Unit 14: Structural Mechanics in Construction and Civil Engineering

Unit code: D/600/0228

QCF Level 3: BTEC Nationals

Credit value: 10

Guided learning hours: 60

Aim and purpose

The unit enables learners to develop an understanding of how structural elements behave under load, the skills needed to solve structural mechanics problems, design simple beams, columns and mass retaining walls, and understand how computer software is used in structural analysis and design.

Unit introduction

Understanding the mechanics of structures is essential for engineers, architects and contractors to enable them to build safely. The structural safety of buildings is about how loads are carried and transmitted to the ground. Certain loads will occur during the construction process and others will arise during the use of a building or civil engineering project. Loads include, or are caused by, the self-weight of the materials used, the use to which the floors are put, and wind, soil and water pressure.

To create the spaces required in a building, and to withstand the forces of nature and normal use, safe structures must be designed. Civil and structural engineers often deal with large and complex structures but each beam, lintel, roof truss, column, foundation and retaining wall must be individually designed to contribute to the safety of the construction project as a whole.

The focus of this unit is on understanding the forces in structures and the behaviour of common structural materials. Learners will develop an understanding of the forces that are created in the building framework and the structural elements, and will learn how to design simple structural units safely. Analysis of the forces in frameworks and elements relies on accurate mathematical skills and it is assumed that learners will have developed sufficient mathematical knowledge, understanding and skills to support this unit, before starting this unit.

The unit also gives learners a sound basis for the analysis and design of more complex structures at a higher level.

Learning outcomes

On completion of this unit a learner should:

1 Understand how structural elements behave under load

2 Be able to solve structural mechanics problems

3 Be able to design simple beams and columns

4 Be able to design mass retaining walls to withstand pressure from water and soils

5 Understand the use of computer software in structural analysis and design.

Unit content

1 Understand how structural elements behave under load

Behaviour of structural elements: beams in bending and shear; stresses and deflection; columns and struts under direct load and eccentric load; effect of restraint on members in compression

Combined behaviour: bracing of frameworks for stability; use of walls for stability

2 Be able to solve structural mechanics problems

Structural mechanics problems: relating to beams; columns; frames

Beams: point loads; uniformly distributed loads (UDLs); combined loads; reactions; shear force values; bending moment values; relationship between shear force and bending moment; point of contraflexure; simply supported beams with cantilever ends; simply supported beams without cantilever ends

Columns: axially loaded; eccentrically loaded; effective length; maximum stress; short columns; long columns

Frameworks: statically determinate; pin-jointed; subject to dead loads and wind loads

3 Be able to design simple beams and columns

Beams: safe loading (for steel, reinforced concrete, timber); shear; bending; limit state design; British Standards

Columns: axial load capacity (for steel, reinforced concrete, timber); limit state design; British Standards

4 Be able to design mass retaining walls to withstand pressure from water and soils

Mass retaining walls: forces (soils, level surcharge, liquid); self-weight; stability; factors of safety eg sliding, overturning, ground bearing capacity, middle third rule

5 Understand the use of computer software in structural analysis and design

Types: spreadsheets; design packages eg STAAD.pro

Advantages: automated loading of structures; integration of CAD drawings; inter-operability; section choices

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the behaviour of beams and columns under load [IE1, IE2, IE4, IE6]	**M1** explain the relationship between shear force and bending moment and the significance of the point of contraflexure	**D1** compare numerical and graphical methods of solving forces in frameworks
P2 determine reactive forces and plot shear force and bending moment diagrams for a simply supported beam [IE1, IE2, IE4, IE6, SM2. SM3]		
P3 determine reactive forces and plot shear force and bending moment diagrams for a cantilever beam [IE1, IE2, IE4, IE6, SM2. SM3]		
P4 determine the forces acting in a determinate frame using mathematical and graphical techniques [IE1, IE2, IE4, IE6, SM2. SM3]		
P5 determine the maximum stress in a short column under axial and eccentric loads [IE1, IE2, IE4, IE6, SM2. SM3]	**M2** explain how the effective length of a column is determined under different restraint conditions	
P6 produce suitable section sizes for axially loaded columns [IE1, IE2, IE4, IE6, SM2. SM3]	**M3** compare alternative methods of designing structural members in terms of British Standards.	**D2** evaluate alternative design methods in terms of their application for a given design brief.
P7 produce suitable section sizes for simply supported beams subject to combined loading [IE1, IE2, IE4, IE6, SM2. SM3]		

Assessment and grading criteria			
To achieve a pass grade the evidence must show that the learner is able to:		**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P8	produce a suitable section for a mass retaining wall that is safe in overturning, sliding and settlement [IE1, IE2, IE4, IE6, SM2. SM3]		
P9	explain the benefits of using computer software in structural analysis and design. [IE1, IE2, IE4, IE6, RL5, RL6]		

PLTS: This summary references where applicable, in the square brackets, the elements of the personal, learning and thinking skills applicable in the pass criteria. It identifies opportunities for learners to demonstrate effective application of the referenced elements of the skills.

Key	IE – independent enquirers	RL – reflective learners	SM – self-managers
	CT – creative thinkers	TW – team workers	EP – effective participators

Essential guidance for tutors

Delivery

Tutors delivering this unit have opportunities to use a wide range of techniques. Lectures, discussions, seminar presentations, site visits, supervised practicals, videos/DVDs, research using the internet and/or library resources and use of personal and/or industrial experience are all suitable. Delivery should stimulate, motivate, educate and enthuse the learners. Visiting expert speakers could add to the relevance of the subject for learners. Wherever possible, delivery should be supported by visits to construction sites.

The first three learning outcomes are sequential.

Learning outcome 1 is intended to develop an understanding of the essential requirement of a structure, to support loads safely and effectively, and the need to ensure the structural stability of frameworks during the construction and use of a building. Learners should view ongoing construction work, including scaffolding and structural frames before cladding. The behaviour of structural elements can be demonstrated in laboratory experiments or class demonstrations using simple apparatus and materials that will readily distort.

Learning outcome 2 is designed to help learners identify the magnitude and effect of forces in a structure as they flow from loads through individual members to the ground. The emphasis should be on the accurate determination of the magnitude of the forces and the stresses they generate in the materials that form the structural members. Understanding the basic principles is essential and calculations involving complex loading systems should be avoided. However, at least two different load configurations should be used in the analysis of beams and columns. In the case of frames, both mathematical and graphical methods should be used for analysis.

An holistic delivery approach to roof trusses, beams and columns, in a simplified but realistic situation, will allow learners to relate the analysis of loading systems to learning outcome 1. The importance attached to the consistent use of tried and tested methods of calculation, and the showing of all working clearly and fully in the determination of accurate solutions to structural calculations, should be emphasised throughout.

Learning outcome 3 deals with the design of simple structural elements. This is the final part of the process. The emphasis should be on learners appreciating the different structural materials and being able to determine material sizes accurately to carry required stresses safely. Learning for learning outcome 2 will provide design data that can be used in the design of structural elements. Three commonly used structural materials (timber, steel and reinforced concrete) should be used in design exercises so that learners can compare the load carrying capacity of structural elements.

Learning outcome 4 is distinct from the first three learning outcomes. The intention is to introduce learners to retaining structures, their purpose, the forces involved, the principles that underpin their design and the actual design of simple examples.

Learning outcome 5 is intended to develop an understanding of the use and advantages of computer software in structural analysis and design. Learners can carry out research using the internet, free software, centre resources and visits to shows and exhibitions. Emphasis should be on an appreciation of the processes involved, and the time needed, to carry out the analysis and design of structural elements. Learners will, therefore, be able to evaluate software in terms of its advantages and use in that context.

Group activities are permissible, but tutors will need to ensure that individual learners have equal experiential and assessment opportunities.

Health, safety and welfare issues are paramount and should be reinforced through close supervision of all workshops and activity areas, and risk assessments must be undertaken before practical activities are taken. Centres are advised to read the *Delivery approach* section in the specification, and *Annexe H: Provision and Use of Work Equipment Regulations 1998 (PUWER)*.

Outline learning plan

The outline learning plan has been included in this unit as guidance and can be used in conjunction with the programme of suggested assignments.

The outline learning plan demonstrates one way in planning the delivery and assessment of this unit.

Topic and suggested assignments/activities and/assessment
Tutor input on introduction to the unit
Tutor input on concept of forces: co-planar and concurrent forces
Learner exercise on determining resultant forces
Tutor input on forces in the context of structures: tension and compression
Class discussion on types and configuration of loads: dead, imposed, wind, point, loads
Tutor input on structural elements: beams, columns and frames
Tutor input on beams under load: bending and shear stresses-
Introduction to frames
Tutor input on determinate and indeterminate structures
Tutor input on bracing of frameworks for stability
Tutor input on types of frameworks: statically determinate; pin-jointed; subject to dead loads and wind loads
Learner exercise: computation of forces using mathematical techniques
Learner exercise: computation of forces using graphical techniques
Analysis of beams
Tutor input on load configurations: point loads; uniformly distributed loads (UDLs); combined loads
Learner exercise: calculation and plotting of reactions; shear force values; bending moment values
Tutor input on relationship between shear force and bending moment
Tutor input on introduction to point of contraflexure
Student exercise: analysis of simply supported beams

Topic and suggested assignments/activities and/assessment
Assignment 1: Structural Behaviour and Analysis of Beams and Frames
Beam design Tutor input on introduction to beam design Didactic input: properties of sections: first moment of area or centroid calculations Learner exercise: calculation of centroid or first moment of area Didactic input: properties of sections: second moment of area or moment of inertia calculations Learner exercise: calculation of second moment of area or moment of inertia Tutor input on bending theory: section modulus Learner exercise: design of timber beams Learner exercise: design of steel beams Learner exercise: design of reinforced concrete beam Tutor input on limit state and other methods of design Independent investigation: limit state and other methods of design
Columns Tutor input on introduction to columns Tutor input on slenderness ratio and effective length Learner exercise: calculation of slenderness ratio and effective length Tutor input on design of columns Learner activity: design of timber columns Learner activity: design of steel columns Learner activity: design of reinforced concrete columns
Assignment 2: Design of Beams and Columns
Retaining walls Tutor input on introduction to retaining walls Class discussion on loads acting on retaining structures, distribution of such loads Tutor input on safety factors, design factors such as sliding, overturning, ground bearing capacity, middle third rule, Learner activity: retaining wall design and safety checks
Software Tutor input on needs for software, typical software available Class discussion on possible reduction in time and expense Didactic input: quality enhancement: improved decision making Independent investigation: exploring the capabilities of a structural software
Assignment 3: Retaining Walls and Use of Computer Software
Review of unit and assignment feedback

Assessment

Evidence for this unit can be gathered from a variety of sources, including well-planned investigative assignments, case studies or reports of practical assignments.

Many suitable forms of assessment can be used and tutors are encouraged to consider and adopt these where appropriate. Some example assessment approaches are suggested below. However, these are not intended to be prescriptive or restrictive and are provided as an illustration of the alternative forms of assessment evidence that would be acceptable.

The structure of the unit suggests that the grading criteria could be addressed fully by using three assignments. The first of these would cover P1, P2, P3, P4, M1, M2 and D1, the second would cover P5, P6, P7, M3 and D2 and the third P8 and P9.

To achieve a pass grade learners must meet the nine pass criteria listed in the grading grid.

For P1, learners must explain, with the use of supportive sketches, the general behaviour of beams and columns under load. Evidence could be in the form of a written report with supportive diagrams.

For P2, learners must determine reactive forces and plot shear force and bending moment diagrams for two different, simply supported beams carrying a combination of point and distributed loads. Emphasis should be on the accurate and logical presentation of calculations and results. Evidence should be presented as calculations and diagrams.

For P3, learners must determine reactive forces and plot shear force and bending moment diagrams for a cantilever beam carrying a combination of point and distributed loads. Emphasis should be on the accurate and logical presentation of calculations and results. Evidence should be presented as calculations and diagrams.

For P4, learners must determine, by using calculations, the forces acting in a statically determinate pin-jointed framework with loads at nodal points. This should then be checked using a graphical method. The calculations should be accurate and indicate the nature of the force in each framework member. Examples of suitable approaches to evidence are as for P2.

For P5, learners must determine the maximum stress in a short column under both axial and eccentric loading. Learners are required to present calculations and results in the correct units. Evidence could be in the same format as for P2.

For P6, learners must produce suitable section sizes for axially loaded columns of different materials (timber, steel and reinforced concrete). The results should be accurate and in the correct units. Evidence could be in the same format as for P2

For P7, learners must determine the size of a simply supported beam carrying combined loads, for example a uniformly distributed load and a point load, for different materials (timber, steel and reinforced concrete). The effects of shear and bending are to be considered. Evidence could be in the same format as for P2.

For P8, learners must calculate the forces acting on a specified mass retaining wall, propose a suitable section and apply stability checks which will involve the resulting factors of safety for overturning, sliding and bearing capacity. This should indicate clearly learner understanding of the stability of the wall. Evidence could be in the same format as for P2.

For P9, learners must explain the advantages of using computer software and how it can help in analysing and designing structural elements. Evidence could be in the form of a report supported by illustrations, printouts or screenshots of a software package.

To achieve a merit grade learners must meet all of the pass grade criteria and the three merit grade criteria.

For M1, learners must explain the relationship between shear force and bending moment, and explain the significance of the point of contraflexure. They should be able to show an understanding of the effect of complex loading on beams. Evidence could be the same as for P2.

For M2, learners must explain how the effective length of a column is determined, and the consequences of restraint. Evidence could be in the form of a report supported by appropriate calculations and diagrams.

For M3, learners must compare alternative design methods, such as limit state design, with British Standards. Evidence could be in the form of a report supported by appropriate details.

To achieve a distinction grade learners must meet all of the pass and merit grade criteria and the two distinction grade criteria.

For D1, learners must compare numerical and graphical methods of solving forces in frameworks. The frameworks should be pin jointed and statically determinate and loaded at their nodal points. Evidence could be the same as for P2.

For D2, learners must evaluate alternative design methods in terms of their application for a given design brief. Learners should be given a design brief outlining serviceability requirements and other relevant details. This can be set as an extension to the activity for M3. Evidence could be in the form of a report supported by appropriate details.

Programme of suggested assignments

The following table shows how the suggested assignments match and cover the assessment grading criteria. The following table shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the grading criteria. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1, M2, D1	Structural Behaviour and Analysis of Beams and Frames	You are working as a junior technician in a design consultancy. You have been asked by your senior engineer to carry out an analysis of beams and frames.	A report containing written responses on the behaviour of structural elements under load and an analysis of beams, frames and columns, along with interpretations of the results.
P5, P6, P7, M3, D2	Design of beams and columns	You are working as a junior technician in a design consultancy. You have been asked by your senior engineer to design beams and columns as part of a housing project. The relevant data is provided. You are advised to follow relevant BS.	A report containing written responses on design methods, and their suitability, and production of design solutions for a given design brief.
P8, P9	Retaining Walls and Use of Computer Software	You are working as a junior technician in a design consultancy. You have been asked by your senior engineer to design a gravity retaining wall and apply checks to ensure safety of design. The senior engineer intends to purchase computer software. You have been asked to investigate uses and advantages of software in structural analysis and design.	A report on the uses and advantages of software in structural analysis and design.

Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

This unit forms part of the BTEC Construction and the Built Environment sector suite. This unit has particular links with the following unit titles in the Construction and the Built Environment suite:

Level 1	Level 2	Level 3
		Science and Materials in Construction and the Built Environment
		Construction in Civil Engineering

This unit links to the Edexcel Level 3 NVQ in Technical Design (Construction Environment).

This unit links to the following Level 3 NOS:

- BE Design
- BE Development and Control
- Construction Contracting Operations.

Essential resources

Experiments, models and visual aids should be used to illustrate the stability of frames, the nature of loading that occurs and the forces that are imposed.

Specialist equipment to demonstrate various structural phenomena is available but not essential to the delivery of this unit.

Health, safety and welfare issues must be considered at all times and risk assessment should be undertaken for all demonstrations, experiments and site visits used in the delivery or assessment of the unit.

Employer engagement and vocational contexts

The use of vocational contexts is essential in the delivery and assessment of this unit. Much of the work can be set in the context of case studies of local employers. Learning outcomes 5 lends itself well to investigating what goes on in the real world of structural analysis and design. Visits to companies/shows/exhibitions will enhance this particular part of the unit. Companies with design sections are likely to be able to show how, and why, software and design packages are used.

Support to enable centres to initiate and establish links to industry, and to networks arranging visits to industry and from property practitioners is given below:

- Learning and Skills Network – www.vocationallearning.org.uk
- National Education and Business Partnership Network – www.nebpn.org
- The Royal Institution of Chartered Surveyors – www.rics.org
- Work Experience/Workplace learning frameworks – Centre for Education and Industry (CEI University of Warwick) – www.warwick.ac.uk/wie/cei/

Indicative reading for learners

Textbooks

Arya C – *Design of Structural Elements, 2nd Edition* (Taylor and Francis, 2002) ISBN 041526845 1

Durka F et al – *Structural Mechanics: Loads, Analysis, Design and Materials, 6th Edition* (Prentice Hall, 2002) ISBN 0582431654

Fiona C – *Structural Engineer's Pocket Book 2nd Edition* (Butterworth-Heinemann, 2008) ISBN 0750686863

Hulse R and Cain J – *Structural Mechanics, 2nd Revised Edition* (Palgrave Macmillan, 2000) ISBN 0333804570

McKenzie W – *Design of Structural Elements* (Palgrave Macmillan, 2003) ISBN 1403912246

Seward D – *Understanding Structures: Analysis, Materials, Design, 3rd Revised Edition* (Palgrave Macmillan, 2003) ISBN 0333973860

Smith P – *An Introduction to Structural Mechanics* (Palgrave Macmillan, 2001) ISBN 0333962559

Journals

The Structural Engineer – IStructE

Websites

www.risatech.com	RISA Technologies, LLC
www.structuralconcepts.org	University of Manchester – Structural Concepts
www.tenlinks.com/cae/products/structural.htm	TenLinks, Inc

Delivery of personal, learning and thinking skills (PLTS)

The following table below identifies the personal, learning and thinking skills (PLTS) opportunities that have been included within the assessment criteria of this unit.

Skill	When learners are ...
Independent enquirers	planning and carrying out research to understand the advantages and use of computer software comparing alternative solutions to design problems using, analysing and evaluating design information, judging its relevance and value
Reflective learners	explaining the benefits of computer software for structural analysis and design
Self-managers	organising time and resources and prioritising actions when evaluating the application of alternative design methods.

Although PLTS are identified within this unit as an inherent part of the assessment criteria, there are further opportunities to develop a range of PLTS through various approaches to teaching and learning.

Skill	When learners are ...
Creative thinkers	trying out alternative or new design solutions
Reflective learners	assessing their own design solutions by applying stability checks
Self-managers	using standard procedures to carry out analysis and design.

Functional Skills – Level 2

Skill	When learners are ...
ICT – Find and select information	
Select and use a variety of sources of information independently for a complex task	evaluating design methods for a given design brief
ICT – Develop, present and communicate information	
Enter, develop and format information independently to suit its meaning and purpose including: • text and tables • images • numbers • records	preparing reports and presenting results of their analysis/design
Present information in ways that are fit for purpose and audience	presenting evidence of analysis and design of structural elements
Mathematics	
Understand routine and non-routine problems in a wide range of familiar and unfamiliar contexts and situations	calculating forces and moments in a beam with different load configurations
Identify the situation or problem and the mathematical methods needed to tackle it	calculating moment of area and section modulus
Select and apply a range of skills to find solutions	determining magnitude and type of forces in a determinate frame
Use appropriate checking procedures and evaluate their effectiveness at each stage	applying stability checks on mass retaining walls
Interpret and communicate solutions to practical problems in familiar and unfamiliar routine contexts and situations	determining the size of a simply supported beam to carry a given load system in three different materials
Draw conclusions and provide mathematical justifications	comparing numerical and graphical methods of solving forces in frameworks
English	
Speaking and listening – make a range of contributions to discussions and make effective presentations in a wide range of contexts	discussing types and configuration of loads acting on a structure
Reading – compare, select, read and understand texts and use them to gather information, ideas, arguments and opinions	explaining alternative methods of designing structural members in the light of British Standards
Writing – write documents, including extended writing pieces, communicating information, ideas and opinions, effectively and persuasively	explaining use and advantages of computer software in structural analysis and design.