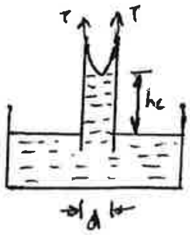
3D8 Building Physics & Env. Geotechnics - 2012

Q1) a)



Let capillary rise = h_c

Weight of water in tube = $\frac{\pi}{4} d^2 h_c \gamma_w$ → ①

Force due to surface tension $F = \pi d T$ → ②

Equating ① & ② ⇒ $\pi d T = \frac{\pi}{4} d^2 h_c \gamma_w$

$$h_c = \frac{4T}{\gamma_w d}$$

[15%]

1) b) Typical pore size in the soil is given by D_{10} size.

$$\therefore h_c = \frac{4T}{\gamma_w D_{10}} = \frac{4 \times 7.1\times10^{-5}}{10 \times 10\times10^{-6}} = 2.84 \text{ m}$$

∴ Capillary rise in this soil = 2.84 m [15%]

c) ii) Leakage through earth dam:

$q = K \Delta h \frac{N_f}{N_h}$; From flownet $N_f = 4$, $N_h = 16$

$$\therefore q = 6.25\times10^{-5} \times 6 \times \frac{4}{16}$$

$= 9.375 \times 10^{-5}$ m³/sec /m width of the earth dam. [20%]

iii) Point A: $y_A = 0.7$m $\bar{h}_A = 5.5$m $h_A = 5.5 - 0.7 = 4.8$m
⇒ $P_A = 48$ kPa

Point B: $y_B = 3.0$ m $\bar{h}_B = 3.30$m $h_B = 0.3$ m
⇒ $P_B = 3$ kPa

Point C: $y_C = 5.06$ m $\bar{h}_C = 3.4$ m $h_C = 3.4 - 5.06 = -1.66$ m
$P_C = -16.6$ kPa Suction

Point D: Point D is above capillary rise line - Dam has low air entry
∴ $P_d = 0$ kPa (atmospheric pressure) above capillary rise [20%]

2a) Fourier's law states that the rate of heat ~~flow~~ transfer through a material is proportional to the negative gradient of the temperature

Heat flux $H \propto -\frac{\partial T}{\partial r}$

$H = W/m^2$

λ = Thermal conductivity $W/m/K$.

$\frac{\partial T}{\partial r} = K/m$

When considering flow through soil, the thermal conductivity of the whole soil matrix is considered although soil is made of solid particles & fluid in the pore space (for saturated soils).

[15%]

2b) Thermal conductivity of soil $\lambda = 3.1 \ W/m^2/K$.

The GSHP causes the temperature to drop as it extracts heat energy.

At $r_1 = 1.0$ m $T_1 = 3°C = 276°K$

$r_2 = 1.5$ m $T_2 = 4°C = 277°K$

$\therefore \frac{\partial T}{\partial r} = \frac{277-276}{1.5-1.0} = \frac{1}{0.5} = 2 \ K/m$

$\therefore$ Heat flux $H = 2 \times 3.1 = 6.2 \ W/m^2$

The surface area of bore hole $= 80 \times \pi \times 0.1$

$= 25.13 \ m^2$

$\therefore$ Heat energy extracted in 1 hour $= 6.2 \times 25.13 \times 3600$

from a single bore hole $=$ <u>560.9 kJ</u>

[20%]

Question 3

(a) U - Value of Regular double-glazed window:

$$\epsilon_{12} = \left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)^{-1} = \left(\frac{1}{0.9} + \frac{1}{0.9} - 1\right)^{-1} = 0.818$$

$$T_{mean} = \frac{(273 + T_i) + (273 + T_e)}{2} = \frac{(273+20)+(273+0)}{2} = 283$$

$$\alpha_{rad} = 4 . \epsilon_{12} . \sigma . (T_{mean})^3$$

$$\Rightarrow 4.(0.818) . 5.67 \times 10^{-8} . (283)^3 \Rightarrow 4.2 \ W/m^2K$$

transmittance

$$\alpha_{cond} = \frac{\lambda_{air}}{d_{air}} = \frac{0.026}{0.03} = 0.866 \ W/m^2K$$

$$\text{U-Value of gap} = \alpha_{rad} + \alpha_{cond} = 5.071 \ W/m^2K$$

R - Value of the Window A

$$= \frac{1}{\alpha_e} + \frac{1}{\alpha_i} + \frac{1}{\alpha_{r+cond}}$$

$$= \frac{1}{25} + \frac{1}{8} + \frac{1}{5.071} = 0.362 \ m^2K/W$$

Total U-Value of Window: $\frac{1}{R_{winA}} = 2.76 \ W/m^2K$ [30%]

(b) Heat Loss Q

$$= U_{winA} \cdot Area \cdot (T_i - T_e)$$

$$= (2.76) \cdot 8 \cdot 20 = 441.98 \ W$$ [20%]

(c) Heat Loss Q with Solar Radiation

$$Q = U_{winA} \cdot Area \cdot (T_i - T_e) - I_{sun} \tau \ Area$$

$$= (441.98) - (300 . 0.76 . 8)$$

$$\Rightarrow (441.98 - 1824) \Rightarrow (-1382.02 \ W)$$ [20%]

(negative value means net heat gain w/ solar radiation)

$R_{win\,B} = 0.862\ m^2K/W$

$U = 1.16\ W/m^2K$

$Q_{win\,B} = 1.16 \times \text{Area} \times \Delta T = 1.16 \times 8 \times 20$

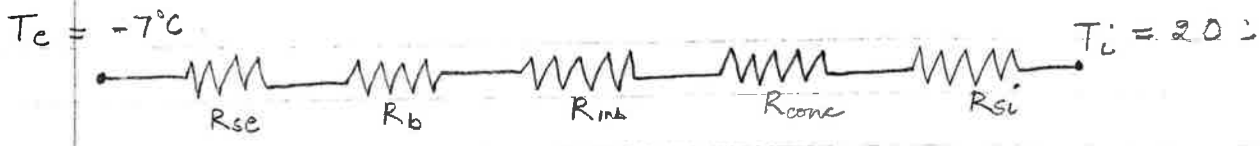
$= 185.6\ W$

It is not possible to lower the heat loss by increasing the width of the glass because the radiative heat transfer coefficient will remain unchanged.

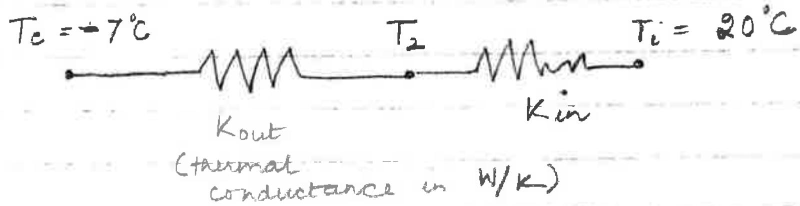
1/8 .12 18/50 18/25

Question 4

4(a) Calculate T_2 (temperature between brick & mineral wool)



Reduced network



$$K_{out} = \frac{Area}{R_{se} + \frac{d_b}{\lambda_b}} = \frac{1}{0.04 + \frac{0.10}{0.50}} = \underline{4.167 \text{ W/K}}$$

$$K_{in} = \frac{Area}{\frac{d_{ins}}{\lambda_{ins}} + \frac{d_{conc}}{\lambda_{conc}} + R_{si}} = \frac{1}{\frac{0.12}{0.04} + \frac{0.10}{0.10} + 0.13} = \underline{0.242 \text{ W/K}}$$

$$T_2 = \frac{K_{out} \cdot T_e + K_{in} \cdot T_i}{K_{out} + K_{in}}$$

[25%]

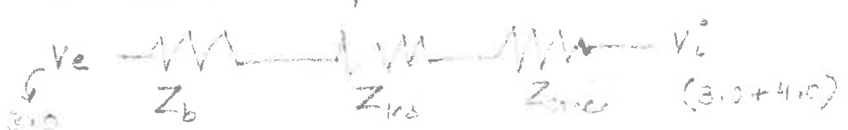
$$= \frac{4.167 \cdot (-7) + 0.242 \cdot (20)}{(4.167) + (0.242)} = \underline{\underline{-5.5 \text{ deg C}}}$$

(b) Risk of condensation

saturation vapor content corresponding to −5.5°C (from data table)

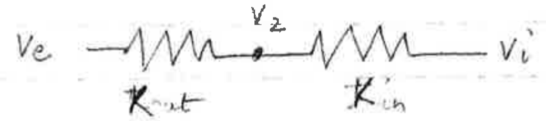
$V_s(-5.5) = 3.12$

The actual vapour content at this interface is:



(7)

Reduced Network



$$K_{out} \;(m^3/s) = \frac{\text{Area}}{\frac{d_b}{\delta_b}} = \frac{1}{0.1/5\times10^{-6}} = 5.0 \times 10^{-5}$$

$$K_{in} = \frac{\text{Area}}{\frac{d_{ins}}{\delta_{ins}} + \frac{d_{conc}}{\delta_{conc}}} = \frac{1}{\frac{0.12}{20\times10^{-6}} + \frac{0.10}{10\times10^{-6}}} = 6.25 \times 10^{-5}$$

$$V_2 = \frac{K_{out}\, V_{out} + K_{in}\,(V_{out} + \Delta V)}{K_{out} + K_{in}}$$

$$= \frac{(5\times10^{-5}).3 + (6.25\times10^{-5}).(3+4)}{5\times10^{-5} + 6.25\times10^{-5}} = \underline{\underline{5.22}}$$

$V_2 > V_s$

$(5.22 > 3.12)$, hence condensation ! [25%]

(c) Quantity of condensate over 60 days in winter

$$G_{cond} = \left\{K_{in}\left[(V_e + \Delta V) - V_s(-5.5)\right] - K_{out}\left[V_s(-5.5) - V_e\right]\right\} \frac{t}{\text{Area}}$$

$$\left\{6.25\times10^{-5}\left[(3+4) - 3.12\right] - 5.0\times10^{-5}\left[3.12 - 3\right]\right\}$$

$$= \underline{1.23 \times 10^3 \; g/m^2}$$ [25%]

(d) Drying over 60 days in summer

$$T_2\,(\text{summer}) = \frac{4.167.(15) + 0.242(20)}{4.167 + 0.242} = 15.27$$

$\therefore V_s(15.27) = 13.07 \; g/m^3$ [25%]

$V_e + \Delta V = 9 + 4 = 13 \; g/m^3 \quad V_e = 9 \; g/m^3$

$$G_{drying} = \left\{K_{out}.\left[V_s(T_2) - V_e\right] - K_{in}.\left[(V_e + \Delta V) - V_s(T_2)\right]\right\} t/A$$

$$= \left(5\times10^{-5}\left[13.07 - 9\right] - 6.25\times10^{-5}\left[13 - 13.07\right]\right) t/A = 1.08\times10^3 \; g/m^2$$

NUMERICAL ANSWERS
ENGINEERING TRIPOS PART IIA 2009
MODULE 3D8: ENVIRONMENTAL GEOTECHNICS & BUILDING PHYSICS

Q1 Flood Protection Dam

(a) See Crib

(b) 2.84 m

(c) i. See Crib   ii. 9.37×10^{-5} m³/s/m   iii. $P_A = 48$ kPa; $P_B = 3$ kPa; $P_C = -16.6$ kPa; $P_D = 0$ kPa

Q2 Heat and Mass Transfer through Porous Media

(a) See Crib

(b) 560.9 kJ

(c) i. 4.78 years   ii. 28.9% ; 3.39% ; 0.16% ; 0%

Q3 Heat Transfer through Transparent Surfaces

(a) 2.76 W/m²K

(b) 441.98 W

(c) −1382 W

(d) 185.6 W

Q4 Condensation in Walls

(a) 5.5°C

(b) 5.22 > 3.12

(c) 1.23×10^3 g × (t/area)

(d) 1.08×10^3 g × (t/area)

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