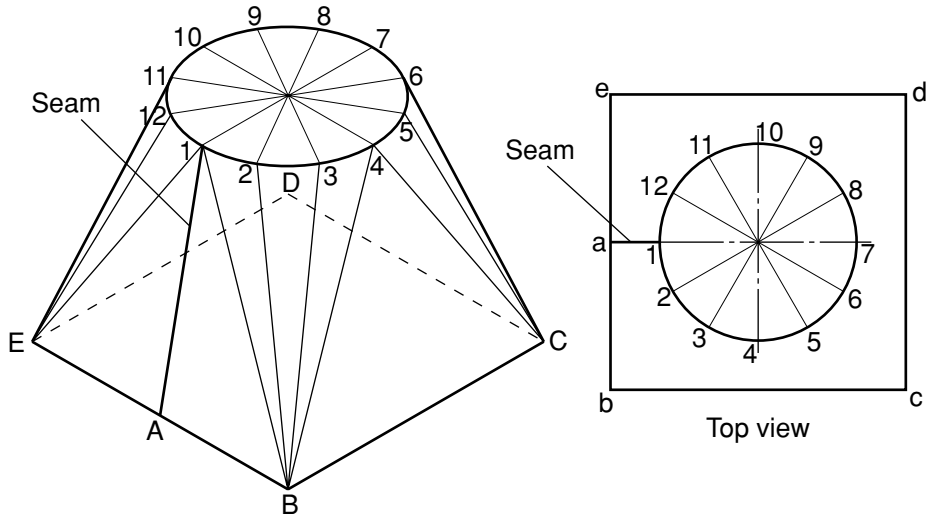


Figure 4.21 Transition piece involving a circular shape

The position of the seam is usually given in this type of transition piece as there are no edges where a seam or join can be formed.

Method of triangulation

The first step in the development is to letter the edges or corners of the transition piece and then to number the twelve divisions in the circular.

To be true length, the line must be parallel to one of the planes or shown as a point in one of the planes, it will then be shown as True Length in the other view. That is, you must be looking at the line at right angles to see its true length.

If you experience difficulty with the triangulation, sketch a pictorial view of the transition piece and draw the triangulation lines on the pictorial.

The development

Once the transition piece is triangulated, the development procedure is a repetition of the method described previously.

- determine the true length of the lines
- construct the first triangular surface *a 1 b* using true lengths commencing at the seam
- letter or number the position of the point
- complete the development by constructing each of the triangular elements
- outline the development using thick dark lines
- draw the fold lines using thin dark lines and include a symmetry line if appropriate.

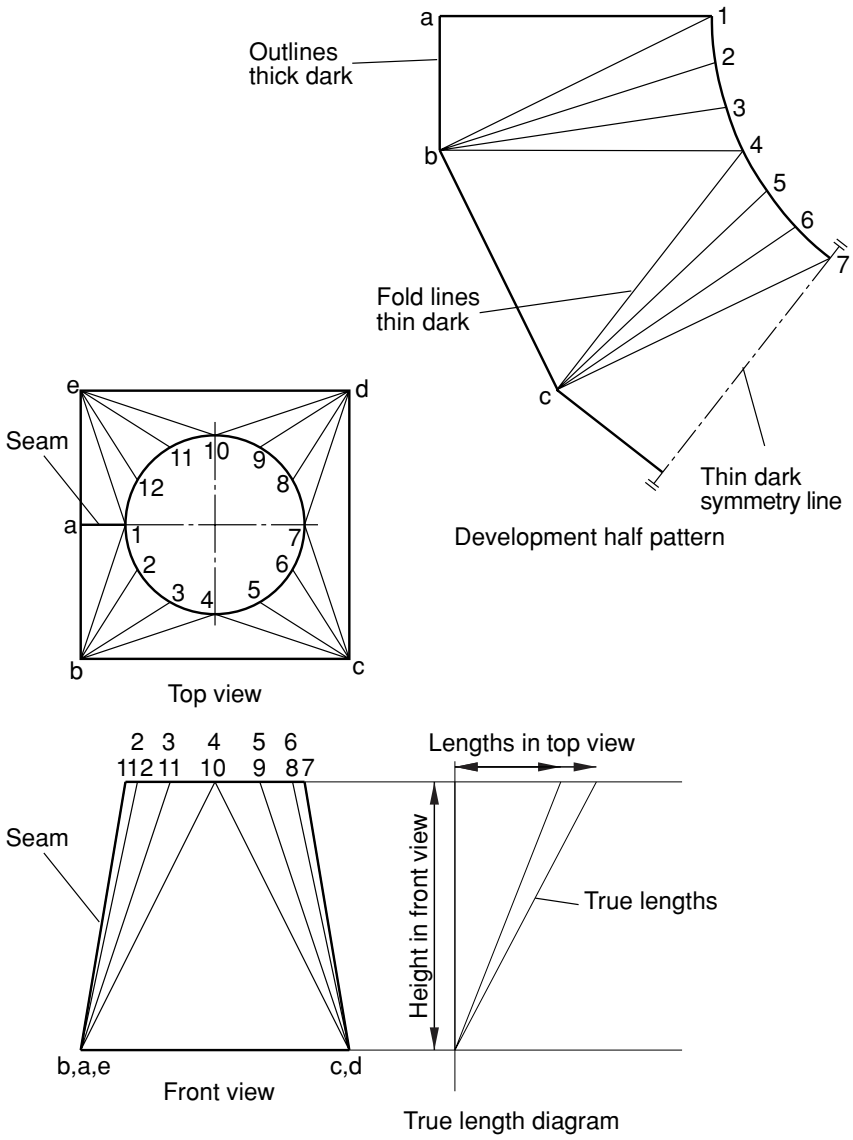


Figure 4.22 The development of a circle to square transition piece

Triangulation practice

Once you have mastered the method of triangulation development you can apply the principles to solve a range of design problems. However, triangulation interpretation is quite difficult. At times a sketched pictorial drawing of the transition piece could be used to assist visualisation. Figure 4.23 shows a pictorial drawing, a top view, front view and triangulation of three transition pieces.

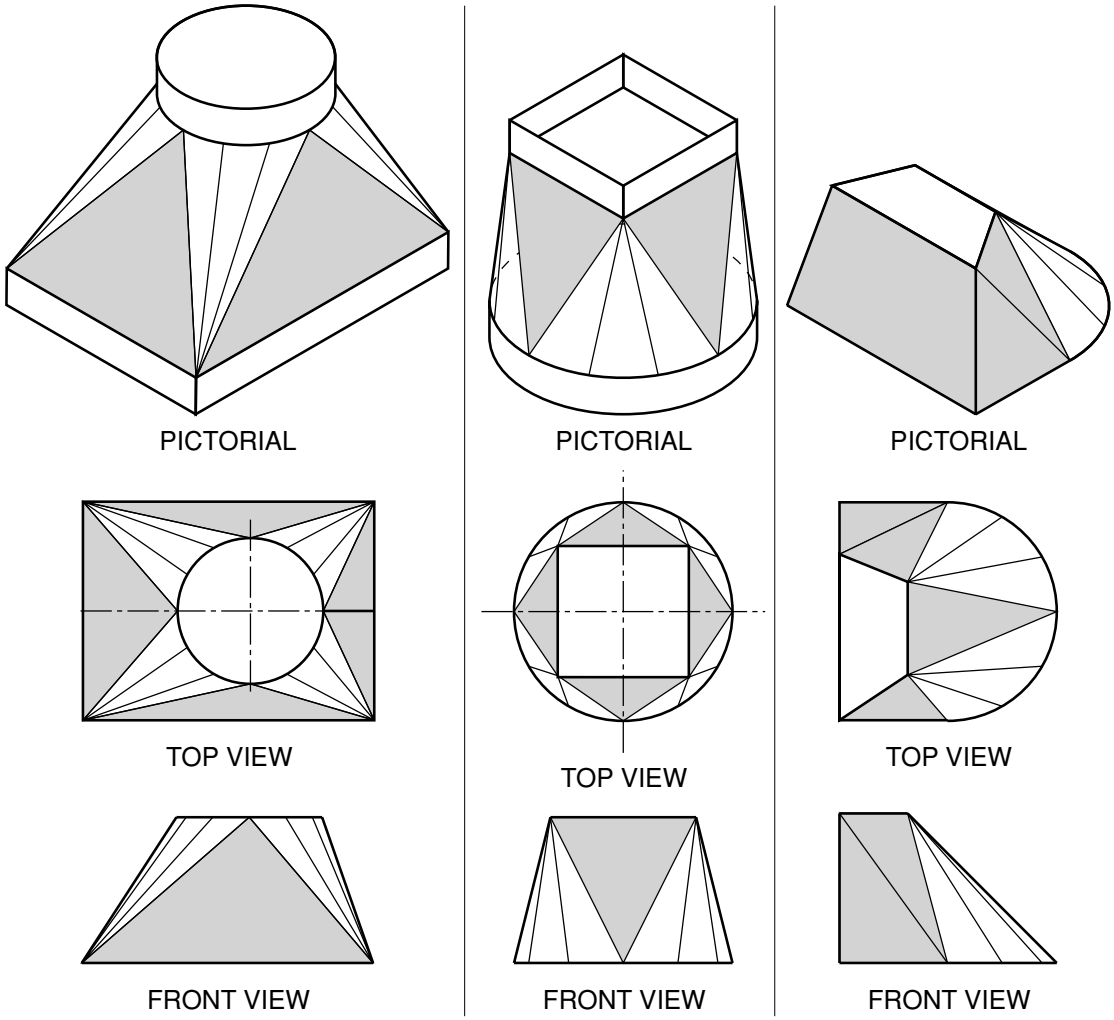


Figure 4.23 Examples of triangulation



Turn to the exercise section and complete 4.4 to 4.6.

Orthogonal drawings, AS 1100 standards

You should be familiar with many AS 1100 drawing standards. You were introduced to standard dimensioning methods, detail drawings and various methods of sectioning in the Preliminary Course modules.

The information and illustrations that follow examine some specialised techniques used in orthogonal drawing as applied to some components found in civil structures. You will learn about webs used to strengthen support brackets and the method of representing webs when they are sectioned. You will also learn more about fastenings, standard and special-sized nuts, bolts and washers and their representation using AS 1100 standards. You will also examine exceptions to the standard projection rules.

A standard hexagonal bolt

The hexagonal bolt is used extensively in civil structures. The following section focuses on the method of drawing a standard machined, hexagonal bolt.

The size of a standard machined hexagonal bolt used to fit a thread of 20 mm, is given as:

M20 x 2, HEX BOLT x 100 mm

This indicates that the bolt has a 20 mm metric thread and therefore a shank diameter of 20 mm, with a pitch of 2 mm, a hexagonal shaped head and a shank length of 100 mm. The length of the thread can also be nominated as in figure 4.24.

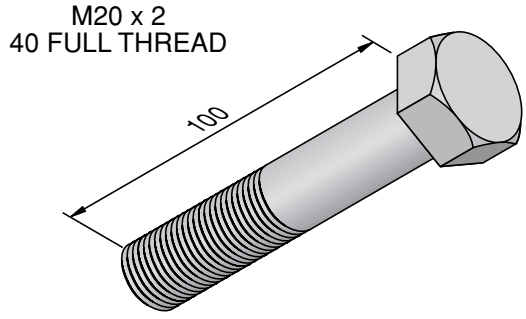


Figure 4.24 M20 x 2 hexagonal bolt

A standard bolt only has the sizes M20 x 2 indicated. The sizes of the hexagonal head are not given as these are based upon and determined by fixed sizes relative to the nominal size of the thread – in this case, a fixed proportion of the 20 mm.

Drawing a standard machined hexagonal bolt head

The hexagonal bolt head should be drawn to show the three-face view so that it will not be confused with a square bolt.

The width or distance across the points of this three-face view is 1.8D and the height is 0.7D, where 'D' is the nominal size of the bolt, in this case 20 mm. These dimensions are shown in figure 4.17.

To draw the hexagonal bolt, mark the position of its centreline, then measure a distance of 0.9D on either size of the centreline. In this case, for the 20 mm, bolt the distance is:

Centreline distances = 0.9D

= 0.9 x 20

= 18 mm

By measuring these two 18 mm distances you have marked off the width or distance across the points of the hexagonal bolt head, that is 1.8D or 36 mm.

The next step is to measure the height of the hexagonal bolt head. In this case, for the 20 mm bolt, the distance is:

Height = 0.7D

= 0.7 x 20

= 14 mm

You now draw the 36 mm x 14 mm rectangle to represent the outside of the hexagonal bolt head using thick dark lines.

The edges of the three-face view must now be drawn. Find the midpoint between the centreline and each of the outside edges of the rectangle and draw the lines to represent the edges between the three faces of the hexagon as thick dark lines.

Figure 4.25 shows the construction and calculations for drawing a standard machined, hexagonal bolt.

Distance across the points = 1.8 D (where D is the nominal size, that is, 20 mm)
Distance from centreline = 0.9 D (that is, 0.9 x 20 = 18 mm)
Height of hexagonal nut = 0.8 D (that is, 0.8 x 20 = 16 mm)
Height of hexagonal bolt head = 0.7 D (that is, 0.7 x 20 = 14 mm)

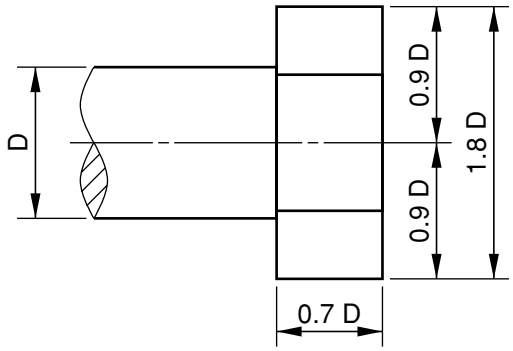


Figure 4.25 Drawing a standard M20 x 2 hexagonal bolt head

A standard hexagonal nut

The size of a standard hexagonal nut is given as M20 x 2 HEX NUT. This indicates that the nut is a standard size hexagonal nut that will fit a metric thread of size 20 mm with a pitch of 2 mm.

A standard nut only has the sizes M20 x 2 indicated. As with the sizes of the bolt head, the sizes of the nut are not given. These are fixed proportions of the nominal size; in this case, a fixed proportion of the 20 mm.

Drawing a standard hexagonal nut

As with the hexagonal bolt head, the hexagonal nut should be drawn to show the three-face view so that it will not be confused with a square nut.

The width or distance across the points of this three-face view is 1.8D, the same as the hexagonal bolt, but the height is 0.8D, where ‘D’ is the nominal size of the bolt, in this case 20 mm. The height of the nut is greater than the height of the bolt head. This is logical, as the bolt head is stronger than the nut and does not need to be the same height.

To draw the hexagonal nut, mark the position of its centreline, then measure a distance of 0.9D on either size of the centreline. In this case the distance is:

$$\begin{aligned} \text{Centreline distances} &= 0.9D \\ &= 0.9 \times 20 \\ &= 18 \text{ mm} \end{aligned}$$

By measuring these two distances of 18 mm, you have marked off the width or distance across the points of the hexagonal nut, that is 1.8D or 36 mm.

The next step is to measure the height of the hexagonal nut. In this case, again for the 20 mm bolt, the distance is:

Height = 0.8D

= 0.8 x 20

= 16 mm

The 36 mm x 16 mm rectangle is drawn to represent the outside of the hexagonal nut using thick dark lines.

The edges of the three-face view must now be drawn. Find the midpoint between the centreline and each of the outside edges of the rectangle and draw the lines to represent the edges between the three faces of the hexagon as thick dark lines.

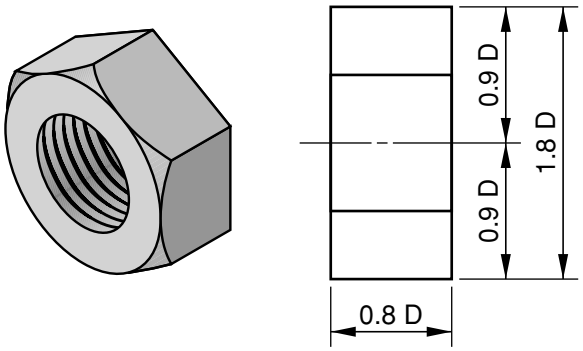


Figure 4.26 Drawing a standard M20 x 2 hexagonal nut

Special-sized nuts and bolts

In some instances, a design engineer may specify special sized nuts and bolts. A special-sized nut and bolt has the full dimensions given so that the nut and bolt can be drawn to size. The sizes are not proportional as in a standard nut and bolt.

An example has been given of size 20 AF x 10. The sizes indicate that the nut measures 20 mm ‘across the flats’ and has a height of 10 mm.

The auxiliary view method to draw nut and bolt heads

To determine the sizes for the rectangular shape that represents the view across the points of the hexagon, that is, the three-face view of the nut, an auxiliary view can be used. This method is demonstrated in figure 4.19.

To draw the auxiliary view, the position of the nut on the centre line is located, then:

i a compass is set to a radius equal to half of the given distance across the flats (in the example the distance across the flats is 20 mm, therefore the compass is set to 10 mm)

ii a very light line is drawn at right angles to the centreline for the nut

iii a semicircle is drawn, using very light construction lines, from where this line crosses the centerline – this is the centre for the auxiliary view

iv two lines at 60° to the centreline are drawn to meet the semicircle from the centre of the semicircle

v two lines at 30° to the centreline are drawn tangential to the semicircle through these two points

vi a line at 90° to the centreline is drawn where the semicircle cuts the centreline

vii the sizes from the auxiliary view are projected to the required position for the nut

viii the height of 10 mm is marked off

ix the rectangular shape and the two edges for the three-face view of the hexagonal nut are outlined.

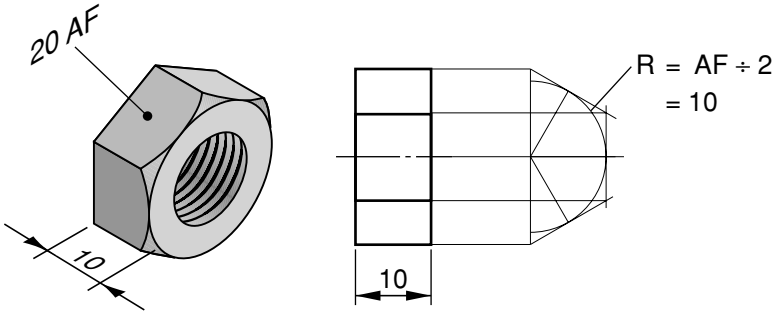


Figure 4.27 Auxiliary view method, special size nut and bolt

Turn to the exercise section and complete 4.7.

Structural hexagonal nut and bolt

The AS 1100.101 standards book includes sizes for the conventional representation, or drawing of, structural hexagonal nuts and bolts.

Structural nuts and bolts are slightly larger than general purpose, or machined, nuts and bolts. They are usually galvanised to prevent corrosion. Unless specified, it is assumed that the nut and bolt is a general purpose nut and bolt. If a structural nut and bolt is to be used then the specifications must state this.

The size of a standard structural hexagonal bolt used to fit a thread of 20 mm, is given as:

M20 x 2, STRUCTURAL HEX BOLT x 100 mm

This indicates that the bolt has a hexagonal head, its shank diameter is 20 mm, it has a 20 mm metric thread with a pitch of 2 mm, and the length of the bolt is 100 mm, and that it is a structural bolt.

Drawing a structural hexagonal bolt head

The structural hexagonal bolt head should also be drawn to show the three-face view so that it will not be confused with a square bolt.

The width or distance across the points of this three face view is 2.0D. The height is not given in the standards book, however, it can be assumed to be 0.8D, where ‘D’ is the nominal size of the bolt, in this case 20 mm.

To draw the structural hexagonal bolt, the position of its centreline is marked, then a distance of ‘D’ is measured on either side of the centreline. In this case, for the 20 mm bolt, the distance is:

Centreline distances = D
= 20 mm

By measuring these two 20 mm distances the width or distance across the points of the structural hexagonal bolt head has been marked off, that is 2.0D or 40 mm in this example.

The drawing below shows the sizes used to draw the conventional representation of a structural hexagonal nut and bolt.

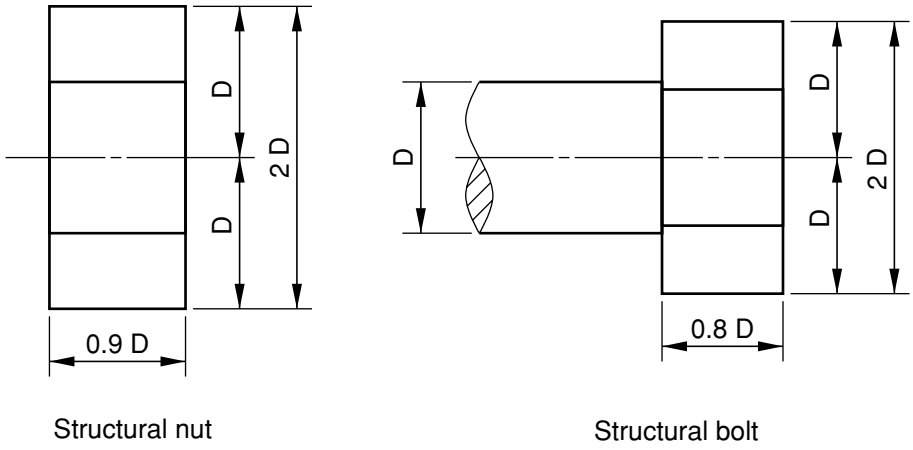


Figure 4.28 A drawing of a structural hexagonal nut and bolt

The height of the structural hexagonal bolt head is now measured and marked off. In this case, again for the 20 mm bolt, the distance would be:

Height = 0.8D

= 0.8 x 20

= 16 mm

Using thick dark lines, the 40 mm x 16 mm rectangle is drawn to represent the outside of the structural hexagonal bolt head. The edges of the three-face view must now be drawn. The midpoint between the centreline and each of the outside edges of the rectangle is located and the lines to represent the edges between the three faces of the hexagon as thick dark lines are drawn.

Drawing a structural hexagonal nut

The size of a standard, structural hexagonal nut is given as:

M20 x 2 STRUCTURAL HEX NUT

This indicates that the nut is a standard size, structural hexagonal nut that will fit a metric thread of size 20 mm having a pitch of 2 mm, and that it is a structural nut.

As with the hexagonal bolt head, the structural hexagonal nut should be drawn to show the three-face view so that it will not be confused with a square nut.

The width or distance across the points of this three-face view is 2.0D, the same as the structural hexagonal bolt, but the height is 0.9D, where D is the nominal size of the structural bolt, in this case 20 mm.

To draw the structural hexagonal nut, the position of its centreline is marked. A distance of 'D' on either side of the centreline is then measured. In this example, for the 20 mm nut the distance is:

Centreline distances = D

= 20 mm

By measuring these two distances of 20 mm, the width or distance across the points of the structural hexagonal nut has been marked off, that is 2.0D or 40 mm in this example.

The height of the structural hexagonal nut is now measured and marked off. In this example, again for the 20 mm bolt, the distance would be:

Height = 0.9D

= 0.9 x 20

= 18 mm

Using thick dark lines, the 40 mm x 20 mm x 18 mm rectangle is drawn to represent the outside of the hexagonal nut.

The edges of the three-face view must now be drawn. The midpoint between the centreline and each of the outside edges of the rectangle is located and the lines to represent the edges between the three faces of the hexagon as thick dark lines are drawn, as shown in figure 4.28.

Specialised techniques in orthogonal drawing

When objects contain features such as webs, holes and bolts, and a sectioned view is drawn, specialised techniques are prescribed by AS 1100 standards for representing these.

Exceptions to the rules of projection

Pitched circle diameter or radius

Holes in circular flanges or holes that have their position indicated by dimensions using the **pitch circle diameter,** (PCD) or **pitch circle radius**, (PCR) should be shown on their true pitch rather than on the true projection.

In a sectional view of the flange these holes must be indicated on the given pitch and be shown as visible outline.

Holes in a flange that are not on a PCD or PCR may be shown as visible outline, even though they are not on the cutting plane.

Figure 4.29 shows the exceptions to the rules of projection. The holes in the top circular flange are pitched on a PCD and therefore must be rotated and projected from their true pitch. They must also be shown as visible outline.

The holes in the lower flange or base are not positioned on a PCD so it is optional whether you show the holes as visible outline or not. This example shows the holes as a visible outline. However, it would also be correct to indicate only a centreline to show the position of the holes. The hidden outline should not be used on a sectional view.

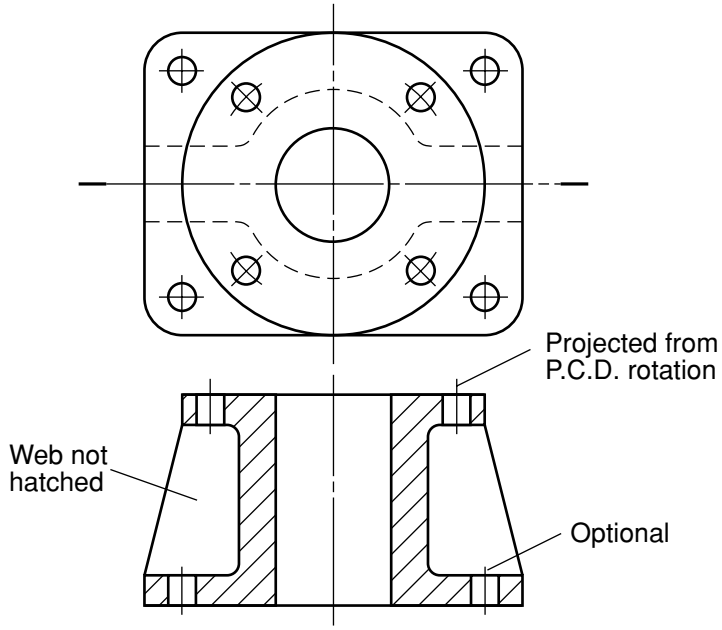


Figure 4.29 Exceptions to the rules of projection

Exceptions to the standard rules of sectioning

Sectioning thin webs

Figure 4.29 also shows thin webs with the cutting plane passing longitudinally through the webs. Although the webs are on the cutting plane, they are drawn without hatching. The webs are drawn as visible outline but are not hatched.

If a web was cut by a cutting plane, across or through the web rather than longitudinally or along the web, the portion of the web cut by the cutting plane would be hatched, as in figure 4.30.

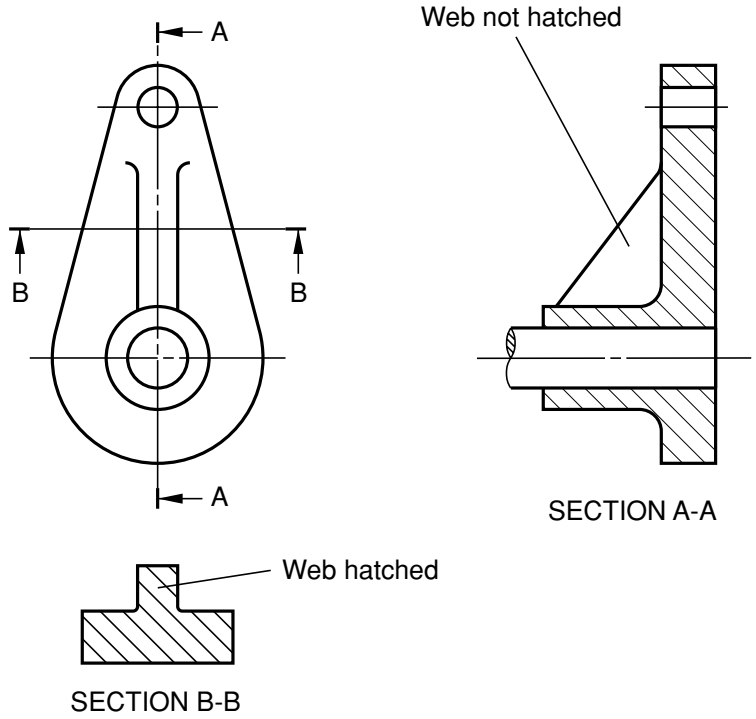


Figure 4.30 Sectioning a web and shaft

Other sectioning rules

There are a number of sectioning rules similar to the one about webs, that are sometimes confusing. Some of these rules follow.

When the cutting plane passes through the centreline of fasteners such as bolts, nuts, washers, shafts, keys, pins and similar components, the components should not be sectioned but shown as visible outline. However:

- if the components are cut across, they are sectioned
- if the components have interior detail that should be shown, they are sectioned, or part-sectioned, to show this interior detail
- if the bolt, nut or washer is not a standard shape or size and there are interior details to show, the component is sectioned.

Figure 4.30 shows examples of the sectioning rules as applied to a web and a shaft.

Shape and size details of a ceiling bracket used to hang ducting from a ceiling are given in figure 4.31 in a pictorial drawing. A top and three possible front views have been drawn. From your work in the preliminary modules, Braking systems particularly, you should be able to determine why the ‘best solution’ has been selected.

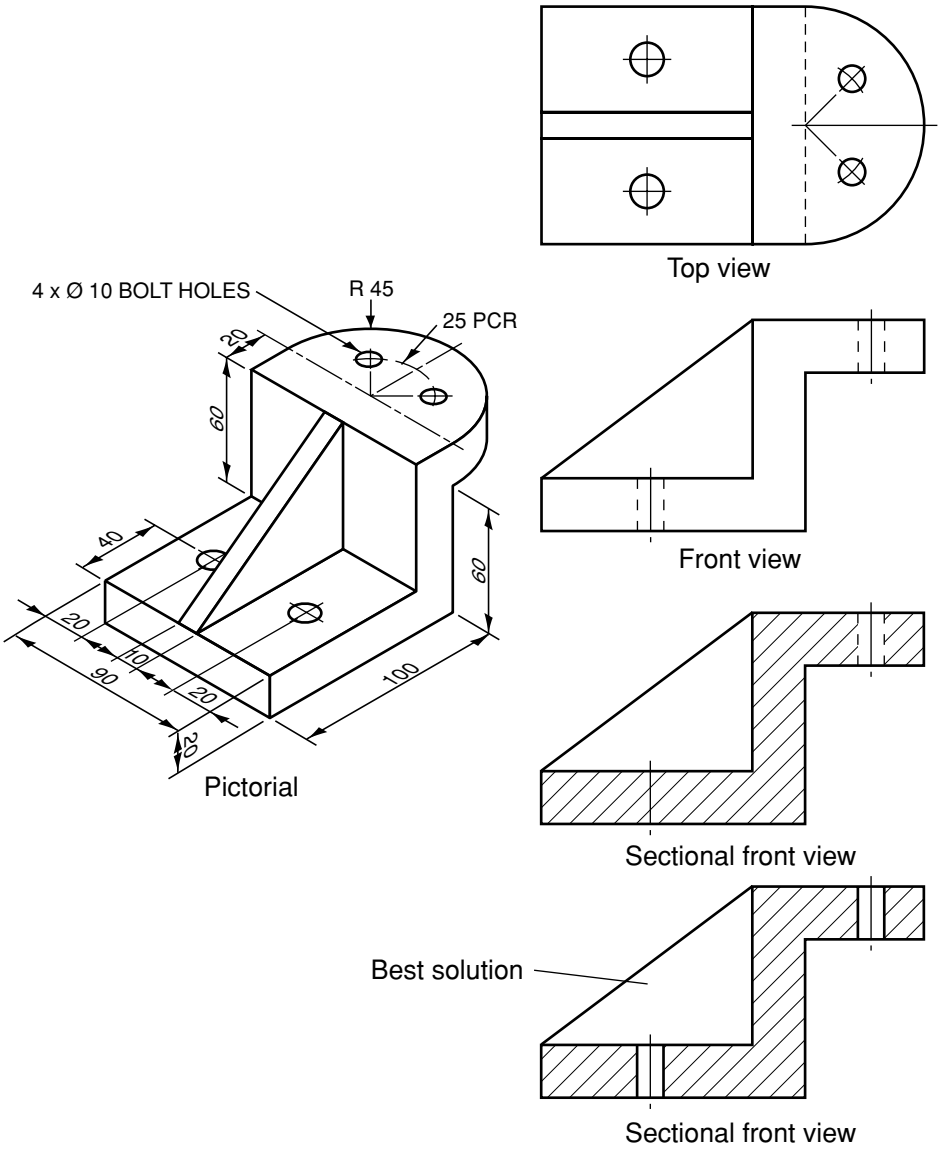


Figure 4.31 Designing solutions for the ceiling bracket

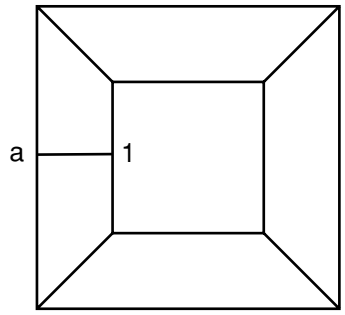


Turn to the exercise section and complete 4.8.

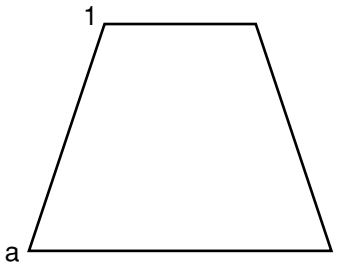
Exercises

Exercise 4.1

The top view and front view of a transition piece used to join a small square duct to a larger square duct are shown below. Commencing at the seam *a 1*, construct a half pattern for the transition piece.



Top view

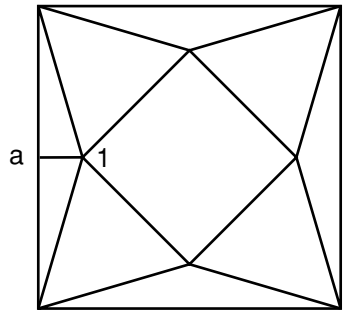


Front view

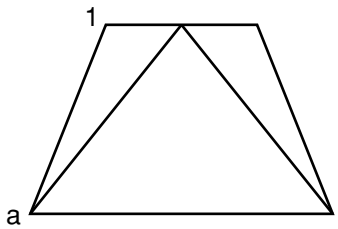
Figure 4.32 Transition piece

Exercise 4.2

The top view and front view of a transition piece used to join a square duct to a rotated square duct are shown below. Commencing at the seam *a 1*, construct a half pattern for the transition piece.



Top view

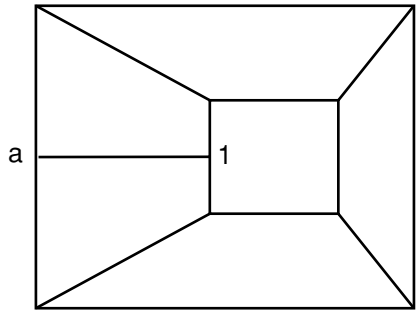


Front view

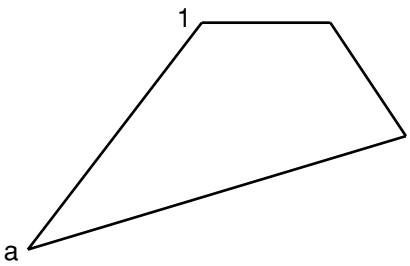
Figure 4.33 Transition piece

Exercise 4.3

The top view and front view of a transition piece used to join a square duct to a sloping rectangular duct are shown below. Commencing at the seam *a 1*, construct a half pattern for the transition piece.



Top view



Front view

Figure 4.34 Transition piece

Exercise 4.4

The top view and front view of four transition pieces are shown. Commencing at the seam *a 1*, complete the triangulation of each of the transition pieces. Do not develop the pieces.

a Letter the base and number the top of each transition piece.

b Triangulate each transition piece:

i triangulate the flat surfaces first, remembering that there is always a flat surface from a straight edge

ii triangulate the curved surfaces – do not triangulate across a curved surface.

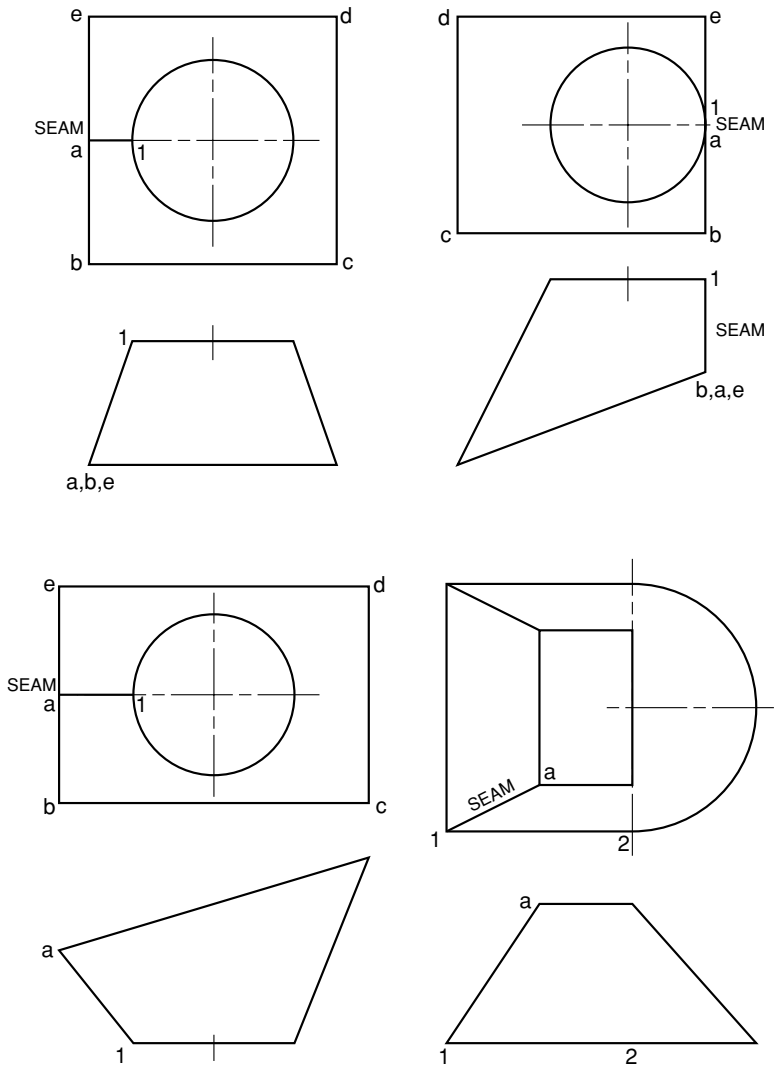


Figure 4.35 Transition pieces

Exercise 4.5

The top view and front view of a transition piece used to join a circular duct to a square duct are shown below. Commencing at the seam *a 1*, construct a half pattern for the transition piece.

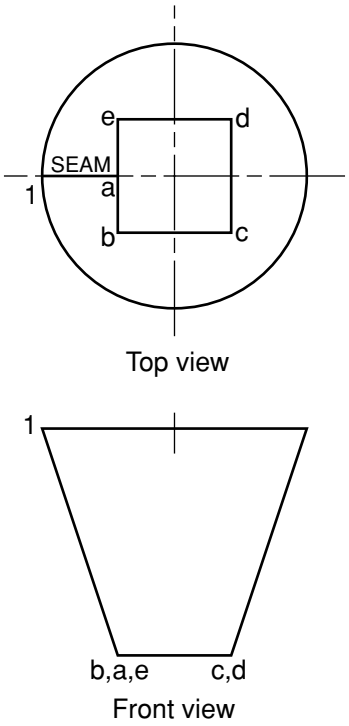
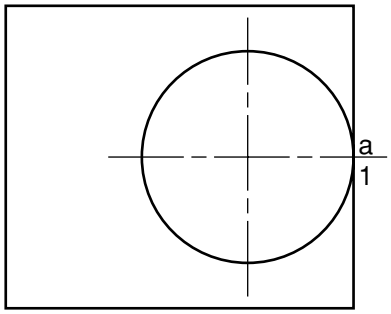


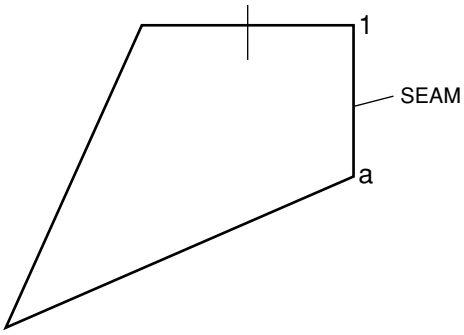
Figure 4.36 Transition pieces

Exercise 4.6

The top view and front view of a transition piece used to join a circular duct to a sloping rectangular duct are shown below. Commencing at the seam *a 1*, construct a half pattern for the transition piece.



Top view



Front view

Figure 4.37 Transition pieces

Exercise 4.7

The pictorial drawing shows shape and size details of an M20 x 2 hexagonal bolt.

Use a CAD program to draw a front view of the bolt.

Use a CAD program to also draw a special hexagonal nut having dimensions of 40 AF and a height of 18 mm, assembled onto the bolt so that there is a space of 60 mm between the nut and the bolt head. If you do not have access to a CAD program, use instruments.

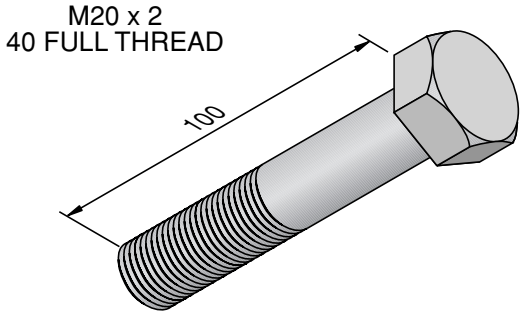


Figure 4.38 Hexagonal bolt

Exercise 4.8

Using a scale of 1:2 draw a freehand orthogonal sketch that includes a top view and sectional front view of the ceiling bracket. Dimension the PCR, a diameter, the length and width of the base, and the thickness of the thin web.

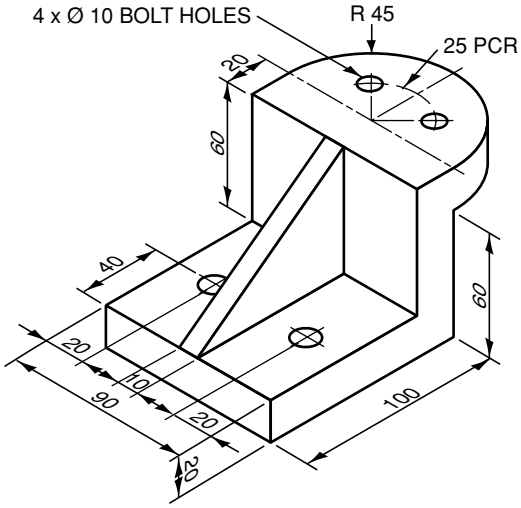


Figure 4.39 Thin web



Exercise cover sheet

Exercises 4.1 to 4.8 Name: _____

Check!

Have you have completed the following exercises?

- ❒ Exercise 4.1
- ❒ Exercise 4.2
- ❒ Exercise 4.3
- ❒ Exercise 4.4
- ❒ Exercise 4.5
- ❒ Exercise 4.6
- ❒ Exercise 4.7
- ❒ Exercise 4.8

Locate and complete any outstanding exercises then attach your responses to this sheet.

If you study Stage 6 Engineering Studies through a Distance Education Centre/School (DEC) you will need to return the exercise sheet and your responses as you complete each part of the module.

If you study Stage 6 Engineering Studies through the OTEN Open Learning Program (OLP) refer to the Learners Guide to determine which exercises you need to return to your teacher along with the Mark Record Slip.

Progress check

In this part you produced technical drawings applying appropriate AS 1100 Standards to communicate engineering concepts relating to civil structures.



Take a few moments to reflect on your learning then tick the box which best represents your level of achievement.

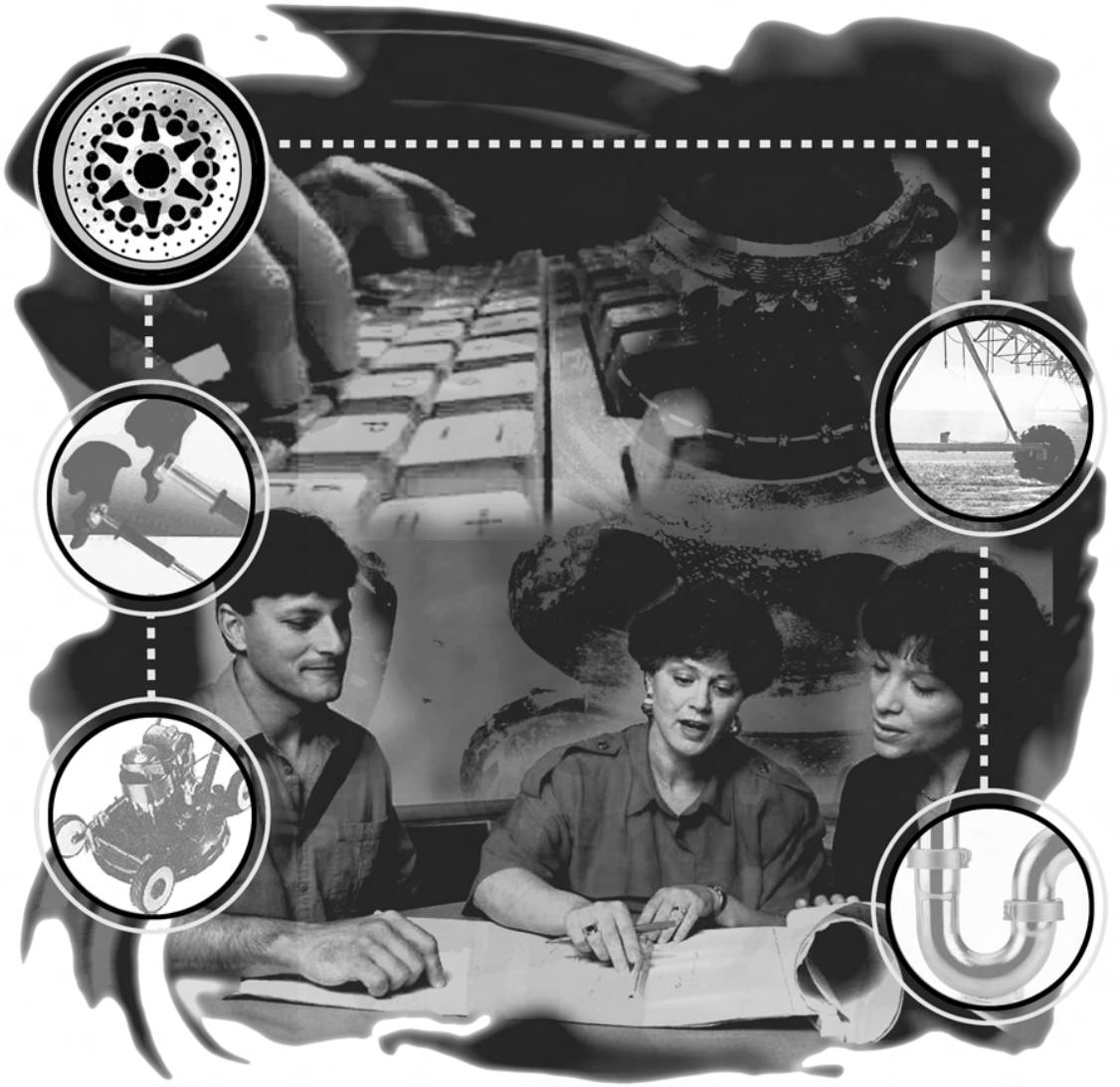
☑ **Agree – well done** ☑ **Disagree – revise your work** ☑ **Uncertain – contact your teacher**	**Agree**	**Disagree**	**Uncertain**
I have learnt about: • Australian Standards (AS 1100) • orthogonal assembly drawings • development – development of transition pieces – computer graphics.			
I have learnt to: • produce orthogonal drawings applying appropriate Australian Standards (AS 1100) • construct the development of non-circular transition pieces • apply graphical methods to the solution of relevant problems.			

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Refer to <http://www.boardofstudies.nsw.edu.au> for original and current documents.

In the next part you will develop an engineering report on an aspect of civil structures.

Part 5: Civil structures – engineering report





Part 5 contents

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Module evaluation 39



Introduction

In the engineering profession an engineering report contributes to the effective management, communication, decision-making and teamwork by providing a synthesis of the various elements that are relevant to a project.

An engineering report can be developed for a new project which involves the synthesis of a new design, or it can be prepared as a result of the analysis of an existing engineering application. Engineering reports may be related to individual components, complex engineered products or engineered systems.

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In this part you will:

- explore the components of an engineering report
- examine a sample engineering report
- compare two solutions to an engineering situation by writing an engineering report.

What will you learn?

You will learn about:

- engineering report writing.

You will learn to:

- complete an engineering report based on the analysis and synthesis of an aspect of civil structures using appropriate software.

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An engineering report

Aims of an engineering report

The aim of an engineering report is to collect and analyse information then to present this clearly and concisely. This is achieved by:

- investigating a wide variety of sources of information
- analysing data using mathematical calculations
- using tables, graphs and diagrams.

Structure of an engineering report

An engineering report is generally structured in a number of sections.

Title page

The title page gives the title of the report, identifies its writer/s and provides the date when the report was completed.

Abstract

The abstract is a concise summary of the report. The purpose of the abstract is to help a reader decide if the report contains information about which they are researching.

The abstract should be no more than two or three paragraphs of text – shorter if possible. It should cover the scope of the report (what it is about), and the approach/es used to complete the analysis (how the information was assembled).

Introduction

The introduction should cover two basic areas.

Firstly, it should put the problem under consideration into a context that most readers will understand. For example, if you were writing a report on the most suitable type of overhead projector for use in a school, the introduction should define technical terms such as 'school'. You should then outline the background for the report – in this case the use of an overhead projector in a school – to allow the reader to focus on what you are investigating.

The second part of the introduction should outline what is contained in the body of the report. This allows the reader to understand each part of the report in the context of the overall document, and if necessary, to quickly locate the part of most interest. It is always reassuring to know what to expect on the next page!

Analysis

The analysis is usually the main part or body of the report.

The analysis and calculations should contain the information required to satisfy the aim and purpose of the report, including evidence of research and experimentation. For example, relevant information about materials and the mechanics of products should be collected or calculated in this section.

Tables and graphs, used to summarise detailed data in a concise form, are common features of an engineering report. Presenting information this way is much more effective than trying to describe physical quantities in words alone. If it is necessary to supply all of the detailed information for reference purposes, this can be included as an appendix.

Results summary

The result summary should present the results concisely. If necessary, the details can be provided in an appendix. The results will be used as the basis for your conclusions and recommendations.

This section should also note any limitations on the results obtained. For example, if you conduct an experiment to find out the average temperature in your home, you might measure the temperature every hour for three days in succession, then calculate the average. In the results section, when stating the average temperature for your home, you should also point out that the figure might be different at other times of the year due to seasonal variations.

Conclusions

In this section the writer draws conclusions based on data collected. If the purpose of the report was to 'select the best ... ', then the selection should be stated and the reason for the choice explained.

Acknowledgments

The acknowledgments section is where you mention or thank other people who have contributed to the report. For example, a local chemist may have lent you a thermometer to enable you to measure the hourly temperature. While the chemist may not have helped you directly with the experiment, the task would have been more difficult without his/her contribution.

Bibliography

This section is important as it demonstrates that the report is well-researched. This is done by including references to all important sources of information used in the investigation.

You will need to demonstrate in your report that you have used a range of sources to research information for your report. Include the Internet sites you have used, CD-ROMs, journals, phone interviews or industry visits where possible, books and the encyclopaedia.

If you use someone else's work you must reference it appropriately. This is the literal basis for 're-search': to re-find a result that someone else discovered. If you use someone else's work without referencing it, you are implicitly claiming it to be your own. This is cheating, or as it is more usually called, plagiarism.

Standards for bibliographic entries must follow established guidelines. A standard academic approach is the Harvard system of referencing. A sample of how to reference this way follows.

Higgins, R. A. 1977, *Properties of Engineering Materials,* Edward Arnold, Sydney.

Appendices

The appendices contain detailed information that has been separated from the main body of the report because it is not essential that every reader look at this information. An example is engineering drawings of beams being compared. The overall dimensions of the product may not

have been part of the report, but some readers may need this specific information.

The history of the product, structure or system (or related products, structures or systems) should also be included in this section.

Appendices are not meant to be read in the same way as the main body of the report. Appendices need only contain scientific formulae, detailed experimental results or other information that needs to be recorded in case it is required again in the future.

Sample engineering report

The following section contains a sample engineering report on a civil structure.

The sample engineering report will investigate and analyse alternative methods of spanning a 7 m gap to support a second story floor in a civil building – a grandstand. The engineer will research several types of beams and trusses and make a recommendation for the most suitable structure to use. Note that the sample report only contains calculations on the recommended solution. Your report should contain calculations on two solutions in order to allow comparisons to be made.

Your report will investigate and analyse alternative methods of spanning a 7 m gap to support a pedestrian footbridge. You will need to research alternative solutions then make recommendations based on your findings. Unlike the sample report, your report should contain calculations on both potential solutions. This should assist in determining your report's recommendation.

Civil structures

Title: Support structure for a floor

Author: Warren Truss

Date: 25 May 2000

Abstract

This report is an analysis of alternative methods for supporting a mezzanine floor in a grandstand at a sporting venue. The alternatives investigated are typical solutions to this engineering situation.

Introduction

This report will investigate the beam or truss structure needed to support a second floor in a two-storey grandstand at a sporting venue in a large, regional town. The dimensions of the floor are 10 m x 7 m, giving a total floor area of 70 m^2. The floor of the second storey to be supported will be made of wood such as laminated sheeting that will be directly attached to the support structure.

The second storey floor of the grandstand must support a maximum of one hundred adults who will sit on tiered or stepped seating. The lower floor of the grandstand needs as much open space as possible to accommodate a canteen.

An orthogonal drawing showing sectioned views through the building to reveal the lower and second floor of the grandstand is provided in Appendix 1.

The analysis contains a comparison of five alternative supporting structures – fabricated trusses, solid timber beams, laminated timber beams, steel beams and prefabricated trusses (wood, steel).

Mathematical calculations will be made to identify the loadings placed on the structure.

The conclusion recommends a prefabricated truss system.

Analysis

There are a wide variety of engineering structures capable of addressing the problem outlined in this report. Often it is difficult to obtain data that allows a satisfactory comparison. The method selected for this report is to list the advantages and disadvantages of each alternative, conclude which is the most suitable and recommend the use of this product.

Typical solutions to the situation would include fabricated trusses specifically designed for the building, timber beams, rolled steel joists of appropriate size to span the distance or prefabricated trusses. The situation requires a number of trusses or beams to be positioned parallel to each other at appropriate distances apart or centres to support the second storey flooring, seating and people, with an acceptable factor of safety.

An analysis of each of the support structures follows.

1 Fabricated trusses

Trusses of this type would be designed specifically for the situation by a structural engineer and made to specifications by an engineering firm. A metal fabricator or welder would construct the structure on site.

The following sketch shows a possible design for a fabricated truss.

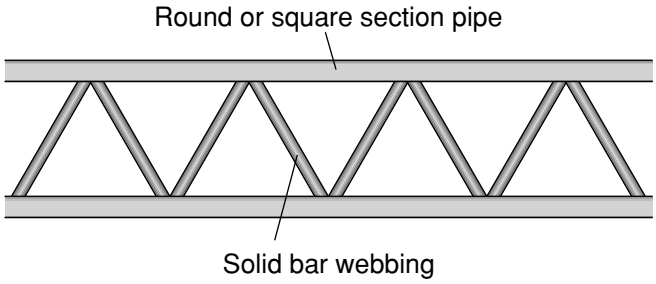


Figure 5.1 Fabricated truss

Advantages	Disadvantages
the trusses would be designed and constructed to specifications that would be acceptable for the situation	the labour and design involved would make fabricated trusses expensive
the trusses have an open design that would allow for pass-through services such as plumbing and electrical connections	an anticorrosion coating would be required after fabrication
trusses of this style are relatively light and easily positioned	welding and fabrication equipment would be required on site

2 Solid timber beams

The maximum single span for timber beams is 4.2 m at 1.8 m centres or spacings. This means timber beams would have to be supported by a column or pier in the centre to span the 7 m distance.

Large sectioned timber beams (290 x 90 mm) are required. These beams are heavy and difficult to position.

Advantages	**Disadvantages**
aesthetically attractive, particularly if the timber is dressed and lacquered to bring out the grain	requires the use of smaller sectioned wooden joists (75 x 25 mm) that lies on the bearers to support the flooring
recycled timber can be used with positive environmental effects	new timber is a comparatively expensive material
flooring would readily attach directly to the beams	
low corrosion	

3 Laminated timber beams

Laminated beams involve layers or laminations of wood that are glued together to give a stronger beam than solid wood of similar dimensions.

Advantages	**Disadvantages**
allows the use of smaller timber sections due to the laminating technique, therefore it is less expensive than solid timber	requires the use of smaller sectioned joists (75 x 25 mm) that lie on the bearers to support the flooring
flooring would easily be attached to the beams	involves similar problems to solid timber in terms of cost, weight and size
low corrosion	

4 Commercial rolled steel beams

These beams are available in a range of sizes and shapes. The following sketch shows two of the cross-sections available in commercial steel beams.

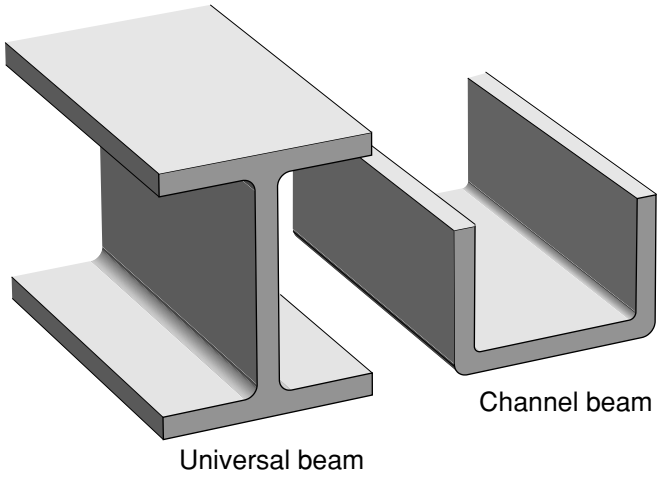


Figure 5.2 Commercial rolled steel beam sections

Advantages	**Disadvantages**
excellent load bearing qualities – a Universal or ' I ' beam 150 mm x 400 mm will support a load of 90 kN/m (Schlenker and McKern 1976, 406)	heavy and therefore difficult to position – a 410 mm universal beam has a mass of 53.7 kg per/metre (www.ezysteel.com.products)
would not require as many beams as other forms of support	flooring could not be attached directly to the beams

5 Prefabricated trusses

Prefabricated trusses of this type can be obtained in:

a steel

b timber.

a Steel prefabricated trusses

An example of steel prefabricated trusses are the Hopleys trusses manufactured by Hunt Engineering Pty Ltd. Technical information and photographs of this type of truss can be found at <www.huntengineering.com.au>.

Advantages	Disadvantages
very light and easy to position – 350 mm depth trusses are 6.1 kg/metre	requires a large number of trusses for the flooring – at 450 mm centres, 22 trusses are needed
trusses of this type have corrosion protection as they are galvanised	
flooring can be attached directly to the trusses	
good strength-to-weight ratio – 350 mm depth trusses at 450 mm spacings or centres will support a 3 kPa live load per m^2 and span 7.4 m (refer to Appendix 2 table 1)	
the trusses have an open design that would allow for pass-through services such as plumbing and electrical connections	
modern fastening devices such as Teks screws can be used on the trusses	
attachments such as 'shoes' allow the trusses to be fixed at each end to walls and/or beams	
trusses can be powder-coated to give a durable, aesthetically pleasing appearance	

b Timber prefabricated trusses

The following sketch shows the design of these with the middle section made of compressed particle board with a flange made of veneered ply.

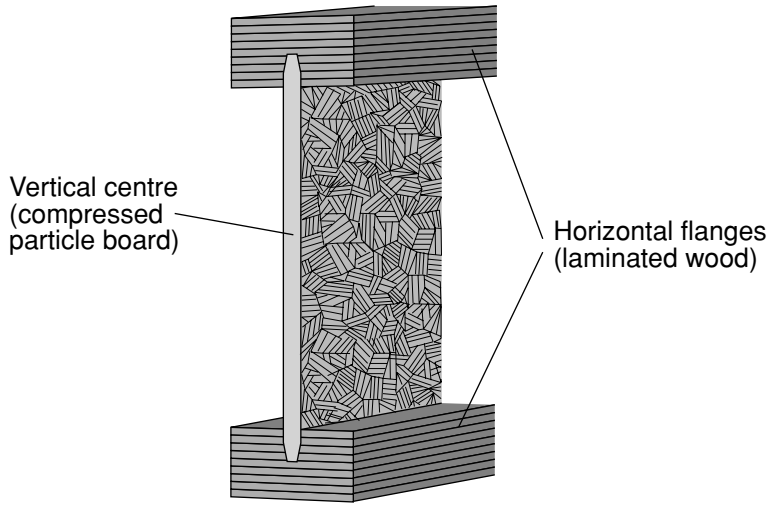


Figure 5.3 A sketch of a timber prefabricated truss

Advantages	**Disadvantages**
lightweight – 356 mm depth joists weigh 4.6 kg/m, thus easily positioned	moisture content in situations where this truss is placed cannot exceed 18%
flooring can be attached directly to the trusses	larger depth required than for similar sizes in steel prefabricated truss, a 356 mm depth truss at 450 mm centres will span 6.4 m (refer to Appendix 2 table 2)
recycled material can be used to make the trusses	attachments such as 'shoes' allow the trusses to be fixed at each end to walls and/or beams (refer to Appendix 3)
	span distances have to be decreased if holes are cut to allow for pass-through services, such as plumbing and electrical services

Calculations – force analysis

A mechanical analysis of the supporting structure should include stress calculations and an analysis of the forces created within the structure.

Tables of data available from manufacturers indicate the mechanical characteristics of available prefabricated beams (refer to Appendix 2).

The spacing between the trusses is important, and is described by the distance between centres. This means the distance from the centre of one beam to the centre of the next beam. Typical spacings are 450 mm and 600 mm.

Truss design HJ350 is an appropriate choice for the construction of the grandstand mezzanine floor. This truss can span the 7 m required, and will be spaced at 450 mm centres.

Weight to be supported

The load placed on the supporting trusses needs to be calculated. A significant safety factor needs to be incorporated into the calculations. This safety factor could be as much as 5 times in the civil structure. Failure of the truss system is not acceptable.

Number of trusses

As the floor dimensions are 7 m x 10 m, the total number of trusses required is 22 at 450 mm spacing.

$$\frac{10\ 000}{450} = 22$$

Weight of the trusses

Each truss is 7 m long. Each metre weighs 6.1 kg. The weight of the truss is:

$$7 \times 6.1 = 42.7 \text{ kg}$$

Weight of the flooring

The flooring is 19 mm thick plywood. It has been determined that this product has a mass of 8 kg per square metre.

As the floor is 70 m^2, the weight of the flooring is:

$$\text{Weight of flooring} = 70 \times 8$$

$$= 560 \text{ kg}$$

This mass is supported by a total of 22 beams.

Each beam therefore supports:

$$\frac{560}{22} = 22.45 \text{ kg}$$

Weight of the seating

It has been calculated that the seating will weigh 5 000 kg. Again, as there are 22 trusses to support this weight, each truss carries:

$$\frac{5\ 000}{22} = 227.3 \text{ kg}$$

Weight of the people

The grandstand is designed to carry 100 people. If, for design purposes, each person is calculated at 100 kg, the total weight of the crowd is:

$$100 \times 100 = 10\ 000 \text{ kg}$$

Again, as there are 22 trusses, each truss will need to support:

$$\frac{10\ 000}{22} = 454.5 \text{ kg}$$

Total weight to be supported by each truss

The total weight will be calculated based on:

1 – weight of the truss = 43 kg

2 – weight of the flooring = 26 kg

3 – weight of the seating = 228 kg

4 – weight of the people = $\frac{455 \text{ kg}}{752 \text{ kg}}$

Note that these weights have been rounded up.

Next, an engineering safety factor of 5 is included:

$$752 \times 5 = 3\ 760 \text{ kg per truss}$$

Reactions at the supports

The calculated load exerted downwards by each truss is 3 760 kg.

This can be converted to a force so that further calculations can be made:

$$F = m \times g$$

$$= 3\,760 \times 10$$

$$= 37\,600 \text{ N}$$

$$= 37.6 \times 10^3 \text{ N} \downarrow$$

This force is supported at each end of the truss.

The reaction therefore at each end must be:

$$\frac{37.6 \times 10^3}{2} = 18.8 \times 10^3 \text{ N} \uparrow$$

This can be represented by the following force diagram:

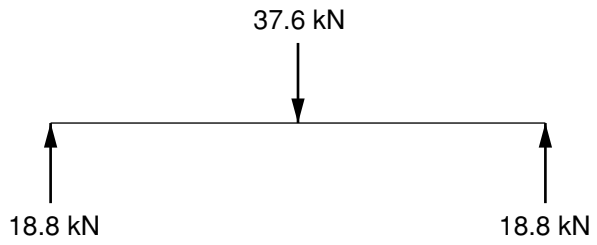


Figure 5.4 Reactions at supports

Internal forces in the truss

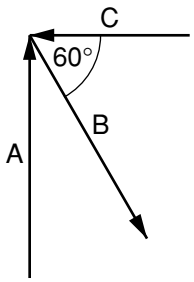
In an experimental situation, the internal force in the first diagonal truss member B, can be calculated by:

1 Drawing the joint to scale, and then measuring the sizes of the vector triangle:

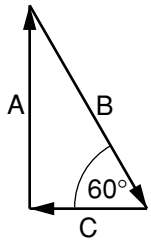
or

2 Trigonometry

1 Graphical solution



Freebody diagram



Vector diagram

Figure 5.5 Truss joint

2 Trigonometry solution

$$A = 18.8 \text{ kN}$$

$$\therefore \sin 60° = \frac{A}{B}$$

$$B = \frac{A}{\sin 60°}$$

$$= \frac{18.8}{0.866}$$

$$= 21.7 \text{ kN}$$

As the internal force in member B aims away from the joint, member B is in tension.

$\therefore$ Member B has a tension force exerted on it of 21.7 kN

The internal force exerted in member C, the top horizontal member is calculated by:

$$\text{Tan } 30° = \frac{C}{A}$$

$$C = \text{Tan } 30° \times A$$

$$= 0.5773 \times 18.8$$

$$= 10.85 \text{ kN}$$

As the internal force in member C aims towards the joint, the member C is in compression.

$\therefore$ Member C has a compressive force of 10.85 kN exerted on it.

Shear stress in the attaching bolt

In an experimental situation, it has been determined that the maximum allowable shear stress on the attaching bolt is 60 MPa. The bolt has a diameter of 10 mm.

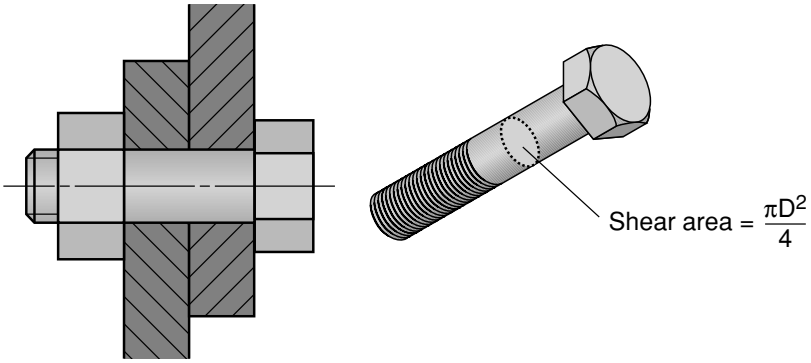


Figure 5.6 Bolt in shear

The following calculation determines the maximum force that should be applied to the bolt.

$$\text{Shear area} = \frac{\pi D^2}{4}$$

$$= \frac{\pi \times 10^2}{4}$$

$$= 78.54 \text{ mm}^2$$

$$\text{stress} = \frac{\text{load}}{\text{area}}$$

$$\text{load} = \text{stress} \times \text{area}$$

$$= 60 \times 78.54$$

$$= 4\,712.4 \text{ N}$$

$$= 4.72 \text{ kN}$$

As the truss may exert a force of 18.8 kN, the minimum number of bolts would be:

$$\frac{18.8}{4.72} = 3.98$$

$\therefore$ a minimum of four bolts should be used.

Result summary

From the previous information it can be seen that on site fabricated trusses would be suitable, however, because they have to be individually constructed they would be comparatively expensive. Timber beams would not be suitable due to the fact that they cannot span the 7 m distance without a pier to support them in the centre. This would require a number of piers on the bottom floor area, which would reduce the space available to accommodate a canteen. Laminated timber beams would also not be suitable to support the flooring of the grandstand. A 305 mm x 130 mm section beam would be needed to span the 7 m distance. However, 75 x 50 mm joists would then have to be put across these laminated bearers at 450 mm centres to support the flooring. This would be a comparatively expensive approach in addition to the weight of the laminated beams.

Commercial rolled steel beams such as universal beams have two disadvantages in that they are very heavy when compared to alternative support structures and the floor boards cannot be directly attached to the beams. Timber floor joists would need to be positioned on the steel beams then the flooring attached to these.

Prefabricated trusses are suitable as support for the flooring due to their lightness, ease of handling and excellent strength-to-weight ratio. The steel prefabricated trusses appear to be superior to those made of timber for the same size due to the fact that they will span a greater distance. Timber trusses are not as heavy as those made of steel.

Conclusion and recommendation

The recommended support structure for the second storey floor of the grandstand is a prefabricated steel truss with a depth of 350 mm. The reasons for this choice are:

- lightness and ease of handling – the trusses could be placed in position without the need for expensive lifting devices
- trusses of this size at 450 mm centres will span the 7 m distance and support the load
- strength-to-weight ratio will easily support the calculated load on the floor

- trusses are galvanized, reducing the possibility of corrosion which would weaken them
- pass-through services such as pipes and electrical cabling can be fitted through the open web design without the need to cut holes that would weaken the trusses
- attachments called `shoes` can be used at either end of the trusses to attach them to brick walls or timber beams (refer to Appendix 3).



Figure 5.7 Fabricated trusses

© Hopleys open web steel joists

The material used to construct prefabricated trusses is a mild carbon steel. This means it has a carbon content ranging from 0.15 to 0.25 percent carbon. The grain structure for this steel is composed of ferrite and pearlite (refer to Appendix 4).

The properties of the mild steel contained in steel prefabricated trusses are flexibility and formability which is suitable to the requirements of a truss under load. The use of mild steel in the truss also allows the truss to be welded together without any appreciable change in brittleness due to the heat generated during this process.

The method used to weld the truss together is to spot weld the middle bracing section of the truss to the top and bottom sections. This technique involves two electrodes that clamp the pieces to be joined and then applying a high voltage, concentrated current that fuses the metal together at one 'spot'. This welding technique is used to join sheetmetal in situations such as car and fridge panels.

A layer of zinc is applied to the truss as a protection against corrosion (refer to Appendix 4).

Zinc occupies a higher position on the reactivity series than iron, so it protects the iron from corrosion due to a transfer of electrons between the zinc and iron.

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Timber Association of NSW Ltd. *Timber Framing Manual*

<www.ezysteel.com/products>

<www.huntengineering.com.au>

<www.tilling.com>

Appendices

Appendix 1

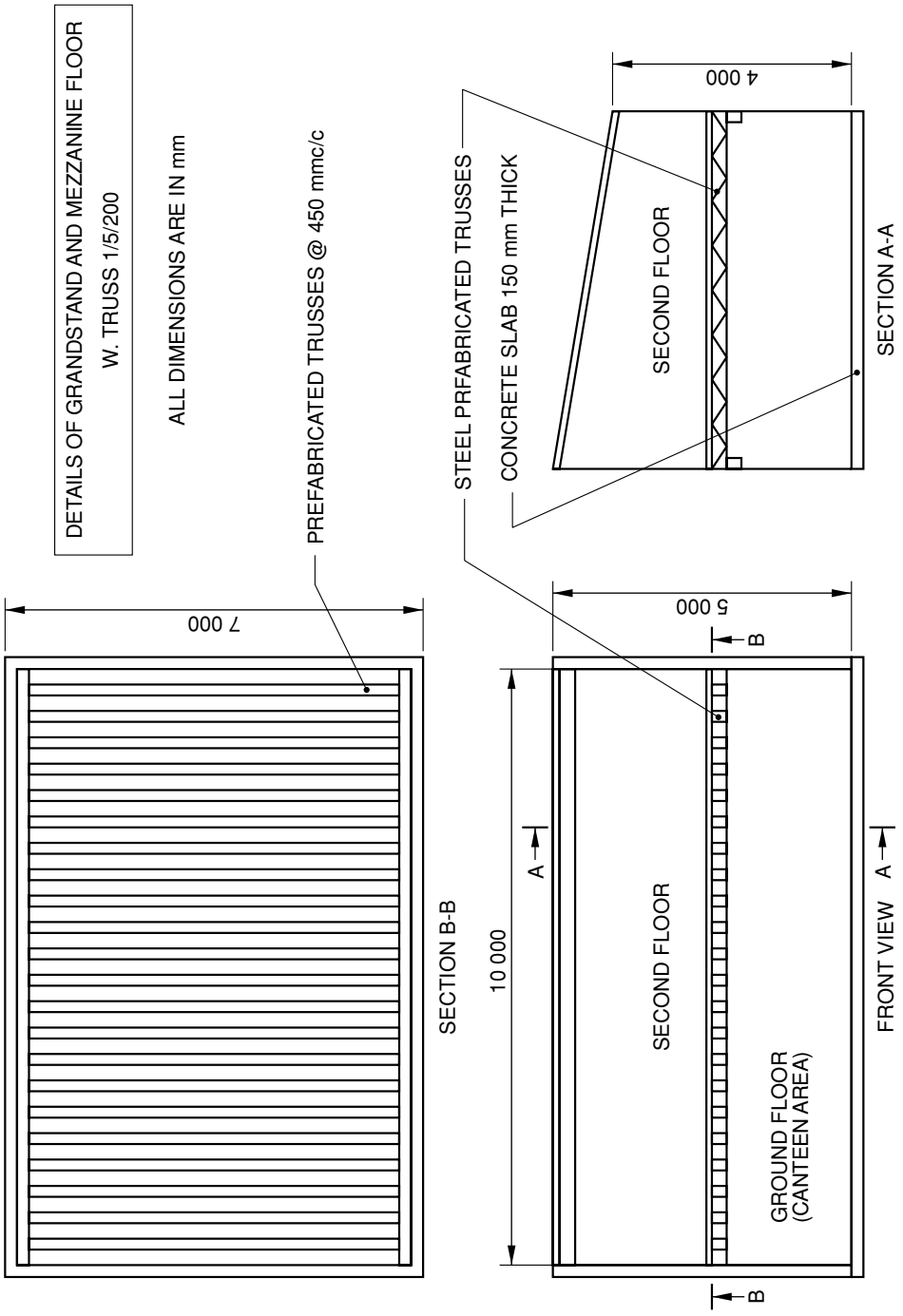


Figure 5.8 Sectioned orthogonal view of the grandstand

Appendix 2

The following table shows the maximum spans that are allowable for simply supported steel prefabricated trusses at centres of 450c/c and 600c/c millimetres at live loads of 3 Kilopascals and 6 Kilopascals. Prefabricated metal trusses are available in 6 widths from 150mm to 400mm; these are indicated in the table as HJ 150 etc.

Table 1 Loading capacities

	Maximum Allowable Spans – Meters Simply Supported											
Live Load	HJ 150		HJ 200		HJ 250		HJ 300		HJ 350		HJ 450	
	450c/c	600c/c	450c/c	600c/c	450c/c	600c/c	450c/c	600c/c	450c/c	600c/c	450c/c	600c/c
3kPa	3.4	2.9	4.2	3.6	4.6	4.0	5.6	4.7	7.4	6.5	8.8	8.0
5kPa	2.2	2.1	3.0	2.6	3.3	2.9	3.9	3.4	6.0	5.2	7.1	6.4

© Hopleys open web steel joists

Table 2 Timber prefabricated trusses

PJ24144 = 241 x 44 mm, PJ30244 = 302 x 44 mm etc.

Joist code	**Joist depth (mm)**	**Flange width (mm)**	**Truss mass (kg/m)**	**Single span 350 mm centres**	**Single span 400 mm centres**	**Single span 450 mm centres**	**Single span 500 mm centres**
PJ 20063	200	63	3.13	4.7	4.4	4.2	3.9
PJ 24144	241	44	3.2	5.3	4.9	4.8	4.4
PJ 30244	302	44	3.6	6.1	5.7	5.5	5.0
PJ 35658	356	58	4.6	7.2	6.6	6.4	6.0
PJ 40658	406	58	4.9	7.7	7.2	7.0	6.4

Table 3 Laminated timber beams

Beam size	Single span 1000 mm centres	Single span 1500 mm centres	Single span 2000 mm centres	Single span 2500 mm centres	Single span 3000 mm centres	Single span 3500 mm centres
190x130	5200	4500	4100	3800	3600	3400
229x130	6100	5400	4900	4600	4300	4100
267x130	6700	6200	5800	5400	5000	4800
305x130	7400	6800	6400	6100	5800	5500
343x130	8000	7400	7000	6600	6400	6100

Laminated timber beams as bearers need smaller section joists on top at 450 mm centres to attach the flooring.

Shear force and bending moment diagram for a truss supporting the grandstand flooring:

Figure 5.9 shows a prefabricated metal truss across the bottom of the floor of the second level in the grandstand. The bending moment diagram and the shear force diagram that would apply to this beam with a uniformly distributed load are shown below this. These diagrams show where the maximum bending force and shear force occur along the truss, which would assist an engineer in selecting an appropriate truss.

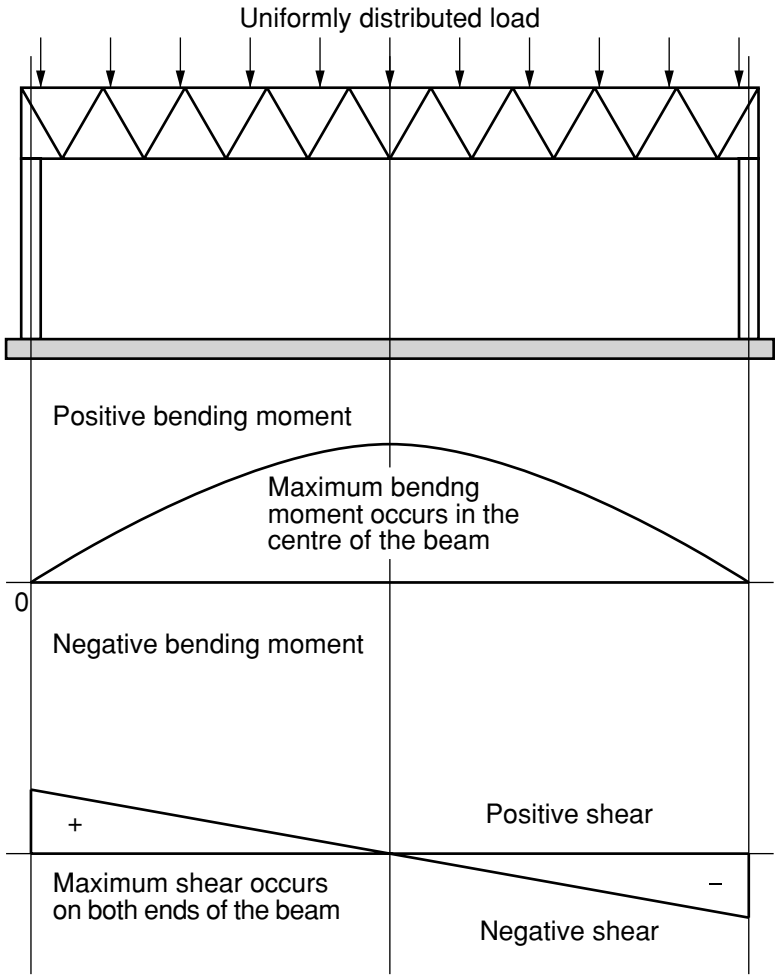


Figure 5.9 Shear force/bending moment diagrams as they apply to a prefabricated metal truss.

Appendix 3

SHOE DETAILS FOR THE PREFABRICATED TRUSS

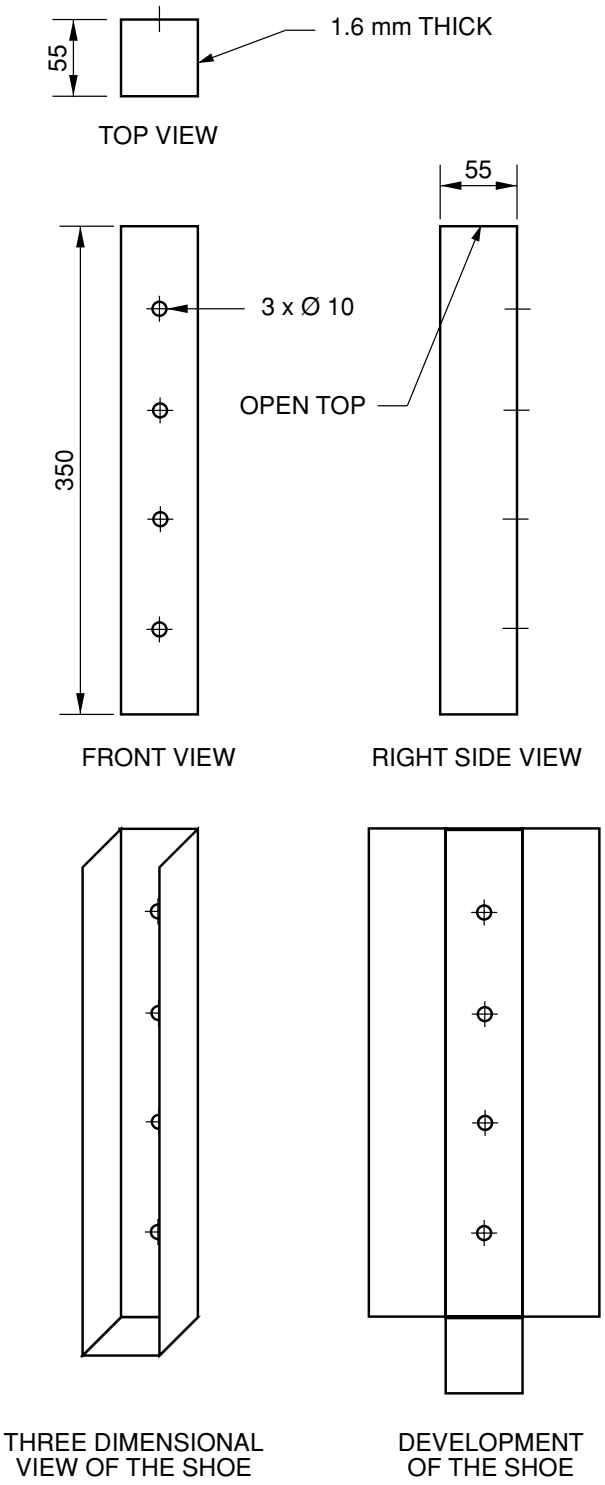


Figure 5.10 Details of the prefabricated metal truss ‘shoe’

Appendix 4

Steel microstructure

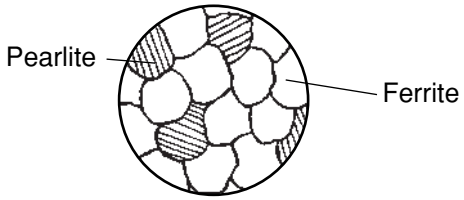


Figure 5.11 Microstructure of prefabricated metal truss steel

Zinc corrosion protection

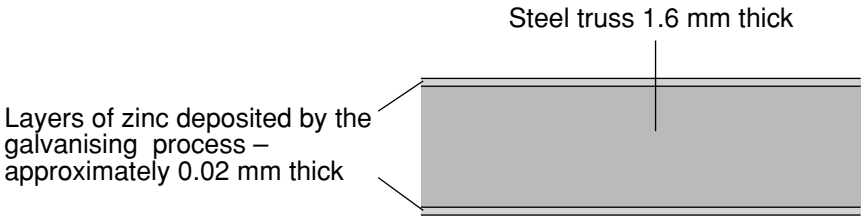


Figure 5.12 Zinc corrosion protection on prefabricated metal trusses

Exercise

Exercise 5.1

The task for this engineering report is to recommend a design for a pedestrian footbridge.

a Describe a situation that requires a pedestrian footbridge.

The introduction should fully describe the design situation that requires a pedestrian bridge. These details should include criteria for assessing the solutions and the emphasis that is going to be placed on each criterion.

b Identify the three main criteria for the bridge.

The criteria for assessing the solutions might include, cost, environmental impact, ease of construction, available materials, strength and aesthetic appearance. The emphasis placed on each criterion will vary depending on the sitaution. For instance, a bridge on an isolated farm property may require emphasis to be placed on cost, ease of construction and available materials, while a pedestrian bridge in a town might require emphasis on road clearance height and aesthetic appearance.

c Analyse two possible solutions based on selected criteria.

In the analysis section of the report identify two engineering solutions for a pedestrian footbridge and provide calculations for the two options, as well as other relevant data and sketches. Comparison tables listing the criteria would be an appropriate way to present your data.

d Recommend the better solution based on the analysis.

Based on your analysis of each solution recommend the better solution in your given situation.

An AS 1100 standard drawing of the recommended solution should be shown in the appendix.

If possible discuss your proposed report with your teacher before you begin. This will help to organise your ideas and insure you use your time effectively.

Include the following sections in your report:

- title page
- abstract
- introduction
- analysis
- results summary
- conclusions and recommendations
- acknowledgments
- bibliography
- appendices.



Exercise cover sheet

Exercise 5.1 Name: _____

Check!

Have you have completed the following exercise?

❒ Exercise 5.1

Locate and complete any outstanding exercises then attach your responses to this sheet.

If you study Stage 6 Engineering Studies through a Distance Education Centre/School (DEC) you will need to return the exercise sheet and your responses as you complete each part of the module.

If you study Stage 6 Engineering Studies through the OTEN Open Learning Program (OLP) refer to the Learner's Guide to determine which exercises you need to return to your teacher along with the Mark Record Slip.

Progress check

In this part you developed an engineering report on an aspect of civil structures.



Take a few moments to reflect on your learning then tick the box which best represents your level of achievement.

☑ **Agree – well done** ☑ **Disagree – revise your work** ☑ **Uncertain – contact your teacher**	**Agree**	**Disagree**	**Uncertain**
I have learnt about: • engineering report writing.			
I have learnt to: • complete an engineering report based on the analysis and synthesis of an aspect of civil structures using appropriate software.			

Extract from *Stage 6 Design and Technology Syllabus*, © Board of Studies, NSW, 1999.
Refer to <http://www.boardofstudies.nsw.edu.au> for original and current documents.

Congratulations! You have completed *Civil structures*.

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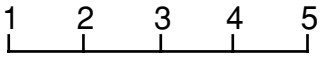
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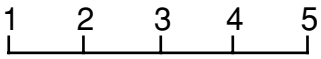
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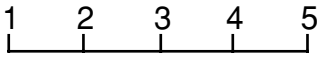
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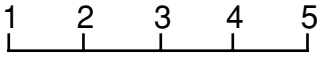
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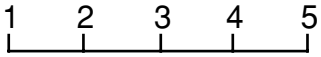
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