CV3014 TRANSPORTATION ENGINEERING AY22/23 SOLUTION

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Q1.

(a) $y = y_0 + g_1 x + \frac{1}{2} r x^2$

$y_0 = 60 + 3\% \times 150 = 64.5m$

$y = 64.5 - 0.03x + \frac{1}{2}(0.06)x^2$

$at\ x = 150m, y = 64.5 - 0.03(150) + \frac{1}{2}\left(\frac{0.06}{300}\right)(150)^2 = 62.25m$

Due to the normal crowned slope of 2%, additional clearance is to be considered.

$gradient = \tan\theta = \frac{2}{100} \rightarrow \theta = \tan^{-1}\frac{2}{100}$

$additional\ clearance = 3.6 \sin\left(\tan^{-1}\frac{2}{100}\right) = 0.07199m$

$total\ clearance = 62.25 - 0.5 - 0.07199 = 61.67801m \approx 61.68m$

(b) Using the given piecewise function, form a new piecewise function for $q = vk$.

$$q = \begin{cases} 69.08k \\ 30k \cdot \ln\left(\frac{200}{k}\right) \\ 2414.16 - 12.07k \end{cases}$$

Subsequently, when speed at capacity occurs, $\frac{dq}{dk} = 0$.

$$\frac{dq}{dk} = \begin{cases} 69.08 = 0\ (rejected) \\ 30 \cdot \ln\left(\frac{200}{k}\right) - 30 = 0 \rightarrow k_0 = \frac{200}{e} veh/km\ (rejected\ as\ 20 \le x \le 40) \\ -12.07 = 0\ (rejected) \end{cases}$$

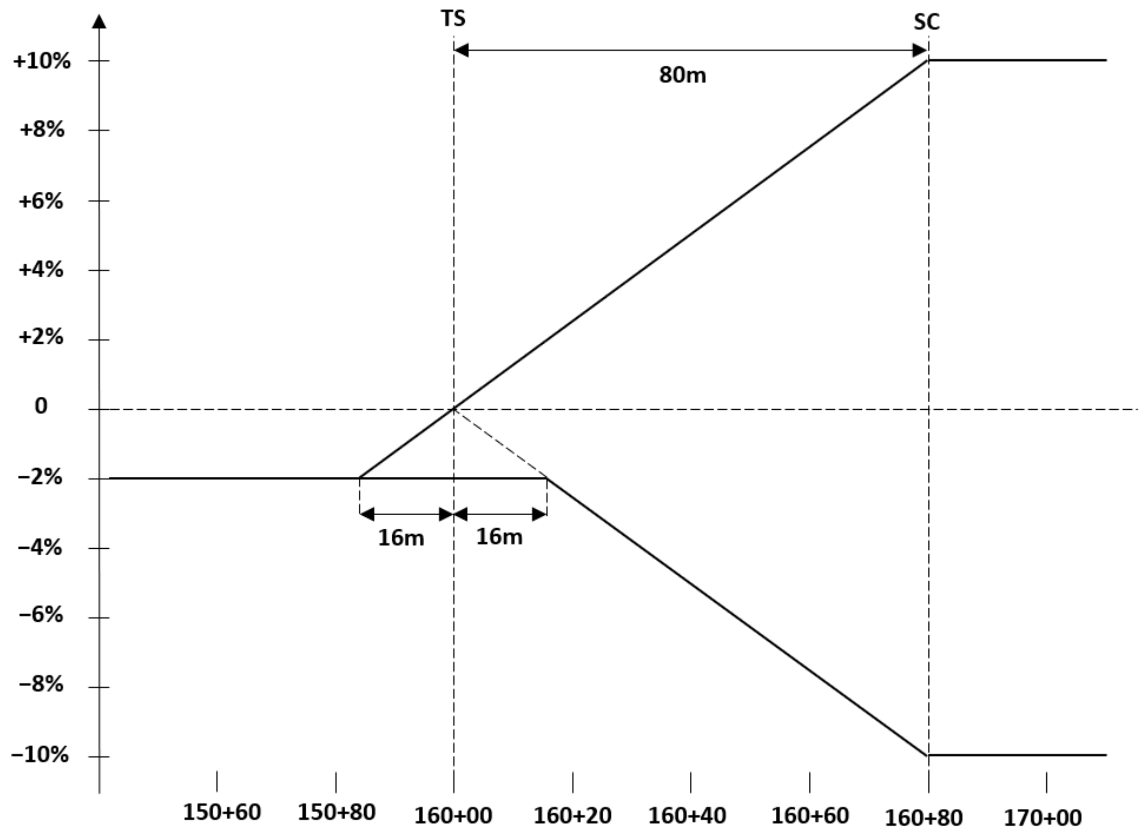
The first and third functions are rejected as a value for density cannot be obtained. The value of density for the second function falls past the boundary, thus we take the maximum value.

As such, the density at capacity is 40*veh/km* instead.

$v_0 = 30 \ln\left(\frac{200}{40}\right) = 48.283km/hr\ (speed\ at\ capacity)$

$q_{max} = v_0 k_0 = 1931.325 = 1931.33veh/hr$

(c)



Q2.

(a) $x_4 = 1 - ①$

$x_2 + x_3 = x_4 \rightarrow x_2 + x_3 = 1 - ②$

$t_2 + t_4 = t_3 + t_4 \rightarrow t_2 = t_3 \rightarrow 12 + 2x_2 = 10 + x_3$

$t_1 = t_2 + t_4 \rightarrow 28 + 2x_1 = 12 + 2x_2 + 8 + x_4$

$2x_1 - 2x_2 = -7 - ③$

$t_1 = t_3 + t_4 \rightarrow 28 + 2x_1 = 10 + x_3 + 8 + x_4$

$2x_1 - x_3 = -9 - ④$

Solving ①, ②, ③ and ④ gives:

$$x_1 = -\frac{23}{6}\ (rejected), x_2 = -\frac{1}{3}\ (rejected), x_3 = \frac{4}{3}, x_4 = 1$$

Let $x_1 = x_2 = 0$, from ① and ②, we can deduce that $x_3 = 1, x_4 = 1$.

(b) $x_1 + x_4 = 5 - ①$

$x_2 + x_3 = x_4 - ②$

$t_1 = t_2 + t_4 \rightarrow 28 + 2x_1 = 12 + 2x_2 + 8 + x_4$

$2x_1 - 2x_2 - x_4 = -8 - ③$

$t_1 = t_3 + t_4 \rightarrow 28 + 2x_1 = 10 + x_3 + 8 + x_4$

$2x_1 - x_3 - x_4 = -10 -$ ④

Solving ①, ②, ③ and ④ gives:

$x_1 = -\frac{3}{11}, x_2 = \frac{12}{11}, x_3 = \frac{46}{11}, x_4 = \frac{58}{11}$

Let $x_1 = 0$, forming new equations gives:

$x_4 = 5 -$ ①

$x_2 + x_3 = x_4 -$ ②

$t_2 + t_4 = t_3 + t_4 \rightarrow t_2 = t_3 \rightarrow 12 + 2x_2 = 10 + x_3$

$2x_2 - x_3 = -2 -$ ③

Solving ①, ②, and ③ gives:

$x_2 = 1, x_3 = 4, x_5 = 5$

(c) $x_1 + x_4 = D -$ ①

$x_2 + x_3 = x_4 -$ ②

$t_2 + t_4 = t_3 + t_4 \rightarrow t_2 = t_3 \rightarrow 12 + 2x_2 = 10 + x_3$

$x_3 = 2x_2 + 2 -$ ③

$t_1 = t_2 + t_4 \rightarrow 28 + 2x_1 = 12 + 2x_2 + 8 + x_4$

$x_1 = x_2 + 0.5x_4 - 4 -$ ④

Sub ③ into ②: $x_4 = x_2 + (2x_2 + 2) \rightarrow x_4 = 3x_2 + 2 -$ ⑤

Sub ⑤ into ④: $x_1 = x_2 + 0.5(3x_2 + 2) - 4 \rightarrow x_1 = 2.5x_2 - 3 -$ ⑥

Sub ⑤ and ⑥ into ①: $D = (2.5x_2 - 3) + (3x_2 + 2) \rightarrow D = 5.5x_2 - 1$

$x_2 = \frac{D+1}{5.5} - (a)$

Sub (a) into : $x_3 = \frac{2(D+1)}{5.5} + 2 - (b)$

Sub (a) and (b) into ②: $\frac{D+1}{5.5} + \frac{2(D+1)}{5.5} + 2 = x_4 \rightarrow x_4 = \frac{3(D+1)}{5.5} + 2 - (c)$

Sub (a) and (c) into ④: $x_1 = \frac{D+1}{5.5} + \frac{1.5(D+1)}{5.5} + 1 - 4 \rightarrow x_1 = \frac{2.5(D+1)}{5.5} - 3$

Sub (a), (b), (c), and (d) into time equations gives:

$t_1 = 28 + 2\left(\frac{2.5(D+1)}{5.5} - 3\right) = 22 + \frac{5(D+1)}{5.5}$,

$t_2 = 12 + \frac{2(D+1)}{5.5}$, $t_3 = 10 + \left(\frac{2(D+1)}{5.5} + 2\right) = 12 + \frac{2(D+1)}{5.5}$,

$t_4 = 8 + \left(\frac{3(D+1)}{5.5} + 2\right) = 10 + \frac{3(D+1)}{5.5}$

$\therefore\ time\ to\ travel\ from\ A\ to\ C = 22 + \frac{5(D+1)}{5.5}$

(d) $x_4 = x_2 + x_3 - 10 - ①$

$D_{AC} = x_1 + x_4 - D_{BC} = x_1 + x_4 - (20 - 0.5t_4)$

$D_{AC} = x_1 + x_4 - 20 + 0.5(8 + x_4) \rightarrow 10 = x_1 + 1.5x_4 - 16$

$x_1 + 1.5x_4 = 26 - ②$

$t_2 + t_4 = t_3 + t_4 \rightarrow t_2 = t_3 \rightarrow 12 + 2x_2 = 10 + x_3$

$2x_2 - x_3 = -2 - ③$

$t_1 = t_2 + t_4 \rightarrow 28 + 2x_1 = 12 + 2x_2 + 8 + x_4$

$2x_1 - 2x_2 - x_4 = -8 - ④$

$t_1 = t_3 + t_4 \rightarrow 28 + 2x_1 = 10 + x_3 + 8 + x_4$

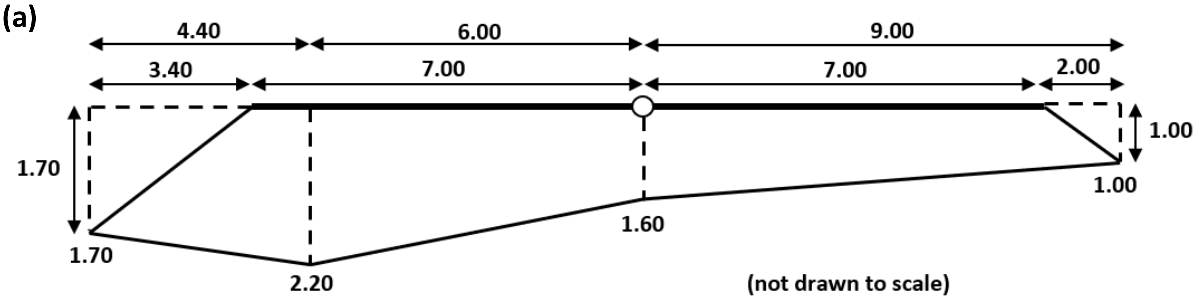
$2x_1 - x_3 - x_4 = -10 - ⑤$

Solving ①, ②, ③, ④, and ⑤ gives:

$x_1 = \frac{59}{7}, x_2 = \frac{46}{7}, x_3 = \frac{106}{7}, x_4 = \frac{82}{7}$

Q3.

(a)



$fill\ cross\ sectional\ area = \frac{1}{2}(1.70 + 2.20)(4.40) + \frac{1}{2}(2.20 + 1.60)(6.00) + \frac{1}{2}(1.60 + 1.00)(9.00) - \frac{1}{2}(1.70)(3.40) - \frac{1}{2}(1.00)(2.00) = 27.79m^3$

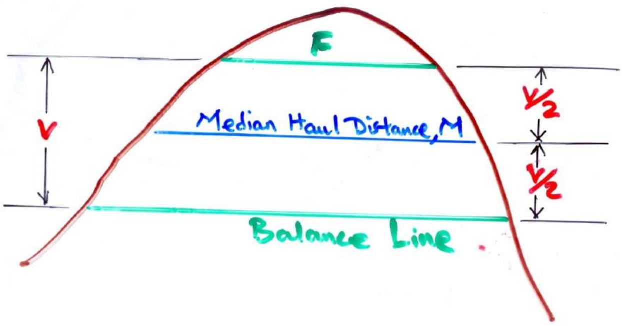
Side-slope at cross section is 1:2 (H:V).

(b) The limit of the economic haul (LEH) is the longest distance material should ever be hauled. As such, we can conclude that the cost of borrowing, C_B (to bring material into from off-site) is as such, $C_B = C_{OH}(LEH - F)$. Where cost of overhaul, C_{OH}, is the cost to haul material beyond the free haul distance, *F*. Cost of borrowing is simply the product of cost of overhaul and the arithmetic difference between limit of economic haul and free haul distance.

By modifying the equation, we can get $LEH = \frac{C_B}{C_{OH}} + F$.

(c) Overhaul is the cost to haul material out of beyond the free haul distance, and it is measured in terms of \$/stn-m^3.

One method to calculate overhaul using the mass diagram is to utilize the median haul distance, such that $OH = V(M - F)$, where OH represents overhaul, V represents the volume of material, M represents the median haul distance, and F represents the free haul line. It can be illustrated as:



The balance line (LEH), if not given, can be obtained using $LEH = \frac{C_B}{C_{OH}} + F$, where C_B, C_{OH} and *F* is the cost of borrowing, cost of overhaul and free haul distance respectively. By reading off the mass diagram, volume of material, V can be measured. M can subsequently be obtained by taking the average of F and LEH. Using the formula mentioned above, we would obtain the overhaul of an earthwork operation.

Q4.

(a) $SN_1 = a_1D_1 = (0.40)(180)/25.4 = 2.8346$

$SN_2 = a_1D_1 + a_2D_2m_2 = [(0.40)(180) + (0.13)(1.20)(220)]/25.4 = 4.1858$

$SN_3 = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 = [(0.40)(180) + (0.13)(1.20)(220) + (0.10)(1.00)(170)]/25.4 = 4.8551$

New two-layer design:

$SN_1 = 2.8346 \times 25.4 = a_1D_1 = (0.40)(180) \rightarrow D_1 = D_1^* = 180mm$ (asphalt concrete)

$SN_2 = 4.8551 \times 25.4 = a_1D_1 + a_2D_2m_2 = [(0.40)(180) + (0.13)(1.20)(D_2)]$

$D_2 = 328.97mm, D_2^* \approx 330mm$ (crushed stone)

<u>Merits of Option 1 (three-layer design) over Option 2</u>

1. One advantage of Option 1 is better load distribution. With more layers, the area the load is distributed over is much higher than that of Option 2. This would mean that the load intensity or stress applied onto the subgrade layer is lower in Option 1. Consequently, this would lead to a reduced probability of subgrade failure, where undulations and corrugation in the bituminous layers would not occur.

2. Better drainage

<u>Merits of Option 2 (two-layer design) over Option 1</u>

1. Option 2 is relatively cheaper than Option 1. Option 1 is 570mm thick while Option 2 is 510mm thick. By comparison, Option 2 requires lesser material and cost of materials would be lesser.

2. Option 2 would also be faster to construct. With a smaller thickness, as well as lesser layers, there is lesser construction procedures. There would be one less layer to lay and one less layer to compact. This would result in significantly lower construction duration and may be more time efficient.

(b) Advantages of flexible pavement over rigid pavement:

1. Generally, the cost of constructing a flexible pavement is much lower. Moreover, repair and maintenance are much more seamless, as the wearing/surface is very easily replaceable. Overall, flexible pavements are more economical due to costs being kept low for construction and maintenance.

2. Overall better ride quality. Due to lack of joints, smoother rides, and lesser sound emission. Moreover, bituminous layer provides excellent surface drainage, ensuring safety on the road.

3. Easy and fast to construct. Relatively short curing time reduces traffic disruption. This is especially useful when road reconfigurations are needed.

(List is non-exhaustive and other answers which are logical should PROBABLY be accepted)

Q5.

(a) $f_g = \frac{(1+0.02)^{20}-1}{0.02} = 24.297$

$design\ lane\ ESAL/day = (1900/2)(0.80)(0.20)(1.750) = 266$

$design\ lane\ ESAL/year = 97970$

$design\ lane\ ESAL\ in\ 20\ years = 97970 \times 24.297 = 2{,}358{,}995 = 2.36million\ (shown)$

(b)

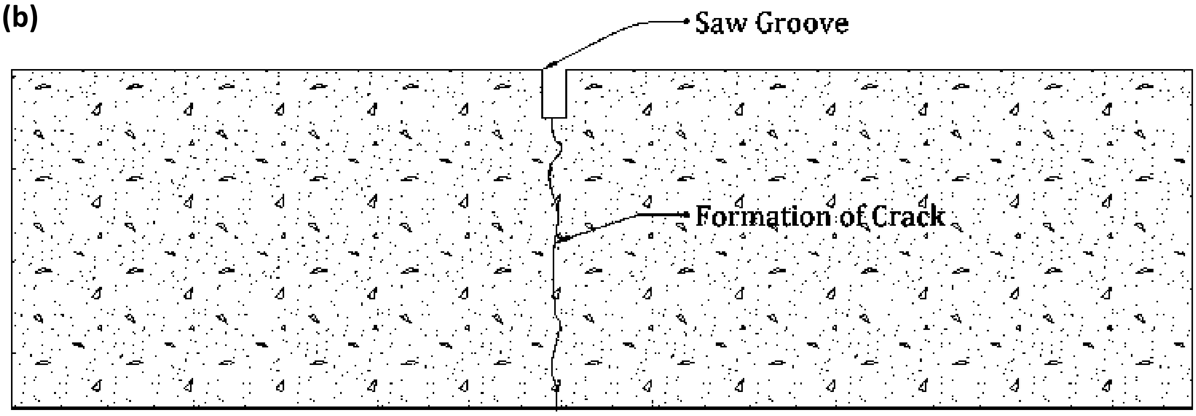


Figure 1. Sketch of naturally-induced contraction joint (source: https://civilplanets.com/difference-between-expansion-joints-contraction-joint-and-construction-joints/)

Method of construction

1. Within the pre-cast PCC, use a road surface saw to cut a small groove along the longitudinal direction.

2. Cap with a bituminous/rubberised sealant.

3. With time, a naturally induced shrinkage crack propagates throughout the PCC slab which acts as a contraction joint.

(c) Longitudinal reinforcing steel:

$$A_s = \frac{FLW}{2f_s} = \frac{F_r}{f_s} = \frac{(0.200)(1.0)(\frac{10}{2})(2400)(9.8)(1.4)}{300\times10^6} \times 10^6 = 109.76mm^2 \approx 110mm^2$$

Transverse reinforcing steel:

$$A_s = \frac{FLW}{2f_s} = \frac{F_r}{f_s} = \frac{(0.200)(1.0)(\frac{5}{2})(2400)(9.8)(1.4)}{300\times10^6} \times 10^6 = 54.88mm^2 \approx 55mm^2$$

NOTE:

Do reach out to me at KEAL0001@e.ntu.edu.sg if you have any queries regarding any of my submitted workings. Feel free to leave an email to ask any questions covered in the curriculum, will be glad to help!