MEM30005A

Calculate force systems within simple beam structures

First Published February 2013

Edition 1 – February 2013

Conditions of Use:

Unit Resource Manual

Manufacturing Skills Australia Courses

This Student's Manual has been developed by BlackLine Design for use in the Manufacturing Skills Australia Courses.

Feedback:

Your feedback is essential for improving the quality of these manuals.

Please advise the appropriate industry specialist of any changes, additions, deletions or anything else you believe would improve the quality of this Student Workbook. Don't assume that someone else will do it. Your comments can be made by photocopying the relevant pages and including your comments or suggestions.

Forward your comments to:

BlackLine Design

blakline@bigpond.net.au

Sydney NSW 2000

Aims of the Competency Unit:

This unit covers understanding and calculating force systems within simple beam structures by solving simple engineering problems involving forces, moments and basic stress and strain calculations, and determining nominal sizes of simple beams subject to loading.

Unit Hours:

36 Hours

Prerequisites:

MEM30012A	Apply mathematical techniques in a manufacturing engineering or related environment.

Elements and Performance Criteria

1.	Determine the resultant and equilibrant of systems of coplanar forces	1.1	Calculate the magnitude and direction of the resultant and equilibrant of coplanar force systems.
		1.2	Calculate the line of action of a resultant using the principle of Moment.
2.	Determine nominal sizes for a simple horizontal beam subject to a combination of uniform and point loading	2.1	Support reactions for a simply supported horizontal beam using the equations of equilibrium and including the moment effect of a couple are calculated.
		2.2	The possible types of failure that need to be considered are determined.
		2.3	Shear force and bending moment diagrams are drawn.
		2.4	Bending stress is determined.
		2.5	Calculations are completed to determine the nominal size for the beam.
		2.6	Factors of safety are applied to finalise nominal size of beam.

Required Skills and Knowledge

Required skills include:

- calculating and using trigonometry, transposition, algebraic formula
- drawing shear force and bending moment diagrams

Required knowledge includes:

- force and gravity
- the concept of force
- characteristics of force
- rectangular components of force
- graphical addition of forces
- mathematical addition of forces
- weight as force
- moment and torque

Lesson Program:

Unit MEM30005A Calculate force systems in simple beam structures, is a 72 hour unit and is divided into the following program.

Topic	Skill Practice Exercise
Topic 1 – Structures; Strength & Stability	MEM30005-SP-0101
Topic 2 – Elements of Coplanar Force Resolution	MEM30005-SP-0201
Topic 3 – Bending Moments	MEM30005-SP-0301
Topic 4 – Types of Forces on Structural Members	MEM30005-SP-0401
Topic 5 – Shear and Bending Moment Diagrams	MEM30005-SP-0501
Topic 6 – Centroid and First Moment of Area	MEM30005-SP-0601
Topic 7 – Second Moment of Area	MEM30005-SP-0701
Topic 8 – Section Modulus	MEM30005-SP-0801
Topic 9 – Bending Stress	MEM30005-SP-0901
Topic 10 – Shear Stresses	MEM30005-SP-1001
Topic 11 – Deflection and Stiffness	MEM30005-SP-1101
Topic 12 – Selection of Steel Beam	MEM30005-SP-1201
Practice Competency Test:	MEM30005-PT-01

Table of Contents

Contents

Topic 1 – Structures; Strength & Stability

Required Skills

- Identify similarities between structures.
- Investigate possible environmental causes of structural failure.

Required Knowledge

- The capabilities of Strength and stability.
- Man-Made and Natural structures.
- Causes of structural failures.

Strength and Stability:

The two issues to be emphasized throughout this course and crucial to the understanding of structural principles are:

Strength: The capacity of the individual elements, which together make up a structural system, to withstand the load that is applied to it.

Stability: The capability of a structural system to transmit various loadings safely to the ground.

These two critical issues are experienced daily from the moment that an individual is born. The structural strength and stability of a newborn baby is so underdeveloped that it cannot hold its own head upright. The large mass of the head requires a support system that has sufficient strength to enable the head to maintain its stability; this strength and stability steadily increases as the bones, muscles and tendons of the skeletal and muscular systems increase. Eventually the extra support provided by the arm or hand is no longer needed. The first challenge posed by gravity is overcome and the baby can sit up, then crawl, then walk and finally run before age and deterioration reduces the functionality of the body.

Crawling on the four points of support (knees and hands) proves to be a very stabile situation for quite a long time. The "leap" to the unstable two point stance is the next development in our understanding of the influence of gravity. Again, the structural system must develop to the point that the individual elements of the system have acquired sufficient strength. The first steps are made: an action of supreme coordination of hundreds of elements that becomes second nature to man.

The list can be extrapolated to touch on many aspects of the human experience; riding skateboards and bicycles, jumping on trampolines, exercising on gymnastic equipment, weight training, sliding on ice skates and snow skis, sailing in a heavy wind, canoeing and kayaking – the list is endless; these are part of the human experience and each and every one rely on an inherent understanding of strength and stability.

The expression "sit on the chair properly!", really means "if you do not put all of the legs of your chair on the ground, you are going to over-balance and tip over or collapse!" Both strength and stability issues are addressed in this simple statement. Under normal conditions, the elements which make up the chair (its legs, bracing and seat) can easily resist the implied vertical loads. The **strength** of the individual elements of the chair has been designed for the static loads to be transferred through the four legs – the chair (as a horizontal load-bearing element) must transfer its load through a connection to the legs (vertical load-bearing elements). Some chairs may withstand a greater load than others, but they all resist the pull of gravity on the person sitting in them. If the legs cannot support the applied load they will fracture or break and are examples of strength failure.

The **stability** of the system of elements depends upon the orientation of the chair in space. When it stands upright, on all four legs, it is a stable system. If it is on its side, the chair might not be able to resist the loads for which it was designed. As it is tilted onto the back two legs, the structural system loses its equilibrium. At a certain point the chair as a system becomes unstable, fails and gravity pulls the supported load to the ground. This is a stability failure. In this type of failure, the individual elements retain their strength even as the system fails. The chair (system) could also have failed if the two supporting legs had experienced a strength failure (broken).

In each of these situations the chair, as a structural system, has reached the limit of its strength. As the saying goes "a chain (structural system) is only as strong as the weakest link (element)!"

Any structural system can be studied in light of these two issues. For example, the column of the Greek temple shown above is an element that can experience a strength (crushing) failure, or a system (buckling) failure. It is/was part of a larger structural system.

Structures:

One of the greatest problems of modern designs is the fact that engineers can solve ANY problem; ANYTHING can be built given time, research and investigation. Structural "realities" are perceived as no longer imposing limitations upon the designer; form does not have to be dictated by structure or even follow a function. Many of the seemingly undeniable "truths" of structural design have been rendered meaningless. Yet, gravity persists despite this incredible freedom of choice and buildings must stand up at the end of a real or virtual working day.

Structures can consist of buildings, bridges, dams, castles, towers, masts and a myriad number of other construction designs dating from pre-Grecian through to modern and extending into the future.

Figure 1.1 – Sophia Hagia, Turkey

The Sophia Hagia in Istanbul Turkey was constructed circa 350. The structural roof loads are transferred through pendentives (devices permitting the construction of a circular dome over a square room or an elliptical dome over a rectangular room) to the floor through 4 columns. The ribs are manufactured from lightweight hollow bricks made in Rhodes.

China Central Television building is not a traditional tower, but a loop of six horizontal and vertical sections. The construction of the building is a structural challenge, especially as it is constructed in a seismic zone. The building was built in three buildings that were joined to become one and a half buildings.

The structure can be described as two towers, 45 and 51 stories each, joined together above the 37th floor and below the 10th floor. The podium bends in the opposite direction from the upper link.

Both towers exhibit an inward incline of six degrees on each plane and are supported by braced steel tubes at the grid's perimeter.

The building has no movement joints and is one of the world's largest single structural systems; it is estimated that 20% less steel was used than in a single tower with the same gross floor area.

Figure 1.2 – China Central Television Building, China

Figure 1.3 – Cantilevered Building, U.S.A.

The 18 metre cantilever over the main entry and drop-off provides shelter and an ascetic effect. The cantilever perches on a solid mass above a transparent, glass box instead of the opposite by treating the whole upper floor as a truss.

In the design of a building, architectural design cannot be based solely upon one of the many aspects and should never be based on architecture alone, yet the structure is the very raw material of building. To use structure without understanding its implications is irresponsible and results in meaningless formalism.

Natural Forms:

Natural forms are shapes created by nature such as the curve of a snail's shell or the edge of a flower petal or leaf. In reality, nothing in nature is straight; every line or curve that appears straight is in fact, broken by some feature or is actually a shape made up of many segments.

Nature can form shapes that appear to be man-made.

The Sphinx is located In Pakistan's Hingol National Park and is a rock formation resembling the Great Sphinx of Giza; this Sphinx, however, is a natural one that was sculpted by coastal semi-desert winds over millions of years.

Tudibaring Point at Copacabana on the New South Wales Central Coat has a rock formation resembling an American Indian head when viewed from MacMasters Beach Beach. The head has been shaped by the wind and waves over many hundreds of centuries.

The Tessellated Pavement at Eaglehawk Neck, Tasmania is a rare erosion+ feature formed in flat sedimentary rock formations lying on the shore and bears the name because the rock has fractured into polygonal blocks resembling tiles, or *tessellations*. The cracks (or joints) were formed when the rock fractured through the action of stress on the Earth's crust and subsequently were modified by sand and wave action.

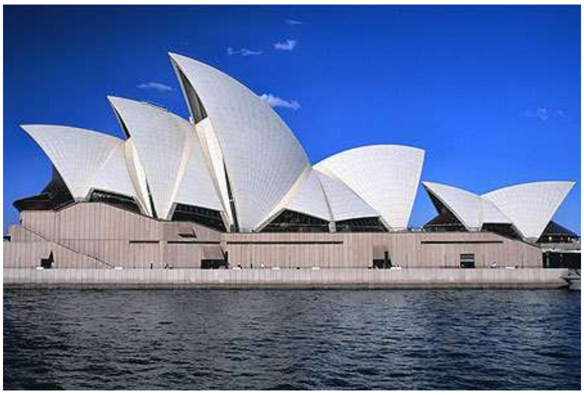
In Scotland, near the eastern coastline of the Caithness district, these magnificent rocks look like ancient building blocks and man-made walls. Instead, ravaging winds and the turbulent sea have carved out the rocks over many centuries. A human's visual perception mistakes natural forces for complex right-angled blocks and walls. Nature, not technology, molded and carved these millions of colored stone layers.

The Organ Pipe Rock is located at Jackson Creek near Melbourne. The river has slowly worn a deep valley in the basaltic plain formation of hard, dark rock revealing the old volcanic geological formations such as the hexagonal basalt columns known as the "Organ Pipes"; the lava deposit in the bed of the creek is of the order of 70 metres. As the lava cooled over several years the interior molten lava became insulated and developed into undisturbed columns of basalt (with uniform composition) as the lava heat dissipated.

Built Form:

The term "Built Form" describes what a building looks like, how tall it is, the proportion of the building area to the block size, the front, rear and side set backs from the street and adjoining properties, the number and size of windows and doors visible from the street, and most important of all, its architectural style.

The design of Fallingwater in Pennsylvania, USA, commenced in 1936 and is a multi storey dwelling constructed on cantilevered reinforced concrete and local stone. The design encompasses the natural beauty of the environment and is built over a creek and incorporates the constantly flowing waterfall.



The Sydney Opera House was designed to complement the history and heritage of Sydney Harbour. The form includes overlapping roof silhouettes, spherical geometry applied to roof shapes and Ancient Greek theatre seating. The construction is reinforced concrete with a precast hollow ribbed vault for the roof construction.

The Horizon Apartments are 143.9 m tall and 43 story prestressed concrete structure, designed by the Australian architect Harry Seidler was constructed between 1990 and 1998. The building contains 260 apartments with a total floor space of 32,000 m². It has a distinctive scalloped facade, and is finished in rendered concrete.

The design allowed for larger apartments in the top quarter, with balconies facing east towards the Pacific Ocean to maximize the panoramic views. The location and shape of the building has also been chosen to benefit views of the Sydney Opera House and Harbour Bridge.

The original Macquarie Lighthouse on Sydney's South Head was designed by Francis Greenway in 1818 but was reconstructed on the same design in 1883. The lighthouse is symmetrical in design with the main construction material being sandstone with an approximately 2 metre sixteen sided dioptric holophotal revolving white light. The lighthouse is 85 metres above sea level and 26 metres high.

Original lighthouse on the left with the new lighthouse on the right in 1882.

Recent image of the lighthouse 2010

Structural Failure:

All efforts are essential to prevent structural failure as it involves dangers to human life and property. There are numerous causes for a structural failure, and there is a requirement for a proper analysis of all the factors before construction. Structural failures can be natural or man-made.

Structural failures caused by nature can be caused by earthquakes, volcanic eruptions, cyclones, hurricanes, tornadoes, high winds, floods, landslides, thunderstorms, lightning, hail storms, fire, erosion, land subsidence and corrosion.

Man-made or human causes of structural failure are two-fold; firstly those related to nature and secondly, those which are purely man-made including design and construction errors, overloading, neglect, explosions, material quality and ethics.

Failures Caused by Nature.

Overcoming structural failures from natural causes is nearly impossible. Structures in an earthquake zone can be designed to withstand an earthquake equivalent to the largest known magnitude in the area may collapse if an earthquake of a larger magnitude strikes; winds in a cyclone, hurricane or typhoon effected area may have reach a certain maximum velocity however future storms may create higher wind velocities. Structural foundations can be designed for soil movement but soil erosion from floods will move the best designed and constructed footings. In the end we can only design and construct to suit the natural forces using figures and data slightly higher than those in recorded history and hope they will never be surpassed.

Figure 1.4

Figure 1.5

Figure 1.4 shows the severe earthquake due sustained by buildings during the Christchurch earthquake, while Figure 1.5 the damage to railway tracks causes by the lateral movement of the earth during the quake.

Figure 1.6

The building in Figure 1.6 sustained major damage to the structure due to excessively high wind velocities creating loads which the individual members were never designed to transmit due to the structural members alternating between tensile, compressive and torsional stresses.

Design and Construction Errors.

Defective construction that causes failure may be due to numerous reasons that may not be easy to predict before or during the construction. The major causes of structural failure are defective designs that have not determined the actual loading conditions on the structural elements. Inferior construction materials may also be the cause since the loads are calculated for materials of specific characteristics.

Structures may fail even if the design is satisfactory, but the materials are not able to withstand the loads. Employment of unskilled labour on construction work is another reason for structural failures. Therefore, it is important that the designers and builders are fully conscious of the reasons of failure, and undertake all preventive measures.

The image opposite shows a shaft that has been under-designed and failed when loads was applied to the assembly.

Figure 1.7

Human Errors.

"*To err is human*" People are not precision machinery designed for accuracy but are a different type of device entirely. Creativity, adaptability and flexibility are our strengths. Continual alertness and precision in action or memory are our weaknesses.

We are amazingly error tolerant even when physically damaged. Humans are extremely flexible, robust and creative, superb at finding explanations and meanings from the evidence provided. The same properties that lead to such robustness and creativity also produce errors. The natural tendency to interpret partial information (often our prime virtue) can cause operators to misinterpret thoughts and actions in such a plausible way that the misinterpretation can be difficult to discover.

The fork lift in Figure 1.8 was driven out the door while those in the immediate vicinity of the area were luck not to have been killed if the bomb has exploded.

Figure 1.8

A designer may take all the steps necessary to prevent failures due to incorrect design and construction however human error cannot be foreseen.

Faulty Construction.

Construction imperfection in design and manufacturing can be extremely expensive to settle. Architectural design and construction defects cause a structure to be improper for its proposed intent. Correct structural design is significant for all buildings, but exceptionally essential for tall buildings. Even a slight probability of failure is not acceptable since the results can be disastrous for human life and property. Therefore, engineers are required to be exceptionally careful and methodical in ensuring an appropriate design that can sustain the applied loads. All failure modes need to be examined by using modern software on the subject. However, a designer and a builder cannot be wholly confident about the design, and therefore an appropriate factor of safety is incorporated on the design calculations.

Defects Due to Inferior Workmanship.

Defects due to inferior workmanship can lead to structural damage and failure. Poor workmanship is often the origin of construction defects. Even superior quality materials, if used imperfectly, may not successfully serve the planned function, or be as durable as designed. Poor workmanship is the actual cause of most construction defects. General defects due to poor workmanship are leaking roofs, cracked floor tiles, shedding paint, and other numerous problems. Proper procedures have been created for almost every construction operation, and only implementation is required. A superior quality paint that is applied to an unclean surface is likely to fail, not because the material was substandard, but because it was used with a poor quality of work.

Foundation Failure.

Past experience shows that many structural foundations were not properly designed or constructed for the existing site soil conditions. Since suitable land is often not available, buildings and structures were constructed on soil that had inadequate bearing capacity to support the weight of the structure. Furthermore, the near surface soils may have consisted of expansive clays that shrank or expanded as the moisture content changed. Movement of foundation may occur if the clay moistening and drying is not uniform; vegetation, inadequate drainage, plumbing leakage, and evaporation, may also contribute to soil variation. The top soil layers provide the bearing capacity to hold the structure, and ensure stability of the foundation; if the bearing soil is inadequately compacted preceding construction, the foundation may be affected by settlement.

Metal Fatigue.

Fatigue occurs when a material is subjected to repeated loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the surface. Eventually a crack will reach a critical size, and the structure will suddenly fracture. The shape of the structure will significantly affect the fatigue life; square holes or sharp corners will lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions or fillets are therefore important to increase the fatigue strength of the structure.

Skill Practice Exercise:

Skill Practice Exercise MEM30005-SP-101:

There is a fundamental rightness in a structurally correct concept. It leads to an economy of means that can be understood by all. Designs which are inherently structurally correct are often perceived as objects of great beauty, even if only truly comprehended by few. One can find structure in everything.

Select two structures, one built prior to 1500 and one after the year 2000 and write a 250 word report on each structure highlighting the similarities, uniqueness about each structure and construction materials.

Include images in the final report.

Skill Practice Exercise MEM30005-SP-102:

Study the video of the Tacoma Narrows Bridge Disaster and supply a 250 word supposition on the causes of the failure and possible changes to eliminate the problem. Research is available on the internet and several structural reference books.