ENGINEERING TRIPOS   PART IB

Friday 10 June 2011   9 to 11.30
9 to 10.30 Foreign Language Option

Paper 8

SELECTED TOPICS

Answer ***one*** *question from Section A. In addition:*

> *If you are not taking the Foreign Language option, answer* ***four*** *questions, taken from only* ***two*** *of Sections B – H. Not more than* ***two*** *questions from each section may be answered.*
> *If you are taking the Foreign Language option, answer* ***two*** *questions from* ***one*** *of Sections B – H.*

All questions carry the same number of marks.

The ***approximate*** *number of marks allocated to each part of a question is indicated in the right margin.*

Answers to questions in each section should be tied together and handed in separately.

Attachments: Data Sheet for Section B (6 pages)
Data Sheet for Section E (2 pages)

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

SECTION A *Introductory Business Economics*

Answer not more than **one** *question from this section.*

1 (a) Describe one model of oligopoly. [5]

(b) Explain the concept of comparative advantage. [6]

(c) What impact would the following have on the level of investment in the macroeconomy:

(i) a rise in the rate of interest; [3]

(ii) new economic forecasts that suggest a slowdown in the rate of economic growth; [3]

(iii) a decline in the willingness of banks to lend? [3]

2 (a) Using an appropriate diagram, explain the profit maximising position for a monopolist. [5]

(b) Why is perfect competition normally considered to be more beneficial than monopoly? [5]

(c) Using the Keynesian consumption function model, explain the potential impact of increasing indirect taxes (such as VAT) on the level of aggregate demand. [5]

(d) Using the life cycle model or the permanent income model, explain the potential impact of increasing indirect taxes (such as VAT) on the level of aggregate demand. [5]

SECTION B *Civil and Structural Engineering*

Answer not more than **two** *questions from this section.*

Note Data Sheets at end of paper.

3 A high speed railway tunnel is being planned between two large cities A and B, each with historic masonry buildings. The ground beneath City A is a stiff clay with an undrained shear strength of 200 kN m^{-2} which is constant with depth. The ground beneath City B is soft marine clay with an undrained shear strength of 25 kN m^{-2} also constant with depth. The unit weight of both types of soil can be taken as approximately 20 kN m^{-3}. The typical depth below ground level of the tunnel axes beneath both cities is 20 m. You are to attend a press conference explaining a number of key features relating to the line beneath the cities.

(a) Give answers to the following questions:

(i) Why is it safe to construct an open face tunnel beneath City A but not beneath City B? Use the concept of stability ratio to illustrate your answer. What will be needed to construct the tunnels beneath City B? [4]

(ii) Explain the significance of differential settlement in the context of potential damage to masonry buildings caused by tunnelling. Why are hogging deformations potentially more significant than sagging deformations? What general deformation shape can be expected? [3]

(iii) How can compensation grouting be used to control damage to buildings in a tunnelling project, and what is the role of instrumentation in the process? What should be the principal aim of the process when it is used to protect a masonry building? [3]

(iv) How are tunnels lined? Explain two different methods of lining a tunnel, and their applicability to the tunnels beneath cities A and B, giving advantages and disadvantages of each. [6]

(b) Part of the proposed tunnel beneath City B will also encounter sands below the water table. Describe the significance of soil permeability in the context of tunnelling below the water table, and give two examples of techniques that can be used to overcome potential problems. [4]

4 A structure for a twin tunnel metro is to be constructed in a shallow river estuary, as shown in Fig. 1. The tunnel is sufficiently heavy to resist uplift. The lowest 3 m of the tunnel is in the clay of the river bed, for which the unit weight is $\gamma = 20$ kN m^{-3}, the undrained shear strength is $S_u = 60$ kN m^{-2} and the critical state angle of friction is $\phi' = 20^{\circ}$. The depth of water in the river estuary is 2 m.

Immediately after construction, one side of the tunnel is backfilled with a dense sand to the top of the structure. The sand has unit weight $\gamma = 20$ kN m^{-3} below the water, and $\gamma = 17$ kN m^{-3} above the water. The critical state angle of friction of the sand is $\phi' = 35^{\circ}$. A surcharge of 50 kN m^{-2} is applied at the surface of the backfill.

It should be assumed that the tunnel moves sufficiently to mobilize active pressures on the backfilled side and passive pressures on the opposite side, and that its walls are smooth.

(a) Calculate the total horizontal stresses acting in the short term on each side of the tunnel structure and sketch the stress distribution with depth. [8]

(b) Ignoring any friction on the base of the tunnel, calculate the factor of safety against sliding in the short term. Comment on its value. [4]

(c) Not long after the tunnel is completed, previously undetected sand seams in the clay on the backfilled side cause the clay to soften rapidly such that long-term conditions are quickly reached. Calculate the resulting total and effective horizontal stresses on the backfilled side. Assuming that there are no sand seams in the clay on the opposite side of the tunnel and therefore undrained conditions remain, calculate the factor of safety against sliding due to the softening of the clay on the backfilled side. Comment on the effect of the softening of the clay. [8]

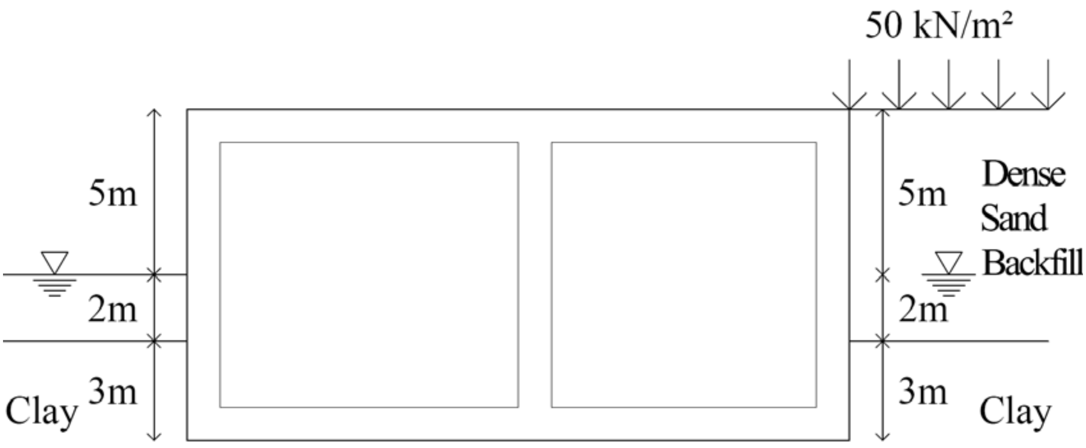


Fig. 1

(TURN OVER

5 An excavation for a new underground station is being built using diaphragm walls that are 25 m deep. The critical design case for the walls is a temporary condition where the base slab has been placed and a closely spaced row of props has been inserted at a depth of 10 m. This situation is illustrated in Fig. 2. For this case, the loading can be regarded as a triangular distribution of forces, which includes the hydrostatic and the soil loads. Note that the pressure loading at the base is 500 kPa.

(a) Determine the bending moment and shear force diagrams for the wall. [5]

(b) The wall is built from concrete with a cube strength of 40 N mm^{-2}. Determine the thickness of the wall that is required if it is to be singly reinforced using high yield steel of yield strength 460 N mm^{-2}. Also, calculate the amount of reinforcement that is required at the propping position and where the bending moment is a maximum between the prop and the base. [7]

(c) Discuss qualitatively whether there would be any economic advantage in making the wall doubly-reinforced. [4]

(d) The props are eventually to be replaced by a cast slab. The reinforcement of the slab is to be joined to the main wall reinforcement by means of screw-in couplers at the face. Suggest a layout for the reinforcement in the wall at this position that satisfies the requirements found in (b) above, and that will facilitate this later work. [4]

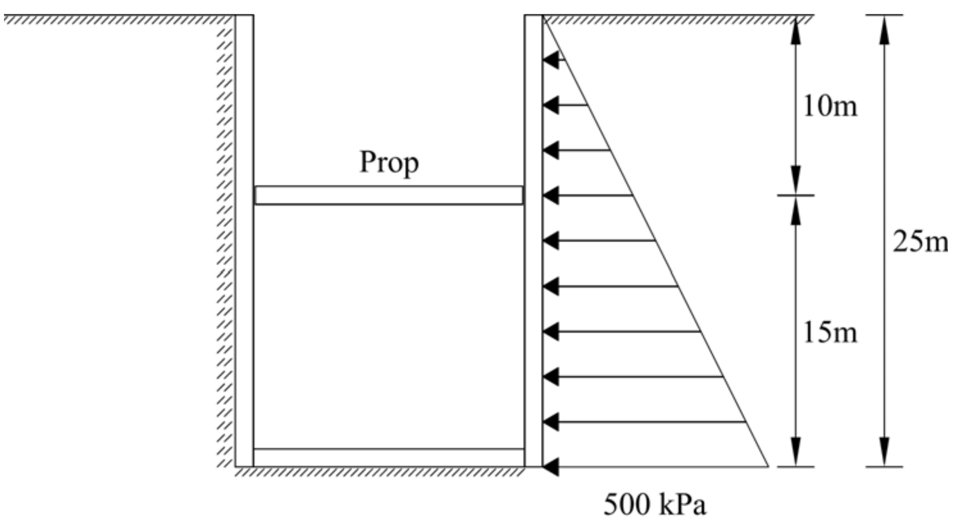


Fig. 2

SECTION C *Mechanics, Materials and Design*

Answer not more than **two** *questions from this section.*

6 (a) Discuss briefly the different types of contribution made by the UK population to their total energy consumption. [3]

(b) Describe how life cycle analysis can be applied to wind power generators. [3]

(c) Estimate the energy payback period for a wind turbine generator with a nominal rating of 1 MW, comprising foundations made from 800,000 kg of concrete, a tower made from 150,000 kg of steel and three blades each containing 7,000 kg of GFRP composite. The production and manufacturing energies for the various materials are given in Table 1 below. Detail any assumptions made. [3]

	Energy (MJ kg^{-1})
Steel	24
Concrete	1.9
GFRP	110

Table 1

(d) Give three reasons why doubly-fed induction generators (DFIG) are the preferred technology for the generators in large-scale wind power. [3]

(e) A 3-phase, star-connected induction generator has 18 poles and is connected to the 6.6 kV, 50 Hz grid. It has the following equivalent circuit parameters: $R_1 = 0.7\ \Omega$, $R_2' = 0.6\ \Omega$, $X_1 = 1.1\ \Omega$, $X_2' = 1.5\ \Omega$. R_0 and X_m are large enough to be ignored. It operates at a slip of -0.02. Determine:

(i) the generator input current, synchronous speed, actual speed and torque; [5]

(ii) the generator output real and reactive powers, power losses, generator input mechanical power and efficiency. [3]

7 An offshore wind turbine is to be designed to produce 2 MW in an incident wind speed of V_0 =10 m s^{-1}. The turbine is expected to operate at a tip speed ratio $\lambda = 8$ with a coefficient of performance of $C_p = 0.4$. The density of air is $\rho = 1.225$ kg m^{-3}.

(a) Find the blade radius R, the angular velocity ω and the total torque T at the hub. [6]

(b) The turbine is to use a standard induction generator operating at 1500 rpm. The generator will be coupled to the blade hub via a three stage gearbox consisting of a single epicyclic low-speed stage followed by two simple parallel-shaft high-speed stages. The parallel-shaft stages each have a 1:4 gear ratio.

Find the input and output angular velocities and torques and required gear ratio for the low-speed epicyclic stage. [4]

(c) The epicyclic gear stage has three planet gears; the ring gear is held stationary, the low-speed input shaft is connected to the planet carrier and the high-speed output shaft is connected to the sun gear.

Find the number of teeth required for the planet, sun and ring gears and the overall size of the epicyclic stage. The gear tooth geometry may be idealised as shown in Fig. 3, where m is the gear module. Relevant gear design data are given in Table 2 below. [10]

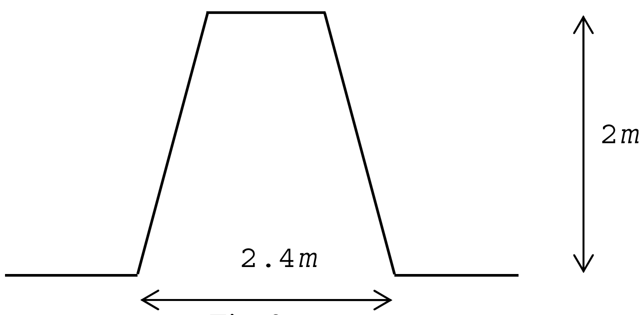


Fig. 3

Gear pitch circle diameter	d
Number of teeth	N
Gear module	$m = d / N =$ 20 mm
Permitted bending stress	$\sigma_b =$ 400 MPa
Gear width	$b = 50$ mm

Table 2

8 (a) Identify the factors which are important when considering mechanical vibration of horizontal axis wind turbine generators. [3]

(b) Consider bending vibration of a horizontal axis wind turbine tower and nacelle. The tower of height L has a uniform bending stiffness and mass M; the nacelle has a mass M_N. Figure 4(a) shows an appropriate model, with a lumped mass $0.24M + M_N$ at the top of a light rigid rod of length L, restrained at the base by a rotational spring of stiffness k_1.

(i) Use this model to estimate the lowest natural frequency of vibration of a tower of height L = 50 m with tower mass M = 417 tonnes, nacelle mass M_N = 50 tonnes and k_1 = 6000 MNm. [4]

(ii) The effect of flapwise blade vibration can be modelled by including an additional mass m = 10 tonnes at a height $0.2L$ above the tower top, connected to the tower top by a spring of stiffness k_2 = 20 MNm, as shown in Fig. 4(b). Values of L, M, M_N and k_1 are unchanged from part (i). Find the lowest natural frequency of this two degree-of-freedom system. [11]

(iii) Would your above estimates of frequency give cause for concern for a three-blade turbine with a design rotational speed of 30 rpm? [2]

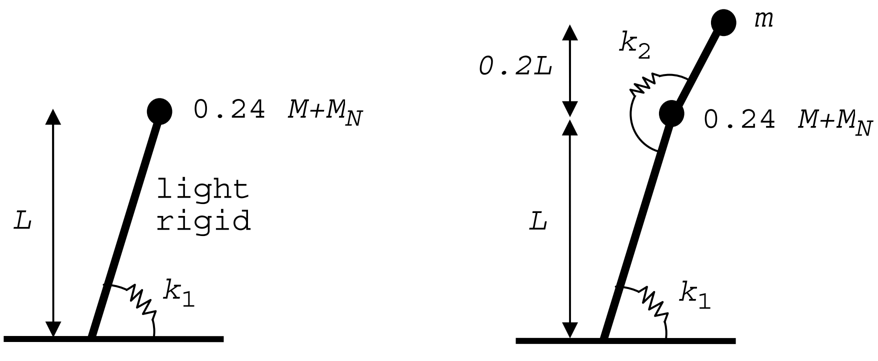


Fig. 4(a) Fig. 4(b)

SECTION D *Aerothermal Engineering*

Answer not more than **two** *questions from this section.*

9 (a) Derive equations for the propulsive, thermal and overall efficiencies of an aeroengine, describing the physical meaning of these equations and their interrelationships. [6]

(b) Depending on the application, turbofan engines are designed with a range of bypass ratios.

(i) Describe how the propulsive efficiency relates to the layout of military and civil aircraft engines.

(ii) State a typical bypass ratio for a modern subsonic civil aircraft engine and also a military engine.

(iii) Note four factors that limit the maximum bypass ratio in civil aircraft engines.

(iv) Sketch how specific fuel consumption varies with bypass ratio both for an installed and bare engine. [7]

(c) Turbine blades are subjected to an extremely hostile thermal environment.

(i) Explain how increasing the turbine inlet temperature can improve engine performance.

(ii) Describe the ways in which blades are prevented from melting.

(iii) State where in the flight envelope the turbine inlet temperature is highest.

(iv) State where in the flight envelope the ratio of the turbine inlet to compressor inlet temperature is highest and explain why this is the case. [7]

10 Figure 5 shows a simplified schematic of a two-shaft bypass engine. It is run on a static test bed. The engine is instrumented at the locations shown in Table 3. The stagnation temperatures and stagnation pressures are recorded at these locations. The missing entries in Table 3 are where instrumentation failed. Based on other rig tests, the high-pressure compressor stagnation pressure ratio is estimated to be 25 and its isentropic efficiency, $\eta = 0.9$. Also, for the high-pressure turbine, $\eta = 0.93$.

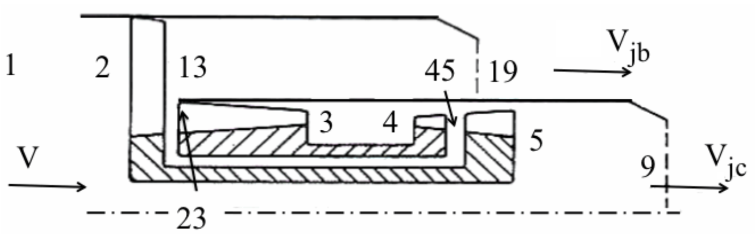


Fig. 5

Location	2	13	23	3	4	45	5
Pressure (kPa)	101	170	170	-	-	-	140
Temperature (K)	293	345	345	-	1650	-	680

Table 3 Measured stagnation temperatures and pressures for the engine.

(a) Sketch the *T-s* diagrams for the core and bypass flows. Explain how the diagram for the bypass flow would change if the engine were in flight. [5]

(b) Using cycle analysis, determine the missing table entries. [7]

(c) Calculate the isentropic efficiency for the low-pressure turbine, commenting on its value. [3]

(d) Find the core jet velocity, V_{jc}. [1]

(e) The measured thrust is 12 kN. Assuming that the bypass and core jet velocities are the same, find the mass flow rate through the engine. [1]

(f) If the engine is on an aircraft moving at a Mach number of 0.85, at an altitude of 12 km (p_1 = 19.7 kPa, T_1 = 216.7 K), what is the expected mass flow? Assume that the dimensionless mass flow rate has not changed from part (e). [3]

[Take γ = 1.4, c_p = 1.005 kJ kg^{-1} K^{-1}, R = 287.3 J kg^{-1} K^{-1}]

11 (a) The temperature, T, of the Earth's atmosphere drops by 6.5 K km^{-1} up to the tropopause at an altitude $z_t = 11$ km, where $T = 216.65$ K. Show that for an altitude $z \leq z_t$ the pressure, p, can be expressed as

$$\frac{p}{p_0} = \left(\frac{T}{T_0}\right)^{c_1} = (1 - c_2 z)^{c_1}$$

where $c_1 = 5.25$ and $c_2 = 2.25 \times 10^{-5}$ m^{-1}. Note that $p_0 = 1.013$ bar and $T_0 = 288.15$ K are the sea level reference pressure and temperature, respectively. [6]

(b) Show that for $z > z_t$

$$\frac{p}{p_t} = \exp[c_3(z - z_t)]$$

where $c_3 = -1.58 \times 10^{-4}$ m^{-1} and $p_t = 0.226$ bar is the pressure at $z = z_t$. [3]

(c) At take off, the aircraft's mass is 5×10^5 kg, its speed 85 m s^{-1} and lift coefficient, $C_L = 1.6$. Estimate the wing area required. Include a safety factor for a 20% variation in density at hot, high altitude airports. [2]

(d) At the top of climb $z = 9.45$ km. The aircraft flies at a Mach number of 0.85. It has a rate of climb of 1.6 m s^{-1}. Assuming negligible fuel burn, find C_L. [4]

(e) At the top of climb the drag force is 5% of the lift. Find the engine thrust to achieve the part (d) rate of climb. Contrast this with the required thrust when there is no margin for climb. [2]

(f) At the end of cruise the aircraft is in the tropopause ($z > z_t$). The aircraft's Mach number is still 0.85 and its C_L the same as at the start of cruise. However, relative to the start of cruise value, its mass has reduced by 45%. Find z. [3]

[Take $\gamma = 1.4$ and $R = 287.3$ J kg^{-1} K^{-1}]

SECTION E *Electrical Engineering*

Answer not more than **two** *questions from this section.*

Note Data Sheets at end of paper.

12 A Si wafer of 300 mm diameter is to be processed in a "Class 1" clean room. The minimum feature size needed in the process is 0.2 μm.

(a) Explain what is meant by a "Class 1" clean room. [2]

(b) For the above process, compare and contrast the merits of the photolithography process based on the contact, proximity and projection methods and indicate which is the most appropriate to use. [6]

(c) If a U.V. photolithographic source centred on 200 nm is used, determine the value of Numerical Aperture required for the optical system and determine whether a full wafer exposure method can be used if the wafer is flat to ± 3 μm. [5]

(d) Describe the electron beam and x-ray lithographic methods which can be utilised for the above process. [4]

(e) If such an electron beam system with an energy of 40 keV is utilised, estimate the resolution limit and explain why, in practice, this cannot be achieved. [3]

13 Figure 6 shows schematically the channel of a silicon FET, with current flow *I* and appropriate dimensions, *W*, *L* and *d*.

(a) Derive the expression for carrier transit time of the FET in terms of the carrier mobility, channel length and drain field. [3]

(b) Derive the gate voltage in terms of a uniform dopant concentration, *N*, and a dopant depth, *d*. Derive an expression for the gate field, stating the assumptions that are made. [6]

(c) As transistors were designed to be faster, this is achieved by scaling all dimensions smaller by some factor, while keeping the electric fields at a constant value.

(i) Assume that in 1970, FETs had a channel length of 10 μm, a gate voltage of 1V, a dopant concentration of 10^{20} m^{-3} and a transit time of 0.1 μs. What is the scaled transit time for 2010 assuming a channel length of 65 nm? [3]

(ii) What is the new value of dopant concentration and scaled gate voltage? [4]

(iii) What are the limits to further improvements to device performance suggested by these answers and other physical limits? [4]

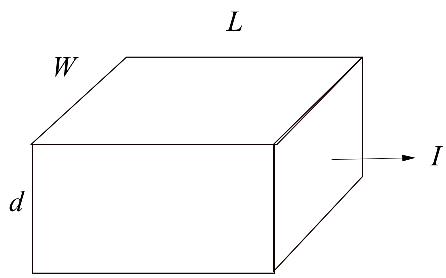


Fig. 6

14 (a) What is the evidence that electrons can behave like waves? [4]

(b) Derive an expression for the wavelength λ of an electron in terms of its kinetic energy E and its effective mass m^*. [3]

(c) The limiting expression for the tunnelling current density through a barrier of length d and energy height V is of the form,

$$J = J_0 \exp(-2\,\beta\,d)$$

Express this in terms of the parameters E, m^* and V. [3]

(d) Derive the tunnelling current density for a 1.5 nm thick SiO_2 layer, assuming that the effective electron mass is 0.5 of the free mass, $V = 3.5$ eV, and taking $J_0 = 2 \times 10^{13}$ A m^{-2}. [3]

(e) It is desired to replace the SiO_2 gate oxide of a MOSFET with an oxide HfO_2 which has a larger dielectric constant in order to reduce the tunnelling current density. The thickness of the SiO_2 layer, d = 1.5 nm, and its relative dielectric constant is 3.9. The relative dielectric constant, K, of the HfO_2 is 22. The thickness of the HfO_2 layer is varied from the SiO_2 case, so that the capacitance per unit area of the gate electrode remains constant. What is the thickness of the HfO_2 layer for this case? [3]

(f) Derive the tunnelling current density through the HfO_2 layer, assuming that its $m^* = 0.7$ and $V = 1.5$ eV. Explain how to maximise the performance of this new gate oxide in terms of the various parameters. [4]

[Take $\hbar = 1.1 \times 10^{-34}$ J s, $e = 1.6 \times 10^{-19}$ C, $m_e = 0.91 \times 10^{-30}$ kg.]

SECTION F *Information Engineering*

Answer not more than **two** *questions from this section.*

15 (a) Common algorithms within photo editing software packages can be split into three main categories:

(i) Algorithms which move pixels around;

(ii) Algorithms which map the intensities or colours of pixels on a pixel-by-pixel basis;

(iii) Algorithms which perform spatial filtering on the pixels.

Give at least two examples of algorithms within each of these three categories. [6]

(b) Briefly describe bi-linear interpolation, as applied to images, and explain how it is used for one of the above categories. [5]

(c) When performing mapping of colour pixels, what are the relative merits of working in YUV or HSV colour spaces, rather than in the RGB space? [5]

(d) Discuss the purposes of performing lowpass filtering, highpass filtering, and spatially adaptive filtering, respectively, on photographic images. [4]

16 A grey scale image, $I(x, y)$, is to be smoothed and differentiated as part of the feature detection and matching process.

(a) Why is smoothing required? Describe the smoothing filter used in practice, and explain the effects of increasing the size of the filter. [3]

(b) Give an expression for computing the intensity of a smoothed pixel in terms of two discrete 1D convolutions. [3]

(c) Show how different resolutions of the image can be represented efficiently in an *image pyramid*. Your answer should include details of the implementation of smoothing within an octave and sub-sampling of the image between octaves. [6]

(d) How can *band-pass* filtering at different scales be implemented efficiently using the image pyramid? [2]

(e) Show how image features such as *blob-like* shapes can be localized in both position and scale. [4]

(f) Give a simple example of an application which requires the detection and description of image features. [2]

17 Consider two models M_1 and M_2 for data x where $p(x \mid M_1)$ is Gaussian with mean 0 and variance 1 and $p(x \mid M_2)$ is Gaussian with mean 1 and variance 2. Consider two data points $x_1 = 1$ and $x_2 = -3$.

(a) Is x_1 more probable under M_1 or M_2? Is x_2 more probable under M_1 or M_2? Describe your reasoning and show your calculations. [6]

(b) What are the parameters for the maximum likelihood Gaussian given the data x_1 and x_2? Show your calculations. [8]

(c) Assuming prior probabilities $p(M_1) = p(M_2) = 1/2$, use Bayesian learning to compute the posterior probability of model M_2 given the data x_1 and x_2,: $p(M_2 \mid x_1, x_2)$. [6]

SECTION G *Engineering for the Life Sciences*

Answer not more than **two** *questions from this section.*

18 (a) Write short notes on:

(i) intracellcular vs. extracellular neuronal recordings;

(ii) optical neuronal imaging;

(iii) implants in the visual cortex vs. implants in the retina. [5]

(b) In the context of the visual system:

(i) describe briefly the receptive fields of the different cell types from retina to primary visual cortex; [4]

(ii) describe the spatial frequency theory of vision and evidence that supports the theory; [4]

(iii) describe the role of Bayesian processing in the perception of the speed and direction of object motion; [4]

(iv) what is colour constancy and how might the brain achieve it? [3]

19 This question regards the sensitivity of the retina to single photons.

(a) Let $P(n \mid \bar{n})$ denote the (Poisson) probability of n photons hitting the retina for a flash of light that on average results in $\bar{n}$ photons at the retina, and let K denote the minimum number of photons that need to reach the retina for us to see (or more precisely, to report seeing). Using these quantities, provide the formula for P_{see}, the probability of seeing, given a mean photon count at the retina $\bar{n}$. [2]

(b) What is the relationship between the intensity of the light emitted by a light source, denoted by I, and the average number of photons that reach the retina from it, $\bar{n}$. [1]

(c) In an experiment, we measure the fraction of trials in which subjects report seeing a brief flash of light, P_{see}, while we systematically vary the light intensity of the flash, I. Describe the qualitative aspects of the curve plotting P_{see} against log I, and explain how we can estimate K from it (as defined in (a)). [3]

(d) In an experiment it was found that each human subject always reported seeing the stimulus whenever at least K photons reached their retina, and they never reported seeing it otherwise. K was estimated to be around 5. Explain why this implies that individual photoreceptor cells generate reliable responses to single photons, and that summation of these responses along the visual pathway must be near ideal. [5]

(e) Does the activation of a receptor cell mean that a photon was received by it? Explain what the answer to this question implies about the minimal number of receptor activations above which a subject should report seeing the flash to maximise the number of correct responses. [5]

(f) The same subjects who participated in the experiment described in (d), also participated in another experiment that used the same light source. The new experiment also found subjects used a hard threshold, but in this case it was estimated to be at $K = 2$ rather than $K = 5$. Assume that both experiments, including the analysis of data, were properly conducted, and that in both experiments subjects behaved optimally given responses in their retina. Discuss potential reasons that could account for this discrepancy in K but also for the fact that a hard threshold was found in both experiments. [4]

20 (a) What affects the imaging depth and resolutions in each dimension which can be achieved when imaging the eye using Optical Coherence Tomography (OCT)? Give approximate values for each. What are the advantages of spectral over time-domain OCT? [4]

(b) Given an ideal OCT system imaging in air, with no dispersion, where:

$E(\omega) = E_0(\omega)e^{j\omega t}$	is the laser pulse
$S_0(\omega) = \lvert E_0(\omega)\rvert^2$	is the input intensity spectrum
$r_s(l)$	is the amplitude reflectivity density function at depth l
l_s, l_m	are round-trip distances to the scatters s and mirror m
c	is the speed of sound in all media

show that the intensity at the output of the interferometer is given by:

$$I(\omega) = S_0(\omega) + S_0(\omega)\left|\int_{-\infty}^{\infty} r_s(l_s)e^{j\frac{\omega}{c}l_s}\,\mathrm{d}l_s\right|^2 + 2\Re\left\{S_0(\omega)\int_{-\infty}^{\infty} r_s(l_s)e^{j\frac{\omega}{c}(l_m - l_s)}\,\mathrm{d}l_s\right\}$$ [6]

(c) With reference to the equation in (b), explain how the amplitude reflectivity density function $r_s(l)$ can be recovered from the intensity $I(\omega)$ in the following systems:

(i) time-domain OCT; [5]

(ii) spectral OCT. [5]

SECTION H *Manufacturing, Management and Design*

Answer not more than **two** *questions from this section.*

21 (a) Explain, illustrating your answer with examples, what is meant by:

(i) radical innovation;

(ii) incremental innovation. [6]

(b) Describe the differences in the characteristics of a start-up firm and a large, long-established firm. [4]

(c) Discuss, illustrating your answer with examples, the challenges of managing innovation in a large, long-established firm. [10]

22 (a) When designing any production system, there is always a trade-off between the volume and variety of products that can be made. Sketch a diagram that illustrates the trade-off between volume and variety. [4]

(b) Describe, illustrating your answer with examples, the characteristics of each of the following four types of production system:

(i) projects;

(ii) job shop;

(iii) batch production;

(iv) mass production. [8]

(c) Many start-up firms cannot afford to develop their own production systems and choose instead to form partnerships with larger, well-resourced firms. Discuss some of the challenges that might be faced by start-up firms when they try to set-up and manage partnerships with larger firms. [8]

23 In discussion with two of your colleagues, you have developed an idea for a novel, low-cost electronic anti-theft alarm for bicycles.

(a) Discuss how you could identify:

(i) who the potential buyers of this product might be;

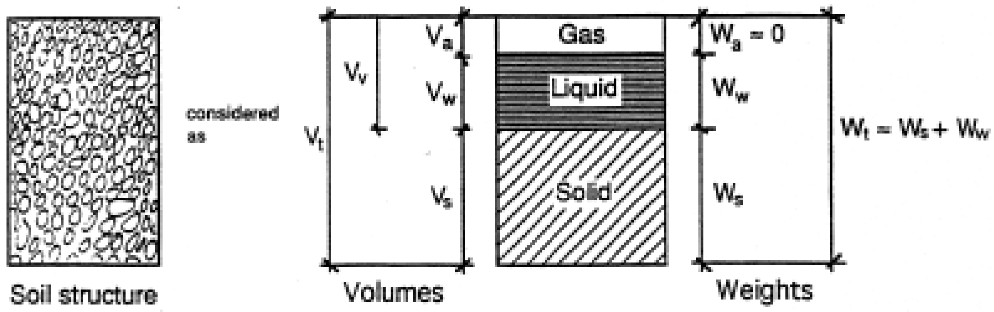
(ii) what the competitors for this product might be. [12]

(b) Describe the types of Intellectual Property (IP) that would be relevant for this product. For each type of IP, identify the issues that would need to be considered in protecting that IP. [8]

END OF PAPER

Data sheet – Soil Mechanics (6 pages)

General definitions



Specific gravity of solid G_s

Voids ratio $e = V_v/V_s$

Specific volume $v = V_t/V_s = 1 + e$

Water content $w = (W_w/W_s)$

Degree of saturation $S_r = V_w/V_v = (w\,G_s/e)$

Unit weight of water $\gamma_w = 9.81\ \text{kN/m}^3$ (although we assume 10 kN/m^3)

Unit weight of soil $\gamma = W_t/V_t = \left(\frac{G_s + S_r e}{1+e}\right)\gamma_w$

Buoyant (effective or submerged) unit weight

$\gamma' = \gamma - \gamma_w = \left(\frac{G_s - 1}{1+e}\right)\gamma_w$ (soil saturated)

Unit weight of dry soil $\gamma_d = W_s/V_t = \left(\frac{G_s}{1+e}\right)\gamma_w$

Relative density $I_d = \frac{(e_{max} - e)}{(e_{max} - e_{min})}$

where e_{max} is the maximum voids ratio achievable in the quick tilt test (for sands), and
e_{min} is the minimum voids ratio achievable by vibratory compaction (for sands).

Classification of particle sizes

Boulders	larger than			200 mm
Cobbles	between	200 mm	and	60 mm
Gravel	between	60 mm	and	2 mm
Sand	between	2 mm	and	0.06 mm
Silt	between	0.06 mm	and	0.002 mm
Clay	smaller than	0.002 mm (two microns)		

D — equivalent diameter of soil particle

D_{10}, D_{60} etc — particle size such that 10% (or 60%) etc.) by weight of a soil sample is composed of finer grains.

Stress components

Principle of effective stress (saturated soil):

total stress σ = effective stress $\sigma' +$ pore water pressure u

$\tau = \tau' + 0$

and

σ_v = vertical stress

σ_h = horizontal stresss

τ = shear stress

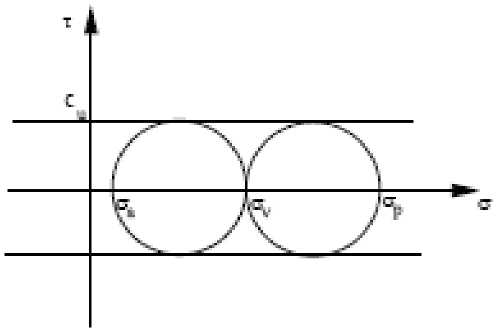
Strength of clays (undrained behaviour only)

Under constant volume (undrained) conditions only, the strength of clays can be characterised by the *undrained shear strength* c_u which is mobilized when the shear stress $\tau = c_u$. This conforms to Tresca's criterion, and the active and passive total horizontal stresses, σ_a and σ_p respectively, are given by

$\sigma_a = \sigma_v - 2\,c_u$

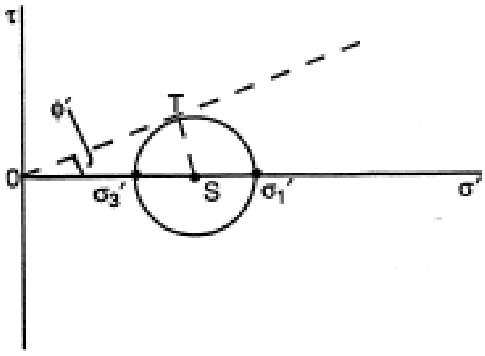
$\sigma_p = \sigma_v + 2\,c_u$

where σ_v is the total vertical stress.



Strength of sands

Mobilised angle of shearing ϕ'
where $\tau = \sigma' \tan \phi'$



$$\sin \phi' = TS/OS$$

$$= \frac{(\sigma_1' - \sigma_3')/2}{(\sigma_1' + \sigma_3')/2}$$

$$\therefore \phi' = \sin^{-1}\left[\frac{\left(\sigma_1'/\sigma_3'\right)-1}{\left(\sigma_1'/\sigma_3'\right)+1}\right]$$

Earth pressure coefficient K: $\sigma_h' = K\sigma_v'$

Active pressure: $\sigma_v' > \sigma_h'$ $\therefore$ $\sigma_1' = \sigma_v'$

$\sigma_3' = \sigma_h'$

$K_a = (1 - \sin\phi'/1 + \sin\phi')$

Passive pressure: $\sigma_h' > \sigma_v'$ $\therefore$ $\sigma_1' = \sigma_h'$

[We assume principal stresses $\sigma_3' = \sigma_v'$

are horizontal and vertical] $K_p = (1 + \sin\phi')/(1 - \sin\phi') = \frac{1}{K_a}$

Angle of shearing resistance:

at peak strength ϕ'_{max} at $\left(\sigma_1'/\sigma_3'\right)_{max}$

at critical state ϕ'_{crit} after large strains.

Sand strength data: friction hypothesis

In any shear test on soil, failure occurs when $\phi' = \phi'_{max}$ and

$$\phi'_{max} = \phi'_{crit} + \phi'_{dilatancy}$$

where ϕ'_{crit} is the ultimate angle of shearing resistance of a random aggregate which deforms at constant volume, so the dilatancy, which indicates an increase in volume during shearing, approaches zero $(\phi'_{dilatancy} -> 0)$ as $\phi'_{max} -> \phi'_{crit}$.

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ϕ'_{crit} is a function of the mineralogy, size, shape and distribution of particles. For a particular soil it is almost independent of initial conditions. Typical values (±2°):

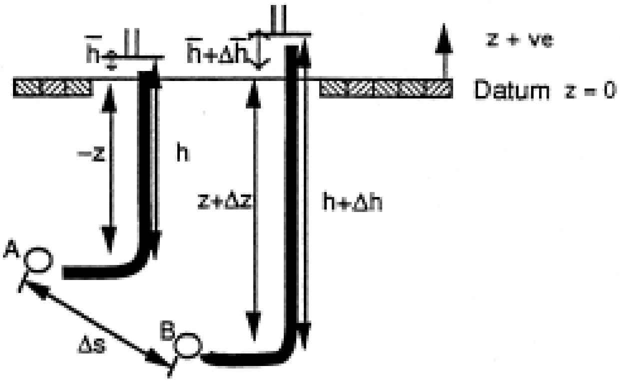
	ϕ'_{crit}	ϕ'_{max}	
feldspar	40°		
quartz	33°	53°	($I_d = 1$, and mean effective stress OS < 150 kPa)
mica	25°		

Seepage

Excess pore water pressure

Head $h = u/\gamma_w$

Potential $\bar{h} = h + z$



Total pore water pressure head at A: $u = \gamma_w h = \gamma_w(\bar{h} - (-z))$

B: $u + \Delta u = \gamma_w(h + \Delta h) = \gamma_w(\bar{h} + z + \Delta\bar{h} + \Delta z)$

[Excess pore water pressure at A: $\bar{u} = \gamma_w \bar{h}$

B: $\bar{u} + \Delta\bar{u} = \gamma_w(\bar{h} + \Delta\bar{h})$]

Hydraulic gradient A–B $i = -\dfrac{\Delta\bar{h}}{\Delta s} = -\dfrac{\Delta\bar{u}}{\gamma_w \Delta s}$

Darcy's law $v = ki$
v = average or superficial seepage velocity
k = coefficient of permeability

Typical permeabilities

$D_{10} > 10$mm	:	non-laminar flow
10 mm $> D_{10} >$ 1µm	:	$k \approx 0.01(D_{10}\text{in mm})^2$ m/s
clays	:	$k \approx 10^{-9}$ to 10^{-11} m/s

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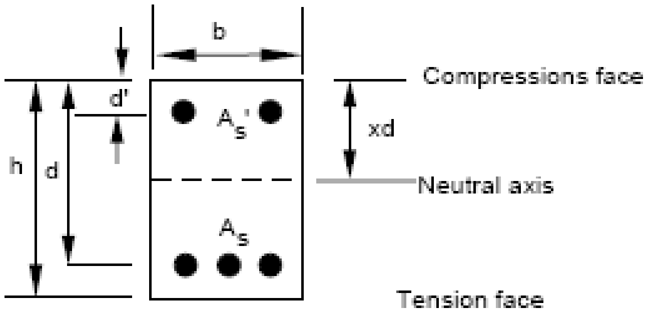
Design of reinforced concrete

Data sheet for use in Part IB Civil Engineering Elective Course.



Design Stresses

Cube strength for concrete f_{cu}. At failure in bending, stress in concrete = $0.4f_{cu}$ over whole area of concrete in compression.

Tensile yield stress of steel f_y. At failure in bending, stress in bars in tension = $0.87f_y$, stress in bars in compression = $0.75f_y$.

Design Equations

Moment capacity of singly reinforced beam

$$M \le 0.15 f_{cu} bd^2$$
$$M = 0.87 f_y A_s d(1 - x/2)$$
$$x = 2.175(f_y / f_{cu}).(A_s / bd) \quad (\le 0.5 \text{ to avoid over reinforcement})$$

Moment capacity of doubly reinforced beam

$$M = 0.15 f_{cu} bd^2 + 0.75 f_y A'_s (d - d')$$
$$0.87 f_y A_s = 0.75 f_y A'_s + 0.2 f_{cu} bd$$

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Shear capacity of all beams

Total shear capacity $V = (v_c + v_s)bd$

Where, $v_c = 0.68(100\,A_s/bd)^{0.33}.(400/d)^{0.25}$ (N/mm^2)

and $v_s = 0.87 f_y\, A_{sq}/(bs)$

in which s = shear link spacing, A_{sq} is total area of all shear bars in a link and A_s is the total area of effective longitudinal *tension* steel at the section.

Standard bar sizes

Diameter (mm)	6	8	10	12	16	20	25	32	40	50
Area (mm^2)	28	50	78	113	201	314	491	804	1256	1963

Available steel types

Deformed high yield steel $f_y = 460$ N/mm^2

Plain mild steel $f_y = 250$ N/mm^2

Lap and anchorage lengths 40 bar diameters

Density of reinforced concrete: $24\ kN/m^3$

Reinforcement areas per metre width

	Spacing of bars (mm)									
	75	100	125	150	175	200	225	250	275	300
Bar Dia. (mm)										
6	377	283	226	189	162	142	126	113	103	94.3
8	671	503	402	335	287	252	224	201	183	168
10	1050	785	628	523	449	393	349	314	285	262
12	1510	1130	905	754	646	566	503	452	411	377
16	2680	2010	1610	1340	1150	1010	894	804	731	670
20	4190	3140	2510	2090	1800	1570	1400	1260	1140	1050
25	6550	4910	3930	3270	2810	2450	2180	1960	1790	1640
32	10700	8040	6430	5360	4600	4020	3570	3220	2920	2680
40	16800	12600	10100	8380	7180	6280	5580	5030	4570	4190
50	26200	19600	15700	13100	11200	9820	8730	7850	7140	6540
Areas calculated to 3 significant figures according to B.S.I recommendations										

April 2010

Part IB Data Sheet: Electrical Engineering (2 pages)
Transistor Design

Gauss's Theorem
$\varepsilon_0\varepsilon_r E_1 - \varepsilon_0\varepsilon_r E_2 =$ charge per unit area enclosed between upper surface 1 and lower surface 2.

FET Design Summary
- $\tau_t \to$ switching time as 1st approx. (scattering limited transit time).
- $\tau_{eff} = \tau_t + R_{load}C_{eff(output)} \to$ switching time as 2nd approx.
- $L = v_s\tau_t$ (source-drain spacing).
- $I_{sat} = e N v_s W d_s = e N W L d_s/\tau_t$
- Aspect ratio W/L (technology?).
- $(1/2)eN(d_s)^2/\varepsilon_0\varepsilon_r =$ (Max Gate Voltage)
- $E'_{peak} = eN d_s/\varepsilon_0\varepsilon_r < E_{breakdown}$
- Minimum Drain Source Voltage $\sim E_s L$ (E_s is the field required to reach limiting velocities).

Mutual Conductance
$g_{mo} \sim I_{sat}/V_{gate(max)}$

Mutual conductance reduces with frequency as $g_m(\omega) \approx g_{mo}/(1 + j\omega\tau_t)$;

$$v_{out} = g_m(\omega)\, R\big/\left(1 + j\omega RC_{eff(out)}\right) \approx g_{mo}R/[1 + j\omega(\tau_t + RC_{eff(out)})]$$
$$= g_{mo}R/[1 + j\omega\tau_{eff}]$$

Capacitances for FET
Parallel Plate Capacitance: $\varepsilon_0\varepsilon_r$ Area/spacing

Used for rough estimates of parasitic capacitance.

Effective Capacitances for FET

$C_{eff(out)} \to C_{gate/drain} + C_{drain/source} + C_{load}$;

$C_{eff(in)} \to MC_{gate/drain} + C_{gate/source\,(proximity)} + C_{gate/source\,(electronic)}$;

$C_{electronic} = g_{mo}\tau_t$; $M = (1 + g_{mo}R_{load})$.

Time Constants for FET
$\mu = e\tau/m^*$ relates mean free time τ and mobility.

Transit time τ_t over distance L and scattering limited velocity v_s are related by $\tau_t = L/v_s$.

$v_{out} \approx g_{mo}R/[1 + j\omega\tau_{eff}] = g_{mo}R/[1 + j\omega/(2\pi f_t)]$

$1/(2\pi f_t) = \tau_t + RC_{eff(out)} = \tau_{eff}$ The transition frequency is f_t.

10% to 90% rise time is $T = 2.2\,\tau_{eff} = (2.2/2\pi)(1/f_t) = 0.35/f_t$.

Tunnel Barrier Design Summary Sheet

Schrodinger's Equation

Complex Wave $\Psi = A\ \exp(-j2\pi f\ t + j2\pi x/\lambda) = A\exp(-j\omega t)\exp(jkx)$;
<momentum> $\Psi = p\Psi = (h/\lambda)\Psi = -j(h/2\pi)\partial\Psi/\partial x$;

<Total energy> $\Psi = E\Psi = hf\Psi = j(h/2\pi)\partial\Psi/\partial t$
$(h/2\pi) \rightarrow \hbar$; $h = 6.625\times 10^{-34}$ J/s.

Schrodinger's equation:-

$$E\Psi = (1/2m)[-j\hbar\partial/\partial x]^2\Psi + e\phi\Psi$$

Tunneling (Rectangular barrier $\varepsilon\phi$)

Propogating waves outside barrier with incident kinetic energy $U_{incident} = (\hbar k_i)^2/2m^*$

Evanescent waves inside barrier: $-(\hbar k)^2/2m^* = (\hbar k_i)^2/2m^* - e\phi$

Technology Design Summary

Diffusion

Constant Surface Concentration:

$$C(x,t) = C_s\ \text{erfc}\left[\frac{x}{2(Dt)^{1/2}}\right]$$

Constant Total Dopant:

$$C(x,t) = \frac{S}{(\pi Dt)^{1/2}}\ \exp\left[\frac{-x^2}{4Dt}\right]$$

W I Milne
13.3.06