Unit 14: Structural Mechanics in Construction and Civil Engineering

NQF Level 3: **BTEC National**

Guided learning hours: 60

Unit abstract

The study of 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 into the ground. Certain loads will occur during the construction process, and others will arise during the use to which the building or civil engineering project is put. The loads include or are caused by the self weight of materials used, the use to which the floors are put, wind, and to soil and water pressures.

To create the spaces required in a building and to withstand the forces of nature and normal use, safe structures are required to 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 safely to the whole construction project.

The focus of this unit is on understanding the forces in structures and the behaviour of some structural materials. Learners will come to understand the forces which are created in the building framework and the structural elements, and be able to safely design simple structural units. The safe analysis of the forces in frameworks and elements relies on accurate mathematical skills.

The unit will also provide learners with a sound basis for learning how to analyse and design more complex structures, at Higher National and degree level.

Learning outcomes

On completion of this unit a learner should:

1 Understand how simple structural elements behave under load

2 Be able to solve structural mechanics problems using both mathematical and graphical techniques

3 Be able to design simple beams and columns in steel, reinforced concrete and timber

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

Unit content

1 **Understand how simple 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 using both mathematical and graphical techniques**

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; application of above to simply supported beams with or without cantilever ends

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

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

3 **Be able to design simple beams and columns in steel, reinforced concrete and timber**

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

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

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

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

Grading grid

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

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 describe, with the aid of sketches, the behaviour of beams and columns under load	M1 illustrate and explain the relationship between shear force and bending moment, and explain the significance of the point of contraflexure	D1 explain and illustrate how roof trusses, floor beams and columns transmit dead and live loads to the ground in a two-storey structure
P2 determine reactive forces and plot shear force and bending moment diagrams for two different simply supported beams, carrying combined loads	M2 explain how the effective length of a column is determined, and the consequences of restraint	D2 justify the selection of an appropriate material for a given UDL loaded beam and column framework from their own calculations.
P3 determine the maximum stress in a short column under an eccentric load	M3 compare numerical and graphical methods of solving forces in frameworks	
P4 determine by either calculation or graphical methods the forces acting in a statically determinate pin jointed framework with loads at nodal points	M4 compare two structural materials in terms of the advantages and disadvantages of each when used as beams and columns.	
P5 determine the size of a simply supported beam carrying combined loads, for two different materials		
P6 produce suitable section sizes for two		

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**:
fully restrained columns, of different materials, subject to safe axial load requirements. P7 calculate the forces acting on a specified mass retaining wall, and hence the resulting factors of safety for overturning, sliding and bearing capacity.		

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, research using the internet and/or library resources and the use of personal and/or industrial experience are all suitable. Delivery should stimulate, motivate, educate and enthuse learners. Visiting expert speakers could add to the relevance of the subject for learners.

Learning outcomes 1, 2 and 3 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. Wherever possible, delivery of the unit should be supported by visits to construction sites.

Learners should view ongoing construction work, including both scaffolding and structural frames prior to 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 here 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. An understanding of the basic principles is paramount and calculations involving complex loading systems should be avoided.

A holistic delivery approach to roof trusses, beams and columns, in a simplified but realistic situation, will allow learners to relate the analysis of the loading systems to the learning outcome 1.

The importance of 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 accurately determine material sizes to safely carry required stresses. Learning outcome 2 provides design data that can be used in the design of structural elements.

Learning outcome 4 is distinct from learning outcomes 1, 2 and 3. 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.

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

Health, safety and welfare issues are paramount and should be strictly reinforced through close supervision of all workshops and activity areas, and risk assessments must be undertaken prior to practical activities. Centres are advised to read the Delivery approach section on page 24, and Annexe G.

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 that be employed and tutors are encouraged to consider and adopt these where appropriate. Some examples of possible 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. General guidance on the design of suitable assignments is available on page 19of this specification.

Some criteria can be assessed directly by the tutor during practical activities. If this approach is used suitable evidence would be observation records or witness statements. Guidance on their use is provided on the Edexcel website.

The structure of the unit suggests that the grading criteria may be fully addressed by using three assignments. The first of these would cover P1, P2, P3, P4, M1, M2, D1, the second would cover P5, P6, M4, and D2, and the third would cover P7.

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

For P1, learners must describe, with the use of supportive sketches, the general bahaviour of beams under load. Evidence could be in the form of a a written report or a presentation 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 given to accurate and logical presentation of calculations and results. Evidence should be presented as calculations and diagrams.

For P3, learners must determine the maximum stress in a short column under an eccentric load. Learners are required to present calculations and results in the correct units. Evidence could be in the same format as for P2.

For P4, learners must determine, by using calculations or graphical methods, the forces acting in a statically determinate pin jointed framework with loads at nodal points. The results could be achieved arithmetically or graphically but they should be accurate and indicate the nature of the force in each framework member. Examples of suitable evidence approaches are as for P2.

For P5, learners must determine the size of a simply supported beam carrying combined loads, eg a uniformly distributed load and a point load, for two different materials. The effects of shear, bending and deflection are to be considered. Evidence could be in the same format as for P2.

For P6, learners must produce suitable section sizes for two fully restrained columns, of different materials, subject to safe axial load requirements. The results should be accurate and in the correct units. Evidence could be in the same format as for P2.

For P7, learners must calculate the forces acting on a specified mass retaining wall, and hence the resulting factors of safety for overturning, sliding and bearing capacity. This should clearly indicate the learners' understanding of the stability of the wall. Evidence could be in the same format as for P2.

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

For M1, learners must illustrate and 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. Contraflexure should be considered in respect of overhanging simply supported beams and reinforced concrete design. Evidence could be in the same format as for P2.

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

For M3, 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 in the same format as for P2.

For M4, learners must compare two structural materials in terms of the advantages and disadvantages of each when used as beams and columns. They should consider different design materials, construction techniques, ease of erection, strength, durability and maintenance. This could be a direct development from P4 and P5. Evidence could be in the same format as for M2.

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 explain and illustrate how roof trusses, floor beams and columns transmit dead and live loads to the ground in a two-storey structure. A clear explanation of the contribution of each structural element to the whole is required. Evidence could be in the same format as for M2.

For D2, learners must justify the selection of an appropriate material for a given UDL loaded beam and column framework, from their own calculations. Learners must select a material and determine the sizes of beam and column for the given framework under load conditions. They must justify the reasons for the material chosen, clearly stating its advantages and disadvantages over other alternative materials. Evidence could be in the same format as for P2.

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

The learning outcomes in this unit are closely linked with, for example, *Unit 4: Science and Materials in Construction and the Built Environment* and *Unit 29: Civil Engineering in Construction*, together with similar units at Higher National and Degree level.

This unit may have links to the Edexcel Level 3 Technical and Professional NVQs for Construction and the Built Environment. Updated information on this, and a summary mapping of the unit to the CIC Occupational Standards, is available from Edexcel. See Annex D

This unit presents opportunities to demonstrate key skills in application of number, communication, information and communication technology, improving own learning and performance, problem solving and working with others. Opportunities for satisfying requirements for Wider Curriculum Mapping are summarised in *Annexe FE*.

Essential resources

Experiments, models and visual aids should be used to illustrate the stability of frames, the nature of loading that occur 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.

Indicative reading for learners

Textbooks

Arya C — *Design of Structural Elements: Concrete, Steelwork, Masonry and Timber Design to British Standard, 2nd Edition* (Spon Press, 2002) ISBN 0415268451

Hulse R and Cain J — *Structural Mechanics* (Palgrave Macmillan, 2000) ISBN 0333804570

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

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

Websites

www. Structuralconcepts.org	Seeing and Touching Structural Concepts

Key skills

Achievement of key skills is not a requirement of this qualification but it is encouraged. Suggestions of opportunities for the generation of Level 3 key skill evidence are given here. Tutors should check that learners have produced all the evidence required by part B of the key skills specifications when assessing this evidence. Learners may need to develop additional evidence elsewhere to fully meet the requirements of the key skills specifications.

Application of number Level 3	
When learners are:	**They should be able to develop the following key skills evidence**:
• determining the size of a simply supported beam to a carry given load system in two different materials.	N3.1 Plan an activity and get relevant information from relevant sources. N3.2 Use this information to carry out multi-stage calculations to do with: a amounts or sizes b scales or proportion c handling statistics d using formulae. N3.3 Interpret the results of your calculations, present your findings and justify your methods.
Communication Level 3	
When learners are:	**They should be able to develop the following key skills evidence**:
• identifying where bracing is necessary to stabilise a structural frame.	C3.1a Take part in a group discussion. C3.1b Make a formal presentation of at least eight minutes using an image or other support material. C3.2 Read and synthesise information from at least **two** documents about the same subject. Each document must be a minimum of 1000 words long. C3.3 Write **two** different types of documents, each one giving different information about complex subjects. One document must be at least 1000 words long.

Information and communication technology Level 3	
When learners are:	**They should be able to develop the following key skills evidence**:
• explaining how the effective length of a column is determined.	ICT3.1 Search for information, using different sources, and multiple search criteria in at least one case. ICT3.2 Enter and develop the information and derive new information. ICT3.3 Present combined information such as text with image, text with number, image with number.
Improving own learning and performance Level 3	
When learners are:	**They should be able to develop the following key skills evidence**:
• determining reactive forces and plot shear force and bending moment diagrams for two beams, carrying combined loads, one of which has a cantilever end.	LP3.1 Set targets using information from appropriate people and plan how these will be met. LP3.2 Take responsibility for your learning, using your plan to help meet targets and improve your performance. LP3.3 Review progress and establish evidence of your achievements.
Problem solving Level 3	
When learners are:	**They should be able to develop the following key skills evidence**:
• identifying the forces acting on a mass retaining wall and selecting an appropriate cross section using available data.	PS3.1 Explore a problem and identify different ways of tackling it. PS3.2 Plan and implement at least one way of solving the problem. PS3.3 Check if the problem has been solved and review your approach to problem solving.
Working with others Level 3	
When learners are:	**They should be able to develop the following key skills evidence**:
• comparing numerical and graphical method of solving forces in frameworks.	WO3.1 Plan work with others. WO3.2 Seek to develop co-operation and check progress towards your agreed objectives. WO3.3 Review work with others and agree ways of improving collaborative work in the future.