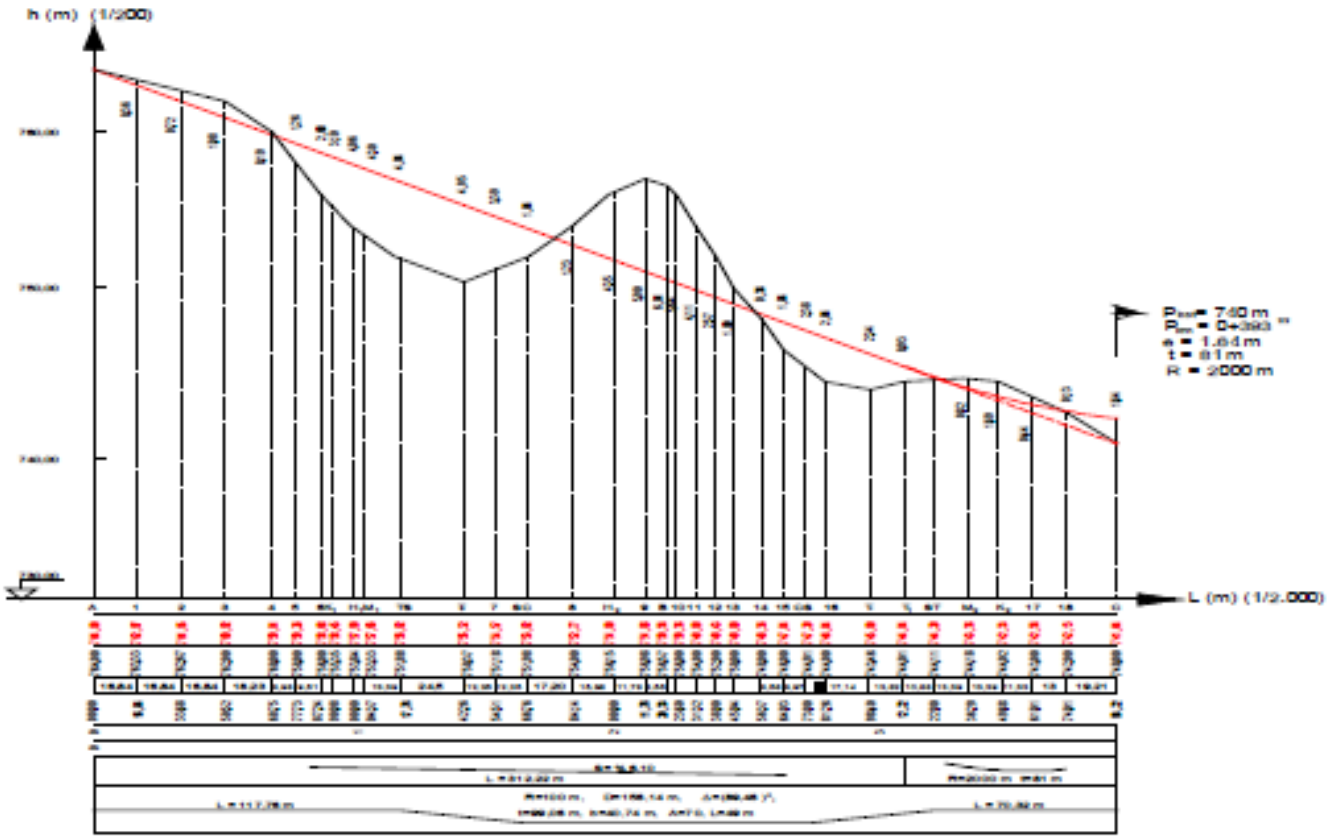
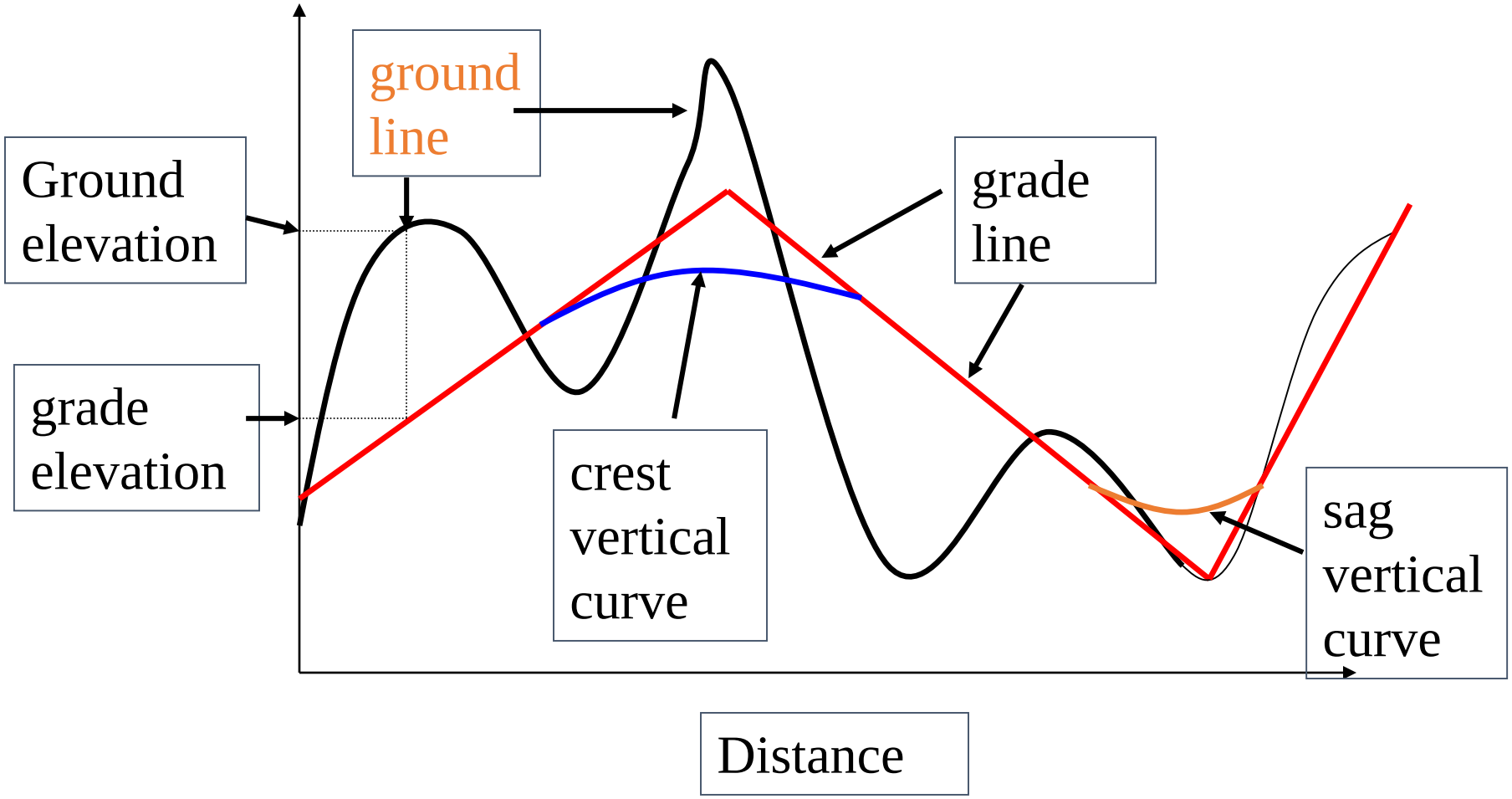
Profile and Vertical Curves

The section taken through the highway axis is named as the profile.

The highway axis on the plan (the projection of the highway) is carried onto the vertical plane by using the cross-section points to obtain the profile as seen on the figure.



The elements of profile



Profile

- The **Ground Elevations** of the cross-sections are read from the contour map and marked on the vertical plane to be connected with a line.
- The line obtained this way shows the situation of the land and is named as the **Ground Line.**
- As the **Ground Line** is a broken line, vehicles cannot move on it with the desired comfort and safety level.
- To obtain a more suitable rolling surface, the primary compulsory (obligatory) points (start and end points of the highway) are connected with each other to obtain the **Grade Line.**
- The **Grade Line** is sometimes a single line having a constant grade, while other times it is consisted of line segments with proper length, having various grades.
- The elevation of any point on the **Grade Line** is named as the **Grade Elevation.**
- If the Grade Elevation is lower than the Ground Elevation of any point cut, else fill has to be made.
- If the slope of the Grade Line is positive (+), this section of the highway is an ascending section, else if the slope is negative (-), this section of the highway is an descending section.
- The curves placed between Grade Lines are named as the **Vertical Curves.**

Station	Km	Ground Elevation (m)
A	0+000	100.00
1	$0+016^{67}$	105.00
2	$0+035^{90}$	110.00
3	$0+058^{67}$	115.00
H1	0+100	118.50
C	$1+250^{75}$	175.00

Table of Profile

Stations	0.5 cm	Horizontal	Black
Grade Elevation	1.0 cm	Vertical	Red
Ground Elevation	1.0 cm	Vertical	Black
Interval of Stations	0.5 cm	Horizontal	Black
Total Distance	1.0 cm	Vertical	Black
Hectometers	0.5 cm	Vertical	Black
Kilometers	0.5 cm	Vertical	Black
Longitudinal Grades	1.0 cm	Horizontal	Red
Curves and Alignments	1.5 cm	Horizontal	Red

Grade

The longitudinal grade given through the highway axis is shortly named as the **Grade**.
As a highway is being designed, grade should not pass a specific value to provide safety, comfort and capacity.
Highway class, situation of the land, climate, dominant vehicle type and project standards are effective on determining the highest grade to be applied.
Low grades are applied on high standard highways.
The maximum grades accepted by the General Directorate of Highways are; 7% on first class highways, 8% on second class highways, 9% on third class highways.
15% of grades are accepted on village roads while on expressways the maximum grade is 4%.
The minimum value of the grade is determined to be 0,35% by the General Directorate of Highways.
However 0,5% is applied practicallly.

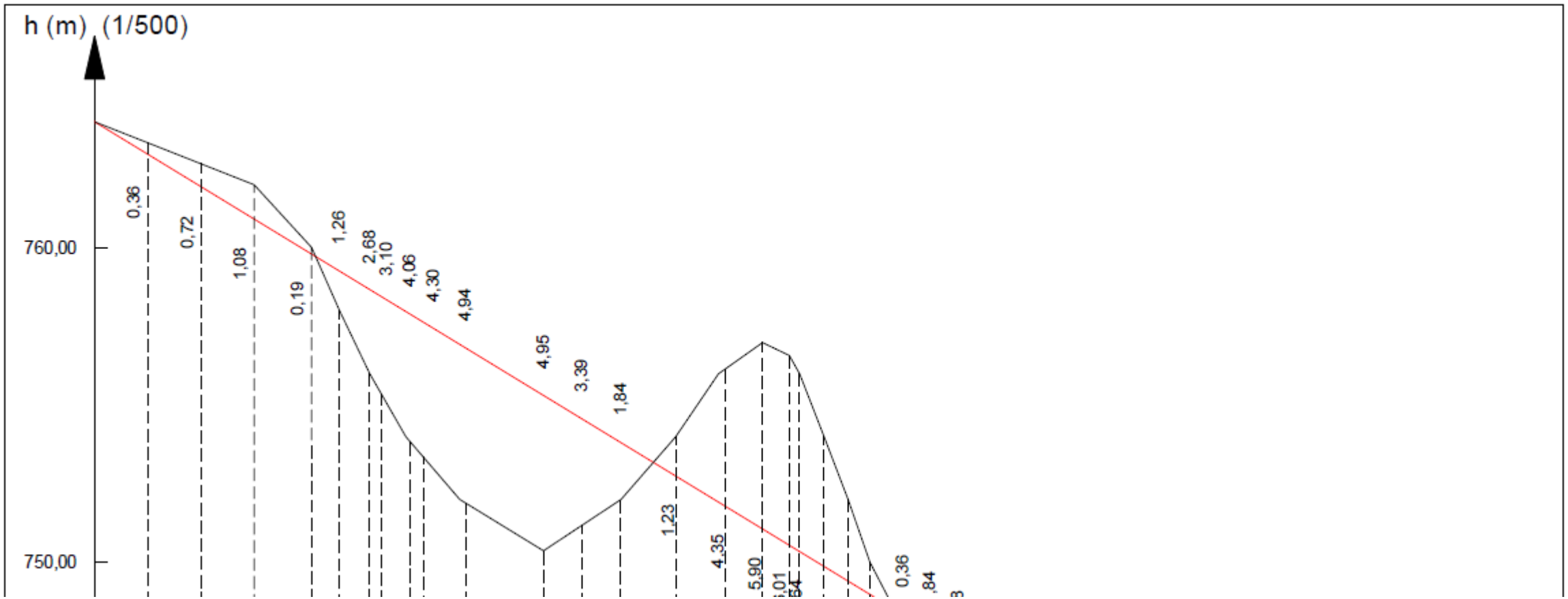
Drawing the Grade Line on the Profile

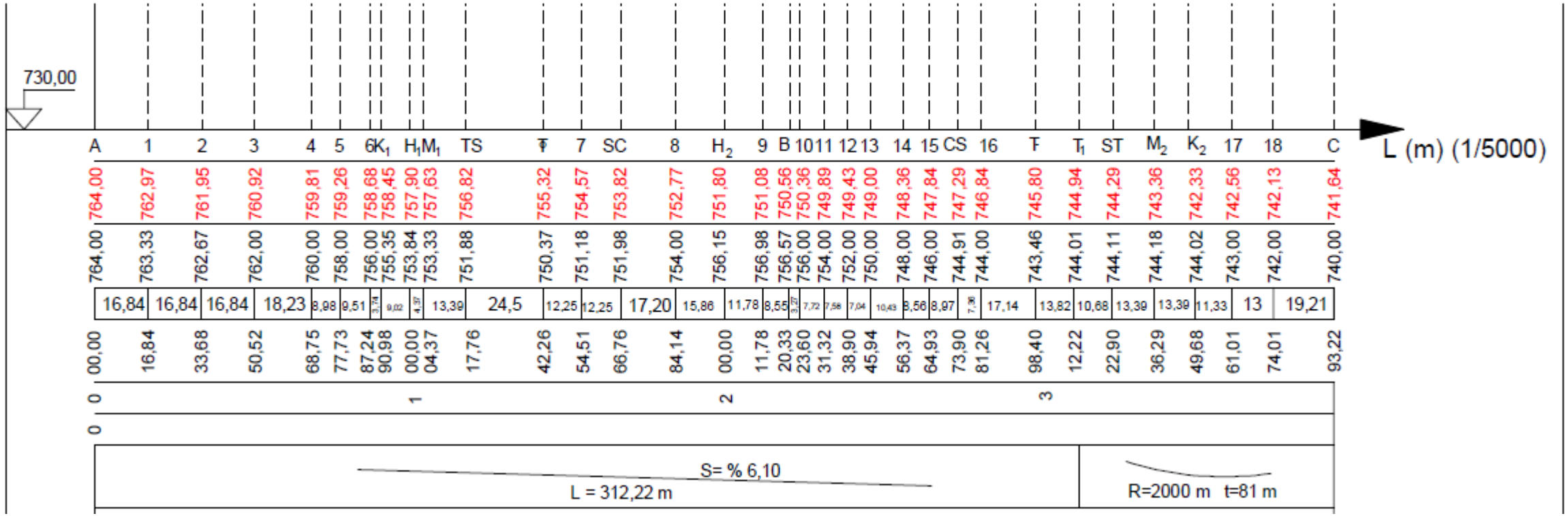
The Grade Line is drawn with specific rules on the profile. The rules to be taken into account can be summarized as:

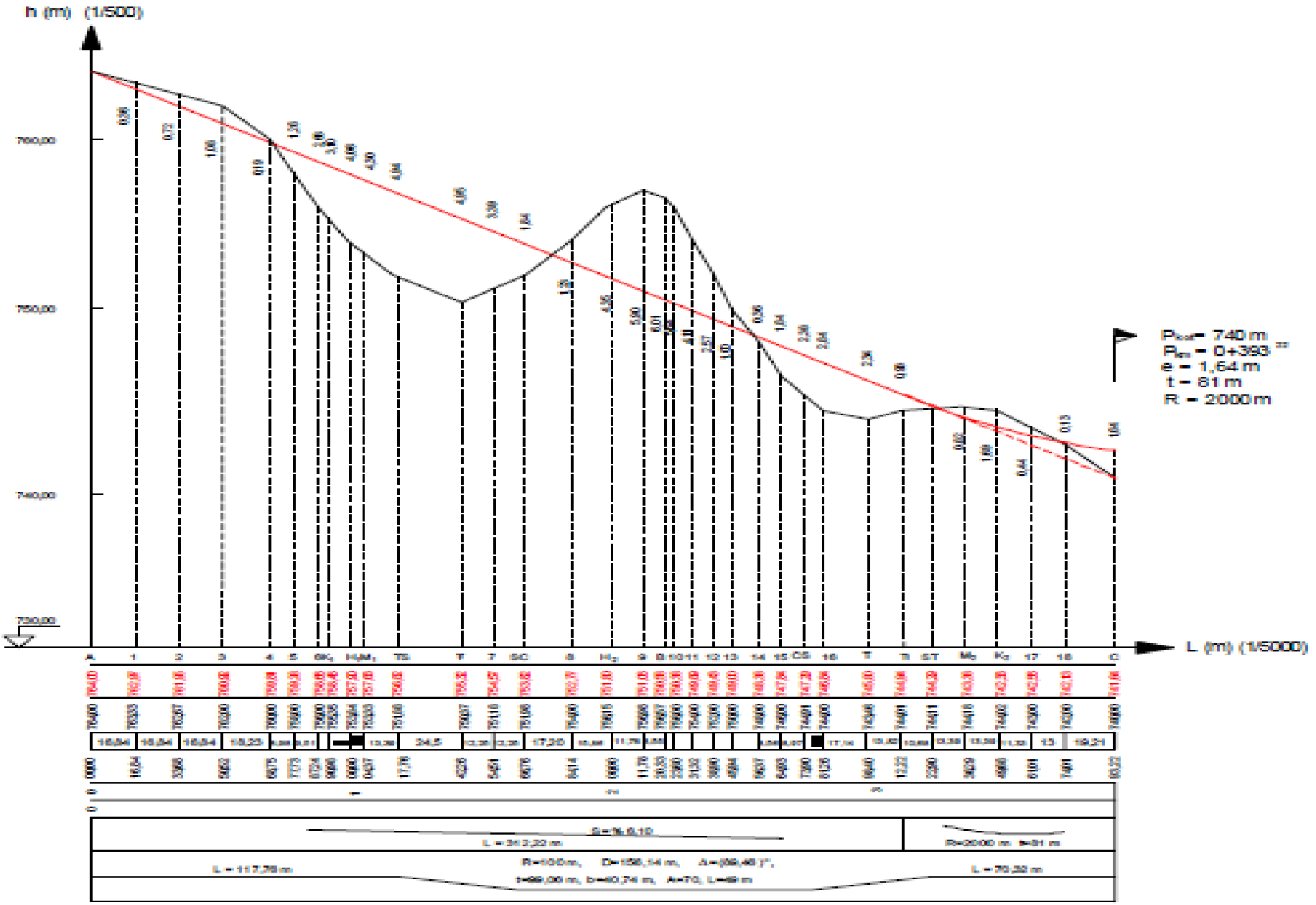
- The Grade Line has to be drawn in a way to minimize the earthwork, if that is not possible, to equalize the cuts and the fills through the route.
- The sight distances have to be provided on the vertical curves that are to be designed.
- To decrease the vehicle operating costs and to increase the safety, high graded sections have to be as short as possible.
- Straight sections have to pass from a higher elevation than the natural land to avoid floods or snow drifts.
- On riverside passes, the route has to pass from a higher elevation than the highest water level.
- To ease the surface drainage, on cut cross-sections, sag vertical curves have to be avoided.
- Horizontal curves and the vertical curves should not intersect with each other.
- Long straight sections with a constant grade have to be avoided in order to provide safe driving.

Calculation of Grade Elevations on The Profile

Station	Km	Ground Elevation (m)	Grade Elevation (m)	Height of Cut (m)	Height of Fill (m)
A	0+000	……	……	……	……
……	……	……	……	……	……


h (m) (1/500)
760,00
750,00
0,36
0,72
1,08
0,19
1,26
2,68
3,10
4,06
4,30
4,94
4,95
3,39
1,84
1,23
4,35
5,90
0,36


730,00
A 1 2 3 4 5 6 K1 H1 M1 TS 7 SC 8 H2 9 B 10 11 12 13 14 15 CS 16 T T1 ST M2 K2 17 18 C
L (m) (1/5000)
764,00 762,97 761,95 760,92 759,81 759,26 758,68 758,45 757,90 757,63 756,82 755,32 754,57 753,82 752,77 751,80 751,08 750,56 750,36 749,89 749,43 749,00 748,36 747,84 747,29 746,84 745,80 744,94 744,29 743,36 742,33 742,56 742,13 741,64
764,00 763,33 762,67 762,00 760,00 758,00 756,00 755,35 753,84 753,33 751,88 750,37 751,18 751,98 754,00 756,15 756,98 756,57 756,00 754,00 752,00 750,00 748,00 746,00 744,91 744,00 743,46 744,01 744,11 744,18 744,02 743,00 742,00 740,00
16,84 16,84 16,84 18,23 8,98 9,51 3,74 9,02 4,37 13,39 24,5 12,25 12,25 17,20 15,86 11,78 8,55 3,27 7,72 7,58 7,04 10,43 8,56 8,97 7,36 17,14 13,82 10,68 13,39 13,39 11,33 13 19,21
00,00 16,84 33,68 50,52 68,75 77,73 87,24 90,98 00,00 04,37 17,76 42,26 54,51 66,76 84,14 00,00 11,78 20,33 23,60 31,32 38,90 45,94 56,37 64,93 73,90 81,26 98,40 12,22 22,90 36,29 49,68 61,01 74,01 93,22
0 1 2 3
0
S= % 6,10
L = 312,22 m
R=2000 m t=81 m


h (m) (1/500)
760,00
750,00
740,00
730,00
L (m) (1/5000)
Pkot = 740 m
Pkm = 0+393 ??
e = 1,64 m
t = 81 m
R = 2000 m
S = % 6,10
L = 312,22 m
R=2000 m t=81 m
L = 117,78 m
L = 70,32 m

Why are the vertical curves constructed?

- It is constructed on the zones which the slope of grade line varies due to decrease of sight distance and traffic safety.
- Vertical curve is done between two grade lines for increasing vertical acceleration due to variation of slope.

Which grade differences are critical to construct the vertical curves?

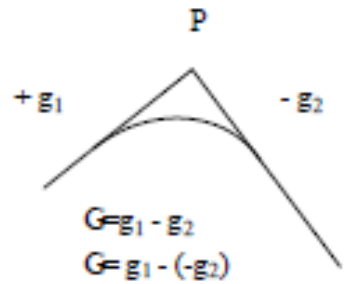
- If grade difference is more than %0.5 on the roads of class 1th , 2th and 3th .
- It is performed on the roads of low standards if grade difference is more than %1.

- The curves placed between different consecutive grade line segments are named as the **vertical curves**.
- •The curves placed as vertical curves are **circle arc** and **2nd degree parabola,** independent of being crest or sag.
- •The first group is named as the **circular vertical curve** and the second group is named as the **parabolic vertical curve**.
- •As the horizontal and the vertical scales are different on the profile, vertical cruves can not be drawn using a compass.
- •The grade elevations for the cross-sections on the vertical curve have to be calculated seperately.
- •The type of the vertical curve is determined with respect to the change of grade between the consecutive grade line, or in other words, according to the algebraic difference between the grades.
- •If the angle between the first grade line and the horizontal line is α, tg α =g_1; If the angle between the second grade line and the horizontal line is β, tg β=g_2.
- •According to the algebraic difference below, a classification is made as a **crest** or **sag** vertical curve.

$$G = g_1 - g_2$$

- On crest vertical curves, the algebraic difference is positive (+), while on sag vertical curves the algebraic difference is negative (-).
- If the absolute value of the algebraic difference between the two consecutive grade lines is more than 0,5%, a vertical curve is placed.
- On low-standard roads, as the comfort is not a priority, if the algebraic difference is below 1%, a vertical curve may not be placed.
- On application, there are 6 types of vertical curves according to the size of g_1 and g_2. Three of them are crest and the other three of them are sag vertical curves.

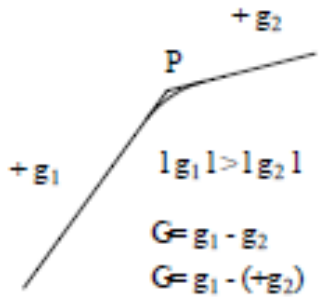
Crest vertical curves



$G = g_1 - g_2$

$G = g_1 - (-g_2)$

$G = g_1 + g_2 > 0$

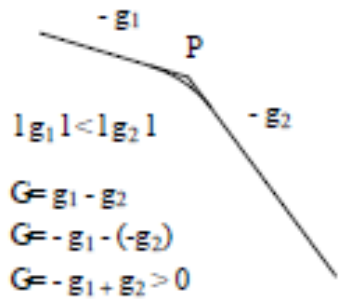


$|g_1| > |g_2|$

$G = g_1 - g_2$

$G = g_1 - (+g_2)$

$G = g_1 - g_2 > 0$



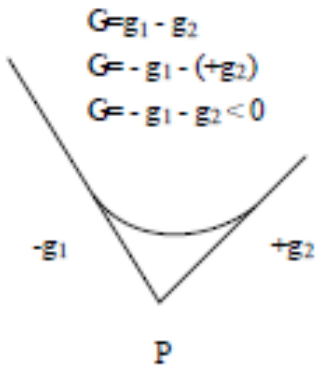
$|g_1| < |g_2|$

$G = g_1 - g_2$

$G = -g_1 - (-g_2)$

$G = -g_1 + g_2 > 0$

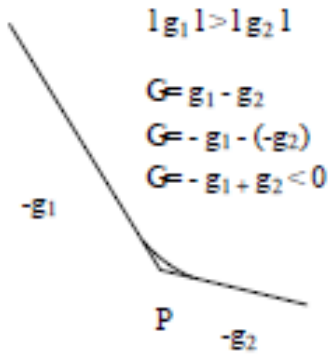
Sag vertical curves



$G = g_1 - g_2$

$G = -g_1 - (+g_2)$

$G = -g_1 - g_2 < 0$

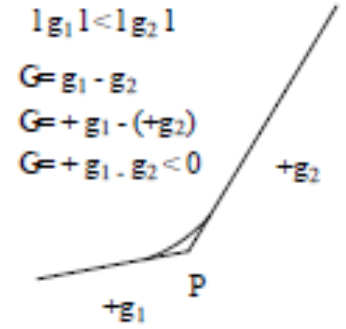


$|g_1| > |g_2|$

$G = g_1 - g_2$

$G = -g_1 - (-g_2)$

$G = -g_1 + g_2 < 0$



$|g_1| < |g_2|$

$G = g_1 - g_2$

$G = +g_1 - (+g_2)$

$G = +g_1 - g_2 < 0$

Circular vertical curves

Another type of the curve that can be placed between the grade lines is a circle arc.

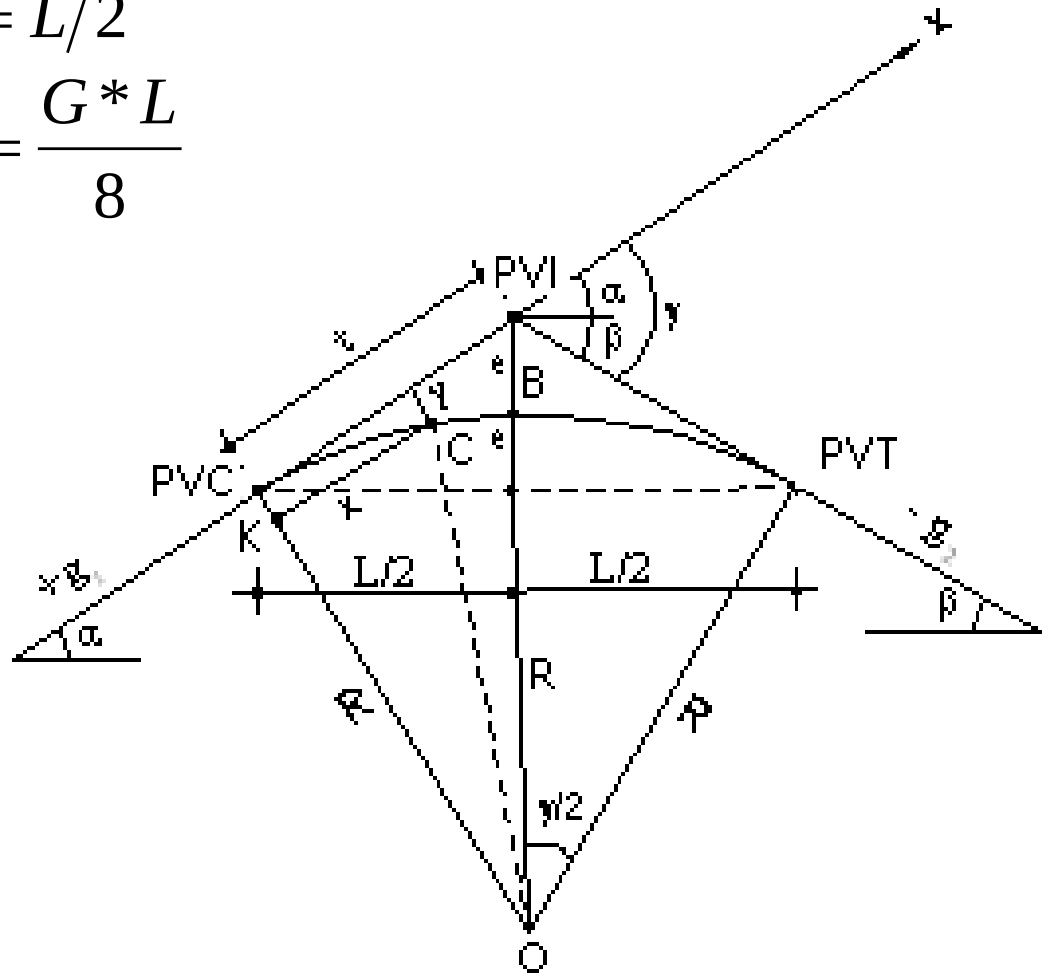
Vertical curves designed using a circle with a radius of R are named as the **circular vertical curves**.

Properties of the circular vertical curves

- Length of the vertical curve: $L = G * R$
- Tangent length of the vertical curve: $t = L/2$
- External distance of the vertical curve: $e = \frac{G * L}{8}$

$$y = k * x^2$$

$$k = \frac{1}{2 * R}$$



Calculation of kilometers of the first and last point of the vertical curve

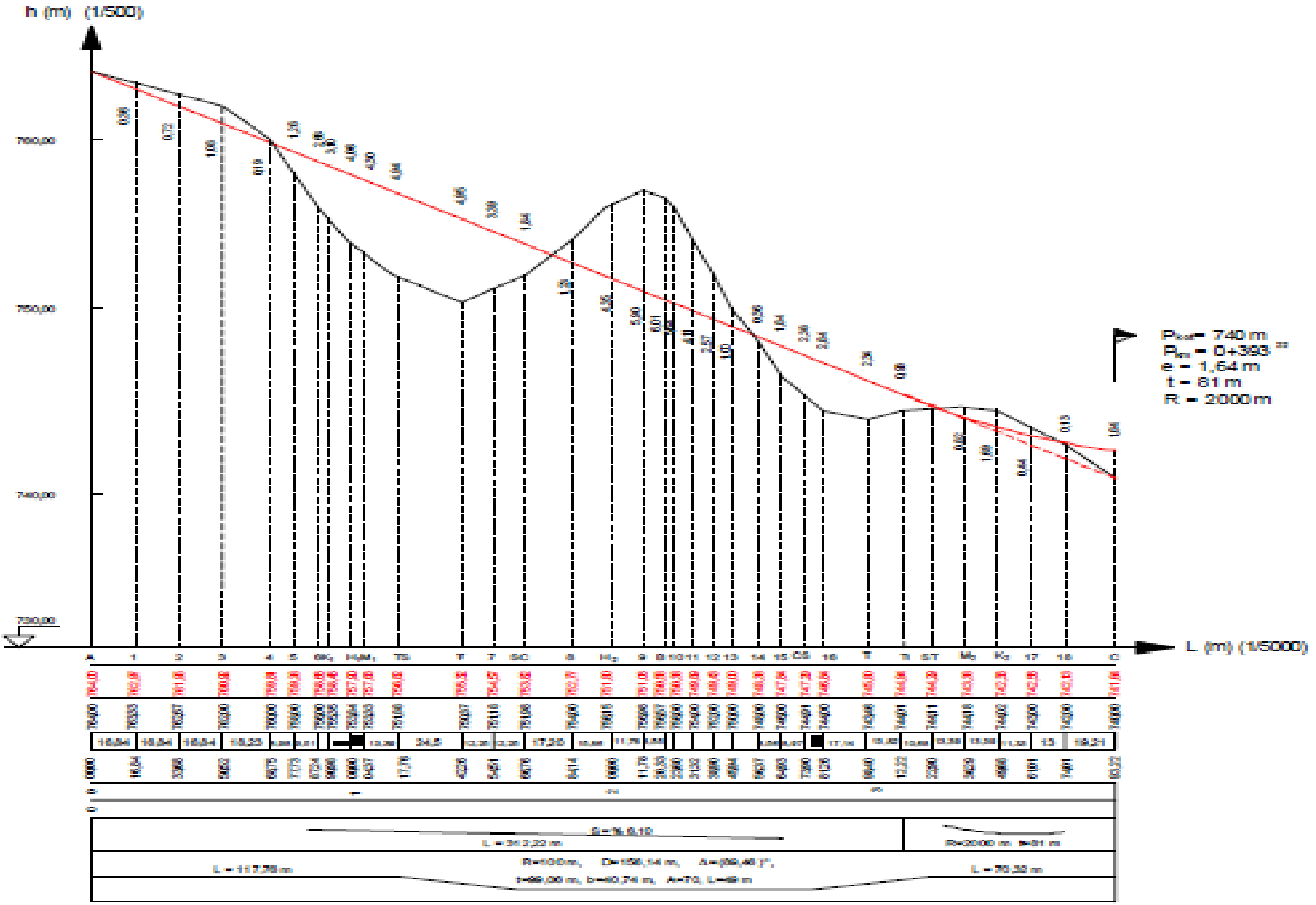
$$PVC_{km} = PVI_{km} - t$$
$$B_{km} = PVI_{km}$$
$$PVT_{km} = PVI_{km} + t$$

Calculation of elevations of the first and last point of the vertical curve

$$PVC_{Elv} = PVI_{Elv} - g_1 * t$$
$$B_{Elv} = PVI_{Elv} \mp e$$
$$PVT_{Elv} = PVI_{Elv} + g_2 * t$$

Calculation of Other Points on The Vertical Curve Using Table

Station	Km	x (m)	$r = g_1 * x$	$PVC_{Elv} \mp r$	$y = k * x^2$	$PVC_{Elv} \mp r \mp y$
PVC						PVC_{Elv}
…						
B		$x = t$		PVI_{Elv}	$y = e$	B_{Elv}
…						
PVT		$x = L$				PVT_{Elv}


h (m) (1/500)
760,00
750,00
740,00
730,00
L (m) (1/5000)
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R=2000 m t=81 m
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L = 70,32 m