Section A.

Part IB Selected Topics - Civil Engineering - June 2000

Answers to Question 1:

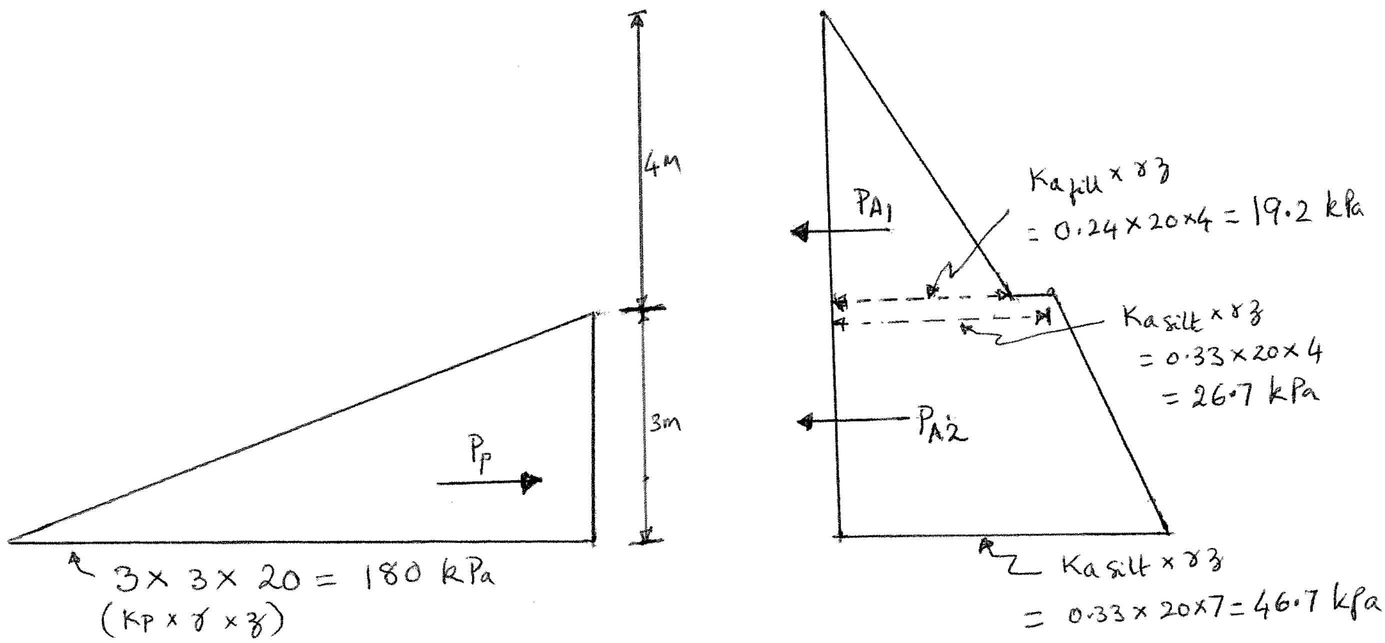
Coefficent of active earthpressure $K_a = \frac{1 - \sin\phi'}{1 + \sin\phi'}$

Coefficent of passive earth pressure $K_p = 1/K_a$

Fill $\phi' = 38°$ $K_a = \frac{0.38}{1.62} = 0.24$

Silty sand $\phi' = 30°$ $K_a = \frac{1-0.5}{1+0.5} = 0.33$ $K_p = \frac{1}{K_a} = 3.$

(a)



Total weight per metre run = 800 kN/m

S = Sliding resistance $= W \tan\phi'_{silt} = 800 \times \tan 30 = 461.9$ kN/m

$P_{A1} = \frac{1}{2} \times 19.2 \times 4 = 38.4$ kN/m

$P_{A2} = \frac{1}{2}(26.7 + 46.7) \times 3 = 110.1$ kN/m

$P_p = \frac{1}{2} \times 180 \times 3 = 270$ kN/m

∴ Factor of safety against sliding $= \frac{S + P_p}{P_{A1} + P_{A2}} = \frac{461.9 + 270}{38.4 + 110.1} = 4.93$

[40%]

Question 1 Solution (contd)

(b) 50 kN/m^2 surcharge

Additional active forces due to surcharge

Fill $P_{A1}^* = 0.24 \times 50 \times 4 = 48$ kN/m

Silt $P_{A2}^* = 0.33 \times 50 \times 3 = 50$ kN/m

Hence Factor of Safety against Sliding $= \dfrac{S + P_P}{P_{A1} + P_{A2} + P_{A1}^* + P_{A2}^*}$

$$= \frac{461.9 + 270}{38.4 + 110.1 + 48 + 50} = \underline{\underline{2.97}}$$

[20%]

(c) Total weight per metre = 800 kN/m

Uplift = weight of water displaced = $10 \times 7 \times 10 = 700$ kN/m

∴ Buoyant weight = 800 − 700 = 100 kN/m

(Equivalent to effective stress acting on the base = 10 kN/m^2)

∴ Sliding resistance $S' = 100 \tan 30° = 57.7$ kN/m

- Active soil forces reduced to 50%, because buoyant weight of soil is 10 kN/m^3 (cf total unit weight = 20 kN/m^3)

  ∴ Active soil forces $= \frac{10}{20}(38.4 + 110.1) = 74.3$ kN/m

- Additional soil forces due to surcharge are unaffected by water pressure, ie same as in b) = 48 + 50 = 98 kN/m

- Passive force reduced to 50%, because buoyant weight of soil is 10 kN/m^3 (cf total unit weight = 20 kN/m^3)

  ∴ Passive soil resistance $= \frac{10}{20} \times 270 = 135$ kN/m

∴ Factor of safety against sliding $= \dfrac{57.7 + 135}{74.3 + 98} = \underline{\underline{1.12}}$

[40%]

Question 2 Solutions

(a) i) Strong clay $C_u = 200$ kPa   Assume $\gamma = 20$ kN/m³

Stability ratio without support $N \simeq \frac{20 \times 20}{200} = 2$

Very low, ∴ Face support not needed.
∴ open face tunnelling is acceptable.

ii) Soft clay $C_u = 20$ kPa.

Stability ratio without support $N \simeq \frac{20 \times 20}{20} = 20$

Far exceeds the critical value ($\simeq 9$)
Hence face support is essential.

Face support could be provided by compressed air, or by using full face tunnelling machines using either slurry shield (SS) methods or by Earth Pressure Balance (EPB) techniques.

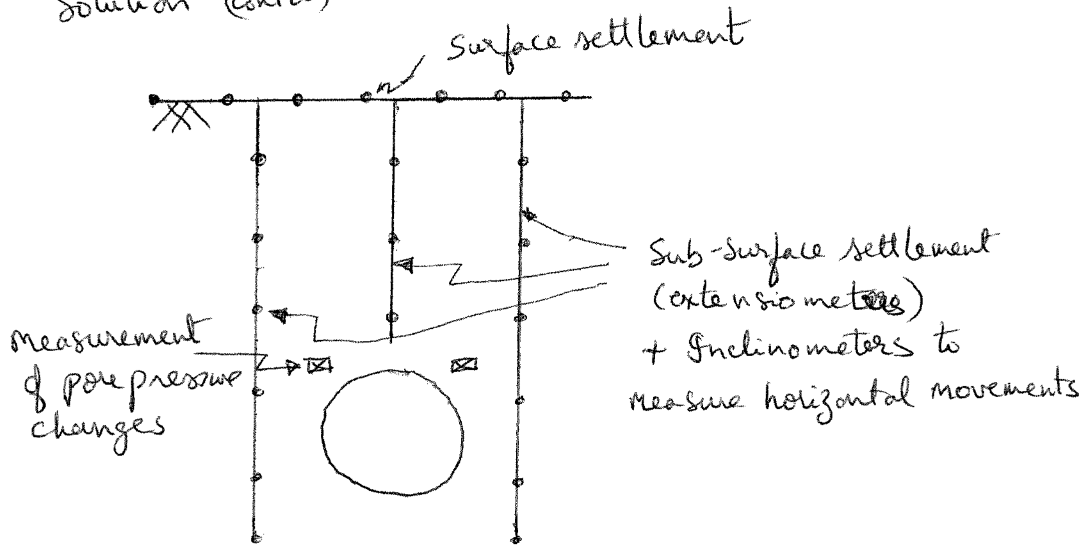
iii) Sands and gravel are permeable and hence water entry must be prevented. This could again be achieved by compressed air, or by SS methods or EPB techniques, or possibly by grouting the ground ahead of the face.

Other important design considerations are
a) ground movements and ~~partial~~ (particularly settlements) and their effects on structures and services.
b) tunnel lining design.

[40%]

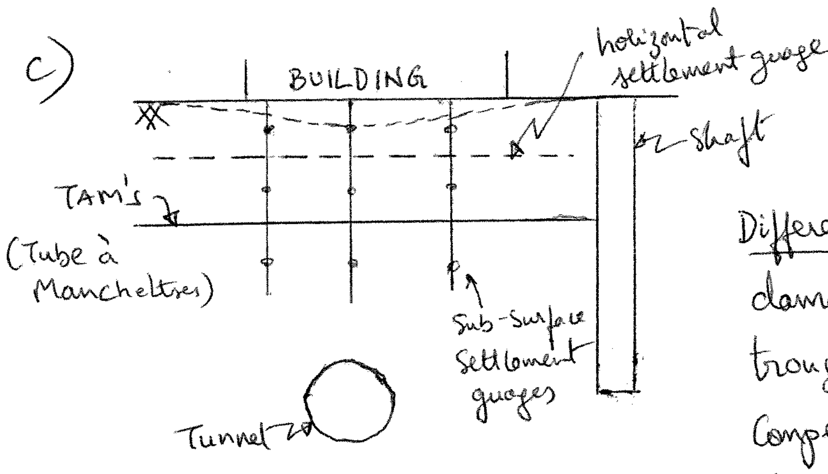
Question 2 Solution (Contd)

b)



Monitoring of settlement could be closely linked to control of face support pressure in case of ground conditions ii) and iii) – thereby optimising the choice of support pressure. (This is an example of the observational method) [30%]

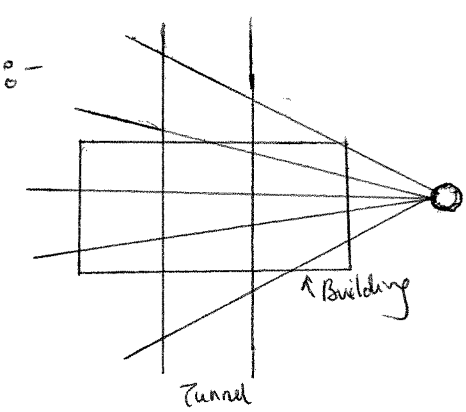
c)



Differential settlement potentially damages buildings. Settlement trough typically as shown. Use compensation grouting in conjunction with instrumentation to reduce differential settlements.

[30%]

Plan View :-



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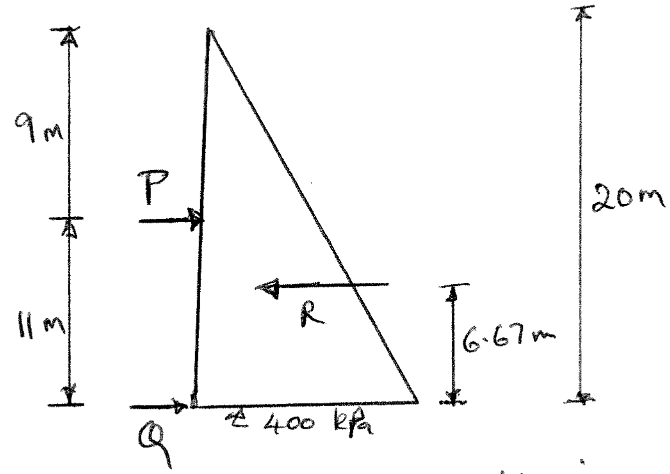
Part IB Selected Topics - Civil Engineering - June 2000

Answers to Question 3:



Resultant force on the wall is

$$R = 400 \times \frac{1}{2} \times 20 \times 10^3 \text{ N} = 4000 \text{ kN/m}$$

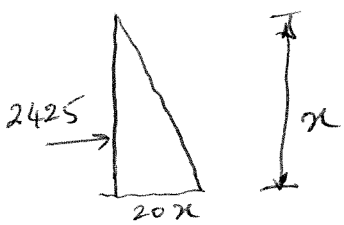
Taking moments about the base

$$4000 \times 6.67 = P \times 11$$

$$P = 2425.5 \text{ kN/m}$$

$$\therefore Q = R - P = 1574.5 \text{ kN/m}$$

$\therefore$ At depth x below prop $(x > 9\text{m})$



shear force $= \frac{1}{2} 20x \cdot x - 2425.5$ kN/m

$\therefore SF = 0$ when

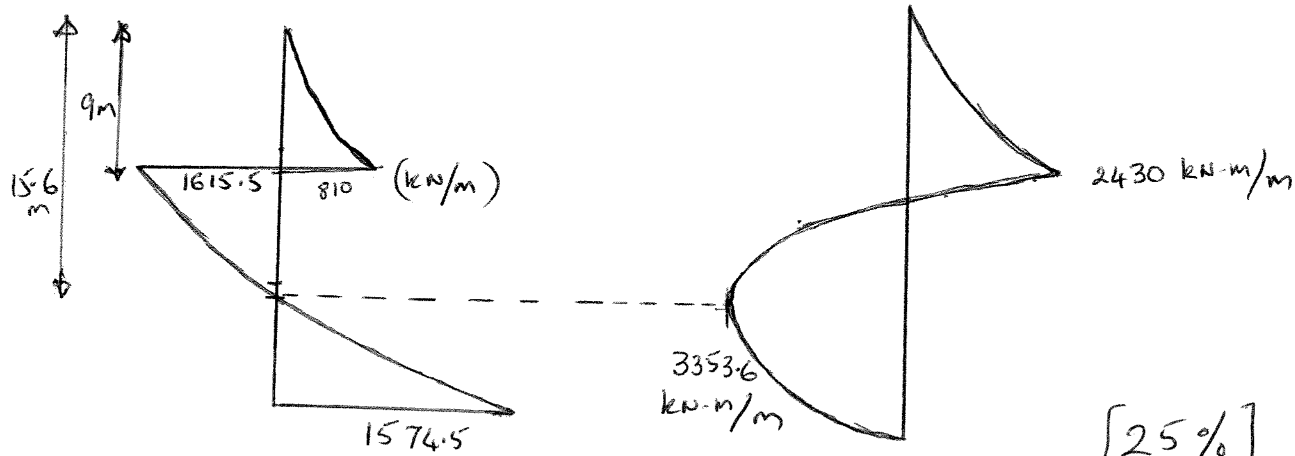
$$10x^2 = 2425.5$$

$$\Rightarrow x = 15.6 \text{ m}$$

Bending moment $= \frac{20x^2}{2} \cdot \frac{x}{3} - 2425 \{x - 9\}$

PTO

Shear Force Diagram Bending Moment Diagram.



[25%]

(b) From Data sheet

$$M = 0.15 f_{cu} bd^2$$

$$3353.6 \times 10^6 = 0.15 \cdot 40 \cdot 1000 \cdot d^2$$

$$\Rightarrow d = 747.6 \text{ mm} \simeq 750 \text{ mm}$$

This is the effective depth

∴ Actual wall thickness will be greater to allow for cover etc.

To find steel required at prop position

Guess $x = 0.5$ and from Data sheet

$$M = 0.87 f_y A_s d \left(1 - \frac{x}{2}\right)$$

$$2430 \times 10^6 = 0.87 \times 460 \times A_s \times 750 \cdot 3/4$$

$$\Rightarrow A_s = 10794.6 \text{ mm}^2/\text{m} \simeq 10795 \text{ mm}^2/\text{m}$$

But $x \simeq 2.175 \frac{f_y}{f_{cu}} \cdot \frac{A_s}{bd}$ (Data sheet)

So $x = 0.36$

Calculate new $A_s = 9873.1 \text{ mm}^2/\text{m}$

(could iterate further, but stop here)

$\therefore A_s = 9873 \text{ mm}^2/\text{m}$.

40mm bars = 1256.6 mm^2 $\therefore$ need = 7.8 /m.

Say 40mm bars at 125mm Centres $\Rightarrow$ 8 bars

At Max Moment position

$M = 3353.6 \times 10^6$ N-mm. Choose $x = 0.5$

$\therefore A_s = 14897.4 \text{ mm}^2/\text{m}$

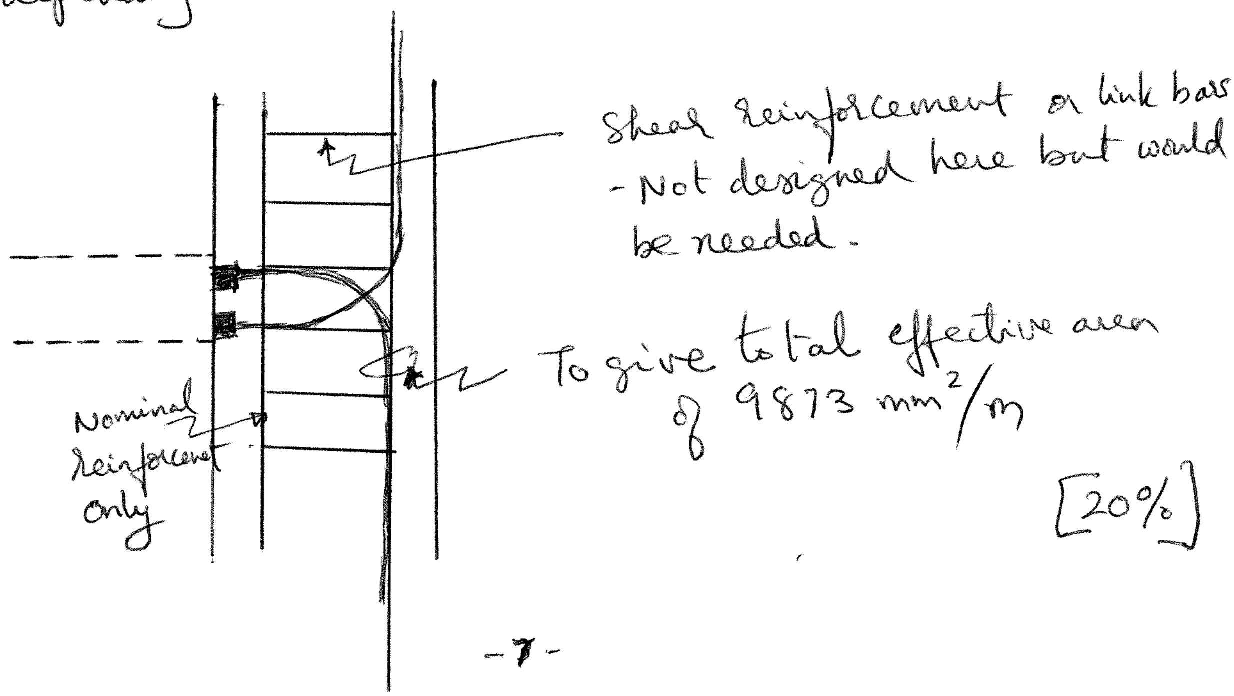
(No need to iterate since d chosen to give balanced section here).

40mm bars @ 80mm Centres
or 50mm bars @ 125mm Centres

[35%]

(c) No real benefits of doubly reinforcing the wall. It would need to be applied over significant length. However, the trench could be narrower so that less material would need to be encountered, so there could be benefit depending on relative costs of excavation and steel.
[20%]

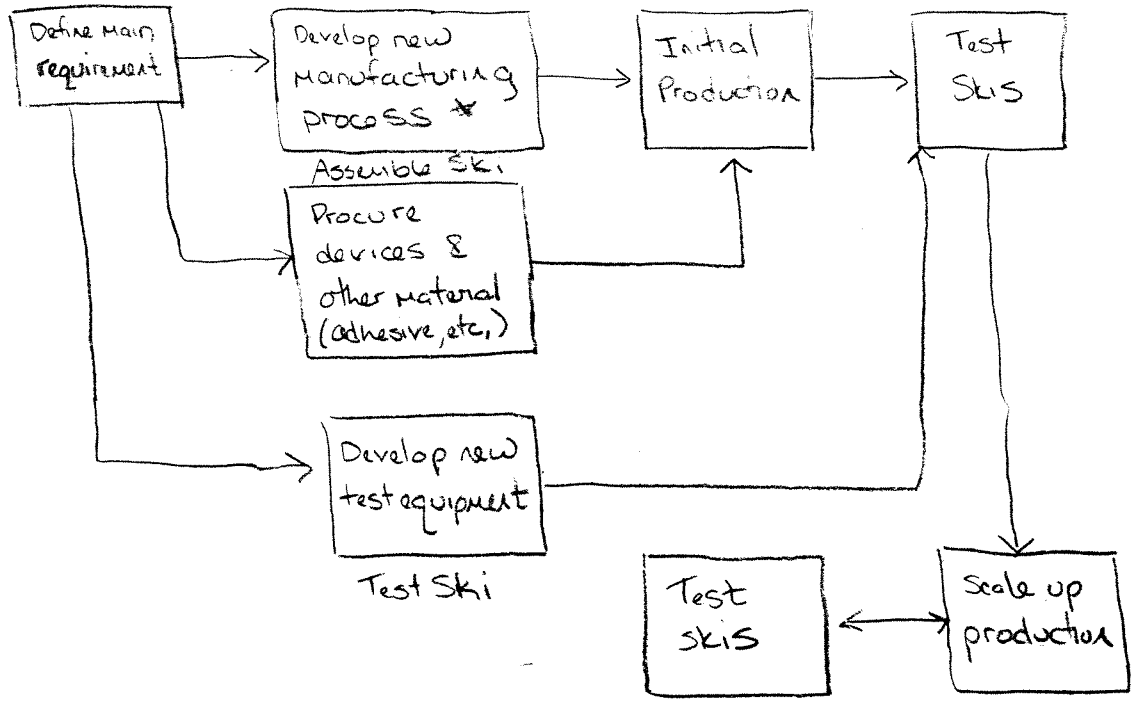
(d)



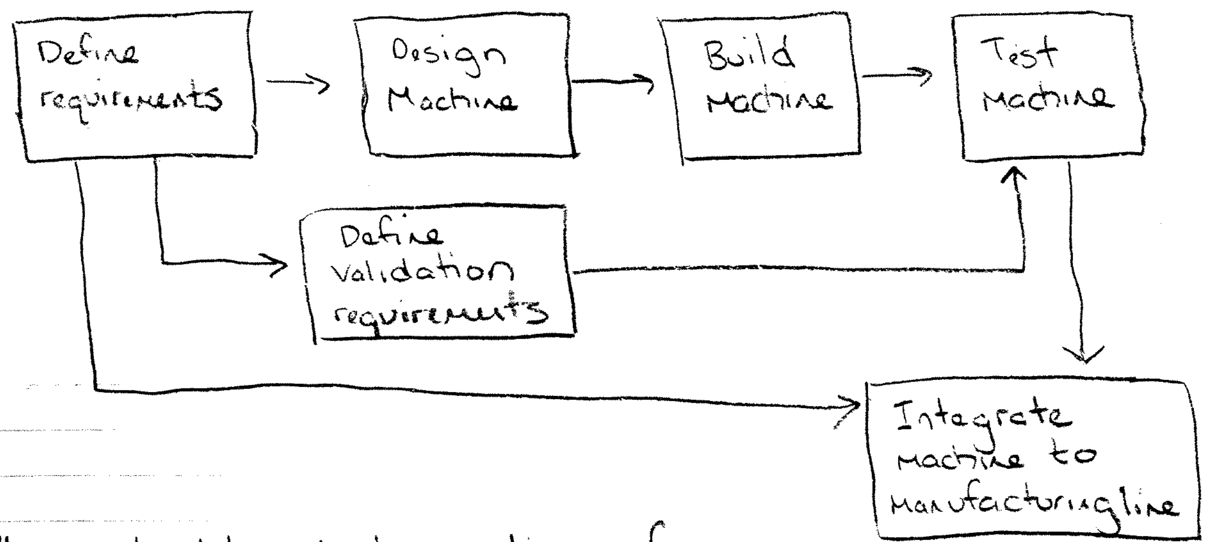
[20%]

Q4

(a) Must identify **key design**, development and validation tasks.

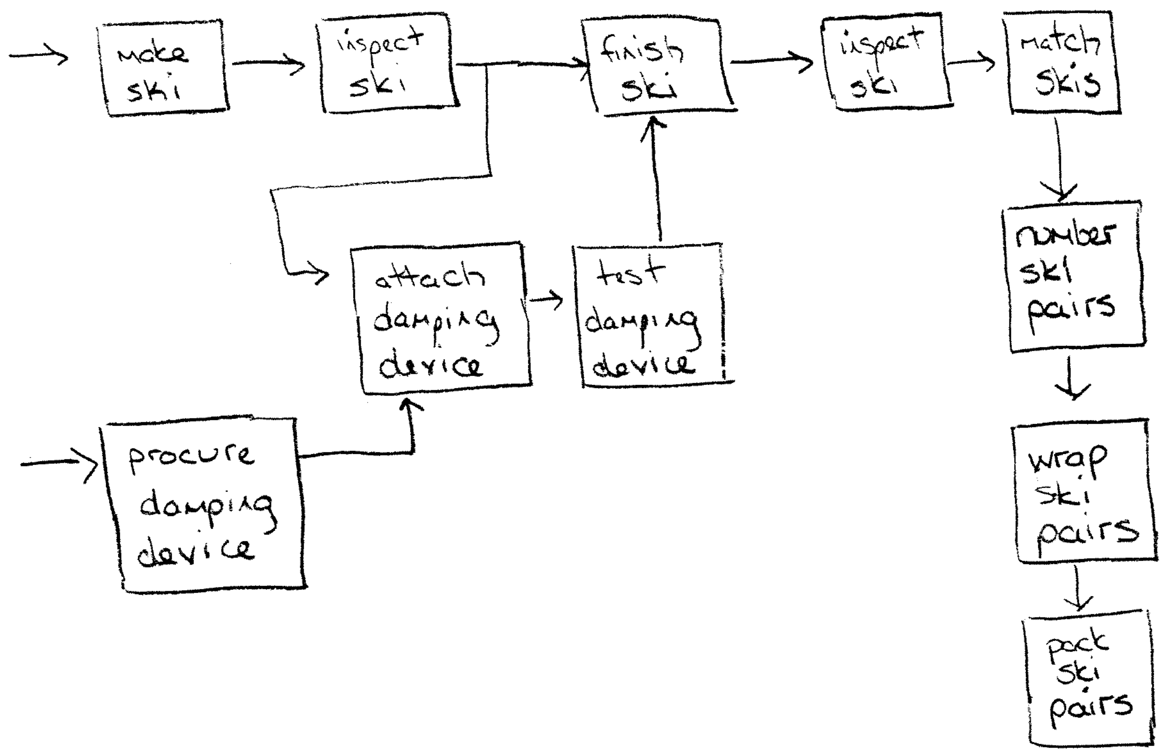


* For each machinery development



Plans should include mention of manufacturing validation and talk of manufacturing processes and test processes.

(b) Existing line will manufacture ski and finish ski. Adding a damping device will require modification to this process to allow for the device to be bonded to the ski, then tested, prior to final finishing. Hence, space must be found in production to bond the device to the ski, then test it before returning the ski to the original line for finishing.



(c.)

Capacity: must allow for increased product sales. Overall capacity may not increase much if new ski replaces older model.

Process: must add device bonding and testing processes.

Human Resources: must train staff to assemble and test new skis. This may require quite different skills to existing workforce.

Quality: new inspection procedure will be required to check modified skis.

Control Policies: must be extended to include damping devices and allow flexibility in production to make skis with damping devices on demand.

Suppliers: manufacturer of damping device and adhesive as well as suppliers of assembly and test equipment must be found.

(d.) Risks may include:

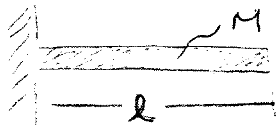
- technological problems, damping device ineffective, wrong adhesive, unreliable system.
- manufacturing problems, procurement of new equipment for bonding and testing the device.
- marketing of new technology is ineffective.
- largest risk is late delivery - must be on time even if over budget.

Q5

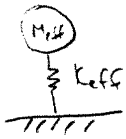
(a) length = 2m
mass = 2.5kg
$EI = 600\,N$

$$\omega_n = 3.52\sqrt{\frac{EI}{M\ell^3}}$$

beam model:

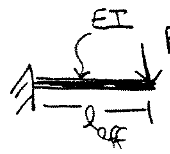


Single degree of freedom model:



$$\omega_n = \sqrt{\frac{K_{eff}}{M_{eff}}} \qquad M_{eff} = \frac{M}{2}$$

where $K_{eff} = \frac{3EI}{\ell_{eff}^3}$ (p.6 structures data book)



cantilever beam w/ point force at tip

$$\therefore \; \omega_n = \sqrt{\frac{3EI}{M_{eff}\,\ell_{eff}^3}}$$

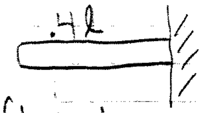
so,

$$\sqrt{\frac{3\cancel{EI}}{\frac{M}{2}\ell_{eff}^3}} = 3.52\sqrt{\frac{\cancel{EI}}{\cancel{M}\ell^3}}$$

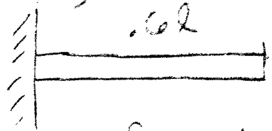
$$6\ell^3 = 3.52^2\,\ell_{eff}^3$$

$$\therefore \; \ell_{eff} = .785\,\ell$$

assume two symmetric models to calculate forebody and afterbody stiffness and natural frequency

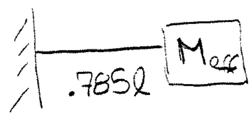


afterbody (.8m)



forebody (1.2m)

both systems equivalent to



$$K_f = \frac{600\,Nm^2 \cdot 3}{(2m \cdot .6 \cdot .785)^3 \Rightarrow (.942)^3} = 2153\,N/m$$

$$\omega_{nf} = \sqrt{\frac{2153\,N/m}{(2.5kg \cdot .6 \cdot .5) \Rightarrow (.75kg)}} = 54\,rad \cdot s^{-1} = 8.6\,Hz$$

$$K_a = \frac{600\,Nm^2 \cdot 3}{(2m \cdot .4 \cdot .785)^3 \Rightarrow (.628)^3} = 7268\,N/m$$

$$\omega_{na} = \sqrt{\frac{7268\,N/m}{(2.5kg \cdot .4 \cdot .5) \Rightarrow (.5kg)}} = 121\,rad \cdot s^{-1} = 19.3\,Hz$$

note: alternate method:
1. calculate using the given formula for ω_n using ℓ, m for each section
2. then use $\omega_n = \sqrt{\frac{K_{eff}}{M_{eff}}}$ to calculate K_{eff}.

b.) wood ski : $c = 0.15$

$\omega_{nf} = 8.6\ Hz$
$\omega_{na} = 19.3\ Hz$ } part (a.)

new ski : $c = 0.10$

given $EI_{new} < EI_{wood}$

$\Rightarrow$ $\omega_{nf_{new}} < \omega_{nf_{wood}}$
$\omega_{na_{new}} < \omega_{na\ wood}$ } from beam formula in part (a.)

- A decrease in damping causes an increase peak response.
- A decrease in natural frequency causes the peak response to shift left on the graph.

Therefore :

Response	Material	section
A	new material	forebody
B	wood	fore body
C	new material	afterbody
D	wood	afterbody

c.) Key design requirements for damping device [NOT whole ski]

[note: demands & wishes were not explicitly required; adding ball-park numbers to requirements where possible was noted]

i.) forces
- must withstand varying forces for intended use
- must have minimal influence on ski stiffness

ii) energy
- must not require supplemental energy input, ie battery
- damping must absorb unwanted vibrations at targeted frequencies dependent on intended use

iv) Material
- if external, must be corrosion/abrasion resistant

c.- cont.)

v.) geometry
- should be compact in size
- must fit on ski without obstructing binding / boot area and normal use

vi.) ergonomics
- must not require any additional operations for user
- could indicate that device is working

vii.) maintenance
- should not require special tools or training of dealers for inspection and maintenance

viii.) signal
- noelectrical signal input
- signal output to LED possible

(c.)- cont.

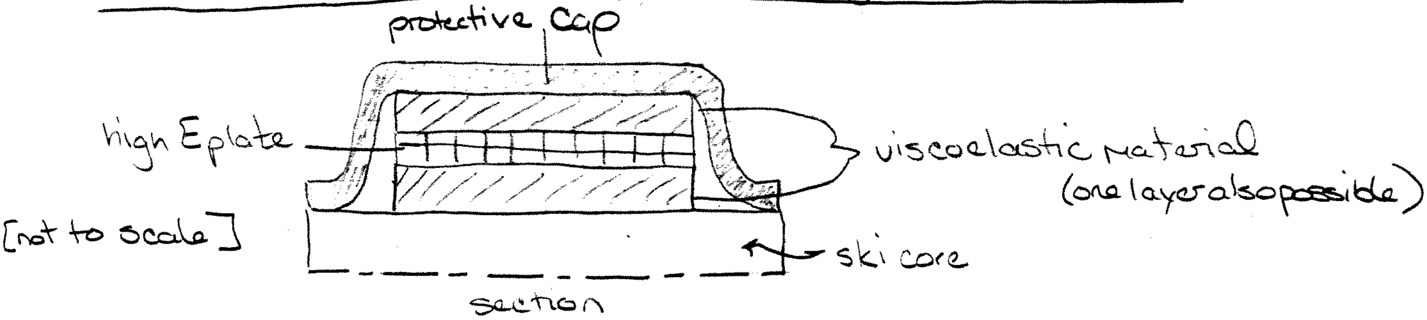
possible concepts (choose 1)

(i.) viscoelastic damper (along length -or- in target locations) (external -or- internal)

(ii.) piezoelectric damper (external or internal)

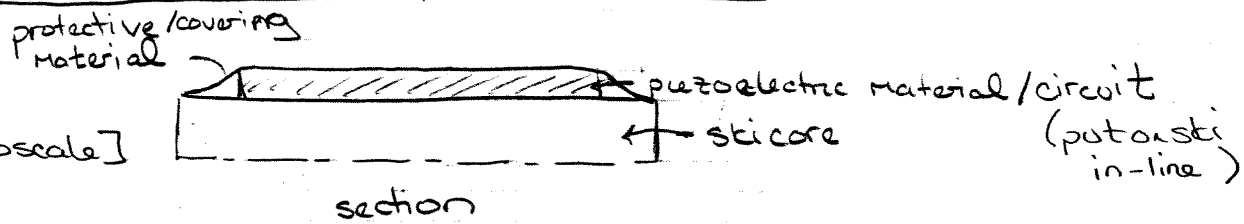
(iii.) tuned-mass damper (external)

(i.) external viscoelastic damper in a target location

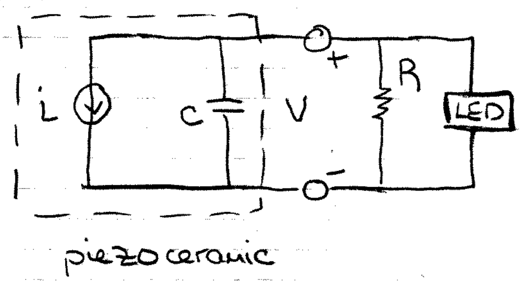


physical principle: Viscoelastic dampers work in shear to disipate energy from the ski. The level of damping can be increased by increasing the number of viscoelastic layers.

(ii) piezoelectric damper (external)



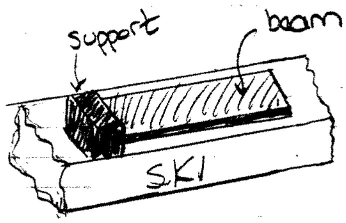
[note: equivalent circuit not necessary]



physical principle: piezoelectric material converts mechanical strain energy to electrical energy. This electrical energy can be dissipated as heat through a resistive element.

- placed at region of max strain which for 1st bending mode would be close to cantilever support, ie near binding region

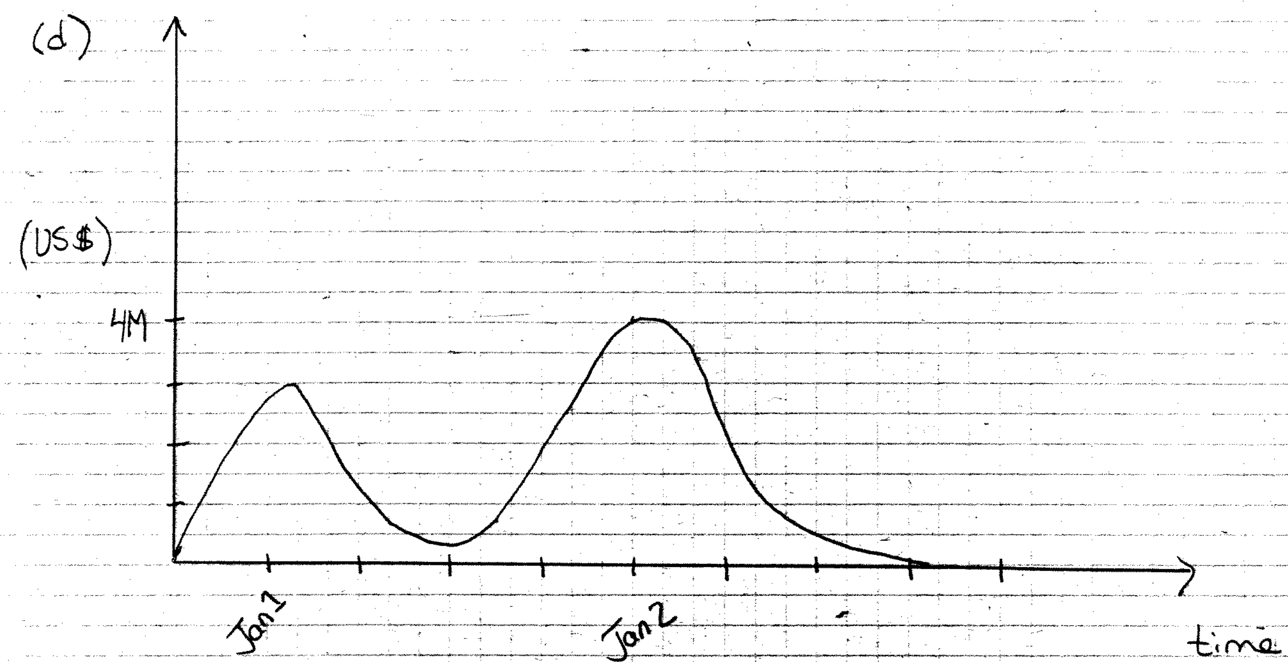
iii) tuned-mass damper



- cantilever beam w/damping treatment mounted at tip of ski (max. displacement for 1st mode)
- a protective cap can be added

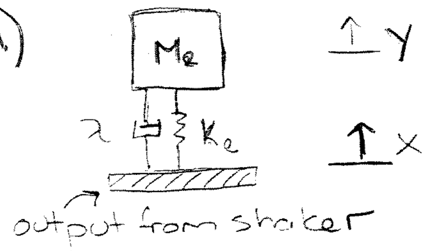
physical principle: neutralises vibration by opposing the motion of the vibrating object with an opposite force

(d)



- sales/time profile should peak for each winter (around December – February) and be much higher in winter months than other months
- after two years the model most likely will be significantly updated giving the fall-off
- give a sensible approximate peak sales number in currency or # of pairs.

a)



$M_{eff} = 1kg$
$K_{eff} = 5685 \ N/M$

$\therefore \ \omega_n = \sqrt{\frac{5685 N/M}{1kg}} = 75 rad \cdot s^{-1} = 12 Hz$

$\lambda = 15 Ns/M \Rightarrow \zeta = \lambda/2m\omega_n = \frac{15 Ns/M}{2 \cdot 1kg \cdot 75 rad \cdot s^{-1}} = .1$

Shaker: $M = .2kg$

$K = 12 \ N/MM$

$F_{max} = 50N$ (½ peak to peak force)

total stroke, s, $= 14mm$ (±7MM)

calculate operational stroke, $s' = s - (2 S_{sd})$

(total mass of ski + mass of armature)

$X_{sd} = \frac{2.2kg \cdot 9.81 m/s^2}{12 \ N/MM} = 1.80 \ MM$

(note: entire weight of ski is supported by the shaker - NOT - Meff)

$s' = 14MM - (2 \cdot 1.80 MM) = 10.40 \ MM \Rightarrow \pm 5.2MM$

displacement input ⇒ case (c) (p. 12 mechanics databook)

$$|Y_{max}| = \frac{5.2 MM}{(2 \cdot .1)}\left(1 + \frac{5}{2}(.1)^2\right) = 26.65 mm$$

lightly damped ($\zeta = .1$) $\Rightarrow |Y_{max}|$ at $\omega \sim \omega_n = 12Hz \cong 75 rad \cdot s^{-1}$

b.) using the maximum operational stroke and at the first resonant frequency

$y = 26.65 \cos \omega t$ (MM)

$|\ddot{y}| = 26.65 \ \omega^2$ (MM·s⁻²)

$\therefore \ |F|_{max} = M_{eff} |\ddot{y}| = 1kg \cdot 26.65 MM \cdot (75 rad \cdot s^{-1})^2$

F = 150N to excite the ski

-BUT- $F_{max} = 50N$ for this shaker! (100N is peak-peak force)

since $F \propto I$ your shaker will exceed the current limit at the first resonant frequency and you won't be able to measure the displacement using the maximum operational stroke so,

use F_{max}

$$50N = 1kg \cdot |y|_{max} (75 \text{ rad} \cdot s^{-1})^2$$

$$\Rightarrow |y|_{max} = 8.88 \text{ mm}$$

$$8.88 \text{ mm} = \frac{|x|}{(2 \cdot .1)} \left(1 + \frac{5}{2}(.1)^2\right)$$

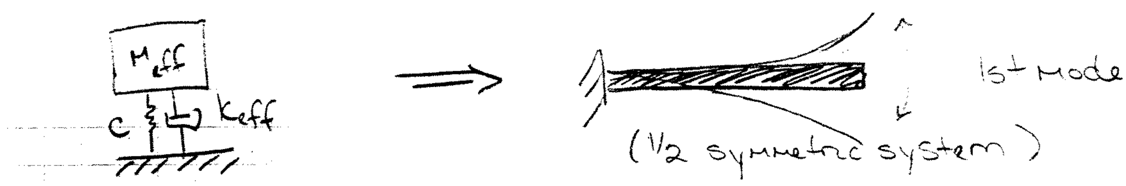
$$\Rightarrow |x|_{max} = 1.73 \text{ mm}$$

For a stroke length of ± 1.73 mm you will not exceed the force limit and can measure the peak displacement at the first resonance frequency.

Alternatively, you could select a shaker with a higher force limit as the shaker performance is limited by force.

(c)

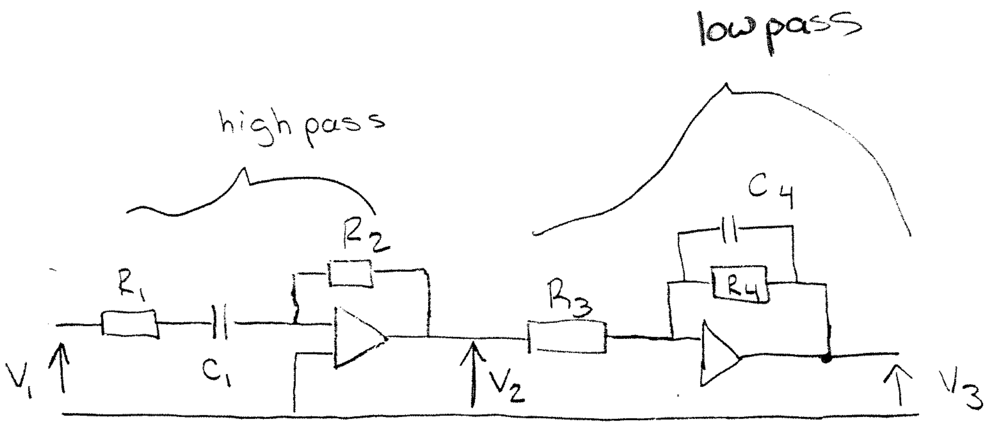
Relating the single degree of freedom model back to the cantilever beam



the maximum displacement of the first resonant frequency will occur at the ski tip and tail (symmetric)

∴ an accelerometer should be place at the ski tip. An additional consideration if measuring higher bending modes would be to place the accelerometers along the centerline so as not to get interference from close torsional modes. Potential sources of error are associated with the accuracy and repeatability of the accelerometer itself. It should be noted that when measuring low frequency vibration noise is a difficulty. Also, errors can result from improper mounting of accelerometers.

d)



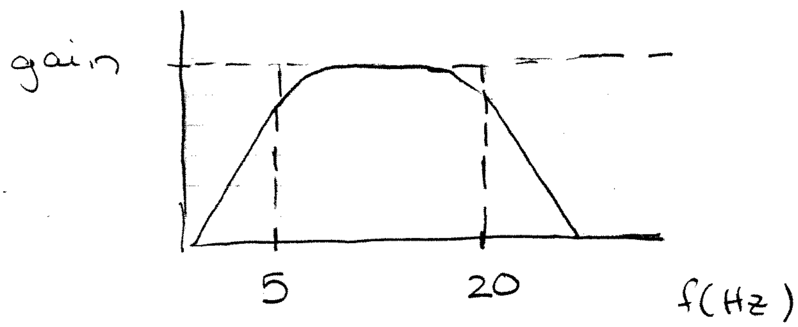
$$\frac{V_2}{V_1} = -\frac{j\omega C_1 R_2}{1 + j\omega C_1 R_1} \quad ; \quad \omega_1 = 1/C_1 R_1 \qquad C_1 = 1/\omega_1 R_1$$

$$\frac{V_3}{V_2} = -\frac{R_4}{R_3(1 + j\omega C_4 R_4)} \quad ; \quad \omega_2 = 1/C_4 R_4 \qquad C_4 = 1/\omega_2 R_4$$

if $R_1 = R_2 = R_3 = R_4$, then midband voltage gain = 1,

if $R_1 = 10\,k\Omega$, and $\omega_1 = 2\pi \cdot (5)$, $\omega_2 = 2\pi \cdot (20)$

then $C_1 = 3.2\,\mu F$ $\quad C_4 = .80\,\mu F$



Section C.

Q7 (a) $M_1 = 0.6 \qquad T_{01} = 260\,K$

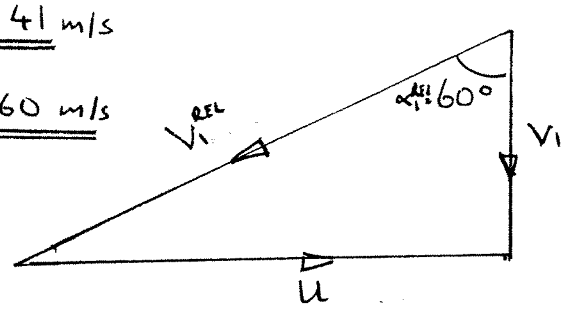
$$T_1 = T_{01} \div \left[1 + \frac{\gamma-1}{2} M_1^2\right] = \underline{\underline{242.53\,K}}$$

$$V_1 = M_1 \sqrt{\gamma R T_1} = 0.6 \times \sqrt{(1.4 \times 287 \times 242.53)}$$

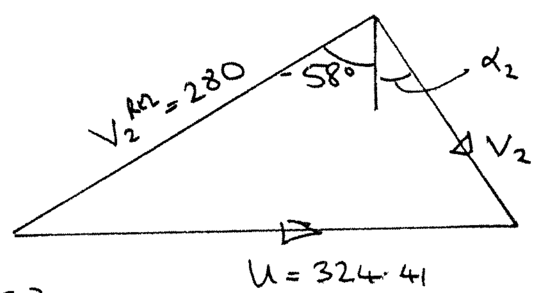
$$= 0.6 \times 312.17 = \underline{\underline{187.30 \text{ m/s}}}$$

(b) $U = V_1 \tan 60 = \underline{\underline{324.41 \text{ m/s}}}$

$V_1^{REL} = V_1 / \cos 60 = \underline{\underline{374.60 \text{ m/s}}}$



(c) $V_2^{REL} = 280$ m/s



From the triangle:

$V_{x2} = 280 \cos 58° = 148.38$ m/s

$V_{\theta 2} = U + V_2^{REL} \sin \alpha_2^{REL} = 324.41 - 280 \sin 58° = 86.95$ m/s

$\therefore \alpha_2 = \tan^{-1}\left(\frac{V_{\theta 2}}{V_{x2}}\right) = \underline{\underline{30.37°}}$

(d) $W_{in} = U(V_{\theta 2} - V_{\theta 1}) \quad ; \quad V_{\theta 1} = 0$

$\therefore W_{in} = 324.41 \times 86.95 = \underline{\underline{28210 \text{ J/kg}}}$

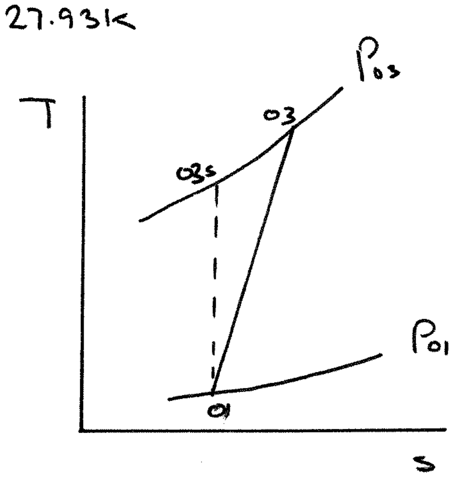
$\therefore T_{02} = T_{01} + W_{in}/C_p = 260 + \frac{28210}{1010} = \underline{\underline{287.93\,K}}$

& $T_{02} - T_{01} = \underline{\underline{27.93\,K}}$

Q7 cont.

(e) No work is done in stator

$\therefore (\Delta T_0)_{fan} = (\Delta T_0)_{Rotor} = 27.93K$



$\therefore \quad T_{03s} = T_{02s} = T_{01} + (T_{02} - T_{01})\eta$

$= 260 + 27.93 \times 0.9$

$= 285.14K$

$\therefore \left(\frac{P_{03}}{P_{01}}\right) = \left(\frac{T_{03s}}{T_{01}}\right)^{\gamma/\gamma-1} = \underline{\underline{1.38}}$

(f) The work input, the rise in h_0, T_0 and also p_0 [except for losses] are all due to the rotor. The stator blades turn the flow to the axial direction prior to the propulsion nozzle. In doing so, the static pressure and temperature rise and the Mach No falls. Because the flow is axial, maximum thrust is obtained upon expansion through the nozzle

8 (a)

$$T_{02} = T_1\left[1 + \frac{\gamma-1}{2}M^2\right] = 228\left[1 + 0.2\times0.84^2\right] = \underline{\underline{260.17\,\text{K}}}$$

$$P_{02} = p_1\left[\frac{T_{02}}{T_1}\right]^{\gamma/\gamma-1} = 29\left[\frac{260.17}{228}\right]^{3.5} = \underline{\underline{46.03\,\text{kPa}}}$$

(b)

$$P_{03} = P_{024}\times PR = 64\times 25 = \underline{\underline{1600\,\text{kPa}}}$$

$$T_{03} = T_{024} + \frac{T_{03s}-T_{024}}{\eta} \; ; \; T_{03s} = T_{024}\left(\frac{P_{03}}{P_{024}}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\therefore T_{03} = 289 + \frac{724.95-289}{0.9} = \underline{\underline{773.39\,\text{K}}}$$

(c)

Work balance for HPT & HPC

$$\dot{m}_{core}\,c_p\left(T_{04}-T_{045}\right) = \dot{m}_{core}\,c_p\left(T_{03}-T_{024}\right)$$

$$\therefore T_{045} = T_{04} - \left(T_{03}-T_{024}\right)$$

$$= 1500 - (773.39 - 289) = \underline{\underline{1015.6\,\text{K}}}$$

Now

$$T_{045s} = T_{04} - \frac{\left(T_{04}-T_{045}\right)}{\eta} = 961.78\,\text{K}$$

$P_{04} = P_{03}$

$$\Rightarrow P_{045} = P_{04}\left[\frac{T_{045s}}{T_{04}}\right]^{\frac{\gamma}{\gamma-1}} = 1600\left[\frac{961.78}{1500}\right]^{3.5} = \underline{\underline{337.73\,\text{kPa}}}$$

8 cont: (d) Work balance for LP turbine + Fan:

$$\dot{m}_{core}\, c_p (T_{045} - T_{05}) = \dot{m}_{core}\, c_p [T_{024} - T_{02}] + \dot{m}_{bypass}\, c_p [T_{013} - T_{02}]$$

$$BPR = \frac{\dot{m}_{bypass}}{\dot{m}_{core}} = \frac{(T_{045} - T_{05}) - (T_{024} - T_{02})}{(T_{013} - T_{02})}$$

$$= \frac{(1015.6 - 610) - (289 - 260)}{301 - 260} = \underline{\underline{9.2}}$$

(e) Assume nozzle isentropic & $P_9 = P_1 = P_{atm}$

$$\therefore \quad T_9 = T_{05} \left(\frac{P_9}{P_{05}}\right)^{\frac{\gamma-1}{\gamma}} = 610 \left[\frac{29}{43}\right]^{1/3.5} = 545\ K$$

$$V_9 = \sqrt{2 c_p (T_{05} - T_9)} = \underline{\underline{362\ m/s}}$$

9/ (a) $\eta_p = \frac{\text{Power to Aircraft}}{\text{Mechanical Power to Jet}} = \frac{\text{flight speed} \times \text{Net thrust}}{\text{in } \Delta KE}$

If we neglect mass flow rate of fuel therefore for a turbojet

$$\eta_p \approx \frac{V_1 \dot{m}_{air}(V_j - V_1)}{\dot{m}_{air}(\frac{1}{2}V_j^2 - \frac{1}{2}V_1^2)}$$

$$\approx \frac{V_1 (V_j - V_1)}{\frac{1}{2}(V_j + V_1)(V_j - V_1)} = \frac{2V_1}{V_j + V_1}$$

η_p represents the effectiveness of the propulsion system excluding the rise in enthalpy across the engine ($T_j > T_1$). It tells us that as $V_j \rightarrow V_1$ $\eta_p \rightarrow 1$ (even though Net thrust $\rightarrow 0$). It is important because it affects the overall efficiency (see below)

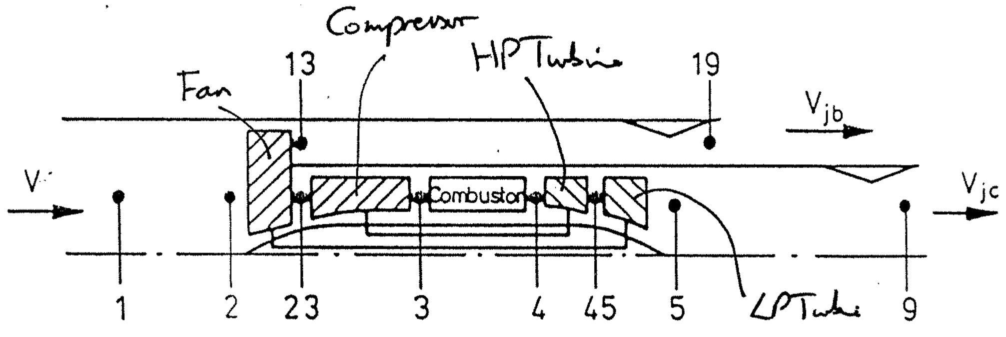
(b) $\eta_{th} = \frac{\dot{m}\Delta KE}{\dot{m}_{fuel} LCV} = \frac{\dot{m}_{air}\frac{1}{2}(V_j^2 - V_1^2)}{\dot{m}_{fuel} LCV}$

$$\eta_o = \eta_p \times \eta_{th} = \frac{\text{flight speed} \times \text{net thrust}}{\dot{m}_f \; LCV} = \frac{V}{sfc \; LCV}$$

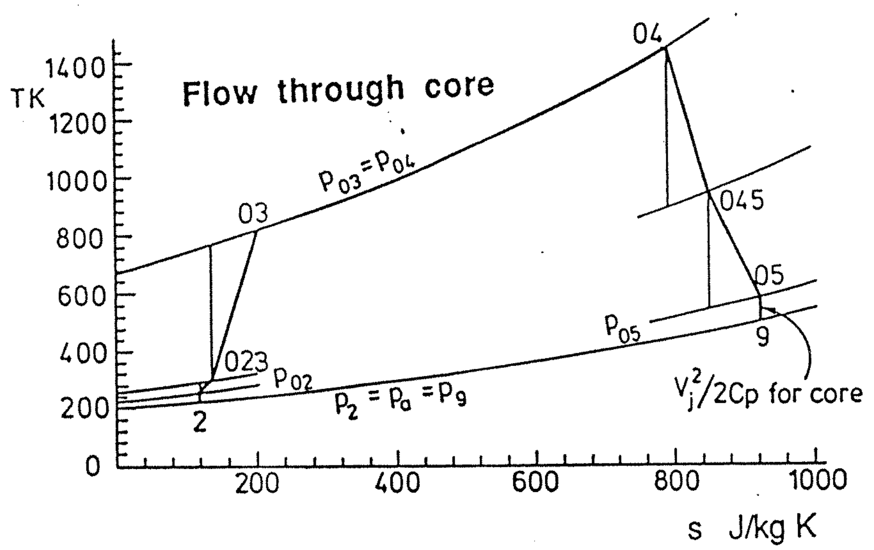
η_{th} is increased by using high cycle pressure ratio and high turbine entry temperature (cf inlet). Note that an optimum will exist. It is also affected by the component efficiencies (eg $\eta_{turbine}$, $\eta_{compressor}$). For a simple turbojet, high η_{th} implies high jet velocities and therefore low η_p. The bypass engine avoids this problem by using the "excess enthalpy" to drive the fan and so accelerate a lot of air to a lower velocity giving high net thrust

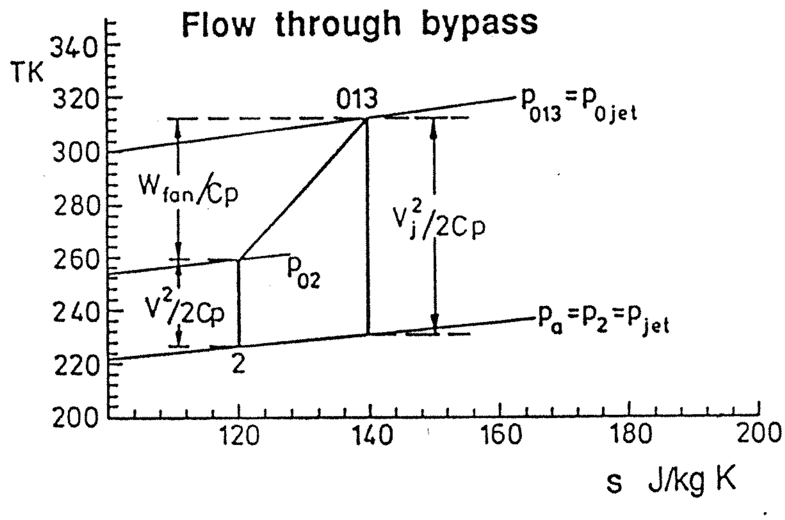
9(b) cont. and high η_p. Therefore, η_o is high. Military engines have requirements of higher V_j due to high flight speed (M, often >1). Use of low BPR / pure turbojet also has higher specific thrust for combat role, smaller frontal area / nacelle dia for less drag.

9(c)



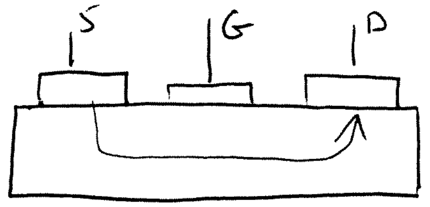
Turbofan (two-shaft)



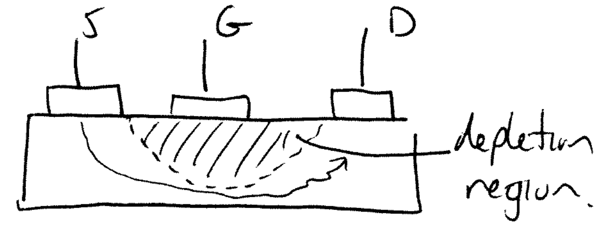


1B Paper 8 Q10 2000.

a)



$V_{GS} = 0$



$V_{GS} = V$

A +ve voltage on the drain attracts the ionised electrons from the donor atoms to the drain give a source-drain current flow. This is the situation for $V_{GS} = 0V$, the channel is neutral with equal negative electrons & positive donor ions. Applying a -ve gate voltage (V_{GS}) repels the moveable electrons to a certain depth below the gate out of the channel, leave +ve ions. The current is reduced due to this depleted region of the channel and will be reduced to zero when the depletion region reaches the bottom of the channel (the conducting region). The channel is "pinched off" as the -ve charge on the gate equals the +ve charge of the ionised donors.

b)

<u>Assumption 1</u>: Gauss' theorem
Electrons are repelled to a depth x. The charge in the box is Nex, where
N = donor density
e = electronic charge

<u>Assumption 2</u> There is no field out of the bottom of the box, as there are still moveable electrons there. Thus the gate field E is given by

$$\varepsilon E = Nex$$

$$\Rightarrow V = -\int_0^h \frac{Nex}{\varepsilon} = \frac{-Neh^2}{2\varepsilon}$$

where h is the depth of the channel

nb/ sign depends on the relative direction of the voltage, so +ve V is also OK.

c) $\sigma = Ne\mu$

$$\Rightarrow N = \frac{80}{1.6\times10^{-19}\times0.01} = 5\times10^{22}\ m^{-3}$$

d) $v = E\mu$, $V = Ed$ $d = vt$

$$\Rightarrow v = \frac{V}{d}\mu = \frac{d}{t} \Rightarrow d^2 = V\mu t$$

$$\Rightarrow d = \sqrt{2.5\times0.01\times10^{-11}} = 5\times10^{-7}m = 0.5\mu m$$

e) from (b) $V = -\frac{Neh^2}{2\epsilon} = -\frac{5\times10^{22}\times1.6\times10^{-19}\times(0.25\times10^{-6})^2}{2\times10^{-10}}$

$$= -2.5V$$

note sign

f) $E = \frac{Neh}{\epsilon} = \frac{5\times10^{22}\times1.6\times10^{-19}\times0.25\times10^{-6}}{10^{-10}}$

$$= 2\times10^{7}\ V/m$$

This is twice the breakdown field of the semiconductor (10^7), hence the device would fail. A new design must be made.

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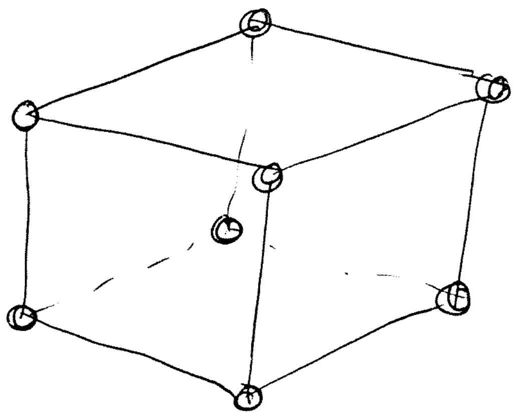
note Part (f) $E \neq V/h$ in this case and cannot be used to calculate the electric field.

1B Paper 8 Q11 2000.

a) Si has 4 valence electrons and 8 atoms per cubic unit cell

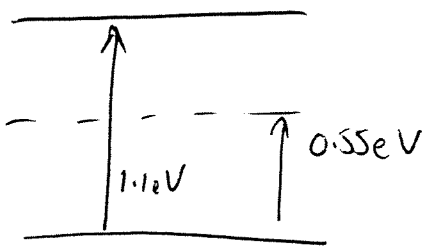


$\Rightarrow$ Electron density

$$N = \frac{8 \times 4}{(0.543 \times 10^{-9})^3}$$

$$= 2 \times 10^{29}\ m^{-3}$$

b)



The fraction of electrons in the conduction band is given by the Maxwell Boltzmann factor

$$x = e^{-eE/kT}$$

$T = 20°C = 293K$

$$= e^{\left(\frac{-0.55 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times 293}\right)} = e^{-21.76}$$

$$= 3.5 \times 10^{-10}$$

c) The temperature can be found from the Maxwell Boltzmann factor

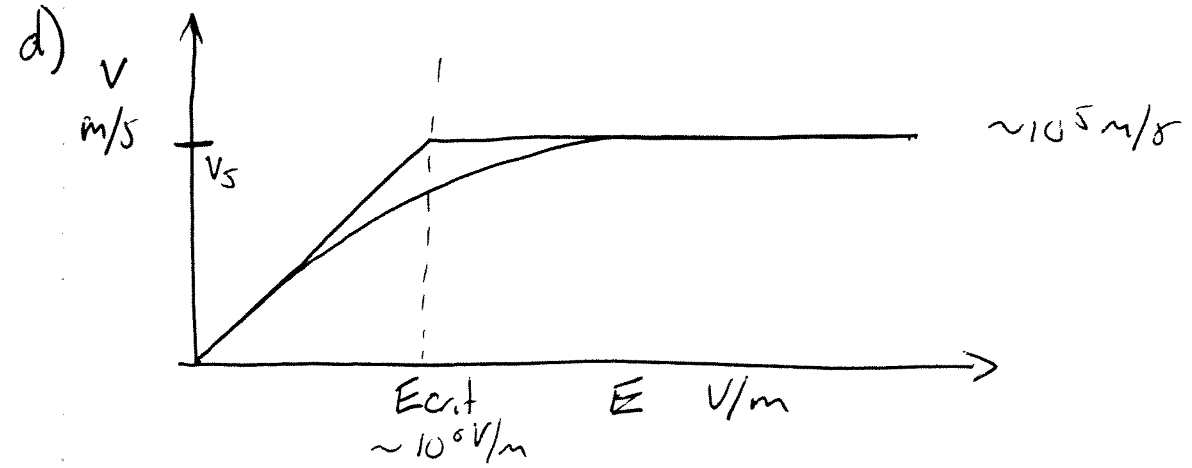
$$x = \frac{10^{22}}{2 \times 10^{29}} = e^{-eE/kT}$$

$$\Rightarrow 1/T = \frac{-\ln(5 \times 10^{-8}) \times 1.38 \times 10^{-23}}{0.55 \times 1.6 \times 10^{-19}} \quad \Rightarrow T = 379K$$

$$= 106\ °C$$

Doping is useful as it avoids high temperatures and gives a fixed controllable carrier density and thus conductivity.

d)



The scatter limited velocity is the maximum velocity that can be achieved in the Si. Increasing the field beyond this limit (Ecrit) will not increase the velocity of the electrons. This limit is due to collisions in the Si between electrons and the static atoms in the Si crystal lattice.

e) The critical field above which carriers are scatter limited

$$E_{crit} = V/\mu = 10^5/0.1 = 10^6 \text{ V/m}$$

for Silicon

The source drain length $L = V/E_{crit} = 2/10^6 = 2 \times 10^{-6}$ m

$= 2\mu m$

Transit time $t = L/v = 2\times10^{-6}/10^5 = 2\times10^{-11}$ s

$= 20$p Sec

f) Yes, Ecrit is not a fundamental limit to carrier speed, only the breakdown field is, which is usually around 50 times higher. Therefore L can be made smaller and the transit time shorter.

IB Paper 8 Q12 2000.

a) Silicon is the dominant semiconductor material in modern VLSI. It can be fabricated into wafers > 200mm in diameter. It can be doped to both p & n types which makes CMOS circuitry easy to make. The band gap of 1.1eV is sufficiently high so that the resistivity is substantially controlled by the impurity content and is stable up to around 80°C.
Si processing is well developed and understood down to sub micron precision and it can be shaped through dry & wet processing & etching. The most important feature of Si is that silicon dioxide can be grown over the surface by heating in steam or oxygen. The interface between the "native" oxide and the Si has low interface charges, making high quality MOSFETs possible.
It is not easy to make Schottky barriers on Si with well defined potential Barriers.

GaAs is a more recent development than Si, it has similar lattice structure & properties to Si. n type material can be made of a similar quality to Si. The band gap of 1.4eV is higher than Si, making it less sensitive to temperature variations.
GaAs also has some very interesting optical properties, making IR lasers and modulating structures possible, especially VCSELS.
Schottky barrier are readily formed with metals like Hg & Ni which are ideal for fast switching speeds in MESFET structure. High speed makes GaAs ideal for telecomms devices. (>1GHz)
Processing GaAs is difficult & the material is expensive. It is also difficult to make p-type material & complementary structures are very difficult. Diffusion processes are difficult as elevated temperatures cause the As to dissociate. The native oxide has a high level of charges, making MOSFETs quite useless.

Ge The first major semiconductor, with a bandgap of 0.67eV, however processing is difficult and the devices are highly sensitive to temperature (30 x worse than Si). They are still used in some specialised applications.

b) Oxide is critical parameter in MOSFET production, hence a reliable method of production is essential. Oxide is grown by heating Si wafer in a furnace in the presence of an oxidising atmosphere such as O_2 or H_2O.

<u>Wet Oxidisation</u> – oxidising atmosphere is water vapour.

Temperature is approx 900 – 1100 °C which leads to a fast growth rate of the order of 0·5µm / hour at 1100 °C.

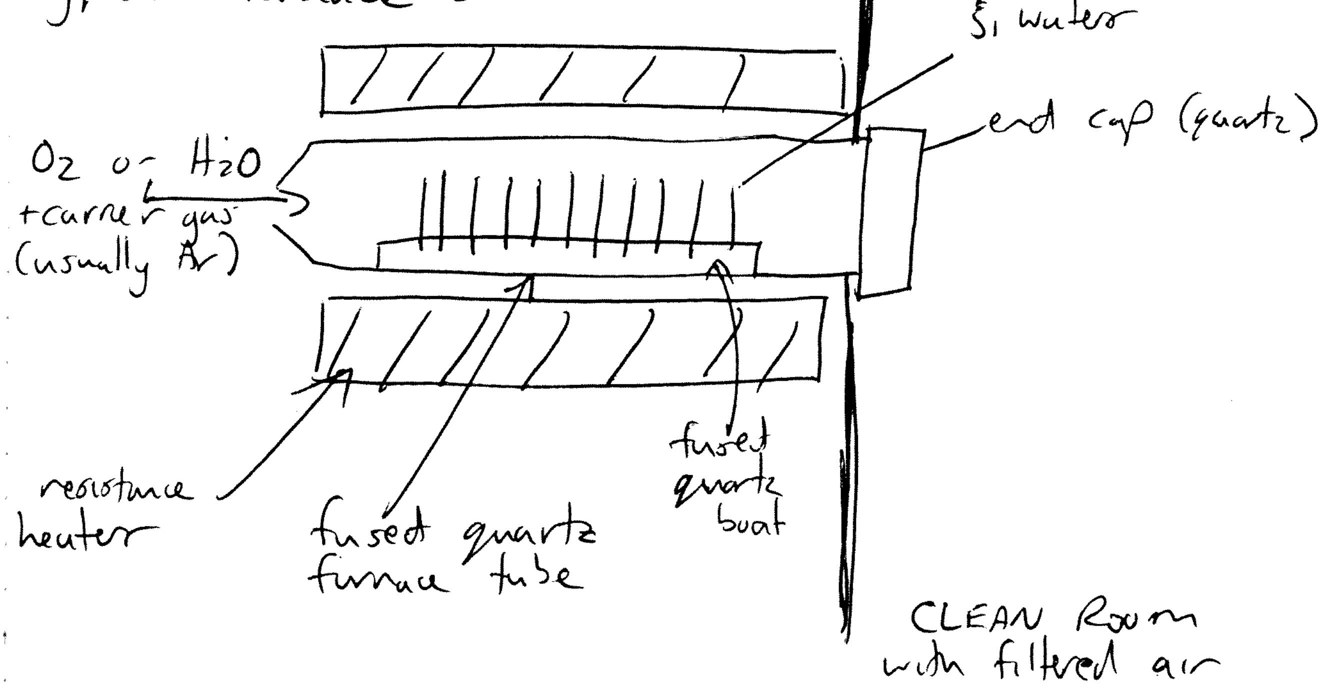
$$Si(solid) + 2H_2O \rightarrow SiO_2(solid) + 2H_2$$

<u>Dry Oxidisation</u> – oxidising atmosphere is pure O_2

Growth temperatures have to be in the region of 1200 °C to achieve growth rates of 0·1µm / hour

$$Si(solid) + O_2 \rightarrow SiO_2(solid)$$

Typical furnace structure



(b) cont

Most important properties:

Resistivity → ~ 10^{16} Ω cm

Dielectric Strength → ~10 MV/cm

Fixed charge density → ~ 10^{11} cm^{-2}

Interface density* → ~10^{11} $eV^{-1} cm^{-2}$

* Not a true oxide property, but vital for good MOST operation.

Problems

1) Eventually as the gate dimension shrinks, the oxide thickness also has to shrink and problems with leakage occur. ⇒ Need a new insulating material

2) Also, high temperature growth of oxide gives problems of dopant spread when oxide dimensions decrease. ⇒ Need new low temp growth process.

c) Volume of 1 mole Si

$$\frac{\text{Molecular wt of Si}}{\text{Density of Si}} = \frac{28.09}{2.33} = 12.06 \text{ cm}^3/\text{mol}$$

$$\text{Volume of 1 mole } SiO_2 = \frac{60.08}{2.27} = 26.46 \text{ cm}^3/\text{mol}$$

$$\Rightarrow \frac{\text{Thickness of Si area}}{\text{Thickness of } SiO_2 \text{ area}} = \frac{12.06}{26.46} = 0.45$$

Hence if the required oxide thickness (t) is reduced by $0.45t$, then the overall total thickness will be increased by $(1-0.45)t = 0.55t$

For 40nm of oxide

$\Rightarrow 0.45 \times 40\text{nm} = 18\text{nm}$ of Si consumed.

New Si thickness $= 475 \times 10^{-6} - 18 \times 10^{-9} = \underline{474.982\ \mu m}$

New total thickness $= 475 \times 10^{-6} + 0.55 \times 40 \times 10^{-9} = \underline{475.022\ \mu m}$

d) i) Passivation of high field regions
ii) Masking for selective ion implantation
iii) Masking to prevent diffusion (except selected areas)
iv) Final wafer passivation & protection
v) Planarisation for multi-layer structures (with CMP)

Section E

Q13

(a) An I/O-bound process is one that spends more of its time doing I/O than it spends doing computations.

A CPU-bound process is one that generates I/O requests infrequently, using more of its time doing computation.

(b) (i) I/O-bound: spends most of its time doing blocking system calls – waiting for requests to come in over the network, reading network requests, reading files, writing data over the network.

(b) (ii) Compute-bound: spends most of its time operating on data in memory (number crunching).

(b) (iii) I/O-bound: spends most of its time reading/writing over network and reading/writing files.

(c) A program is compute-bound if it exceeds its timeslice. A timeslice is a defined amount of time for which the process can have the processor. An I/O-bound process typically performs a blocking system call before its timeslice runs out. So if a process exceeds its timeslice it is preempted and noted as compute-bound.

(d) The aims of a multi-user operating system is to make maximum use of resources and to be fair to all processes. Therefore, while compute-bound processes are taking up the processor it is desirable to have all the other devices working (disks, networks etc.) so work is being done for the I/O-bound processes.

The mechanism for scheduling is multiple run queues based on priority. A process that exceeds its timeslice is added to a low priority run queue. A process that blocks before exceeding its timeslice and then completes its I/O operation is added to a higher priority queue (the priority depends on the criticality of the device being accessed). The idea here is that we want to start the I/O-bound process as soon as possible because (a) we want to get as much device parallelism as possible – i.e. get the disks spinning and the network buzzing continuously (b) it is more likely to block quickly anyway – thus being fair to it and freeing up the processor quickly.

(e) Page frames are the fixed-size chunks of real memory that are used to map in the pages in the virtual memory when they are currently being used for program or data (when a page is accessed it generates a page fault and the data is required in main memory).

If a process doesn't have enough page frames to fit in its current *working set* (current set of referenced program and data pages) then it will generate loads of page faults – requiring the data in a page frame to be swapped to disk and the required page to be swapped in. A page that it needs will have to be swapped out to disk and inevitably that page will soon be referenced again. Thus too few page frames can generate loads of I/O – called thrashing.

Q14

(a) NB This question seeks an understanding of what a system call is, the general socket system calls and the sequence in which things are done in a connection setup, not a parameter perfect answer.

(i) The Web server must first set up a socket and bind it to a port – to enable clients to have an endpoint to request connection to.

```
s = socket(AF_INET, SOCK_STREAM,0);
bind(s,ServerAddress);
```

It must then tell the OS it is reading to accept connections and block to await them. When a connection eventually is made on the appropriate port, the accept system call returns a new socket descriptor – over which the server can read and write.

```
listen(s,QueueLength);
NewSocket = accept(s);
n = read(NewSocket, buffer, amount);
```

(ii) The Web client must create a socket and then connect to the address and port of the server process. The IP routing is beyond the scope of this question. It can then read and write over this socket.

```
s = socket(AF_INET, SOCK_STREAM, 0);
connect(s, ServerAddress);
write(s, WebRequest, length);
```

(b) The disk block cache is a buffer pool in memory, each entry of which is the size of a disk block. The most recently read in disk blocks are stored here. Because accessing memory is faster than disk it is possible to get better performance if these blocks are needed again whilst they are in the cache because there is no need to go to disk.

The cache can improve the performance of the Web server if a Web page is requested that has been requested recently. Under these circumstances the file is in memory so no disk operation is needed before the data can be sent out on the network.

(c) Yes we can handle more traffic with 5 servers on a uniprocessor. Even though we only have one processor, one process can be accessing the disk, whilst another is reading off the network etc.

An understanding of the following is sought

- blocking system calls. When a system call such as waiting for a socket connection, doing a disk access etc. is invoked, the process is blocked. This means it goes to sleep until its operation is completed.
- preemptive scheduling – when a process blocks or exceeds it timeslice, another process can run.

On a multi-processor we can also handle more traffic. The only difference is that we don't have to do so much sharing of the processor so if 2 processes finish doing I/O at similar times then both can run rather than just 1 – so its even quicker.

(d) UNIX provides advisory locking. Instead of enforcing concurrency control you take out a lock using a system call and other cooperating processes also use this method. The OS ensured only one process is allowed past the lock at once. 2 marks for this.

```
fd = open("file",O_RDWR);
flock(fd,LOCK_EX);
... ...
flock(fd,LOCK_UN);
close(fd);
```

You wouldn't need to provide concurrency control over the Web page because they are read only. 2 marks here. No marks if they say you do have to lock.

Q 15

(a) Networked systems are built on a client-server model.
Control is distributed amongst various processes in the system.
Processes are generally classified as clients or servers.
At the highest level messages are sent between clients and servers.
Usually servers are allocated to individual computers.
Normally clients compete for resources at the servers.
Multiple servers can be used for reliability and performance.

(b)(i) In a PC connected to the internet services are one side of the network and the data, applications, rendering, and pixel display are on the other (local) side. This works well with relatively slow networks. It is the thickest type of client :-)

(ii) In an X based system services, data, and applications are on one side of one or many networks while rendering and pixel display are on the other side. (Confusingly the terminal is called an X-server because at the lower level it operates it is serving the client application). For example fonts are stored in the X-terminal and characters are displayed by identifying the font, the character, and scaling as appropriate. The X-terminal also has some graphics primitives. The display cannot be affected directly; a request for a change has to be sent to the X-terminal. More bandwidth is required for this approach.

(iii) VNC is an example of a very thin (stateless) client where only the displaying of pixels is done on the client side. Services, data, applications, <u>and rendering</u>, are all done across one or many networks. The basic primitive is a rectangle which has a size, a colour, and position in a frame buffer. This is what VNC handles and displays one after another. This approach requires more bandwidth than the previous two.

(c) Inherent properties of stateless clients are:

Persistence – pick up where you left off even after a crash.
Mobility – reconnect from a different place; follow-me computing.
Portability – simple client, easy to write.
Any-to-any – can work across all platforms and can be used with wearable devices.