Unit 48: Structural Behaviour and Detailing for Construction

Unit code: J/600/0370

QCF Level 3: BTEC Nationals

Credit value: 10

Guided learning hours: 60

Aim and purpose

This unit will enable learners to gain an understanding of the serviceability requirements of structures and gain the skills required to calculate the maximum deflections of loaded beams and design and detail structural elements.

Unit introduction

The study of structural behaviour under imposed loading, together with an understanding of load transference to individual elements, is essential for engineers, architects and contractors. In this unit, the various factors that affect structural behaviour and underpin the design of simple structural elements are explored. Standard design calculations and relevant British Standards are investigated, as is the subsequent translation of calculation results into detailed drawings. Production of these detailed drawings is an important aspect of industrial practice. Learners will develop a deeper understanding of structural elements and also of the connection details used for the purposes of fabrication and construction.

This unit also includes the preparation of schedules and cutting lists. The emphasis is firmly on the standard methods of detailing used for a variety of structural elements constructed using a variety of structural materials.

The unit will also give learners a sound basis for learning how to analyse and design more complex structures at a higher level of study.

Learning outcomes

On completion of this unit a learner should:

1 Understand the serviceability requirements of structures

2 Be able to perform calculations on the deflection of beams under load

3 Be able to design structural elements

4 Be able to detail structural elements.

Unit content

1 Understand the serviceability requirements of structures

Serviceability requirements: intended use of the structure; location context; relevant British Standards; limit state design; factor of safety; partial safety factors

2 Be able to perform calculations on the deflection of beams under load

Deflection of beams: factors that affect deflection; methods used to determine deflection

Factors: magnitude of loads; load configuration; sectional properties of beams; materials used Methods: Moment Area Method; Macauley's method

3 Be able to design structural elements

Design of structural elements: information and data requirements; determination of section sizes

Information and data requirements: loading and support conditions; sectional properties of simple beam sections determined from the use of standard formulae or manufacturer's published tables in timber, steel and in-situ reinforced concrete

Section sizes: requirements for simply supported reinforced concrete, timber and steel beams, design of timber floor joists to carry a given load over a simply supported span

4 Be able to detail structural elements

General arrangements: framing plans; elevations; sections

Individual details: fabrication details for steel members; reinforcement details; schedules and cutting lists

Connection details: beam-to-column; beam-to-beam; joist-to-joist; joist-to-support

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 concept of serviceability limit state design as applied to steel and concrete [IE2, IE3, IE4]	**M1** compare the methods used to determine deflections in terms of their fitness for purpose	**D1** evaluate the effect of different materials and beam sections on deflection in beams
P2 explain the factors affecting the deflection of beams [IE2, IE3, IE4]		
P3 calculate the maximum deflection in beams using Moments of Area and Macauley's method [IE2, IE3, IE4]		
P4 calculate required section sizes for beams [IE2, IE3, IE4]	**M2** compare the methods used to determine section sizes in terms of their fitness for purpose	
P5 calculate required section sizes for timber floor joists [IE2, IE3, IE4]		
P6 produce general arrangement details [IE2, IE3, IE4, SM2, SM3]	**M3** prepare schedules for individual structural elements **M4** prepare cutting lists for individual structural elements.	**D2** design structural details to an acceptable industry standard.
P7 produce details of individual structural elements [IE2, IE3, IE4, SM2, SM3]		
P8 produce connection details for structural members. [IE2, IE3, IE4, SM2, SM3]		

PLTS: This summary references where applicable, in the square brackets, the elements of the personal, learning and thinking skills which are embedded in the assessment of this unit. By achieving the criteria, learners will have demonstrated 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

It is recommended that this unit is delivered at a later stage in any programme when learners have completed the units *Structural Mechanics in Construction and Civil Engineering* and *Graphical Detailing in Construction and the Built Environment*.

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, use of industry standard drawings as examples as well as personal and/or industrial experience are all suitable. Delivery should stimulate, motivate, educate and enthuse learners.

Learners should view ongoing construction work, including both scaffolding and structural frames before cladding. The behaviour of structural elements under load can easily be demonstrated using simple apparatus and materials that will readily distort.

Learning outcome 1 is intended to develop an understanding of the serviceability requirement of a structure and the need to ensure structural stability at all times. The emphasis should be on understanding safety and partial safety factors and how these apply in limit state design.

Learning outcome 2 is designed to help learners understand the factors contributing to deflection. Learners will be able to apply the Moment Area method and Macauley's method to determine maximum deflection in a beam. Emphasis should be on the accurate determination of the magnitude of deflection. An understanding of the basic principles is paramount and calculations involving complex loading systems should be avoided. However, at least two different load configurations should be used.

Learning outcome 3 deals with the design of simple structural elements using limit state design. The emphasis should be on learners appreciating the different structural materials and being able to determine sizes accurately and apply appropriate safety factors. Three commonly used structural materials (timber, steel and reinforced concrete) should be used in design exercises so that learners are able to compare the load carrying capacity of structural elements.

Learning outcome 4 deals with detailing of structural elements. The emphasis should be on learners following industry standards in terms of level of detail, accuracy and conventions. Learning outcome 3 will provide design data that can be used in detailing individual structural elements. Three commonly used structural materials (timber, steel and reinforced concrete) should be used.

Learners should be encouraged to work through problems related to real-life situations so that they become familiar with the application of calculations to real structures. Once the design for an element of a structure has been clarified, the tutor's role should be supporting rather than directing. Learners should be encouraged to study recent completed drawings and designs so that they become familiar with current practice and standards of presentations.

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
Introduction to the unit
Class discussion: intended use of a structure and serviceability requirements
Tutor delivery: serviceability limit states (SLS) and limit state design
Tutor delivery: factor of safety and partial factors of safety
Tutor demonstration or learner practical: concept of deflection and its significance
Tutor delivery: factors contributing to/affecting deflection
Tutor delivery: Moment Area Method to calculate deflections
Learner exercise: determination of deflection in beams
Tutor delivery: Macauley's method
Learner exercise: determination of deflection in beams-
Assignment 1: Structural Behaviour
Design of structural elements
Tutor delivery: types of loads and configuration, support conditions
Tutor delivery: review of first and second moments of area, section modulus
Tutor input: design of in-situ RC beams using limit state design method
Learner exercise: determination of section size and reinforcement
Tutor delivery: design of steel beams using published data
Learner exercise: determination of section size
Tutor input: introduction to timber properties, flooring systems and load distribution and design of timber joists
Learner exercise: designing timber floor joists
Assignment 2: Design of Structural Elements
Detailing structural elements
Tutor delivery: drawing standards, conventions, standards expected, examples of industrial practice
Tutor delivery: general arrangement drawings, framing plans, elevations and sections
Learner exercise: production of framing plans, elevations and sections
Tutor delivery: detailing individual members, reinforcement details, schedules and cutting lists, drilling holes, attaching plates, cleats and notches
Learner exercise: production of individual member details in steel, in-situ reinforced concrete and timber
Tutor delivery: introduction to connection details
Tutor delivery: structural steelwork connections, beam-to-beam, column-to-column
Learner exercise: production of structural steelwork connection details
Tutor input: structural timber connection details, types of connectors such as bolts, plates, gang nail connectors, hangers and shear rings, strutting and trimming
Learner exercise: production of structural timber connection details
Tutor delivery: calculation and production of reinforcement schedules
Tutor delivery: preparation of lists for ordering

Topic and suggested assignments/activities and/assessment
Assignment 3: Structural Detailing
Review of unit and assessment feedback

Assessment

It is recommended that evidence for learning outcomes is produced through well-planned course work, assignments and projects. Assessment may be formative and summative and both may feature as part of the process. Learner evidence may be in the form of calculations. Drawings should indicate manual drafting abilities. At least one drawing should be taken to completion, with full construction details for a complete element of a structure. The presentational aspects of the evidence need to be considered carefully. Integrative assignments and project work will help to link this unit with other related units.

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, M1 and D1, the second would cover P4, P5 and M2 and the third P6, P7, P8, M3, M4 and D2.

To achieve a pass grade learners must meet the eight pass criteria.

For P1, learners must explain, with the help of appropriate details, the concept of serviceability limit state design under different serviceability requirements. This should be applied to both steel and concrete. Evidence could be in the form of a written report with supportive diagrams.

For P2, learners must explain the factors affecting deflection of beams. They should take into account section size, load configuration and material properties such as modulus of elasticity. Evidence should be as for P1.

For P3, learners must calculate the maximum deflection in beams. They should apply both the Moment Area Method and Macauley's method. The results should be achieved arithmetically. 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 carry out calculations to determine the required section sizes for beams. Limit state design method should be applied and beams should be designed in steel, timber and in-situ reinforced concrete. Learners are required to present calculations and results using the correct units. Evidence could be in the same format as for P3.

For P5, learners must carry out calculations to determine required section sizes for timber joists. The results should be accurate and in the correct units. Evidence could be in the same format as for P3.

For P6, learners must produce general arrangement details. These may include steel/in-situ reinforced concrete framing plans, elevations and sections. Standard conventions should be followed. Evidence could be in the form of a set of detailed drawings.

For P7, learners must produce details of individual structural elements. These may include the elements designed in P4 and P5. Evidence could be in the same format as for P6.

For P8, learners must produce connection details for individual structural elements. These may include the elements designed in P4 and P5. Evidence could be in the same format as for P6.

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

For M1, learners must compare the methods used to determine deflections in terms of their fitness for purpose. This can be for a given scenario where learners can carry out calculations and, compare and interpret the results. Evidence could be in the same format as for P3 with written descriptions included.

For M2, learners must compare the methods used to determine section sizes in terms of their fitness for purpose. Reference should be made to the methods used to determine section sizes for rectangular structural elements such as joists and non-rectangular structural elements such as universal beams.

For M3 and M4, learners must prepare schedules and cutting lists for individual structural elements. This can be either an extension of P7 or learners can be given a set of drawings to produce both schedules and cutting lists. Evidence could be in the form of schedules supported by calculations.

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 evaluate the effect of different materials and beam sections on deflection in beams. This is an holistic view of deflection and learners should be provided with an appropriate tutor brief. Evidence could be in the form of a report supported by sketches, illustrations and reference to real world situations.

For D2, learners must design structural details to an acceptable industry standard. Evidence could arise out of the work for P6, P7, P8, M3 and M4 and can be set as an extension of these criteria.

Programme of suggested assignments

The following table shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the grading grid. 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, M1, D1	Structural Behaviour	You are working as a junior design engineer and have been asked to determine deflection using standard methods, as detailed in the tasks. The senior engineer has also asked you to carry out research on limit state design and its application. This is to be given to trainee design engineers during induction.	A detailed report on limit state design and factors affecting deflection, as well as calculations to determine maximum deflection.
P4, P5, M2	Design of Structural Elements	You are working as a junior design engineer and have been asked to design beams and joists for a low-rise housing project.	A report containing design solutions for a given design brief.
P6, P7, P8, M3, M4, D2	Structural Detailing	You are working as a junior design engineer and have been asked to produce structural details for a housing project. You are required to follow industry standards as these drawings will be kept as an exemplar for new entrants to the company.	A portfolio of drawings with schedules and lists.

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
		Graphical Detailing in Construction and the Built Environment
		Structural Mechanics in Construction and Civil Engineering
		Construction in Civil Engineering

This unit links to the Edexcel Level 3 NVQ in Technical Design (Construction Environment) and also to the following National Occupational Standards at Level 3:

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

Essential resources

Experiments, models and visual aids should be used to illustrate structural behaviour, the nature of loading that occurs and the forces that are imposed. Specialist equipment to demonstrate various structural phenomena is available but not essential for delivery of this unit. Health, safety and welfare issues must be considered at all times and risk assessments should be undertaken for all demonstrations, experiments and site visits used in the delivery or assessment of this 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 outcome 4 lends itself well to investigating what goes on in the real world of structural design and detailing. Visits to companies/shows/exhibitions will enhance this particular part of the unit. Companies with design sections could show how elements are designed and detailed.

Learners should have access to recently completed drawings and designs so that they become familiar with current practice and standards of presentations.

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

Anthony A et al – *Reynolds's Reinforced Concrete Designer's Handbook, 11th Edition* (Taylor and Francis, 2007) ISBN 0419258302

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

Mosley, H – *Reinforced Concrete Design, 6th Revised Edition* (Palgrave, 2007) ISBN 0230500714

Ozelton, E – *Timber Designers' Manual* (Wiley Blackwell, 2006) ISBN 1405146710

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

Steel Construction Institute – *Steel Design Manual, 6th Edition* (Wiley Blackwell, 2005) ISBN 1405134127

Journals

The Structural Engineer – IStructE

Websites

www.risatech.com	Structural design and optimization software
www.structuralconcepts.org	The University of Manchester – structural concepts
www.tenlinks.com/cae/products/structural.htm	Directory of CAD, CAM and CAE

Delivery of personal, learning and thinking skills (PLTS)

The following table identifies the 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 evaluate the factors affecting deflection. comparing methods to determine deflection in beams using, analysing and evaluating design information, judging its relevance and value
Self-managers	organising time and resources and prioritising actions when producing industry, standard details.

Although PLTS opportunities 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 safety checks
Self-managers	using standard procedures to carry out structural detailing.

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	designing and detailing structural elements
Access, search for, select and use ICT-based information and evaluate its fitness for purpose	carrying out research using internet or web-based resources
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
Bring together information to suit content and purpose	preparing schedules and lists
Present information in ways that are fit for purpose and audience	presenting evidence of design and detailing of structural elements
Mathematics	
Understand routine and non-routine problems in a wide range of familiar and unfamiliar contexts and situations	designing and detailing structural elements with different materials
Identify the situation or problem and the mathematical methods needed to tackle it	calculating sectional properties
Select and apply a range of skills to find solutions	determining maximum deflection in beams
Use appropriate checking procedures and evaluate their effectiveness at each stage	carrying out safety checks on designed elements
Interpret and communicate solutions to practical problems in familiar and unfamiliar routine contexts and situations	detailing the elements of a structure
Draw conclusions and provide mathematical justifications	comparing methods to calculate deflection in beams
English	
Speaking and listening – make a range of contributions to discussions and make effective presentations in a wide range of contexts	evaluating factors affecting deflection
Reading – compare, select, read and understand texts and use them to gather information, ideas, arguments and opinions	explaining alternate methods of determining deflection
Writing – write documents, including extended writing pieces, communicating information, ideas and opinions, effectively and persuasively	explaining limit state design as applied to steel and concrete.