CV3014 TRANSPORTATION ENGINEERING AY20/21 SOLUTION

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Q1.

(a) The maximum length of the vertical curve is to be set to clear the overhead object. This is because if the length of the curve is designed to be larger than the maximum length, the vertical distance between the object will be shorter than the clearance.

(b) At overhead object, located at station 99+20, $z = 0.8sta$

$elevation\ of\ tangent = 69.50 - (0.5/100)(80) = 69.1m$

$elevation\ of\ roadway = 77.45 - 5.67 = 71.78m$

Using the formula provided,

$y' = 71.78 - 69.1 = 2.68,$

$A = |0.5 - 2.0| = 2.5$

$w = \frac{y'}{A} = 1.072$

$L = 4w - 2z + 4\sqrt{w^2 - wz}$

$L = 4(1.072) - 2(0.8) + 4\sqrt{(1.072)^2 - (1.072)(0.80)} = 4.8479sta = 485m$

Q2.

(a) $x_1 + x_4 = 10 - ①$

$x_4 = x_2 + x_3 \rightarrow x_2 + x_3 - x_4 = 0 - ②$

$t_1 = t_2 + t_4 \rightarrow 18 + 2x_1 = 12 + 2x_2 + 8 + x_4$

$2x_1 - 2x_2 - x_4 = 2 - ③$

$t_1 = t_3 + t_4 \rightarrow 18 + 2x_1 = 10 + x_3 + 8 + x_4$

$2x_1 - x_3 - x_4 = 0 - ④$

Solving ①, ②, ③, and ④ gives:

$x_1 = \frac{52}{11}, x_2 = \frac{12}{11}, x_3 = \frac{46}{11}, x_4 = \frac{58}{11}$

(b) $x_4 = x_2 + x_3 + 10 \rightarrow x_2 + x_3 - x_4 = -10 - ①$

$x_1 + x_2 + x_3 = 10 - ②$

$t_1 = t_2 + t_4 \rightarrow 18 + 2x_1 = 12 + 2x_2 + 8 + x_4$

$2x_1 - 2x_2 - x_4 = 2 - ③$

$t_1 = t_3 + t_4 \rightarrow 18 + 2x_1 = 10 + x_3 + 8 + x_4$

$2x_1 - x_3 - x_4 = 0 - ④$

Solving ①, ②, ③, and ④ gives:

$x_1 = \frac{82}{11}, x_2 = \frac{2}{11}, x_3 = \frac{26}{11}, x_4 = \frac{138}{11}$

(c) $x_2 + x_3 = x_4 + 10 \rightarrow x_2 + x_3 - x_4 = 10 - ①$

$x_1 + x_4 = 10 - ②$

$t_1 = t_2 + t_4 \rightarrow 18 + 2x_1 = 12 + 2x_2 + 8 + x_4$

$2x_1 - 2x_2 - x_4 = 2 - ③$

$t_1 = t_3 + t_4 \rightarrow 18 + 2x_1 = 10 + x_3 + 8 + x_4$

$2x_1 - x_3 - x_4 = 0 - ④$

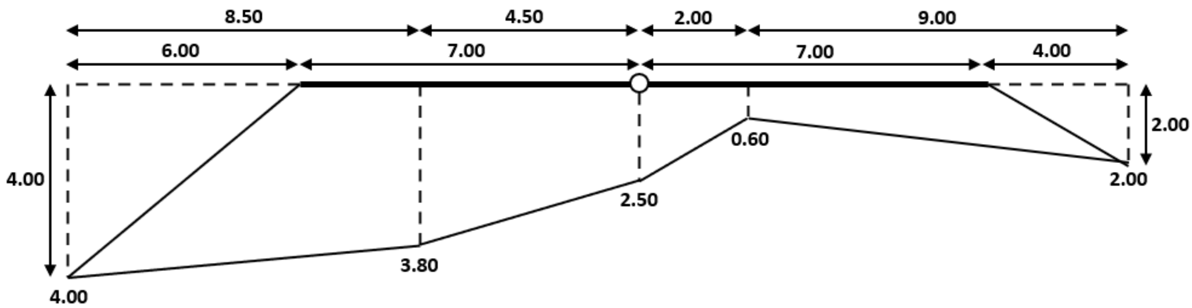
Solving ①, ②, ③, and ④ gives:

$x_1 = \frac{72}{11}, x_2 = \frac{42}{11}, x_3 = \frac{106}{11}, x_4 = \frac{38}{11}$

(**NOTE:** Numerical answer provided for x_1 is incorrect, 142/11 gives 13.1 which far exceeds travel demand from A to C and is incorrect.)

Q3.

(a)



$fill\ area = area\ of\ trapeziums - area\ of\ triangles$

$fill\ area = \frac{1}{2}(4.00 + 3.80)(8.50) + \frac{1}{2}(3.80 + 2.50)(4.50) + \frac{1}{2}(2.50 + 0.60)(2.00) + \frac{1}{2}(0.60 + 2.00)(9.00) - \frac{1}{2}(6.00)(4.00) - \frac{1}{2}(4.00)(2.00) = 46.125m^2\ fill$

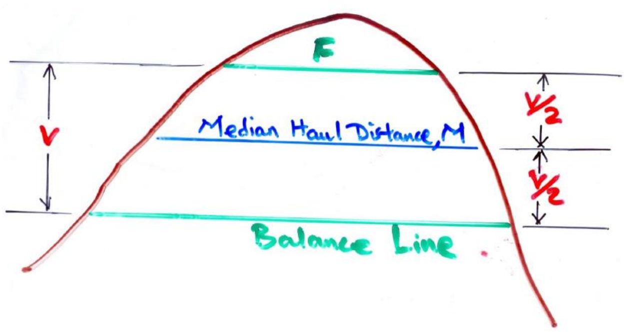
(b)

Station	Cross Sectional Areas (m^2)		Sectional Volumes (m^3)	
	Cut	Fill	Cut	Fill
126+00	11.20	---		
			$\frac{11.20+8.50}{2} \times 50 = 492.5$	---
126+50	8.50	---		
			$\frac{8.50+1.20}{2} \times 20 = 97$	---
126+70	1.20	0		
			$\frac{1.20+0.20}{2} \times 30 = 21$	$\frac{6.45}{3} \times 30 = 64.5$
127+00	0.20	6.45		
			$\frac{0.20}{3} \times 50 = 3.33$	$\frac{6.45+11.50}{2} \times 50 = 448.75$
127+50	0	11.50		
			---	$\frac{11.50+17.40}{2} \times 50 = 722.5$
128+00	---	17.40		
Total Volume (m^3)			613.83	1235.75

$$deficiency\ in\ earthwork\ volume = 1235.75 - 613.83(1-0.10) = 683.30m^3$$

(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) One ESAL represents a standardized load unit of 8160 kg (18000 lbs) or 80 kN, on a wheel configuration of one single axle with a pair of two-wheels on each side.

However, given that a pavement would be used by different types of vehicles with different wheel configurations, the axle loading of different vehicles can be converted to ESAL units.

One way to determine the ESAL unit of an axle is to refer to the Load Equivalency Factors Table provided by AASHTO. If not given, the axle loading can be determined by using the fourth power relationship where $converted\ ESAL = \left(\frac{axle\ loading}{80}\right)^4$.

(b) Using the given data,

$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$

$SN = (0.45)(80) + (0.26)(125)(1.20) + (0.20)(140)(1.20) = \frac{108.6}{25.4} = 4.2756$

Applying the SN to design a full-depth asphalt concrete pavement,

$SN = a_1D_1 \rightarrow 4.2756 \times 25.4 = 0.45D_1$

$D_1 = 241.33, D_1^* \approx 250mm$

Advantages:

1. Full-depth asphalt concrete pavement requires only one type of material as compared to the conventional flexible pavement which requires different layers of materials for the wearing and binding course, base, and sub-base layers. Given that a full-depth asphalt concrete pavement (as its name suggests) only requires one material, which is asphalt concrete, a full-depth asphalt concrete pavement may be beneficial when there are logistical issues in obtaining the other materials needed for a conventional flexible pavement. Moreover, asphalt concrete is a relatively cheap and easily obtainable material given that it is recyclable. This would mean that a full-depth asphalt concrete pavement would be inexpensive to construct.

2. Due to its smaller depth of 250mm as compared to the 3-layer design of 345mm, it is possible that the construction time of a full-depth asphalt concrete pavement would be much lower than that of a 3-layer flexible pavement. This is because much lesser compaction work would be required for the full-depth asphalt concrete pavement due to the lack of base and sub-base layer made up of aggregate. Moreso, the setting and curing time of asphalt concrete is known to be very minimal and reduces any form of delay for commuters. A full-depth asphalt concrete pavement would possibly be viable as a form of emergency roadway opening or even be used as a method to replace sections of current roadways. (based on my interpretation)

Disadvantages:

1. Flexible pavement is usually compacted in layers to ensure interlocking between the particles to ensure stiffness of the different layers. As such, when a whole full-depth layer of asphalt concrete is cast, it is impossible to compact the entire layer. This is because no amount of achievable force would be able to overcome the frictional forces of the asphalt and aggregate particles nearing the bottom sections of the asphalt concrete layer. This would subsequently lead to high porosity of the asphalt concrete in many areas. High porosity would then allow water and contaminants to infiltrate into the deeper portions of the asphalt concrete layer. Due to asphalt cement's susceptibility to moisture, the infiltration of water would lead to moisture damage in the form of stripping and softening, where stripping is the loss of adhesion between asphalt cement and aggregate, and softening is the loss in cohesion that results in a loss of strength, stiffness, and other engineering properties. All in all, resulting in a non-durable pavement, which requires regular and/or heavy maintenance, leading to heavy expenditure.

2. Full-depth asphalt concrete pavement may be more susceptible to temperature due to its increased thickness as compared to usual thickness of asphalt concrete in a conventional flexible pavement. In hot temperatures, the asphalt concrete layer would absorb and store heat and due to its thickness, it would have trouble dissipating heat. This would cause the "softening" of asphalt and rutting resistance would decrease, leading to higher possibility of rutting to occur. On the contrary, in cold climates, water which infiltrated into the asphalt concrete would freeze and subsequently cause cracking due to expansion of water volume. These would result in bad pavement quality with low durability.

(**NOTE:** The list of solutions to this question is non-exhaustive and there will be other advantages/disadvantages not being in this list. I believe that as long as the elaboration is theoretically sound, you would not be marked down for the point that you mentioned.)

(c) Present Serviceability Index (PSI) is a pavement performance measure and is measured based on a rating scale, where a rating of 0 indicates poor condition while a rating of 5 indicates excellent condition. These ratings are closely correlated to the measured physical conditions of the pavements. In the AASHTO procedures for flexible and rigid pavement design, serviceability loss (ΔPSI) is utilized, and it is the difference between initial serviceability (p_i) and terminal serviceability (p_t). Initial serviceability is the condition of pavement immediately after construction and terminal serviceability is the lowest quality (after t years) tolerated before reconstruction/resurfacing warranted.

Some shortcomings include:

1. Panels of different demographics (say, of different countries) may indicate slightly different ratings for a similar pavement. This is because a different demographic may have varying acceptability levels of pavements in general.

2. Many parameters must be considered for an accurate rating of the pavement. Such parameters include surface irregularities and defects that can be measured in terms of longitudinal and transverse profiles, cracking, spalling, faulting, etc.

Q5.

(a) $growth\ factor\ f_g = \frac{(1+g)^n - 1}{g} = \frac{(1+0.03)^{15} - 1}{0.03} = 18.599$

ESAL/day of different truck types are as follows:

$2 - axle \rightarrow\ (850)(0.45) = 382.5$

$3 - axle \rightarrow\ (520)(0.80) = 416$

$4 - axle\ \rightarrow (270)(1.25) = 337.5$

$5 - axle\ or\ more \rightarrow\ (350)(2.00) = 700$

$Sum\ of\ ESAL/day\ = 1836$

$Sum\ of\ ESAL\ in\ one\ year = 660{,}960$

$Sum\ of\ ESAL\ in\ 15\ years = 660{,}960 \times 18.599 = 12{,}293{,}195$

$Design\ Lane\ ESAL\ in\ 15\ years = \frac{12{,}293{,}195}{2} \approx 6{,}146{,}598$

Important assumptions:

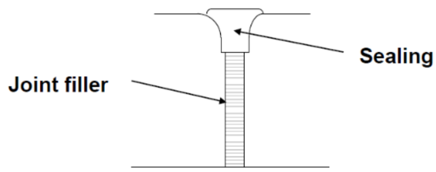
1. Directional split of 50-50
2. Lane distribution factor, D_L of 100% in design lane

(b) The four functional requirements are:

1. Water-proof at all times.
2. Riding quality should not be impaired.
3. Positioning of joints should not cause or encourage possible cracking or failure of pavement.
4. Should not interfere with placing of concrete i.e., as few joints as possible.

<u>Expansion Joints</u>

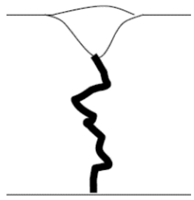
<u>Method of construction:</u>



1. With pre-cast PCC, arrange them next to each other.
2. Injection of compressible filler to close gaps between PCC slabs.
3. Cap with a bituminous/rubberised sealant.

<u>Purpose:</u> It allows the concrete to expand and contract as or when the temperature changes. With an allowance for movement without causing significant stress within PCC slabs. This would reduce risk of cracking. Essentially, expansion joints help to relieve compressive forces built up within the PCC slabs.

Contraction Joints



Method of construction

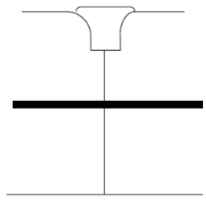
1. Within the pre-cast PCC, use a road surface saw to cut a small groove along the longitudinal direction.

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.

Purpose: It helps to control cracks happening due to shrinkage. This occurs when the joints help to relieve tensile stress from contraction and warping.

Longitudinal/Warping Joints



Method of construction

1. With pre-cast PCC, arrange them next to one another.

2. Cap with a bituminous/rubberised sealant.

Purpose: To accommodate the effect of differential settlement of pavement foundation. When uneven settlement occurs, the tie bars in longitudinal joints perform as hinges which allow for the settlement of concrete carriageway. it also serves to cater for the effect of warping of concrete due to moisture and temperature gradients by permission of a small amount of angular movement to occur so that stresses induced by restrained warping can be avoided.

(c) Temperature and moisture stresses are expected to cause cracking between joints, hence steel mesh is used to hold these cracks tightly together. The amount of steel mesh controls the spacing between joints and smaller bar mesh is preferred due to its higher effectiveness. Most importantly, its elongation properties is the main criterion, rather than strength. The exact location of such steel mesh is not important but good bonding and corrosion protection is necessary.

$$A_s = \frac{FLW}{2f_s} = \frac{F_r}{f_s} = \frac{(0.300)(1.0)(\frac{12}{2})(2400)(9.8)(1.3)}{300\times10^6} \times 10^6 = 183mm^2 \approx 190mm^2$$

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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!