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Methodical instructions

for"Engineering geodesy" course work

on the topic

"Drawing profile of the trace"

for Bachelor's degree students

of the field 192

"Civil Engineering"

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Introduction

Geodesy is the science of production measurements on the ground, determining the shape and size of the Earth and images of the earth's surface in the form of maps and plans.

The name of the subject shows that geodesy as a science arose from practical needs. The task of determining the shape and size of the Earth is the subject of higher geodesy.Issues related to represent small parts of the surface in the form of plans are the subject of geodesy or topography. Cartography is a study of methods and processes of creation ofcontinuous images of large areas of the earth's surface in the form of maps. With the development of photographyand especially aviation, photography has been widely used to create plans and maps ofEarth's surface. Photo topography is a section of topographyabout obtaining plans and maps by photographing the terrain of the land from the ground;Aerial photo topography is a section of topography about obtaining plans and maps by photographing the terrain of the land from the air.

Geodesy is developing in close connection with other scientific disciplines. A huge influence on development of geodesy has been made by mathematics, physics and astronomy. Mathematics equips geodesy with methods of analysis and methods of processing of measurement results. Based on physics a lot of optical devices and instruments are designed for geodetic measurements. Astronomy provides the necessary initial data for geodesy. Geodesy also has close relationship with geography, geology, and especially geomorphology. Knowledge of geography provides the correct interpretation of landscape elements, which are: terrain, natural cover of the earth's surface (vegetation, soils, seas, lakes, rivers, etc.). Landforms and patterns of their change are learned using geology and geomorphology.

To properly solve engineering problems students of building specialties should receive: appropriate theoretical training; know modern surveying methods and devices and be able to apply them. The purpose of the proposed guidelines is to assist students in carrying out course work in engineering geodesy.

1. Field work during geodetic tracing

During the construction of linear structures technical documentation which contains the longitudinal and transverse profiles of the trace with complicated design decisions is performing.

Work during tracing of linear structures include: drafting of the project, reconnaissance of traces, placing ofsurvey stakes, levellingof the trace and creating its profile. According to the plans or maps the most probable direction of trace that meets all specifications is indicated. Reconnaissance of rotational angle of the traces has to be done to clarify chosen direction on the terrain. Rotational angle is measured using theodolite. Thrace points are bonded to the state support of altitude location and marks ofwhich are reveal in advance.

Before levelling the trace next steps have to be done: fixing trace beginning and end, finding rotational angles and placing of survey stakes. Placing of survey stakes means that along the axis of the trace segments, horizontal projection of which is equal to 100 m, have to be determined. The end of each segment is called survey stakeand is marked by wooden stake that is hammered in the ground. Near survey stake a special pointer is also hammered, which record the number of survey stake (for example St4). The beginning of the track is called "Survey stake zero" and is marked as St0. Typical terrain breaking points between pickets are also indicated by stakes. These points are called plus-points (St1+80). Their location is determined by passed distance from last survey point (80 m from St1).

In places where trace turns, horizontal circular or transitional curves elements are determined by special tables or using formulas. Vertexes of the turning angles of trace are indicated as VA1, VA2.

Tracing is made using “Serial levelling method” which serves to transfermarks over long distances and to plot the profile of the area (Figure 1.1).

During placing of surveys stakes measurement results are recorded in special surveying journal, in which indicate the values of turning angles of trace, numbers of all survey stakes and plus-points. Trace conventionally portrayed in straightened form, and turning angles are denoted by arrows. In surveying journalis the number of all benchmark and their location, as well as data that describing curves.

Simultaneously with the placing of surveys stakesthe surveying of the areas adjacent to the trace are performed. To characterize the topography of the relief, where construction will be done,placing of surveys stakes for transverse profiles that are perpendicular to the axis of the trace on both sides. Transversal profiles aredetermined at a certain distance from each other that the area between them has the same slope.

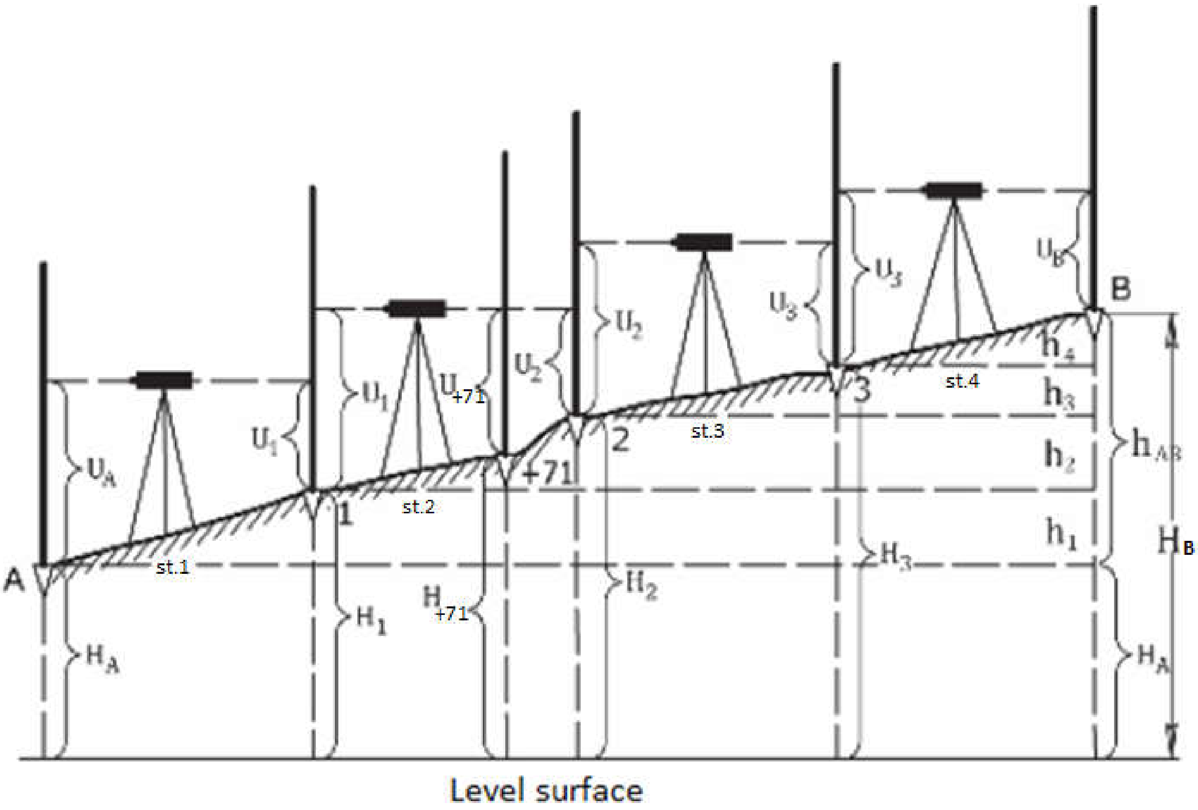


Figure 1.1. Serial levelling

Levellingof the traceis performed using method “Levellingfrom the middle point”shown in the Figure 1.2with next condition: the distances from the survey stakes to levellinginstrument are the same.Levelling instrument can be set on the line that connect two survey stakes or near it. Duringlevellingthe elevation of each subsequent survey stake point over the previous one has to be measured (i.e. among all connecting points). At each station firstly levelling of connecting points has to be completed, what means taking mark of the back and then the front levelling rod. Before taking marks, control of position levels has to be done, i.e. sighting axis of telescope oflevellinginstrument must be horizontal. To control and increase the accuracy of thelevelling the elevation between the connecting points is determined using the second side of levelling rod(if they are bilateral). When working with one-sided levelling rods change of the height of the levelling instrument have to be done for at least 10 cm. Whenlevellingintermediatepoints the marks is taken only from the main side of levelling rods. During levelling the steep slopes when sighting ray in one direction hit the ground, and another - is above the levelling rod, additional connecting point have to be added (“x-point” - X1, X2). There is no need to measure distance to the “x-points”, but their location have to be indicated on the area. As connecting point,plus-points can be used on a steep slope. The beginning and the end of the trace are tied to the closest reference points (benchmarks).

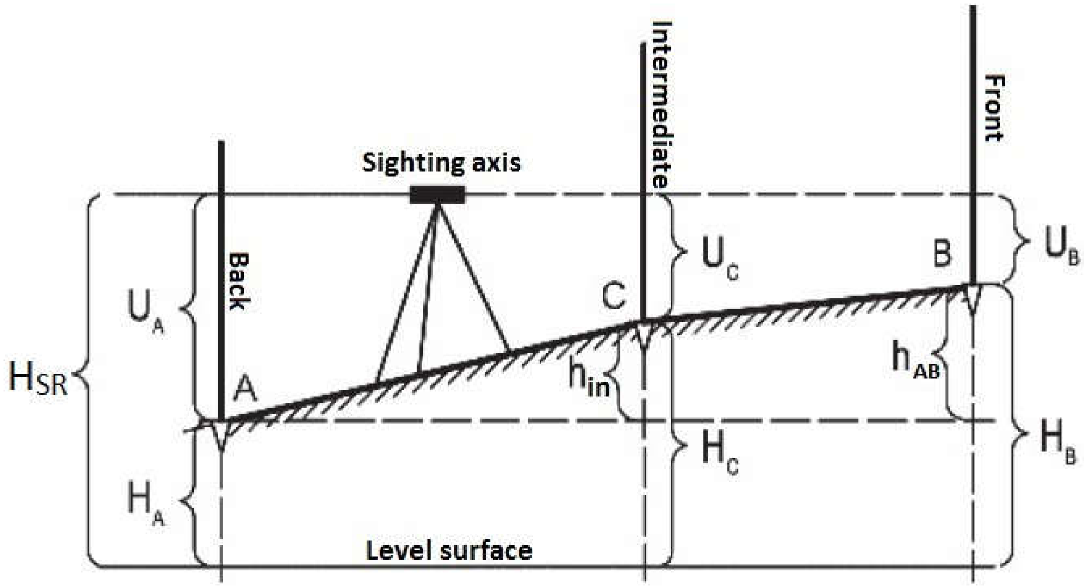


Figure 1.2.Levelling from the middle point

Results of field tracing to perform course work are given in Appendix A.

2. Processing of technical levelling journal

The initial data for the processing of the journal is the results of field tracing presented in the technical levelling journal. (Table 1, columns 3-5)

2.1.Calculation of elevation

Elevation between connecting points can be calculated by next formulas:

$$h' = B_{Bl} - F_{Bl}$$

$$h'' = B_{Red} - F_{Red}$$

Where h' is elevation between connecting points that is determined by black scale (black side) of levelling rod, mm;

$h''$is elevation between connecting points that is determined by red scale (red side) of levelling rod, mm;

$B_{Bl}$is mark of back point that is taken from black side of levelling rod, mm;

$B_{Red}$is mark of back point that is taken from red side of levelling rod, mm;

$F_{Bl}$is mark of front point that is taken from black side of levelling rod, mm;

F_{Red}ismark of front point that is taken from red side of levelling rod, mm.

Table 1.Technical levelling journal

№Station	№Point	Marks of levelling rod, mm			Elevation, mm		Averageelevation, mm		Height of sighting axis, m	Height, m	
		Back	Front	Intermediate	+	-	+	-		H=0,001	H=0,01
1	2	3	4	5	6	7	8	9	10	11	12
1	Rp №1	2860					2			123,123	123,12
		7523			1465		1466				
			1395		1466						
	St0		6057							124,591	124,59
2	St0	2758					2			124,591	
		7441			2010		2011				
			748		2012						
	St1		5429							126,604	126,6
3	St1	620						2		126,604	
		5304				2130		2130			
			2750			2130					
	X		7434							124,476	124,48
4	X	809						2		124,476	
		5494				1756		1757			
			2565			1757					
	St1+80		7251							122,721	122,72
5	St1+80	2875					2			122,721	
		7560			2350		2351				
			525		2352						
	St2		5208							125,074	125,07
6	St2	125							125,199	125,074	
		1981				2825		2			
	St2+70			2015				2827		123,184	123,18
			2950			2829					
	St3		4810							122,249	122,25

7	St3	2888					2			122,249	
		7573			2222		2221				
			666		2220						
	St4		5353							124,472	124,47
8	St4	2987							127,459	124,472	
		7578									
	rightside										
	20			512			2			126,947	126,95
	11			978	2789		2790			126,481	126,48
	leftside				2791						
	10			1654						125,805	125,81
	20			2345						125,114	125,11
			198								
	St5		4787							127,264	127,26
9	St5	2468					2			127,264	
		7149			1234		1232				
			1234		1230						
	St6		5919							128,498	128,5
10	St6	662						2		128,498	
		5347				753		754			
			1415			755					
	Rp №2		6102							127,746	127,75
		82002	72796		24141	14935	12071	7468		4623	
		4603			4603		4603				
										20	

Difference between elevations ($h'$and h'') calculated by black and red scale should not exceed ±5 mm. If elevation is positive then it has to be written in column 6. If elevation is negative then it has to be written in column 7. All numbers in column 6 and 7 have to be positive.

Average elevation (mm) can be calculated by next formula:

$$h_{av} = \frac{h' + h''}{2}$$

If the ending of average elevation is 0.5 then it have to be round to higher or lower value. // *Example: 112.5 have to be round to 112 or 113.*

Calculated average elevations have to be written in column 8 and 9 depending on their sign. If elevationsh' and h'' are in column 6 then average elevation will be in column 8 respectively. If elevations h' and h'' are in column 7 then average elevation will be in column 9 respectively.

2.2. Control of calculation of received field data

Control of the correctness of calculations technical levelling journal can be made using next formula,mm.

$$\frac{\sum B - \sum F}{2} = \frac{\sum h}{2} \sim \sum h_{av}$$

Where $\sum B$ is sum of all back points marks from black and red side (sum of all numbers in column 3), mm;

$$\sum B = \sum B_{Bl} + \sum B_{Red}$$

$\sum F$is sum of all front points marks from black and red side (sum of all numbers in column 4), mm;

$$\sum F = \sum F_{Bl} + \sum F_{Red}$$

$\sum h$isalgebraic sum of all elevation (sum of all numbers in column 6subtracted by sum of all numbers in column 7), mm;

$\sum h_{av}$is algebraic sum of all average elevation (sum of all numbers in column 8 subtracted by sum of all numbers in column 9), mm.

If the amount of numbers is huge it can be divided into smaller parts.

2.3. Determination of residual distance receiving during levelling and its distribution

All measurements are received with certain accuracy, that's why residual distance can occur. Residual distance can be determined by next formula:

$$f_h = \sum h_{av} - \Delta h_T$$

Where $\sum h_{av}$ is algebraic sum of all average elevation (look previous chapter), mm;

$\Delta h_T$is theoretical elevation, mm;

$$\Delta h_T = H_{Rp2} - H_{Rp1}$$

Where H_{Rp1}, H_{Rp2} are heights of reference points 1 and 2 respectively, m. // *It's important to remember that units of* Δh_T*and* H_{Rp1}, H_{Rp2} *are different. So "m" has to be transformed into "mm".*

In the project marks of the reference pointshave to be taken according with you variant.

The resulting residual distancemust not exceed the maximum allowable residual distance of levelling equipment, which is determined by the formula, mm:

$$f_{h,al} = 50 \cdot \sqrt{L}$$

If the amount of station is more than 25 per 1 kilometer, then the maximum allowable residual distance of levelling equipment have to be calculated using next formula:

$$f_{h,al} = 10 \cdot \sqrt{L}$$

Where L is distance between first (St0) and last survey stakes taken in kilometers.

If the actual residual distance is not greater than allowable residual distance:

$$f_h \leq f_{h,al}$$

thencorrections have to be added into the average elevationswhich are determined by next formula, mm:

$$\delta = \frac{f_h}{n}$$

Where n is amount of station.

Corrections are distributed equally to all the average elevations. The sum of all corrections must be equal to residual distance but with opposite sign. Corrections should be written on top of the value of average elevation in the table in columns 8 and 9.

If the actual residual distance is greater than allowable residual distance then big mistake was made in calculation of elevationor in field surveying. Huge mistakes are corrected by redoing field works.

2.4.Calculation of heights of connecting points

Heights of connecting points are calculated sequentially starting from the first point (station) using next rule: Height of next point is equal to height of current point plus the corrected elevation between them, m:

$$H_1 = H_{Rp1} + h'_1$$

$$H_n = H_{n-1} + h'_n$$

Where H_{Rp1} is height of reference point 1, m;

$H_1$is height of first point, m;

$H_n$is height of next point, m;

$H_{n-1}$is height of current point, m;

h'_1andh'_n are corrected elevation that is equal to calculated elevation plus correction, m:

$$h'_n = h_n + \delta_n$$

Where h_n is average elevation for point n, m; δ_n is correction for point n, m. // *It's important to remember that units of* h_n*and* δ_n *in table is "mm". So it has to be transformed into "m". Correction has to be added to the values in column 8 and 9. Notice that elevation in column 9 is negative.*

Calculated by previous equations heights of connecting points should be written in column 11 in corresponding row. Control correctness of calculations of heights isthat obtained height of the second reference point is equal to the given in the variant.

Heights of intermediate points are calculated using height of sighting axis by next equation, m:

$$H_{SR} = H_A + a$$

$$H_C = H_{SR} - c$$

Where H_A is height of current point A, m;

$H_{SR}$is height of sighting axis, m;

$H_C$is height of intermediate point C, m

a is mark of current point A that is taken from black side of levelling rod, m;

c is mark of intermediate point, m.

Height of sighting axis is written in column 10 in the table 1 in a row that corresponds to connecting point A. Heights of intermediate points is written in corresponding rows in column 11 in table 1. // *It's important to remember that units of* a, c *and* H_A, H_{SR}, H_C *are different. So "mm" has to be transformed into "m".*

3. Calculation of main elements of the curve

Initial data for determining the elements of the curve are angle of rotation $\varphi$and radius R (Figure 3.1). To perform the calculation for course work the angle of rotation and radius is taken in accordance to variant fromAppendix B. // *It's important to remember that units of φ is degrees with minutes that have to be transformed into degrees only.*

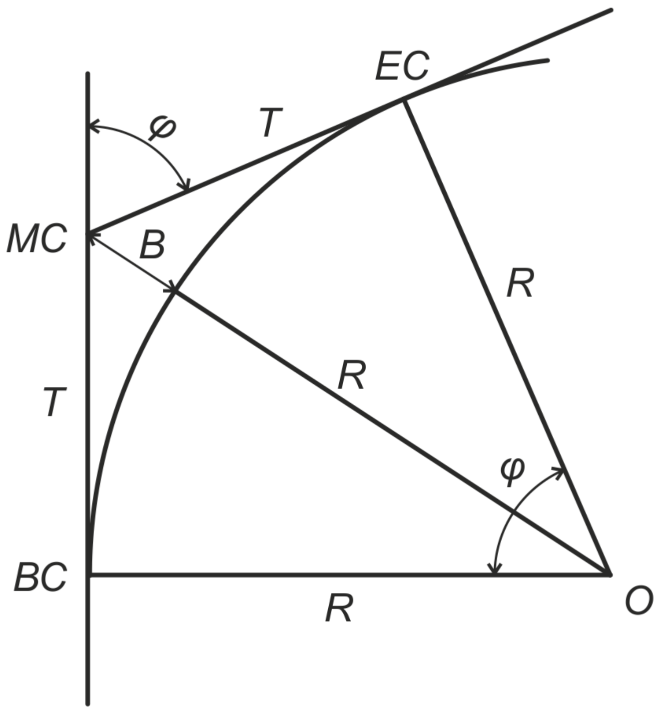


Figure 3.1.Curve

Elements of the horizontal circular curve are calculated by next formulas:

- Length of the tangent, m

$$T = R \cdot \tan\frac{\varphi}{2}$$

- Length of the curve, m

$$C = \frac{\pi \cdot R \cdot \varphi}{180}$$

- Additional length, m

$$A = 2 \cdot T - C$$

- Bisector, m

$$B = R \cdot \left(\frac{1}{\cos\frac{\varphi}{2}} - 1\right)$$

The beginning and end of the curve is determined by next dependence:

$$BC = MC - T$$
$$EC = MC - T + C$$

Control correctness of calculation is performed by next formula:

$$EC = MC + T - A$$

Where BC – beginning of the curve, m;

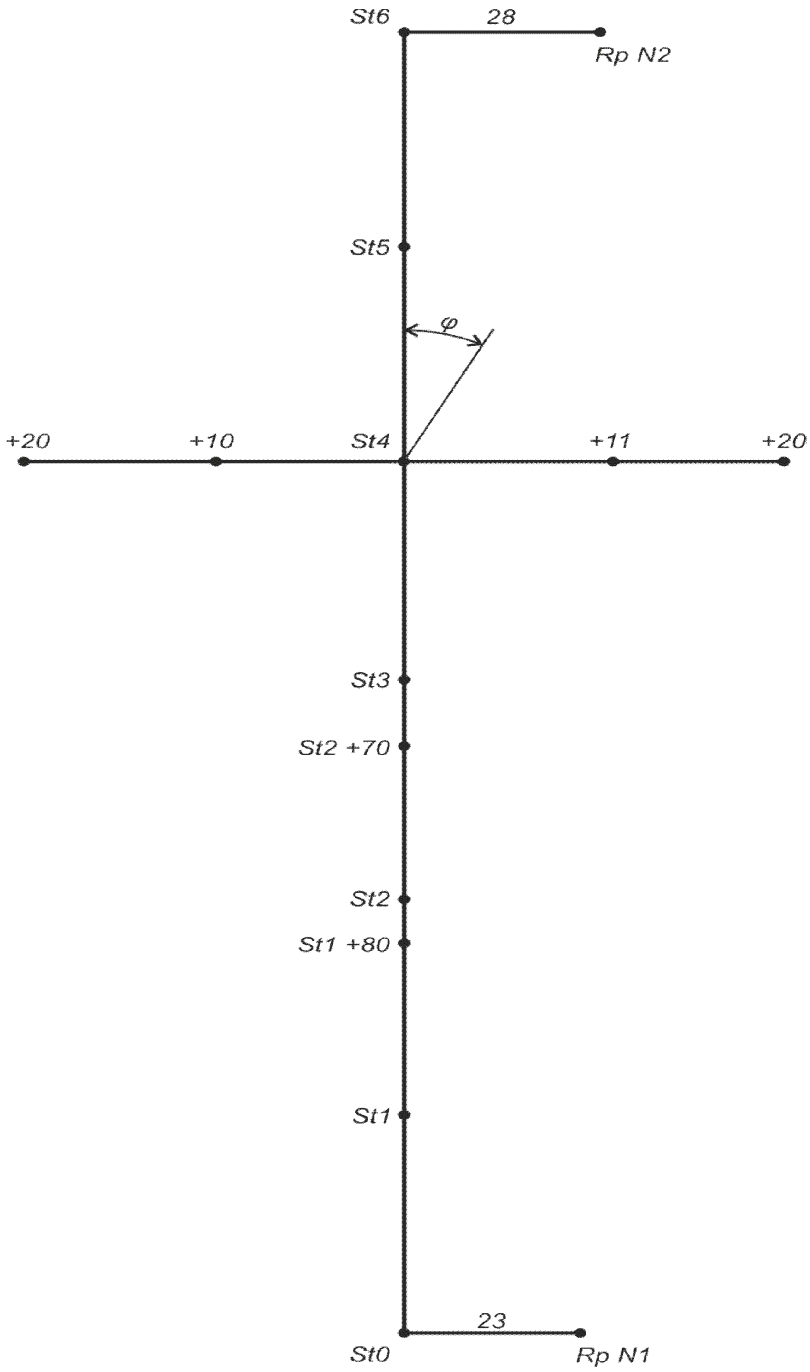
EC – end of the curve, m;

MC – distance from the beginning of trace to the point for angle of rotation, m.

// If the values for EC are different it means that some mistake was made during calculation.

If you are going to round some values you can round it to the number with at least two digits after coma.

The results of calculation of main elements of the curve are written in a specific order in field surveying book (Figure 3.2).



$\varphi = 37°45'$

R = 100 m

T = 34,19 m

C = 65,89 m

B = 5,68 m

A = 2,49 m

Figure 3.2.Field surveying book

Directional angel of final direction and its rhumb can be determined using directional angle of prime direction of the trace and angle of rotation of the trace (taking the direction of rotation as right one).

$$\alpha_F = \alpha_0 + \varphi$$

Where α_0 is directional angle of prime direction;

$\alpha_F$is directional angle of final direction;

$\varphi$is right angle of rotation.

4. Drawing of longitudinal and transversal profile of the trace

Longitudinal and transversal profiles of the trace as graphical models of the terrain along the route of linear structure are justification of geodetic calculations when designing the profile of the trace. Longitudinal and transversal profiles of the traceare drawing using materials of field surveying bookand technical levelling journal.

4.1.Drawing of longitudinal profile of the trace

Longitudinal profile of the trace has to be made on graph paper using next scales: horizontal - 1:2000; vertical - 1:200. Drawing has to be made in the following order:

1. At the bottom grid line system has to be plottedwith next information:“number of point”, “height of point”, “distances”, “plan of lines and curves”. Information must correspond to the one from Technical levelling journal.
2. All survey stakes have to be plotted in a given horizontal scale of 1: 2000 and raw of“distances” should be fill. The distance to the plus-points has to be written. Record of distance between 2 survey stakes (100 m) is optional.
3. The row “height of point” has to be filled according to the Technical levelling journal (table 1, column 12).
4. In the row “plan of lines and curves”direction and lengths of the individual straight sections of the trace are determined;locationsof curves are indicated and curve parameters are determined according to the performed calculations. Curves that turns right from the direction of the trace are indicated as convex upward from the line of the trace. Curves that turn left from the direction of the trace are indicated as convex downward from the line of the trace.
5. Using “height of point” and “distances” the profile of the trace is plotted. The height of the points is set upwards from the line of the conditional horizonH_A, which is chosen depending from the value of the minimal actual mark (minimal height of all points)H_{min}, m.

$$H_A = H_{min} - 8$$

The resulting value of the height of the conditional horizon is rounded to a value with m only. Vertical graphical scale is drawn on the left side of the profile, which simplify total drawing. Positions of benchmarks are shown above the profile line.

An example of drawing of a longitudinal profile is shown in the figure.

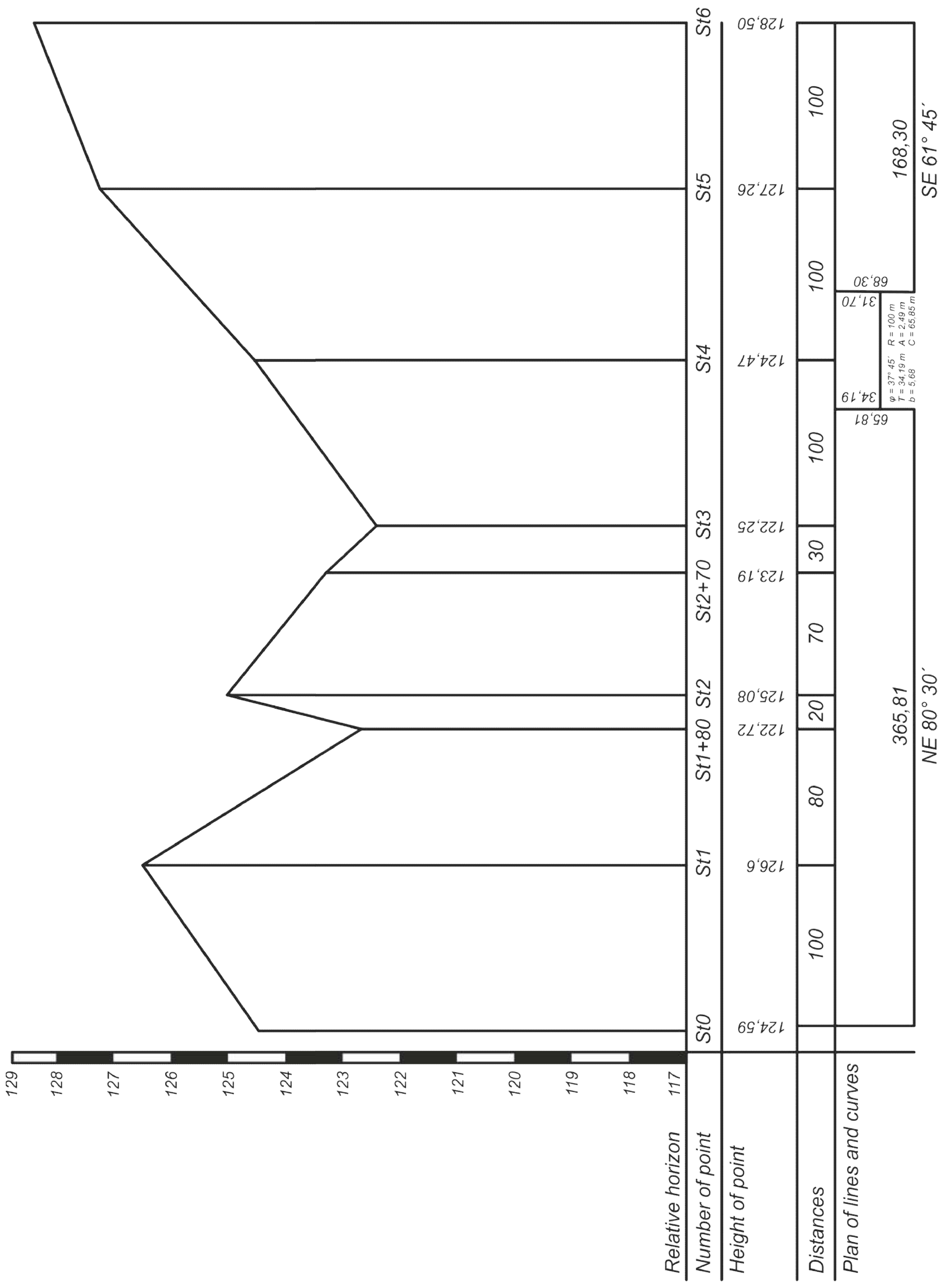


Figure 4.1.Longitudinal profile of the trace of linear structure

Scales: horizontal: 1:2000

vertical: 1:200

4.2.Drawing transversal profile of the trace

Transverse profile is plotted in the same horizontal and vertical scales of 1: 500. The actual marks (heights) and distances are indicated in the bottom of the profile. Horizontal distances are determined in accordance with Table 1 column 2, and laid down to the left and to the right of the vertical segment defining the axis of the trace. Actual marks are determined from the technical levellingjournal (column 12). The line of the surface of the earth of the transverse profile is constructed according to actual marks relative to the conditional horizon, which are taken the same as for the longitudinal profile. An example of a transverse profile is shown in Figure 4.

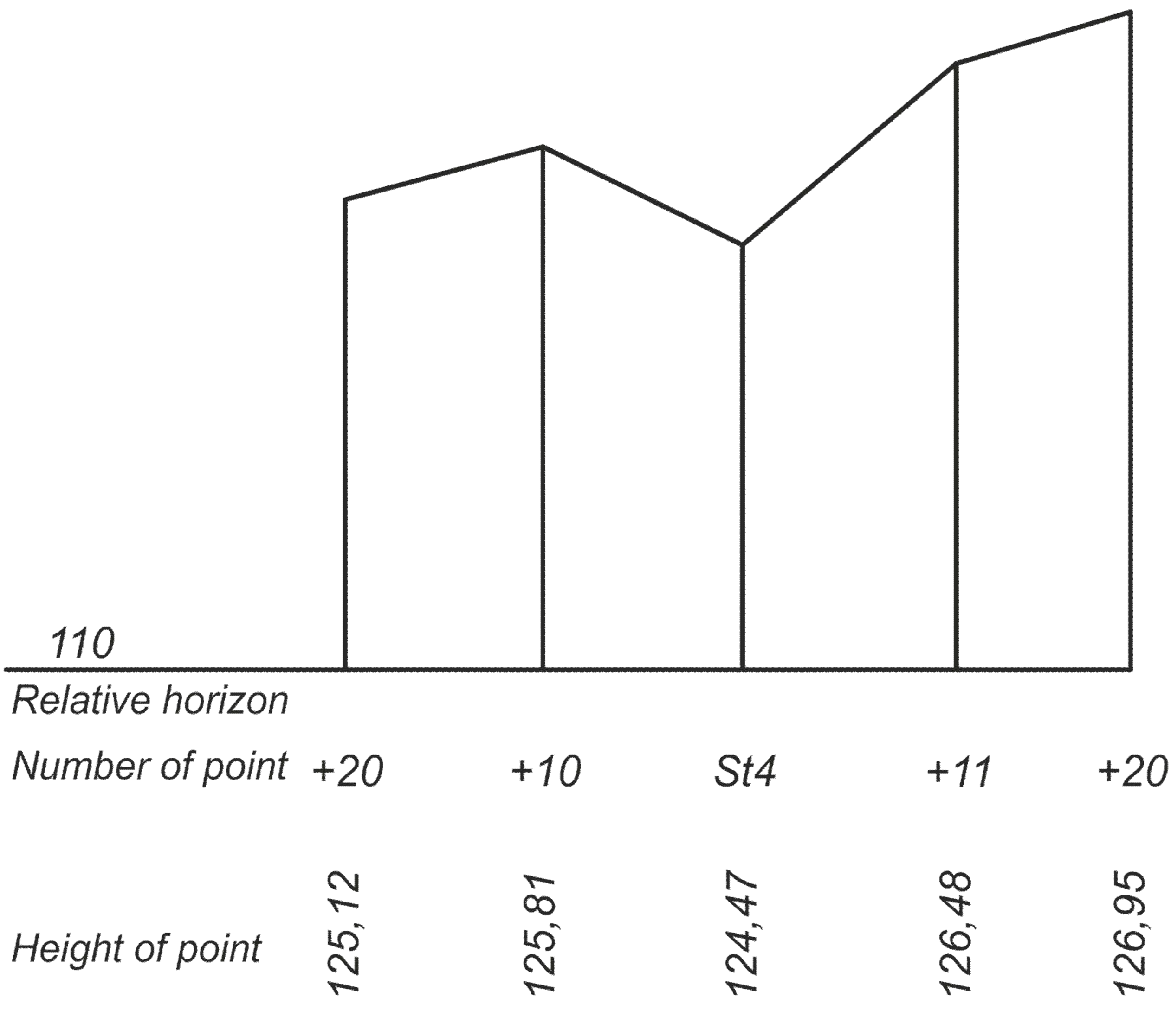


Figure 4.2.Transversal profile for St4

Scales: horizontal: 1:500
vertical: 1:500

5. Control questions

1. Types of field works.
2. Levelling from the middle.
3. Processing of technical levelling journal.
4. Control of the data in technical levelling journal.
5. Calculation of the element of the curve.
6. Drawing order for longitudinal and transversal profile of the trace.

Appendix A

Technical leveling journal

№Station	№Point	Marks of levelling rod, mm			Elevation, mm		Average elevation, mm		Height of sighting axis, m	Height, m	
		Back	Front	Intermediate	+	-	+	-		H=0,001	H=0,01
1	2	3	4	5	6	7	8	9	10	11	12
1	Rp №1	2772									
		7460									
			1419								
	St0		6104								
2	St0	2626									
		7313									
			836								
	St1		5523								
3	St1	806									
		5491									
			2803								
	X		7489								
4	X	1084									
		5769									
			2696								
	St1+80		7382								
5	St1+80	2772									
		7454									
			577								
	St2		5262								
6	St2	218									
		4903									
	St2+70			1987							
			2888								
	St3		7573								
7	St3	2899									
		7578									
			536								
	St4		5218								
8	St4	2867									
		7554									
	right side										
	20			448							
	11			888							
	left side										
	10			1556							
	20			2232							
			189								
	St5		4874								
9	St5	2442									
		7122									
			1110								
	St6		5795								
10	St6	1234									
		5919									
			2060								
	Rp №2		6745								

Appendix B

Variants for course work: values of benchmarks, angle of rotation, radius of the curve, directional angle of prime direction

Variant №	Heightofbenchmarks, m		Angle of rotation of the trace φ, (degrees, minutes)	Radius of the curve R, m	Directional angel of prime direction α, (degrees, minutes)
	RP №1	RP №2			
1	129,921	134,544	32°20'	130	80°10'
2	134,134	138,758	33°45'	120	35°55'
3	128,123	132,748	40°40'	150	33°53'
4	124,456	129,082	57°10'	140	47°07'
5	129,987	134,614	56°00'	150	56°06'
6	127,89	132,518	55°55'	130	65°05'
7	138,78	143,409	60°01'	120	28°15'
8	136,631	141,251	54°40'	120	29°40'
9	133,113	137,734	56°00'	150	30°30'
10	137,731	142,353	29°55'	150	15°15'
11	131,131	135,754	30°05'	150	28°28'
12	125,987	130,611	33°30'	140	39°40'
13	138,891	143,516	26°00'	130	40°39'
14	112,234	116,86	31°40'	150	41°41'
15	127,765	132,392	59°00'	150	55°55'
16	135,531	140,159	43°20'	160	27°55'
17	101,101	105,73	30°30'	120	15°15'
18	117,117	121,737	44°15'	120	22°10'
19	121,121	125,742	49°14'	120	24°45'
20	118,811	123,433	31°25'	130	15°45'
21	119,927	124,55	38°45'	110	20°20'
22	116,612	121,236	41°00'	110	56°18'
23	113,113	117,738	40°50'	110	48°45'
24	127,127	131,753	36°10'	120	24°10'
25	119,222	123,849	31°15'	120	60°50'

Appendix B (cont.)

Variant №	Heightofbenchmarks,m		Angle of rotation of the trace φ, (degrees,minutes)	Radius of the curve R, m	Directional angel of prime direction α, (degrees, minutes)
	RP №1	RP №2			
26	126,621	131,249	35°50'	140	68°00'
27	128,128	132,757	47°30'	130	64°25'
28	116,678	121,298	46°45'	130	66°10'
29	114,456	119,077	51°15'	130	70°40'
30	125,521	130,143	53°45'	140	77°07'
31	121,999	126,622	52°30'	130	79°30'
32	134,14	138,764	33°45'	120	235°55'
33	128,13	132,755	40°40'	150	133°53'
34	124,464	129,09	57°10'	140	147°07'
35	129,996	134,623	56°00'	150	256°06'
36	127,9	132,528	55°55'	130	165°05'
37	138,791	143,42	60°01'	120	128°15'
38	136,643	141,263	54°40'	120	129°40'
39	133,126	137,747	56°00'	150	130°30'
40	137,745	142,367	29°55'	150	215°15'
41	131,146	135,769	30°05'	160	128°28'
42	126,003	130,627	33°30'	120	139°40'
43	138,908	143,533	26°00'	120	140°39'
44	112,252	116,878	31°40'	120	141°41'
45	127,784	132,411	59°00'	130	155°55'
46	135,551	140,179	43°20'	110	127°55'
47	101,122	105,751	30°30'	110	115°15'
48	117,139	121,759	44°15'	110	122°10'
49	121,144	125,765	49°14'	140	224°45'
50	118,835	123,457	31°25'	150	145°45'

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For notes