Unit 19: Further Mathematics in Construction, Civil Engineering and Building Services Engineering

NQF Level 3: BTEC National

Guided learning hours: 60

Unit abstract

Civil engineers and building services engineers need to use appropriate mathematical techniques and formulae in their work to determine many important physical properties. These include finding the location of the centre of gravity of an irregular shaped pre-cast cladding unit so that it can be safely lifted, or calculating the root mean square value of an alternating electric current, and much more.

This unit provides learners with an opportunity to study some relevant aspects of 'pure' mathematics and to explore how complex practical problems can be solved. Learners will be able to solve applied mathematical problems involving statistical data, structural properties for beams and columns, complex linear/angular/area and volume measurements, trigonometrical identities, rates of change and decay, differentiation of maxima and minima, numerical integration, complex areas or volumes by definite integration and indefinite integration.

Although complex calculations can be undertaken using specialist software, a clear understanding of the underpinning fundamental mathematical techniques is essential to enable the results of calculations to be manually evaluated and validated as a part of the design process.

Successful completion of this unit will provide learners with a sound basis for further study within the construction, civil engineering or building services engineering sectors at Higher National or degree level.

Learning outcomes

On completion of this unit a learner should:

1 Be able to transpose and manipulate formulae to simplify and solve mathematical problems

2 Understand and apply mathematical techniques to process data for a variety of engineering-related problems

3 Know how to apply the principles of differential and integral calculus to solve practical engineering problems

4 Be able to produce appropriate and accurate solutions to engineering problems using various statistical methods.

Unit content

1 **Be able to transpose and manipulate formulae to simplify and solve mathematical problems**

Manipulation techniques: rearrangement of formulae to determine new subjects; use of given and rearranged formulae to evaluate data.

Mathematical problems: trigonometrical problems; binomial theorem applied to errors; complex formulae and expressions (including logarithms, fractional powers and roots, indices, compound fractions and partial fractions)

2 **Understand and apply mathematical techniques to process data for a variety of engineering-related problems**

Engineering-related problems: irregular areas and volumes using standard formulae; numerical integration methods for irregular areas; arithmetical calculation of various properties of sections (including cross-sectional area, location of centroid, neutral axis, moment of inertia, section modulus and radius of gyration for simple, regular and irregular shapes)

3 **Know how to apply the principles of differential and integral calculus to solve practical engineering problems**

Basic differentiation techniques applied to: algebraic, trigonometric and logarithmic functions; products and quotients; function of a function; second order derivatives; the location of stationary values and the solution of appropriate problems involving maxima and minima

Indefinite and definite integration techniques applied to: algebraic, trigonometric and exponential functions; the solution of problems involving centroids, moments of inertia, areas under curves and volumes of revolution

4 **Be able to produce appropriate and accurate solutions to engineering problems using various statistical methods**

Presentation of data: histograms; frequency graphs; cumulative frequency graphs

Use of graphs and standard formulae to determine: measurements of central tendency (including mean, mode and median; standard deviation; quartiles, deciles and percentiles; for grouped and ungrouped data)

Sampling distributions: normal distribution tables; confidence limits; significance testing; large samples only

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 apply rules of transposition to simple mathematical formulae and expressions		
P2 recognise the arithmetical techniques used to determine values for a range of properties of sections, including irregular areas and volumes	M1 transpose and evaluate complex formulae.	D1 independently solve industry-related problems using appropriate algebraic, trigonometric and logarithmic functions
P3 use differential calculus to solve a range of algebraic, trigonometric and logarithmic expressions	M2 use first and second order differentials for the solution of a range of industry-related problems	D2 independently apply differential calculus to the determination of maxima or minima in industry-related problems.
P4 use integral calculus to solve a range of simple algebraic, trigonometric and exponential expressions	M3 apply the rules of integral calculus to determine solutions for a range of complex industry related problems	
P5 use a range of simple statistical methods to produce accurate and appropriate solutions to statistical data.	M4 apply a range of statistical methods to analyse engineering data and make realistic assessments of such data.	

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.

Learning outcome 1 forms the basis for all the following learning outcomes and as such should be delivered first. Learning outcomes 2 and 3 reflect the development of different mathematical skills and techniques and would be best introduced and developed separately, but with clear links drawn between their 'pure' and 'applied' aspects. The final learning outcome regarding statistical methods is essentially a stand-alone element and could be delivered at any point throughout the programme.

Teaching and learning strategies designed to support delivery of this unit should involve theory, worked examples and then most importantly practice. There needs to be time and resources provided for differentiated support. Within the scheme of work there should be time allowed for regular workshops and/or tutorials as some learners may find this unit particularly challenging. Delivery should of course stimulate, motivate, educate and enthuse the learner.

Evidence should be generated as thoroughly worked calculations, graphical solutions and other mathematical exercises. It is acceptable for early examples to be of the 'pure' mathematics variety but the intention is that the great majority of the evidence should be linked to the learning found in other areas of the learners' programme of study.

In mathematics, possibly more so than in any other area, assessment drives delivery. It is therefore reasonable to consider delivery methods in terms of how the unit is to be assessed. Practice is, as noted above, the key word and the learners must be given many opportunities to practise the relevant techniques. The use of formative tests and coursework will help the learner to see where they may be going wrong and the tutor should provide feedback but should not grade the formative work. This process then becomes part of the delivery.

Formal formative assessment techniques, such as short time-controlled assessments or case studies/projects, are suggested to enable learners to demonstrate their level of ability. It is suggested that every attempt should be made to provide industry-based scenarios relevant to learners' vocational aims, for use in the delivery of the unit and in formative assessments.

The statistical elements of the unit can be used to link learners to the industrial environment by the careful choice of scenarios. For example, there is a great deal of statistical data relating to health, safety and welfare issues freely available from various government and industry bodies. Alternatively, the testing of materials such as concrete, bricks and metals will yield useful data to support delivery of statistical analysis.

It is anticipated that this unit will be delivered in the second half of the programme, preferably after completion of *Unit 3: Mathematics for Construction, Civil and Building Services Engineering*.

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: Provision and Use of Work Equipment Regulations 1998 (PUWER)*.

Assessment

Evidence for this unit may be gathered from short time-controlled phase tests, tutor-provided practical construction scenarios, case studies, practical work or traditional example-based methods.

There are many suitable forms of assessment that could be employed. 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 19 of 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 the use of these is provided on the Edexcel website.

The complexity of the techniques covered in this unit would imply that learners need regular incremental assessment as they progress through the unit.

The structure of the unit suggests that the grading criteria may be fully addressed by using three assignments.

The first assignment would cover P1, P2, M1 and D1. Assessment criteria P1 is essentially 'pure' mathematics and provides an introduction to the later M1 criteria which also builds upon activities covered in P2. D1 would allow the most able learners to appraise and apply earlier techniques to real industrial applications.

The second assignment would cover the calculus element of the unit comprising P3, P4, M2, M3 and D2. The third assignment for P5 and M4 would cover the statistical part of the unit including its industrial application.

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

For P1, learners must be able to apply rules of transposition to simple mathematical formulae and expressions. They must transpose and simplify a variety of expressions and solve by substitution. The formulae to be solved include linear, quadratic and cubic expressions, binomial expansions for errors, logarithms, and fractional powers. The work should have a logical structure, using correct mathematical conventions and appropriate units where required.

For P2, learners must be able to recognise the arithmetical techniques used to determine values for a range of properties of sections, including irregular areas and volumes. They must find the cross-sectional area, volumes, and position of the centroid of a variety of symmetrical and non-symmetrical composite shapes using a range of arithmetic and trigonometrical formulae. Their work should have a logical structure, use correct mathematical conventions and the correct units should be stated for the final answer.

For P3, learners needs to use differential calculus to solve a range of algebraic, trigonometric and logarithmic expressions. They must demonstrate a clear understanding that differentiation arises out of considering the gradient of a line on a graph, and that this represents the rate of change of the function of the line. They should be able to find the gradient of a line or curve at any point for the following functions using differentiation; ax^n, sine ax, cosine ax, $\log_e x$ and e^{ax}. They will also be able to differentiate using 'function of a function', ie differentiation by substitution. Their work should have a logical structure and use correct mathematical conventions.

For P4, learners need to use integral calculus to solve a range of simple algebraic, trigonometric and exponential expressions. They must demonstrate a clear understanding that integration arises out of considering a thin strip of area summated between limits along the x-axis of graph. With this knowledge the learner must be able to determine indefinite and definite integrals of functions involving ax^n, sine ax, cosine ax, 1/x, and e^{ax} . The work should have an understandable structure and use correct mathematical conventions.

For P5, learners need to use a range of simple statistical methods to produce accurate and appropriate solutions to statistical data. They must demonstrate satisfactory understanding and knowledge of basic data handling and statistical manipulation techniques. They should be able to interpret the results and draw relevant conclusions.

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

For M1, learners must transpose and evaluate complex formulae. They must do so with limited tutor support. Examples could include the moment of inertia, section modulus or radius of gyration of given standard symmetrical (about y-y axis only) composite cross-sections. Their work should have a clear, understandable and well presented structure. It should apply the correct mathematical conventions and use the correct units throughout.

For M2, learners must use first and second order differentials for the solution of a range of industry-related problems. With limited tutor support, they should be able to explain the notation for second order derivatives, and find the second order derivative by applying the basic rules of differential calculus to the simplified result of a first order differentiation. They should also be able to solve first order differential equations given specific boundary conditions, and be able to determine the turning point positions using second order differentiation methods. Their work should have a clear, understandable and well presented structure. It should apply the correct mathematical conventions and use the correct units throughout.

For M3, learners needs to apply the rules of integral calculus to determine solutions for a range of complex industry related problems. They need to solve, with limited tutor support, integration problems involving the position of centroids of areas/volumes and the volumes of revolution. These problems should be clearly specified in written or diagrammatic form to enable the student to grasp the functions to be integrated. Their work should have a clear, understandable and well presented structure. It should apply the correct mathematical conventions and use the correct units throughout.

For M4, learners must apply a range of statistical methods to analyse engineering data and make realistic assessments of such data. This should be done with minimal tutor support, and should be based on given industrial situations. Access to secondary research data will be sufficient to cover these criteria as learners are not expected to be undertaking primary research at this level.

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 be able to independently solve industry-related problems using appropriate algebraic, trigonometric and logarithmic functions. Alternative methods of solution should be undertaken where appropriate. Their work should have a neat, efficient, logical and clear structure. It should apply the correct mathematical conventions and use the correct units throughout.

For D2, learners must be able to independently apply differential calculus to the determination of maxima or minima in industry-related problems. They must independently develop from the industry-based case study particular formulae for the required area or volume. Using this mathematical model the learner must be able to apply the principles of differentiation, learnt from previous theory, to find maximum and minimum values of areas/volumes. Learners needs to demonstrate awareness of the correct solution where more than one solution is possible, ie two or more roots. Learners' work should have a neat, efficient, logical and clear structure. It should apply the correct mathematical conventions and use the correct units where applicable.

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 3: Mathematics in Construction and the Built Environment* together with similar units at Higher National and degree level.

There are no specific mapping links with 2005 CIC Occupational Standards at Level 3.

The unit provides opportunities to gain Level 3 key skills in application of number and problem solving. Opportunities for satisfying requirements for Wider Curriculum Mapping are summarised in *Annexe F: Wider curriculum mapping*.

Essential resources

The resource requirements are limited. The application of mathematical techniques requires little in the way of resources other than scientific calculators and simple drawing equipment. Both of these are implicit requirements of many other units and, therefore, no extra resources are required for this unit other than a range of realistic and feasible project materials appropriate to the application of a range of mathematical methods.

Indicative reading for learners

Bird J and May A — *Technician Mathematics: Level 3, 2nd Edition* (Pearson, 1994) ISBN 0582234247

Greer A and Taylor G — *BTEC National NIII: New Level 3 (Mathematics for Technicians)* (Nelson Thornes, 1989) ISBN 085950932

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:**
• selecting mathematical formulae to solve industry based problems • applying mathematical formulae to solve industry based problems • manipulating and presenting statistical data • interpreting, presenting and justifying the results of calculations.	N3.1 Plan an activity and get relevant information from relevant sources. N3.2 Use your information to carry out multi-stage calculations to do with: a amounts or sizes c handling statistics d using formulae. N3.3 Interpret the results of your calculations, present your findings and justify your methods.
Problem solving Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• applying various statistical • methods to analyse engineering data and make realistic assessments of such data.	PS3.1 Explore a complex problem, come up with **three** options for solving it and justify the option selected for taking forward. PS3.2 Plan and implement at least one option for solving the problem, review progress and revise your approach as necessary. PS3.3 Apply agreed methods to check if the problem has been solved, describe the results and review your approach to problem solving.