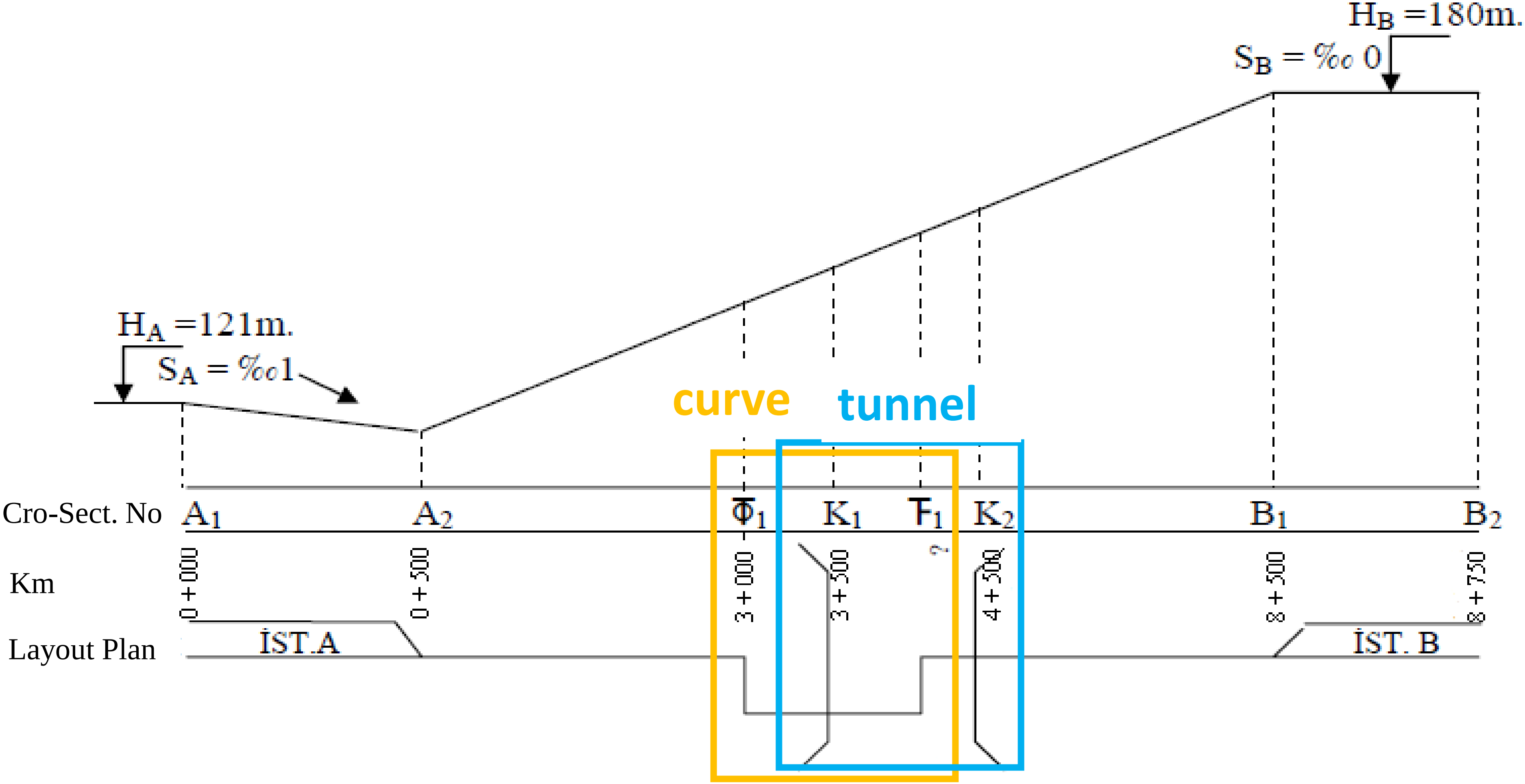
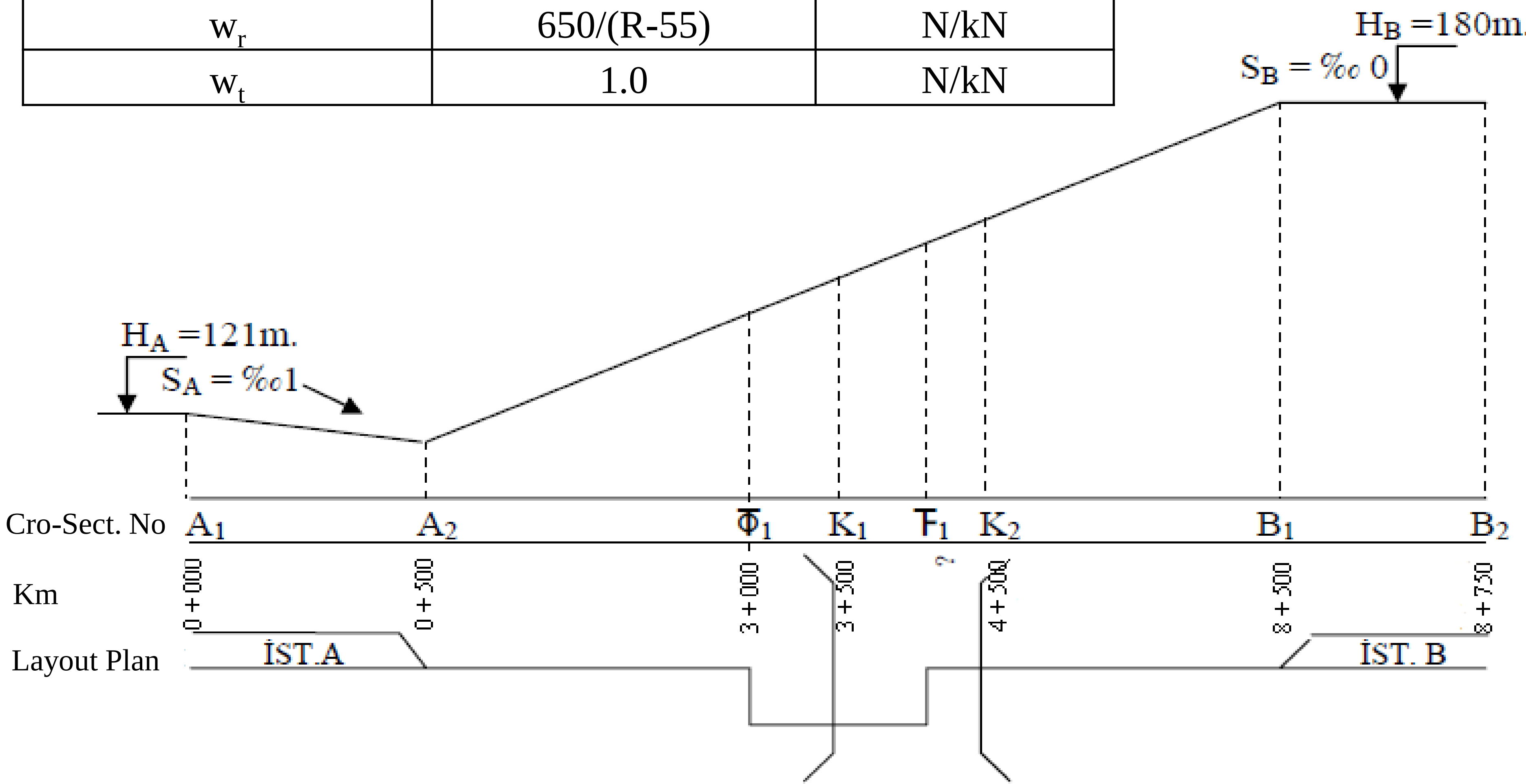
2023-2024 Spring Semester Railway Engineering
1st Problem Session-Group 5

Question-1: Stations A and B are placed at both edges of a railway section which is designed according to the principle of constant resistance. The profile of the railway section is provided above. On this section a tunnel and a curve coincides.



H_A	121	m
H_B	180	m
Δ	66	Degree
R	1000	m
Length of Tunnel (L_t)	1000	m
w_0	$1.7+(V^2/4000)$	N/kN
w_r	650/(R-55)	N/kN
w_t	1.0	N/kN



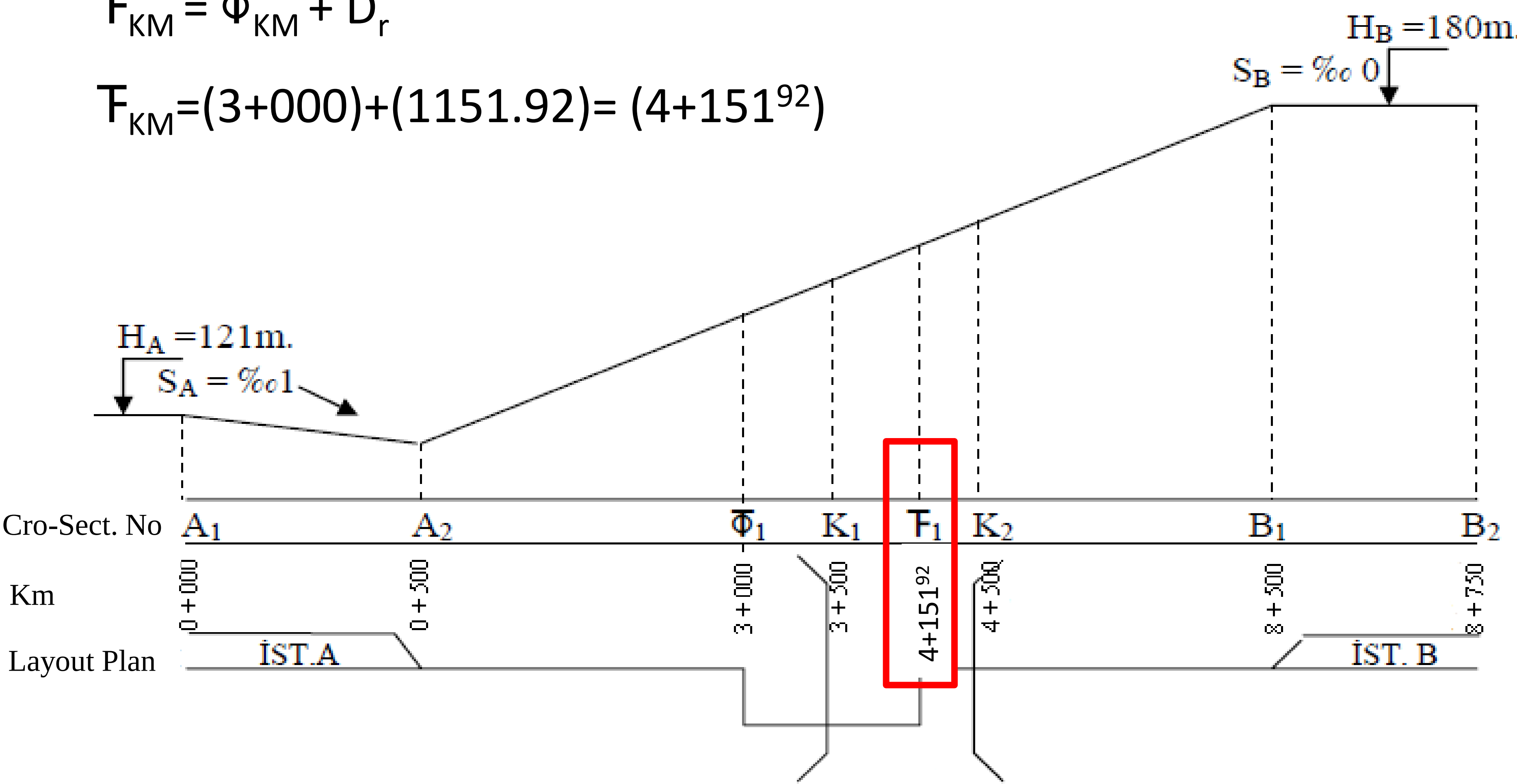
By using the given data answer the following questions:

a) Find km value of tangent point Ŧ_1.

$$D_r = \frac{2*\pi*R*\Delta}{360} = \frac{2*\pi*1000*66}{360} = 1151,92m$$

$$\text{Ŧ}_{KM} = \bar{\Phi}_{KM} + D_r$$

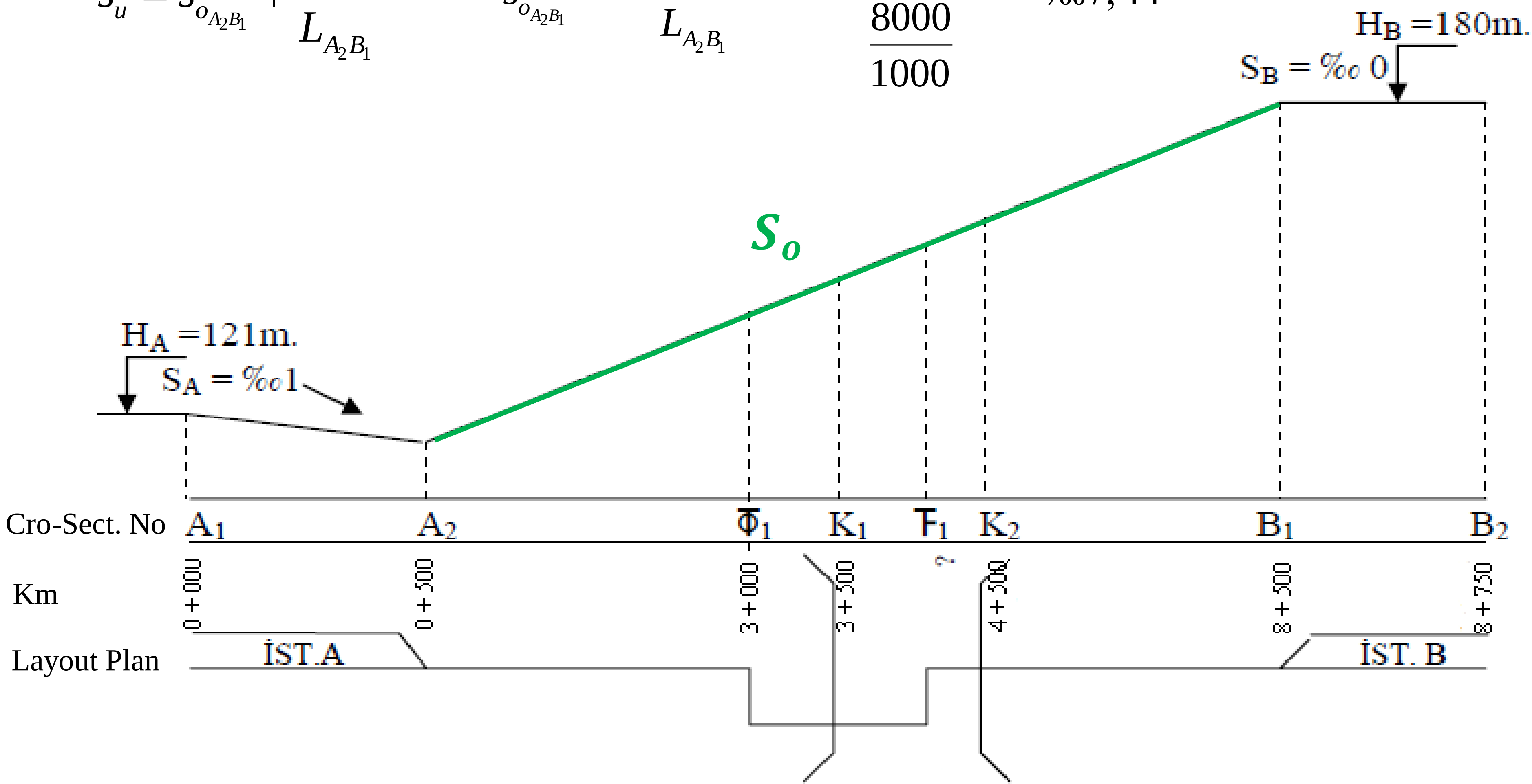
$$\text{Ŧ}_{KM} = (3+000)+(1151.92) = (4+151^{92})$$



b) Calculate the applied gradient (S_u) on this section.

$$H_{A_2} = 121 - 1 \times \frac{500}{1000} = 120{,}5m$$

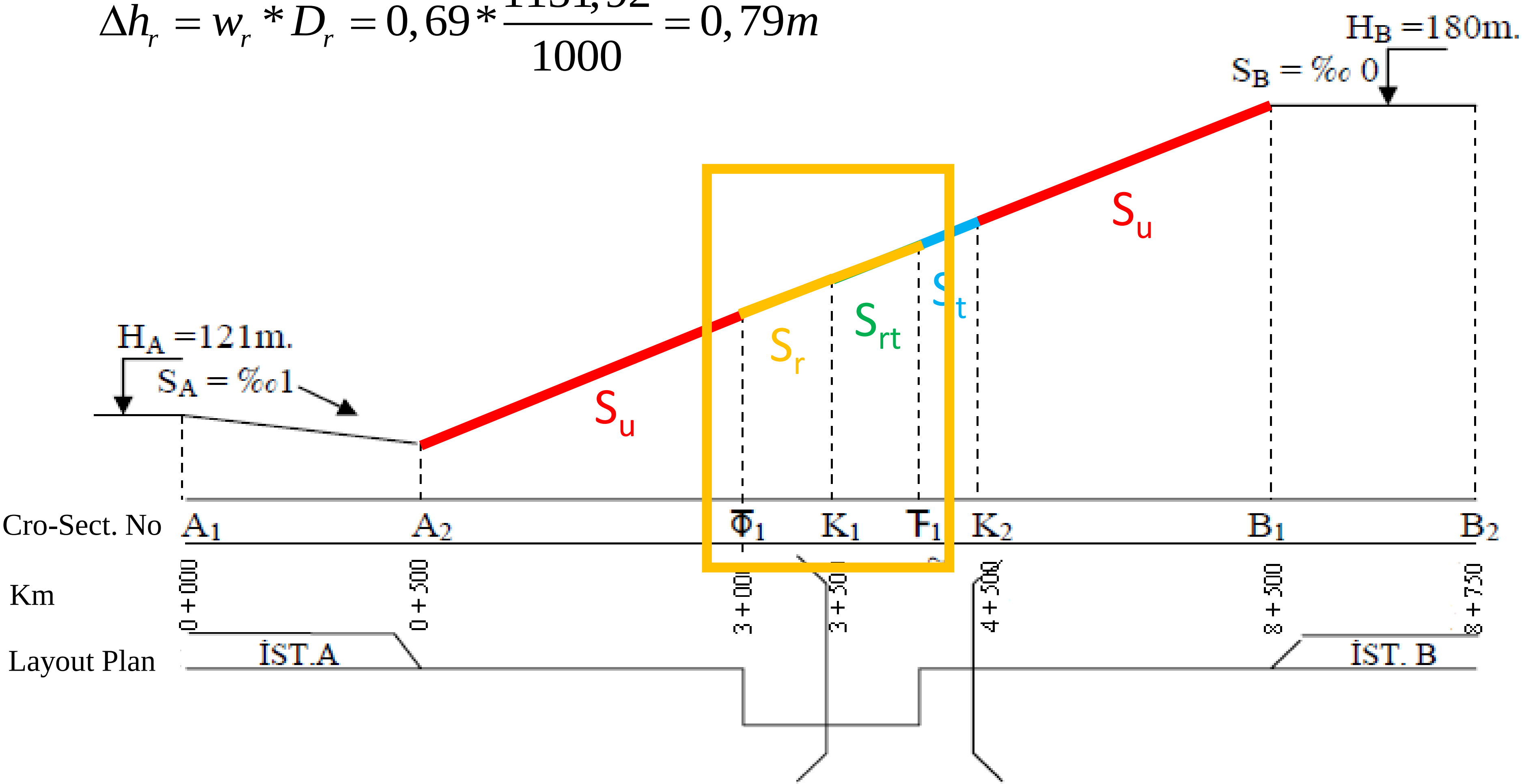
$$s_u = s_{o_{A_2B_1}} + \frac{\sum h}{L_{A_2B_1}} \qquad s_{o_{A_2B_1}} = \frac{H_{B_1} - H_{A_2}}{L_{A_2B_1}} = \frac{180 - 120{,}5}{\frac{8000}{1000}} = \text{‰}7{,}44$$



b) Calculate the applied gradient (S_u) on this section.

$$w_r = \frac{650}{R-55} = \frac{650}{1000-55} = 0,69 N / kN$$

$$\Delta h_r = w_r * D_r = 0,69 * \frac{1151,92}{1000} = 0,79m$$



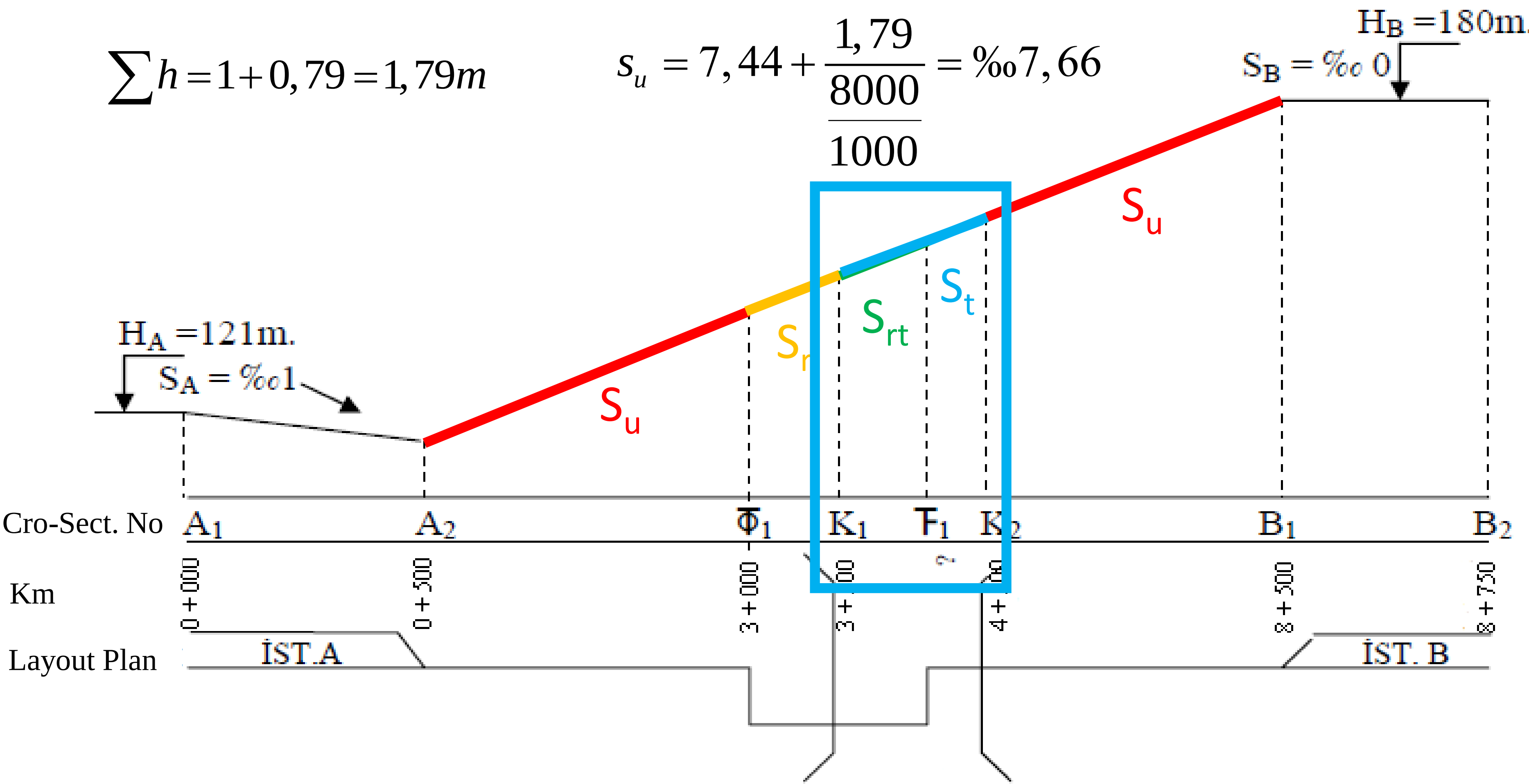
b) Calculate the applied gradient (S_u) on this section.

$$w_t = 1N / kN$$

$$\Delta h_t = w_t * L_t = 1 * \frac{4500-3500}{1000} = 1m$$

$$\sum h = 1 + 0,79 = 1,79m$$

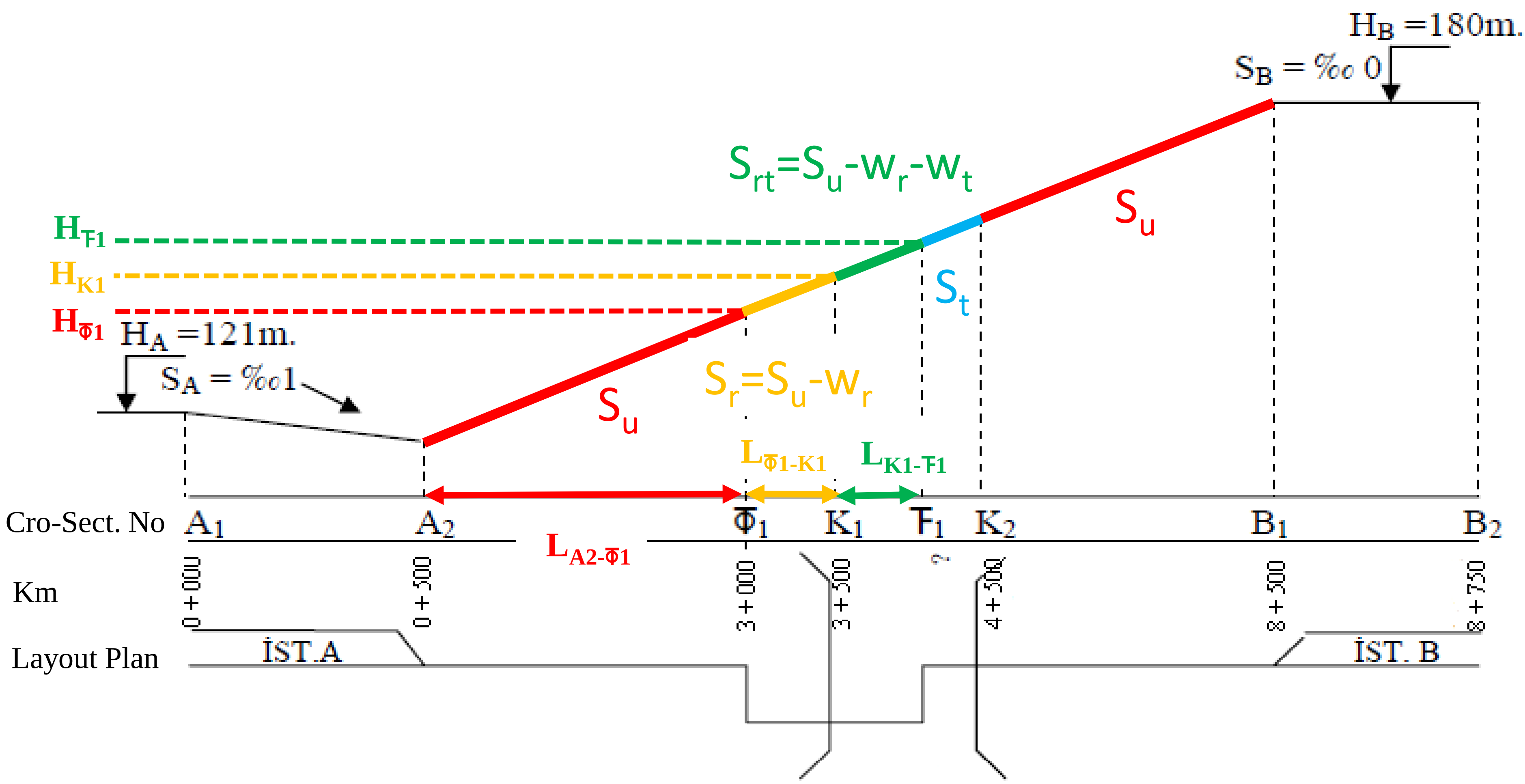
$$s_u = 7,44 + \frac{1,79}{\frac{8000}{1000}} = ‰7,66$$



c) Find elevations of points K_1, $Ŧ_1$.

$$H_{K1} = H_{A2} + s_u * L_{A2\text{-}Φ1} + (s_u - w_r) * L_{Φ1\text{-}K1} = 120.5 + (7.66/1000)*2500 + (7.66-0.69)/1000*500 = 143.14$$

$$H_{Ŧ1} = H_{K1} + (s_u - w_r - w_t) * L_{K1\text{-}Ŧ1} = 143.14 + (7.66-0.69-1.00)/1000*(4151.92-3500) = 147.03$$



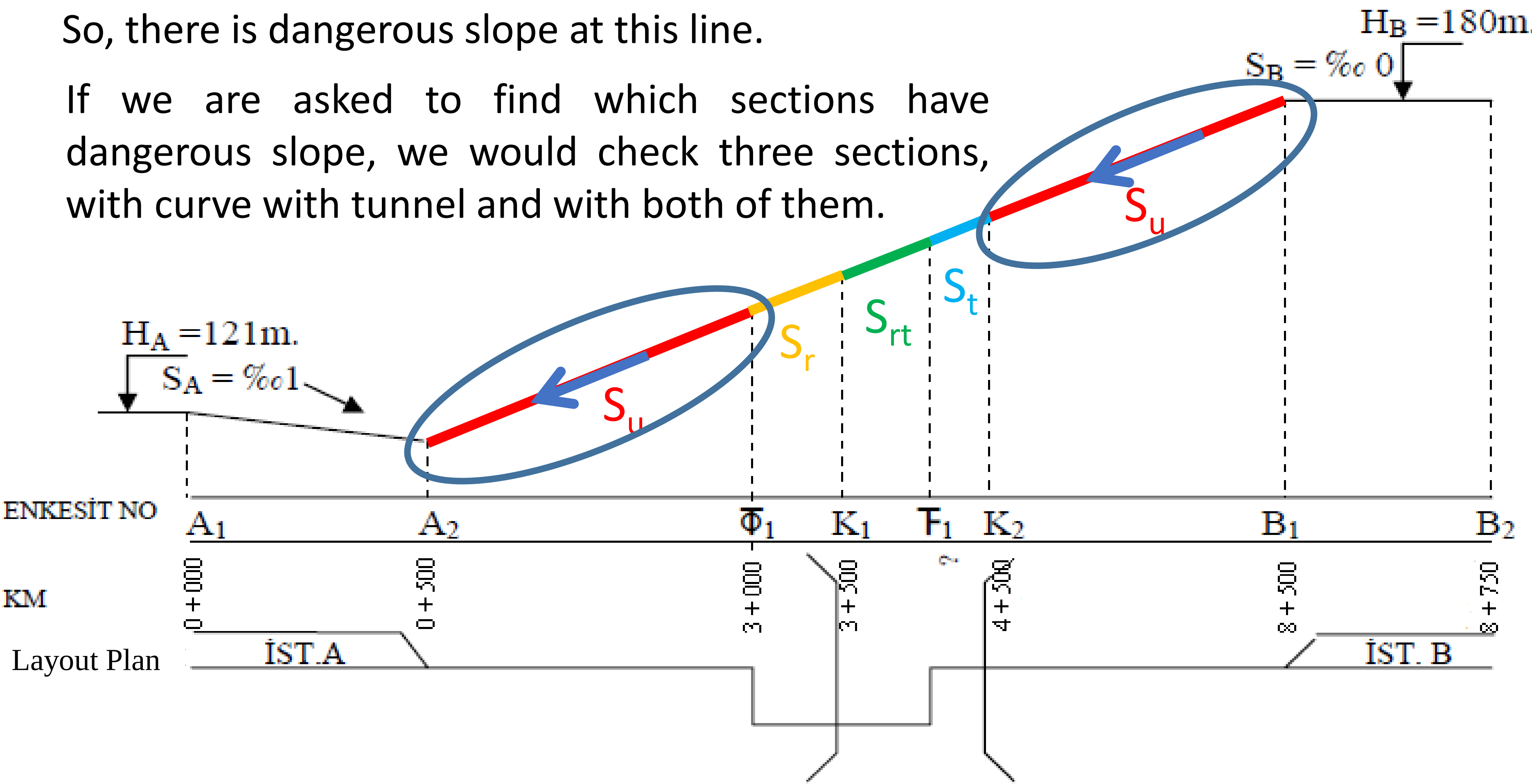
d) Is there a negative (dangerous) grade for a train which is running downwards from station B to station A with a constant speed 120 km/h. Why?

Dangerous slope occurs when, s > w. We have checked the section with highest gradient and lowest resistances where only w_0 exists.

$$w_0 = 1,7 + \frac{V^2}{4000} = 1,7 + \frac{120^2}{4000} = 5,3 N / kN \qquad s_u = 7.66 > w = w_0 = 5.3$$

So, there is dangerous slope at this line.

If we are asked to find which sections have dangerous slope, we would check three sections, with curve with tunnel and with both of them.



Question-2: On a railway network freight trains are pulled by the locomotives which have the features provided in the table below. Also data about the whole train provided in the same table. Trains (wagons) are pulled by a single locomotive. The given grades are upwards. According to the given data, calculate the values for the parameters below. Consider the criteria below during calculations.

Note 1: The principle of constant resistance will not be implied on the network. Do not make any changes on the given grades related to the principle of constant resistance.

Note 2: Each part of the problem is independent from each other; therefore, do not transfer data between the parts of the problem.

By using the given data answer the following questions:

2 + 2 + 2 = 6 driving axles

Locomotive Axle Configuration	Bo'Bo'Bo'	
Weight of Locomotive	135	tons
w_o	$2.5 + V^2 / 3000$	N / kN
$1/\rho$	105	
Acc. of Gravity (g)	10	m / s^2
μ_y (rail-wheel)	$160 + 7500/(V + 44)$	N / kN
Locomotive Power	4500	kW
Curve Resistance	$650 / (R - 45)$	N / kN

a) G_w = 1500 tons is given. Calculate the maximum upgrade value that this train can climb at 90 km/h constant speed on a straight (no curve) and open air (no tunnel) section.

Stages (regimes)	Forces acting upon the train	Acceleration or deceleration rate	Equation of motion in the stage
regime (constant speed)	$z-w$	$\frac{dv}{dt}=0$	$z=w$

$$z-w=\frac{1}{\rho}*\frac{dV}{dt}$$

z = w ➔ z = w_o + s ➔ s = z − w_o

$$w_o=2,5+\frac{V^2}{3000}=2,5+\frac{90^2}{3000}=5,2N/kN$$

$$Z=\frac{3600*N}{V}=\frac{3600*4500}{90}=180000N$$

$$z=\frac{Z}{10*(G_L+G_W)}=\frac{180000}{10*(135+1500)}=11,01N/kN$$

$$s=z-w_o=11,01-5,2=‰5,81$$

b) What is the total weight of wagons for which this train can run at 90 km/h constant speed on a 7.5‰ upgraded, straight (tangent) and open air (no tunnel) alignment section?

$$z - w = \frac{1}{\rho} * \frac{dV}{dt}$$

Since the speed is constant $\frac{dV}{dt} = 0$ and $z = w$

$$z = w \Rightarrow z = w_o + s \Rightarrow s = z - w_o$$

$$w_o = 2,5 + \frac{V^2}{3000} = 2,5 + \frac{90^2}{3000} = 5,2 N/kN$$

$$Z = \frac{3600 * N}{V} = \frac{3600 * 4500}{90} = 180000 N$$

$$z = \frac{Z}{10*(G_L + G_W)} = \frac{180000}{10*(135 + G_w)}$$

$$s = 7,5 = z - w_o = \frac{180000}{10*(135 + G_w)} - 5,2 \Rightarrow G_w = 1282,32 \text{ ton}$$

c) What is the horizontal curve radius, which allows the train to run at maximum constant speed of 75 km/h when s_r = 2.83‰ and G_w = 2500 tons?

$$z - w = \frac{1}{\rho} * \frac{dV}{dt}$$

Since the speed is constant $\frac{dV}{dt} = 0$ and z = w

$$Z = \frac{3600 * N}{V} = \frac{3600 * 4500}{75} = 216000N$$

$$z = \frac{Z}{10*(G_L + G_W)} = \frac{216000}{10*(135+2500)} = 8,2N / KN$$

$$z = w = w_o + s + w_r \Rightarrow w_r = z - w_0 - s$$

$$w_0 = 2,5 + \frac{V^2}{3000} = 2,5 + \frac{75^2}{3000} = 4,38N / kN$$

$$w_r = z - w_0 - s = 8,2 - 4,38 - 2,83 = 0,99N / kN$$

$$0,99 = \frac{650}{R - 45} \Rightarrow R = 700m$$

d) Train with G_w = 2000 tons is accelerating on a horizontal track (s=0‰), straight (no curve) and open air (no tunnel) alignment section. What is the Acceleration ratio when speed is exactly equal to critical speed (transition speed), V = V_g?

For transition speed $Z_a = Z_m$

$$10 * \mu * G_A = \frac{3600 * N}{V_g}$$

Stages (regimes)	Forces acting upon the train	Acceleration or deceleration rate	Equation of motion in the stage
acceleration (speed up)	$z - w$	$\frac{dv}{dt} > 0$	$z - w = \frac{1}{\rho}\frac{dv}{dt}$

$$10 * (160 + \frac{7500}{V_g + 44}) * 135 = \frac{3600 * 4500}{V_g} \Rightarrow V_g = 50,05 km / sa$$

$$z - w = \frac{1}{\rho} * \frac{dV}{dt}$$

$$Z = \frac{3600 * 4500}{50,05} = 323676,32 N$$

$$z = \frac{Z}{10 * (G_L + G_W)} = \frac{323676,32}{10 * (135 + 2000)} = 15,16 N / KN$$

$$w = w_0 = 2,5 + \frac{50,05^2}{3000} = 3,34 N / kN$$

$$z - w = 15,16 - 3,34 = 11,82 N / kN$$

$$11,82 = \frac{1}{\rho} * \frac{dV}{dt} = 105 * \frac{dV}{dt} \Rightarrow \frac{dV}{dt} = 0,11 m / s^2$$

e) What is the maximum wagon load (weight), which allows the train to start moving with 0.2 m/s² acceleration ratio on a 5‰ upgraded, straight and open air alignment conditions?

$$z - w = \frac{1}{\rho} * \frac{dV}{dt}$$

$$\frac{1}{\rho} * \frac{dV}{dt} = w_D$$

When a train starts moving, an **acceleration resistance (w_d)** acts on the train depending on the acceleration rate applied.

$$z - w = w_D$$

$$w = w_0 + s \Rightarrow z = w_0 + s + w_D$$

$$w_D = \frac{1}{\rho} * \frac{dV}{dt} = 105 * 0,2 = 21N / kN$$

$$w_0 = 2,5 + \frac{V^2}{3000} = 2,5 + \frac{0^2}{3000} = 2,5N / kN$$

$$z = w_0 + s + w_D \Rightarrow \frac{10 * \mu * G_A}{10 * (G_L + G_W)} = w_0 + s + w_D$$

$$\frac{10 * (160 + \frac{7500}{0 + 44}) * 135}{10 * (135 + G_W)} = 2,5 + 5 + 21 \Rightarrow G_W = 1430 \text{ ton}$$

f) When G_w = 2000 tons, what is the limit gradient (smallest value) on which the train cannot move with any value of acceleration on a straight (no curve) and open air (no tunnel) section.

$$z - w = \frac{1}{\rho} * \frac{dV}{dt}$$

$$\text{no movement condition} = \frac{dV}{dt} = 0$$

$$z = w$$

$$\frac{10 * \mu * G_A}{10 * (G_L + G_W)} = w_0 + s \Rightarrow s = \frac{10 * \mu * G_A}{10 * (G_L + G_W)} - w_o = \frac{\mu * G_A}{(G_L + G_W)} - w_0$$

$$\frac{\mu * G_A}{G_L + G_W} = \frac{135 * (160 + \frac{7500}{0 + 44)}}{135 + 2000} = 20{,}9 N / kN$$

$$w_0 = 2{,}5 + \frac{V^2}{3000} = 2{,}5 + \frac{0^2}{3000} 2{,}5 N / kN$$

s = 20,9 – 2,5 = ‰18,4

Question-3: Data about a freight train is given below. By using the given data answer the following questions:

Number of Locomotives	**2**	unit
Loco. power	4000	kW
Loco. driving axle weight	20	tons/axle
Loco. axle configuration	Bo'Bo'Bo'	**6 driving axles**
Loaded weight of wagons	60	tons
Number of wagons	40	unit
Coeff. of train mass increa. $(1 + \xi)$	1,05	
Acc. of Gravity (g)	10	m/s^2
Running Resistance (w_0)	$2{,}4 + V^2 / 3000$	N / kN
μ_y (rail-wheel)	200 (constant)	N / kN
μ_f (brk.shoe-wheel)	$5000 / (50 + V)$	N / kN
$\alpha / \beta / \gamma$	0,6 / 0,8 / 1,0	
Max. (regime) velocity	90	km/h

Note: All acceleration calculations will be performed in **one interval from zero to transition speed** and **one interval from transition speed to regime speed**. All braking calculations will be performed in **2 equal intervals from regime speed to zero** (V=0).

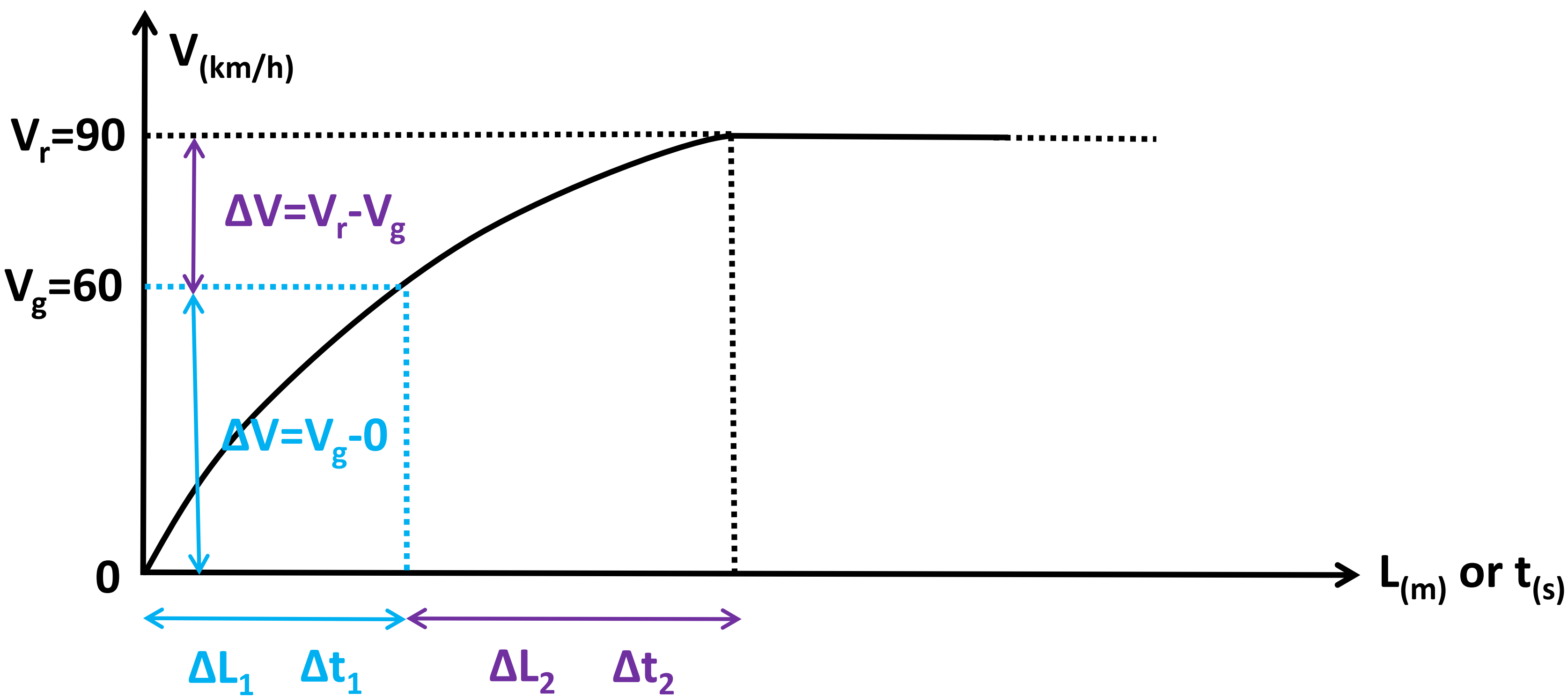
a) Calculate the length of the horizontal track (palye) and time required for the train to reach regime speed under the condition that train started to move 500 meters before the exit point of a zero graded (horizontal) station.

Transition Speed Calculation:

$$Z_{aderans} = Z_{motor} \qquad \frac{3600 * N}{V_g} = \mu_y * G_A * g$$

Axle conf. Bo'Bo'Bo' => $G_A =$ 20*6*2=240 ton since there are two locomotives.

$$2*\frac{3600*4000}{V_g} = 200*120*10*2 \quad V_g = 60 km/sa$$



	Speed interval (km/h)	ΔV (km / h)	V_{ort} (km/h)	Z (N)	z (N / kN)	w_0 (N / kN)	s (‰)	∑w=w_0 ± s (N / kN)	Δt (s)	Δℓ (m)
1	0 - 60	60	30	480000	18,18	2,7	0	2,7	113,05	942,08
2	60 - 90	30	75	384000	14,55	4,28	0	4,28	85,2	1775
								Total	198,25	2717,08

1 row tractive force calculation: $Z = 2 * \mu * g * G_A = 2 * 200 * 10 * 120 = 480000N$

2. row tractive force calculation: $Z = \dfrac{3600 * 2 * N}{V_{ort}} = \dfrac{3600 * 2 * 4000}{75} = 384000N$

1. row unit tractive force calculation: $z = \dfrac{Z}{g(G_L + G_W)} = \dfrac{480000}{10 * (120 * 2 + 40 * 60)} = 18,18N / kN$

1. row running resistance calculation: $w_0 = 2,4 + \dfrac{V_{ort}^2}{3000} = 2,4 + \dfrac{30^2}{3000} = 2,7N / kN$

Acceleration is performed on the horizontal section therefore, s is taken as 0.

1. row Δt calculation:

$$\Delta t = \frac{1}{\rho} * \frac{\Delta V}{3,6 * [z - (w_0 \pm s)}$$

$$\frac{1}{\rho} = \frac{1000}{g} * (1 + \xi) = \frac{1000}{10} * 1,05 = 105$$

$$\Delta t = 105 * \frac{60}{3,6 * (18,18 - 2,7)} = 113,05s$$

1. row Δℓ calculation:

$$\Delta \ell = \frac{V_{ort}}{3,6} * \Delta t = \frac{30}{3,6} * 113,05 = 942,08m$$

Horizontal track length = acceleration length – station length = 2717,08 – 500 = 2217,08 meters.

b) In case of having 3‰ downgraded station and speeding track (palye) section, what will be the values calculated in previous part (a) of the problem?

	Speed interval (km/h)	ΔV (km / h)	V_{ort} (km/h)	Z (N)	z (N / kN)	w_0 (N / kN)	s (‰)	∑w=w_0 ± s (N / kN)	Δt (s)	Δℓ (m)
1	0 - 60	60	30	480000	18,18	2,7	-3	-0,3	94,7	789,17
2	60 - 90	30	75	384000	14,55	4,28	-3	1,28	65,94	1373,75
								Total	160,64	2162,92

Sample calculations: Numerical values and all calculations are same with part a of the problem until slope.

Acceleration is performed on the ‰3 downgraded section therefore, s is taken as -3

1. row calculation of $w_0 \pm s$: $w_0 \pm s = 2,7 - 3 = -0,3 N / kN$

1. row Δt calculation:

$$\Delta t = \frac{1}{\rho} * \frac{\Delta V}{3,6 * [z - (w_0 \mp s)]}$$

$$\Delta t = 105 * \frac{30}{3,6 * [18,18 - (-0,3)]} = 94,7 s$$

1. row Δℓ calculation:

$$\Delta \ell = \frac{V_{ort}}{3,6} \Delta t = \frac{30}{3,6}(94,7) = 789,17 \text{ m}$$

c) In case of stopping on a 4‰ upgraded, straight (no curve) and open air (no tunnel) line section, what is the time and distance required for this train to reach the regime speed again?

	Speed interval (km/h)	ΔV (km / h)	V_{ort} (km/h)	Z (N)	z (N / kN)	w_0 (N / kN)	s (‰)	$\sum w = w_0 \pm s$ (N / kN)	Δt (s)	Δℓ (m)
1	0 - 60	60	30	480000	18,18	2,7	4	6,7	152,44	1270,33
2	60 - 90	30	75	384000	14,55	4,28	4	8,28	139,55	2907,29
								Total	291,99	4177,62

Sample Calculations. Numerical values and all calculations are same with part a of the problem until slope.

Acceleration is performed on the ‰4 upgraded section therefore, s is taken as 4

1. row calculation of $w_0 \pm s$: $w_0 \pm s = 2,7 + 4 = 6,7 N / kN$

1. row Δt calculation:

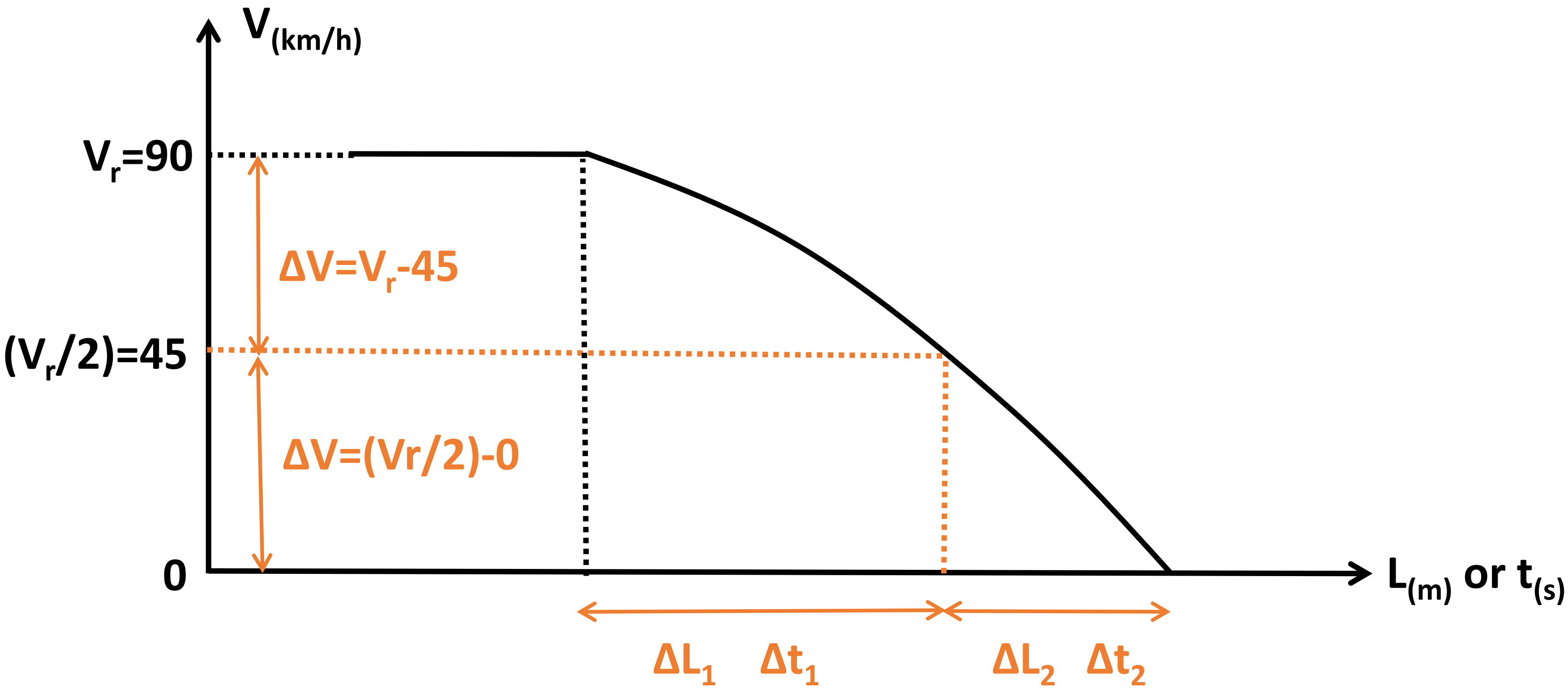
$$\Delta t = \frac{1}{\rho} * \frac{\Delta V}{3,6 * [z - (w_0 \pm s)]}$$

$$\Delta t = 105 * \frac{30}{3,6 * (18,18 - 6.7)} = 152,44 s$$

1. row Δℓ calculation:

$$\Delta \ell = \frac{V_{ort}}{3,6} \Delta t = \frac{30}{3,6} (152,44) = 1270,33 \text{ m}$$

d) In case of starting to brake while running on a 4‰ upgraded, straight and open air section with the regime velocity, what will be the time and distance until a complete stop? Repeat the calculations for 4‰ downgraded section and horizontal (zero grade) sections.



Stages (regimes)	Forces acting upon the train	Acceleration or deceleration rate	Equation of motion in the stage
deceleration (braking)	$-w - w_f$ $(z = 0)$	$\frac{dv}{dt} < 0$	$-w - w_f = -\frac{1}{\rho}\frac{dv}{dt}$

4‰ upgraded section:

	Speed interval (km/h)	ΔV (km / h)	V_{ort} (km/h)	w_f (N / kN)	w_0 (N / kN)	s (‰)	$\sum w = w_0 \pm s$ (N / kN)	Δt (s)	Δℓ (m)
1	90 - 45	45	67,5	20,43	3,92	4	7,92	46,3	868,13
2	45 - 0	45	22,5	33,1	2,57	4	6,57	33,09	206,81
							Total	79,39	1074,94

1. row w_f calculation: $\frac{\alpha * \beta}{\gamma} = \frac{0,6 * 0,8}{1,0} = 0,48$ ➔ $w_f = \mu_f * \frac{\alpha * \beta}{\gamma} = \frac{5000}{50 + V_{ort}} * 0,48 = \frac{5000}{50 + 67,5} * 0,48 = 20,43 N / kN$

1. row running resistance calculation

$$w_0 = 2,4 + \frac{V_{ort}^2}{3000} = 2,4 + \frac{67,5^2}{3000} = 3,92 N / kN$$

Braking is performed on the ‰4 upgraded section therefore, s is taken as 4

1. row calculation of $w_0 \pm s$: $w_0 \pm s = 3,92 + 4 = 7,92 N / kN$

1. row Δt calculation:

$$\Delta t = \frac{1}{\rho} * \frac{\Delta V}{3,6 * [w_f + (w_0 \pm s)]}$$

$$\Delta t = 105 * \frac{45}{3,6 * (20,43 + 7,92)} = 46,3 s$$

1. row Δℓ calculation

$$\Delta \ell = \frac{V_{ort}}{3,6} * \Delta t = \frac{67,5}{3,6} * 46,3 = 868,13 m$$

Without grade:

	Speed interval (km/h)	ΔV (km / h)	V_{ort} (km/h)	w_f (N / kN)	w_0 (N / kN)	s (‰)	∑w=w_0 ± s (N / kN)	Δt (s)	Δℓ (m)
1	90 - 45	45	67,5	20,43	3,92	0	3,92	53,9	1010,63
2	45 - 0	45	22,5	33,1	2,57	0	2,57	36,8	230
							Total	90,7	1240,63

Calculations until slope are same with calculation for ‰4 upgraded section:

Braking is performed on the horizontal section therefore, s is taken as 0

1. row Δt calculation:

$$\Delta t = \frac{1}{\rho} x \frac{\Delta V}{3{,}6x[w_f + (w_0 \pm s)]}$$

$$\Delta t = 105x \frac{45}{3{,}6 * (20{,}43 + 3{,}92)} = 53{,}9s$$

1. row Δℓ calculation

$$\Delta \ell = \frac{V_{ort}}{3{,}6} * \Delta t = \frac{67{,}5}{3{,}6} * 53{,}9 = 1010{,}63m$$

‰4 downgraded section:

	Speed interval (km/h)	ΔV (km / h)	V_{ort} (km/h)	w_f (N / kN)	w_0 (N / kN)	s (‰)	$\sum w = w_0 \pm s$ (N / kN)	Δt (s)	Δℓ (m)
1	90 - 45	45	67,5	20,43	3,92	-4	-0,08	64,5	1209,38
2	45 - 0	45	22,5	33,1	2,57	-4	-1,43	41,44	259
							Total	105,94	1468,38

Calculations until slope are same with calculation for ‰4 upgraded and horizontal sections:

1. row calculation of $w_0 \pm s$: $w_0 \pm s = 3,92 - 4 = -0,08 N/kN$

Braking is performed on the ‰4 downgraded section therefore, s is taken as -4

1. row Δt calculation:

$$\Delta t = \frac{1}{\rho} * \frac{\Delta V}{3,6 * [w_f + (w_0 \pm s)]}$$

$$\Delta t = 105 * \frac{45}{3,6 * [20,43 + (-0,08)]} = 64,5 s$$

1. row Δℓ calculation:

$$\Delta \ell = \frac{V_{ort}}{3,6} \Delta t = \frac{67,5}{3,6}(64,5) = 1209,38 \text{ m}$$

e) In case of slowing down without using tractive force and braking force while moving on a 7‰ upgraded, straight and open air section, what will be the time and distance required for a complete stop.

	Speed interval (km/h)	ΔV (km / h)	V_{ort} (km/h)	w_f (N / kN)	w_0 (N / kN)	s (‰)	$\sum w=w_0 \pm s$ (N / kN)	Δt (s)	Δℓ (m)
1	90 - 45	45	67,5	0	3,92	7	10,92	120,19	2253,56
2	45 - 0	45	22,5	0	2,57	7	9,57	137,15	857,19
							Total	257,34	3110,75

No brake therefore $w_f = 0$. Rest of the equations are calculated by using the similar calculation at previous sections.

1. row Δt calculation:

$$\Delta t = \frac{1}{\rho} x \frac{\Delta V}{3,6x(w_0 \pm s)}$$

$$\Delta t = 105x \frac{45}{3,6*(\quad 10,92)} = 120,19s$$

1. row Δℓ calculation:

$$\Delta\ell = \frac{V_{ort}}{3,6} \Delta t = \frac{67,5}{3,6}(120,19) = 2253,56 \text{ m}$$

Question-4: For passenger and freight trains operating on a railway line, their regime speeds, weights and number of daily trips are given. By using the given data answer the following questions:

Train Name	**Speed (km/h)**	**Total train weight (tons)**	**Daily trip number**
Passenger1	140	120	7
Passenger2	120	170	9
Freight1	40	1200	8
Freight2	30	2000	10

Project speed: 180 km/h
Max superelevation: 160 mm
Upper limit of uncompensated transverse (comfort) acceleration: 0.9 m/s^2
Max superelev. excess for freight trains: 40 mm
Track gauge: 1500 mm
Acc. of gravity (g): 10 m/s^2

a) Calculate the permissible minimum curve radius.

$$R_{min} = \frac{11{,}8 * V_P^2}{d_{maks} + 153\gamma_{maks}} = \frac{11{,}8 * 180^2}{160 + 153 * 0{,}9} = 1284m$$

Min curve radius has to be multiples of 50; therefore $R_{min} = 1300$ m.

b) Calculate the applied superelevation based on even (rail) wearing requirement, and check this value if it is between the minimum (for passenger trains) and maximum (for freight trains) allowable values.

According to even wearing requirement, superelevation will be calculated as follows:

Find average speed by considering the trip numbers and the weights. Apply theoretical superelevation to the railway. Use the formula below.

$$V_o = \sqrt{\frac{\sum_i n_i * G_i * V_i^3}{\sum_i n_i * G_i * V_i}}$$

i, is the index for train; n_i, is the daily trip number;

V_i, is the velocity; G_i, is the weight of the train.

Train Name	Speed (V_i) (km/h)	Total train weight (G_i) (Tons)	Daily trip number (n_i)	$n_i G_i V_i$	$n_i G_i V_i^3$
Passenger1	140	120	7	117.600	2.304.960.000
Passenger2	120	170	9	183.600	2.643.840.000
Freight1	40	1200	8	384.000	614.400.000
Freight2	30	2000	10	600.000	540.000.000
			Total	1.285.200	6.103.200.000

$$V_o = \sqrt{\frac{6.103.200.000}{1.285.200}} = 68,91 km/sa$$

$$d_{applied} = d_{teo,V_o} = \frac{11.8 * 68.91^2}{1300} = 43.10 \text{ mm}$$

Maximum missing superelevation should be checked from fastest train.

Amount of missing superelevation for passenger train is $153 * \gamma_{max}$

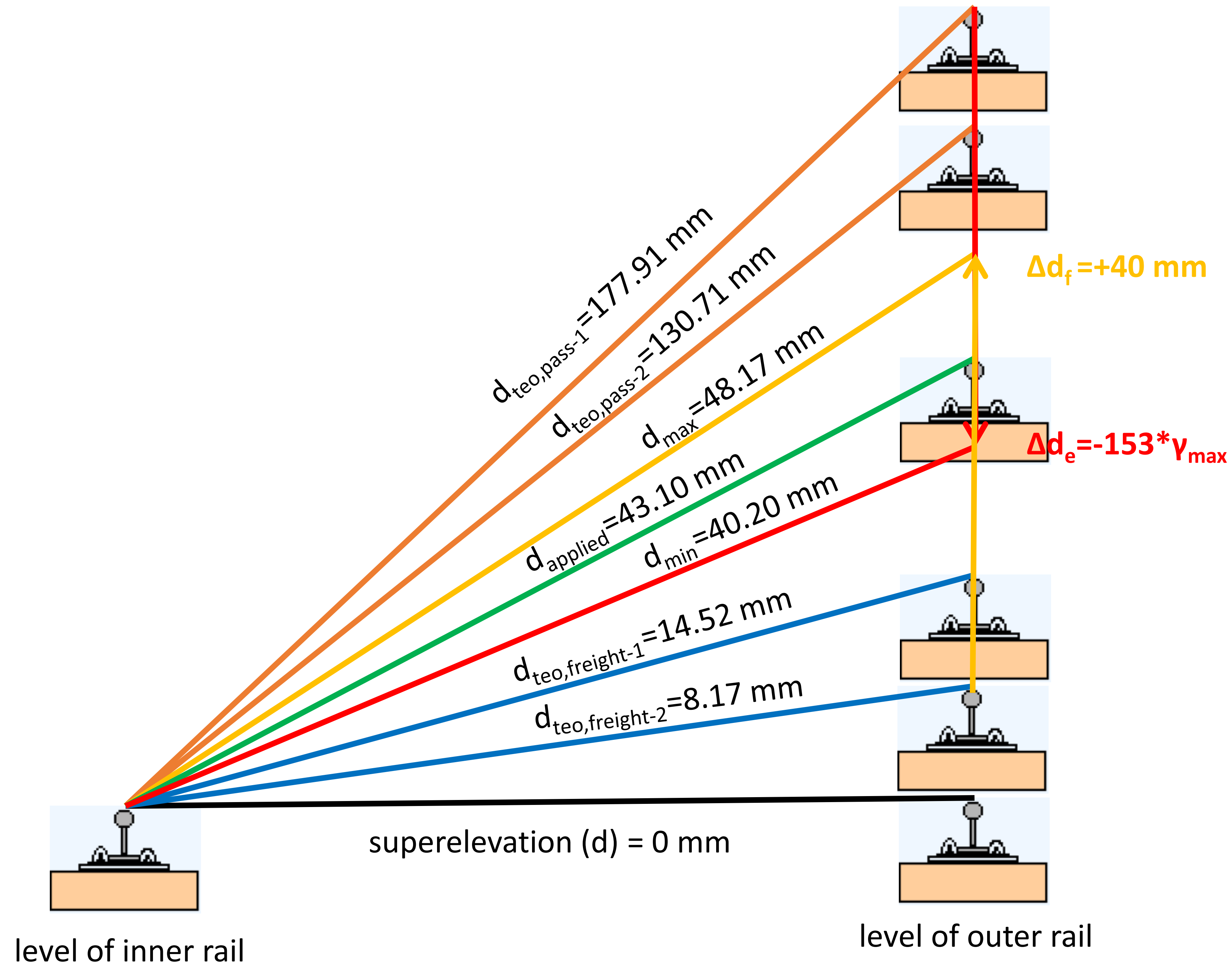
$$d_{min,passenger} = d_{teo,\ passenger} - 153 * \gamma_{max}$$

$$d_{min,pass1} = d_{teo,\ pass1} - 153 * \gamma_{max} = \frac{11,8 * 140^2}{1300} - 153 * 0,9 = 40,20mm < 43,10mm$$ ➔ Satisfied.

Maximum excess superelevation should be checked from slowest train.

Max superelev. excess for freight trains is given as 40 mm.

$$d_{min,freight2} = d_{teo,\ freight2} + 153 * \Delta d_f = \frac{11,8 * 30^2}{1300} + 40 = 48,17mm$$ ➔ Satisfied



$d_{teo,pass-1}$=177.91 mm
$d_{teo,pass-2}$=130.71 mm
d_{max}=48.17 mm
$d_{applied}$=43.10 mm
d_{min}=40.20 mm
$d_{teo,freight-1}$=14.52 mm
$d_{teo,freight-2}$=8.17 mm
Δd_f =+40 mm
Δd_e=-153*γ_{max}
superelevation (d) = 0 mm
level of inner rail
level of outer rail

c) Find the direction and magnitude of the net force acting on train "Passenger 1" when it passes on a curve with minimum radius and having the applied superelevation with given speed.

When passenger train passes the curve with given speed it will be affected by a comfort acceleration of γ. According to Newton laws mass times acceleration will give the net force on the train. Which is called the centrifugal force for this case.

$d_{applied} = d_{teo,pass1} - 153 * \gamma$

$43.10 = \frac{11.8 * 140^2}{1300} - 153 * \gamma \Rightarrow \gamma = 0.88\ m/s^2$

$\gamma = \frac{F_{net}}{m_{train}} \Rightarrow F_{net} = m_{train} * \gamma = 120 * 0.88 = 105.6\ kN$

If speed of the train > V_o, then uncompensated outward (centrifugal) force exist.

If speed of the train < V_o, then uncompensated inward (centripetal) force exist.