MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

O. M. BEKETOV NATIONAL UNIVERSITY
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Methodological guidelines
for laboratory classes and independent work
on the subject

“FUNDAMENTALS OF GEODESY”

(for students of first (bachelor's) education level of specialty 191 –Architecture and Urban Planning)

Kharkiv – O. M. Beketov NUUE – 2021

Methodological guidelines for laboratory classes and independent work on the subject “Fundamentals of Geodesy” (for students of first (bachelor's) education level of specialty 191 – Architecture and Urban Planning) / O. M. Beketov National University of urban economy in Kharkiv; com. : M. O. Pilicheva, L. O. Maslii. – Kharkiv : O. M. Beketov NUUE, 2021. – 69 p.

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Recommended by the department of land administration and geoinformation systems of O. M. Beketov National university of urban economy in Kharkiv, record № 7 on 05.02.2021.

CONTENT

INTRODUCTION

The discipline «Fundamentals of Geodesy» belongs to the compulsory discipline of specialty 191 – Architecture and Urban Planning, which studies the methods, instruments and techniques of geodetic surveying, production of topographic materials and solving various tasks on maps and plans. Modern planning of settlements, design and construction of various engineering buildings are required from students to know the fundamentals of geodesy. Future specialists in the field of architecture and urban planning must have geodetic training, to know geodetic instruments, have an idea of geodetic surveying and solve geodetic tasks in the process of designing and planning of settlements.

The purpose of studying the discipline is to teach students:

- to understand the content of topographic maps, plans and profiles;
- to be able to solve geodetic tasks on them;
- to know the structure of geodetic instruments;
- to do the geodetic surveying.

In the methodical guidelines for laboratory classes and independent work on the discipline "Fundamentals of Geodesy" for each stage of laboratory class are given detailed explanations, basic diagrams and figures. Theoretical material, necessary formulas and calculation methods are presented for improvement of the perception, systematization and assimilation of the information. There are questions for student's independent work at the end of each laboratory class.

LABORATORY CLASS №1
Measurements on the topographic plan

The purpose of the class. Get acquainted with the scale and their accuracy. Explore the measurements and drawing of line lengths on the plan. Learn to determine the rectangular coordinates of points, measure the directional angles of given lines.

Equipment and implements. Dividers, drawing ruler, geodetic protractor, topographic plan of scale 1: 2000, pencil 2T, form for laboratory class №1.

THEORETICAL MATERIAL

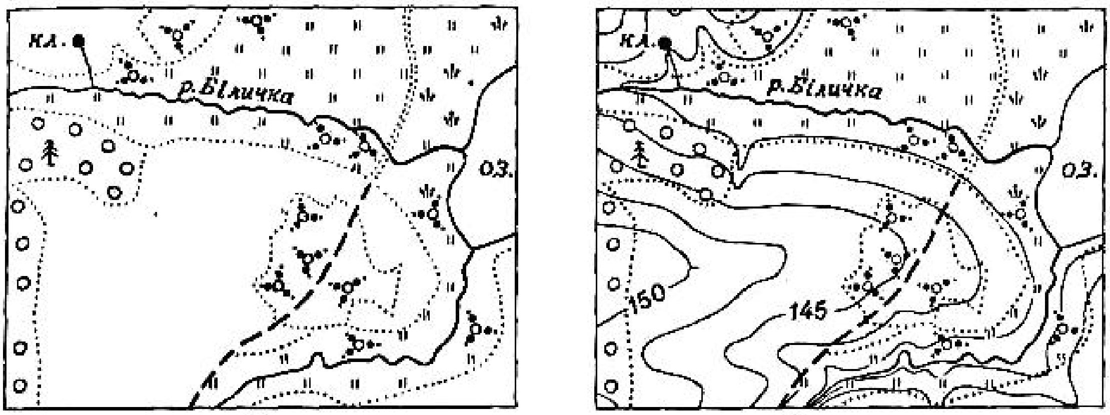
1 Scales and their types. Scale accuracy

The physical surface of the Earth is quite complex, it is depicted on plans and maps for solving of practical and engineering tasks.

The ***plan*** is a reduced similar image of a small (≈ 40 km^2) area with preservation of similarity of a situation and a relief forms without taking into account curvature of the Earth.

Plans are divided into:

- contour –only the boundaries of different lands are depicted (forest, swamp, etc.);
- situational – only objects of the area (buildings, roads, etc.) are depicted;
- topographic –the contours, objects of the situation and the relief are depicted (fig. 1.1).



а *б*

Figure 1.1 – Plans:
a) – contour; b) – topographic

Topographic plans of scales 1: 5000 – 1: 2000 are used in the development of master plans of cities, complex technical projects of engineering structures, design of railways, roads, canals, etc., scales 1: 1000 – 1: 500 – in the development of working drawings for details of building elements, geodetic marking of engineering structures.

Horizontal projections of lines on the ground cannot be plotted on paper in full size, so usually the objects of the terrain are plotted on a map, plan, profile, with are reduced to the appropriate scale.

The ***scale of a topographic map or plan*** is the ratio of the length of a line on a map or plan to the corresponding horizontal projection of this line on the ground.

Scales are expressed in ***numerical, linear and named forms.***

The ***numerical scale*** is expressed as a simple fraction 1:M or $\frac{1}{\mathrm{M}}$. The number M indicates in how many times the terrain lines or the dimensions of the structures on the plan are reduced. It should be noted that the scale is a dimensionless quantity, for example, for a scale of 1: 1000, if the measurement is made in mm, then one millimetre on the plan corresponds to 1000 mm on the ground; if the measurement is made in cm, then one centimetre on the plan corresponds to 1000 cm on the ground, etc. The numerical scale allows to easily determining the length of the line on the ground, if you know its length on the plan, and vice versa. The basic formulas for determining the lengths of lines in the scale are derived from formula 1.1 and have the following form:

$$\frac{1}{\mathrm{M}} = \frac{s}{D}, \tag{1.1}$$

$$D = s \times M, \tag{1.2}$$

$$s = \frac{D}{M}. \tag{1.3}$$

where M – scale denominator of the plan;

s – length of line on the plan;

D – horizontal projection of the line on the ground.

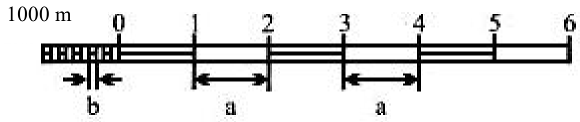
The ***named scale*** is signed under the numerical (fig. 1.2) and indicates the length of the horizontal laying on the ground, which corresponds to 1 cm on the map or plan. For example, for a scale of 1: 2000, under the south side of the frame of the topographic plan the signature «in 1 centimetre – 20 meters» is made.

The ***linear scale*** is a segment that is represented as a line divided into equal intervals a, with are called the base of the scale.

To the left and right from the beginning of the reference «0» the segments a – the basis of the scale, which equals to two centimetres, are laid. The left base of the line is divided into ten or twenty parts. Each division of the linear scale is digitized according to the scale of the map or plan. The linear scale is displayed under the southern frame of the topographic plan or map and is used to measure or plot the lengths of the lines with dividers without performing arithmetic operations (fig. 1.2).

1 : 100 000 — ***numerical scale***

on 1 centimetre – 1 kilometre — ***named scale***



linear scale

Figure 1.2 – Forms of scale on plans and maps

The most accurately length of the line between points on the topographic plan (map) can be determined using a scale ruler (metal plate), which is applied to the transverse scale.

The ***transverse scale*** is a graphical scale in the form of a nomogram, the construction of which is based on the proportionality of segments of parallel lines, with intersect the sides of the angle.

It is drawn as follows. On the line *MM* several times the basis of the scale length of 2 cm is laid and from the obtained points perpendiculars are built up. The ends of the bases are signed in the same way as in the construction of a linear scale, starting from point 0. On the extreme perpendiculars at points *M* and *M* equal segments (for example, 2 mm) are laid up 10 (m = 10), through which straight parallel lines *MM* are drawed.

The first base (left from zero) is divided on the lower and upper lines into 10 equal parts (divisions n = 10), which are connected in series: the beginning (0) of the lower division with the end of the first division on the upper line *NN*, etc. The transverse scale, in which the base a=2 cm and m=n =10, is called cellular or normal (fig. 1.3).

The smallest division of this scale is determined from the similarity of triangles, which is equal to: $\frac{a}{n\times m}=\frac{a}{100}$.

The accuracy of measuring of distances on a topographic plan or map using a dividers and a transverse scale does not exceed 0.1 mm, because the naked eye can recognizes segments at least 0.1 mm long. This segment corresponds to the diameter of the needle pricking made with a sharp needle on a sheet of paper. The value of

0.1 mm is called the ***maximum graphical accuracy*** of measurements, and the value of the line of horizontal laying on the ground, which equal to 0.1 mm on the plan or map is called the ***maximum accuracy of the scale***. Thus, the maximum accuracy of the scales 1: 500, 1: 1000, 1: 2000 and 1: 5000 is equal to 0.05, 0.1, 0.2 and 0.5 m, respectively.

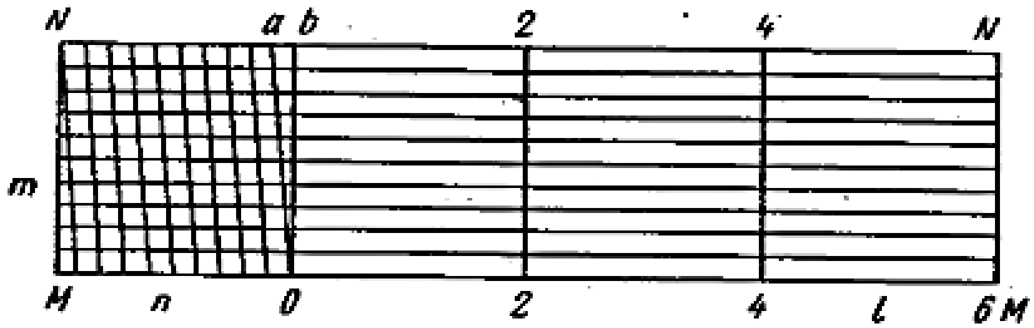


Figure 1.3 – Transverse scale

The accuracy of determining the distance on the topographic plan is equal to twice the maximum accuracy of the scale.

The transverse scale is used in solving of engineering and geodetic tasks in determining of distances on a topographic plan or a map of a specific scale.

2 Rectangular coordinates

Flat rectangular coordinates are a coordinate system, which consists of two perpendicular lines: the X-axis and the Y-axis. They divide the plane into quarters (fig. 1.4).

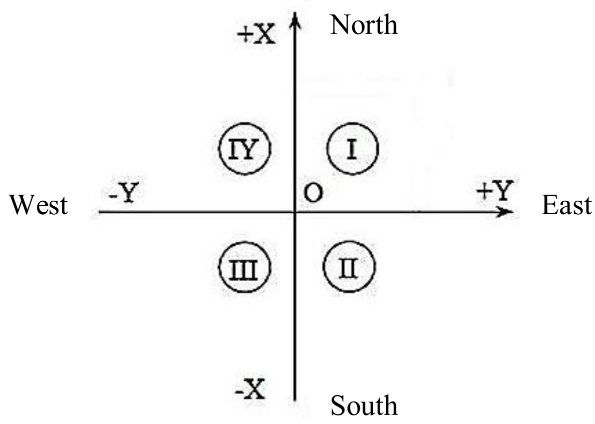


Figure 1.4 – Flat rectangular coordinates

In this system, the plane that coincides with the plane of the horizon at point 0, is the origin. The *X*-axis is coincided with the direction of the axial meridian that passing through the origin, or the direction which is parallel to this meridian. The *Y*-axis passes through the point «0» perpendiculary to the X-axis (fig. 1.4).

In a flat rectangular coordinate system the area at the point 0 is divided into four quarters, which are counted clockwise. The directions of the axes from the origin are assigned to the north and east by a «+», and to the south and west - «-».

For example, the position of point A is determined by the abscissa X and the ordinate Y, namely the segments of the corresponding axis from the origin to the base of the perpendicular, which is lowered from point A to the X-axis and Y-axis (fig. 1.5).

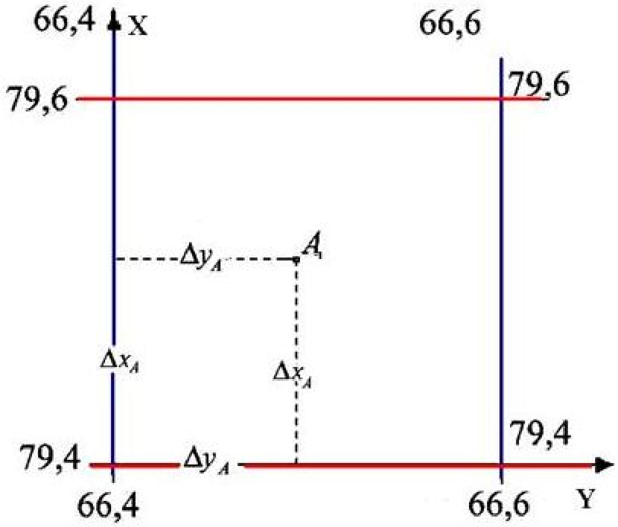


Figure 1.5 – The scheme of determining the rectangular coordinates of point A

3 Directional angles

When you use topographic plans or maps, directional angles are applied for orientation of the lines. The initial direction is the direction of the axial meridian of the zone or line that parallel to it.

Directional angle is the horizontal angle between the north direction of the X-axis or a line, that parallel to it, to the direction of this line, calculated by clockwise.

Depending on the location of the line on the ground, the directional angles can be ranged from 0º to 360º. There are ***forward*** and ***reverse*** directional angles, which are different by 180º (fig. 1.6).

If the directional angle α_{AB} of the direction AB is called direct, and α_{BA} for the direction BA is reverse, then

$$\alpha_{AB} = \alpha_{BA} \pm 180^{\circ}. \quad (1.4)$$

It should be noted that relation (1.4) is valid for all points of this line and is independent from which directional angle is taken as the forward and which as the reverse.

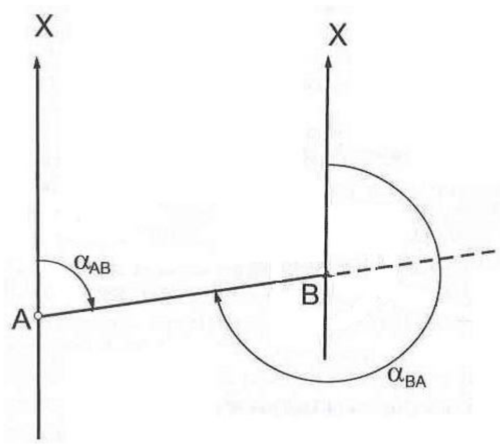


Figure 1.6 – Direct and reverse directional angles

THE ORDER OF WORK IMPLEMENTATION

1 Measurement and plotting of line lengths

1.1 Determining the length of the horizontal laying line on the ground

Example: to determine the length of the horizontal laying of the line D_{AB} on the ground, which is given on the plan of scale 1:2000 by points A and B (fig. 1.7).

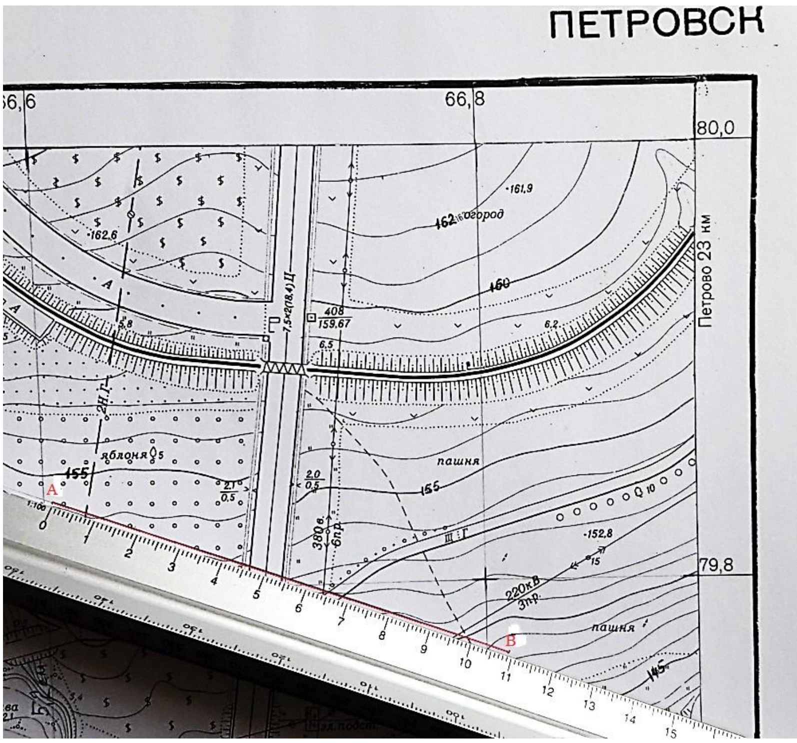


Figure 1.7 – Determining the length of the horizontal laying of the line AB using a drawing ruler

After connecting of points *A* and *B* on the plan using a drawing ruler, measure the length of the segment s_{AB}. In the example, it is equal to $s_{AB} = 10.9$ *cm.*

The length of the horizontal laying of the line D_{AB} on the ground is found by formula 1.2:

$$D = s \times M = 10{,}9\ cm \times 2000 = 21800\ cm\ =\ 218\ m.$$

The founding length of the horizontal laying of the line *AB* on the ground is transferred into meters, because usually measurements on the ground are exploited in meters. Similarly, we find other given lines according to the variant and the results are entered in the form table.

1.2 Plotting of horizontal laying on the plan

On the topographic plan, you need to note a segment of a given length, which corresponds to a given value of the horizontal laying of the line D_{BK}. So we solve the opposite problem, according to the known value of the horizontal laying of the line on the ground, we build the length of this line on the plan of a given scale.

Example: the horizontal laying of the line D_{BK} on the ground is 56.75 m. Determine the length of this line (mm) on a plan with scale 1: 2000. Using formula 1.3, we find the length of the segment D_{BK}:

$$s = \frac{D}{M} = \frac{56{,}75}{2000} = 0{,}0284\ m = 0{,}0284 \cdot 1000 = 28{,}4\ mm.$$

The calculated value of the length of the line is postponed from the starting point *B* in the direction of point *K* using a drawing ruler, previously continuing the line *AB*.

1.3 Determining the length of the horizontal laying of the line D_{AB} on the ground using the transverse scale

The transverse scale is engraved on the geodetic protractor. You need to adapt it to a given numerical scale, namely you need to determine how many meters on the ground are the base of the transverse scale, small and the smallest divisions. Since the base of the normal transverse scale (fig. 1.3) is 2 cm, at a scale of 1:2000 (20 cm in one centimetre) we have the following:

$a = 20$ *м;*

$n = a/10 = 2$ *м;*

$m = a/100 = 0{,}2$ *м.*

On a map with a scale of 1: 2000 the length of the line is fixed by dividers, it is transferred to the lower horizontal line of the transverse scale, setting the right leg of dividers on one of the perpendiculars to the right of zero, and the left leg must be within the extreme left base.

If the left leg exactly coincides with the end of the small division on the lower horizontal line, then immediately the distance is found.

If the left leg of the dividers does not coincide with the end of the division on the bottom line of the left base of the scale, the dividers is moved sequentially up from one horizontal parallel line to another. The right leg should move along one of the perpendiculars until the left leg hits one of the transversals (oblique lines) (fig. 1.8).

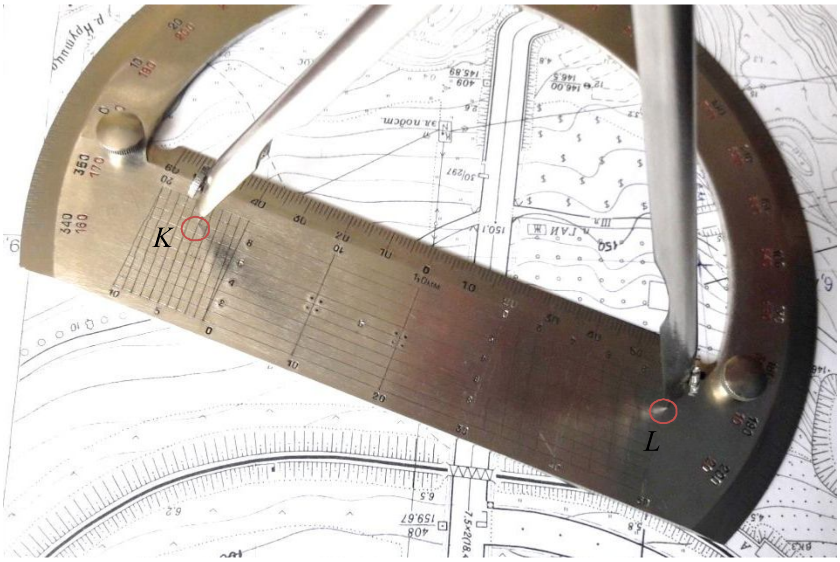


Figure 1.8 – Determining the length of the horizontal laying line on the ground using a transverse scale

In the example (fig. 1.8) the segment *KL* consists of five bases (*20 m* × *5 = 100 m*) and four tenths of the base (small divisions), that it equals to *2 m* × *4 = 8 m* and the eight smallest divisions (*0,2 m* x *8 = 1,6 m*) The total length is *100 + 8 + 1,6 = 109,6 m*.

1.4 Drawing of a line segment using a transverse scale on a topographic plan at a scale of 1: 2000

Example. For the horizontal laying of the line D_{AB}, which is equal to 157.2 m, to draw a segment on the topographic plan using a transverse scale.

For drawing a segment, if you know the horizontal laying of the line on the ground, to use the transverse scale. To do this, at first you must calculate the required number of bases, divisions and small divisions to tilt the legs of the dividers by a certain value. In our example, the slope of the legs, which is expressed in the total number of bases of the scale, is equal to:

$$N_{AB} = \frac{D_{AB}}{a}, \quad (1.5)$$

where a – the basis of the transverse scale in meters, which corresponds to the set scale of the plan.

In laboratory class, the basis of the transverse scale is $a = 2\ cm$, then on the plane of scale 1: 2000 the total number of bases is equal to (formula 1.5):

$$N_{AB} = \frac{D_{AB}}{a} = \frac{157{,}2\ m}{40} = 3{,}93\ basis.$$

This means that for drawing a segment of the line s_{AB}, 3 bases (3 a), 9 divisions ($9 \cdot a/10$) and 4 small divisions ($9 \cdot a/10$) must be placed in the slope of dividers. If the length of the segment is measured in millimetres, then $s_{AB} = 3{,}93 \cdot 20 = 78{,}6\ mm$.

2 Determining the rectangular coordinates of a given point

There are several points on the plan. Their rectangular coordinates X and Y are determined relative to the lines of the grid. To do this, carefully cross the intersections of the lines of the grid of squares plotted on the plan, restore the squares of the kilometre grid, which are drawn through 10 cm, that corresponds to 200 m on the ground (for a scale of 1: 2000) (fig. 1.9). Next you need to determine the coordinates of the angles of the square in which the point C is laid.

Figure 1.9 – Determination of rectangular coordinates of point C

Example. Determine the rectangular coordinates of point C (fig. 1.9). They are determined relative to the coordinates of the southwest corner of the square of the grid – point K, which is the point whose coordinates must be found (fig. 1.10). On the topographic plan, the coordinate kilometre grid is displayed in kilometres, and the coordinates are calculated in meters, so the initial coordinates of the grid angle must also be translated into meters.

The coordinates of the point *K* are equal to:

$$Х_К = 79600\ m;\ \ У_К = 66400\ m.$$

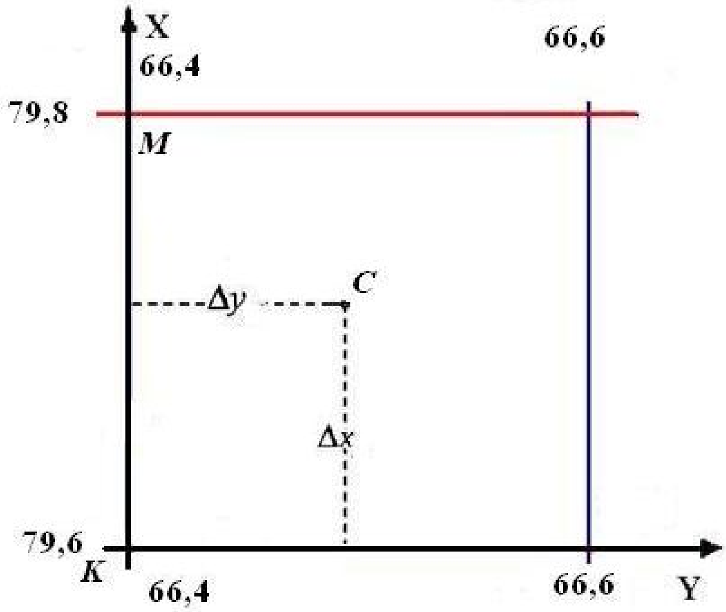


Figure 1.10 – Determining the coordinates of the angles of a given square of the kilometre grid

From point C, the perpendiculars are lowered to the sides of the square. Using a drawing ruler or dividers (or numerical scale) the increments of the coordinates ΔX_1 and ΔY_1 (the length of the perpendiculars relative to the point *K*) on the scale of the plan are measured (fig. 1.9):

$$\Delta Х_1 = 4{,}9\ cm \cdot 2000 = 98\ m;\ \Delta Y_1 = 3{,}5\ cm \cdot 2000 = 70\ m.$$

Then the coordinates of point *C* are equal to:

$$Х_С = Х_К + \Delta Х_1 = 79600 + 98 = 79698\ m;$$
$$Y_С = Y_К + \Delta Y_1 = 66400 + 70 = 66470\ m.$$

To control the determination of these coordinates of point *C*, the perpendiculars are lowered to opposite sides of the square. Determine its coordinates relative to the coordinates of the northeastern corner (point *M*) of the same square, lengths of the perpendiculars are measured, the negative increments of the coordinates of point *C*

($-\Delta X_2$ and $-\Delta Y_2$) relative to point *M* are found. For point *C*, respectively, we have increments of coordinates (fig. 1.9):

$$\Delta X_2 = 5{,}2\ cm \cdot 2000 = 104\ m;\ \Delta Y_2 = 6{,}4\ cm \cdot 2000 = 128\ m.$$

The coordinates of point *M* are equal to:

$$X_M = 79\ 800\ m;\ \ Y_M = 66\ 600\ m.$$

The coordinates of point *C′* are equal to:

$$X'_C = X_M - \Delta X_2 = 79\ 800 - 104 = 79\ 696\ m;$$
$$Y'_C = Y_M - \Delta Y_2 = 66\ 600 - 128 = 66\ 472\ m.$$

The final coordinates of point *C* are calculated by the formulas:

$$X_C = \frac{X_C + X'_C}{2};\ Y_C = \frac{Y_C + Y'_C}{2}.$$

$$X_C = \frac{79\ 698 + 79\ 696}{2} = 79\ 697\ m;\ Y_C = \frac{66\ 470 + 66\ 472}{2} = 66\ 471\ m.$$

In laboratory class, the difference between the defined coordinates (ΔX_1 and ΔX_2), (ΔY_1 and ΔY_2) is allowed up to four meters, if the difference exceeds the allowable value, you need to check the measurements and calculations.

3 Determining the directional angles of given lines

Measurements (or drawing) on the plan of directional angles of lines are performed, as a rule, by a geodetic protractor. The scale of the protractor is built in degrees. The value of the smallest division is 30’.

The protractor scale has two graduations: from 0° to 180° and from 180° to 360°. The first graduation (0° – 180°) is used when the directional angle of the line does not exceed $\alpha \leq 180°$ (fig. 1.11, the direction of the line *AB*), the second – at $\alpha = 180° \div 360°$ (the direction of the line BA, fig. 1.12). The measurement is performed with an accuracy of 15’.

Example. For measuring the directional angle of the line *AB* (fig. 1.11) through the starting point *A* the line are drawn (or use already drawn vertical lines of the kilometre grid) parallel to the line of abscissa of the grid.

At point A, measure the angle from the north direction of the drawn abscissa line *X* to the direction to point *B* in a clockwise direction. To do this, point *A* is aligned with the center of the arc of the protractor (zero scale on the ruler), and its gradation diameter

(0° – 180°) is aligned with the abscissa line. The value of the angle α_{AB} is determined (read) on the edge of the line of the degree scale of protractor. In our example α_{AB} = 110º 30'.

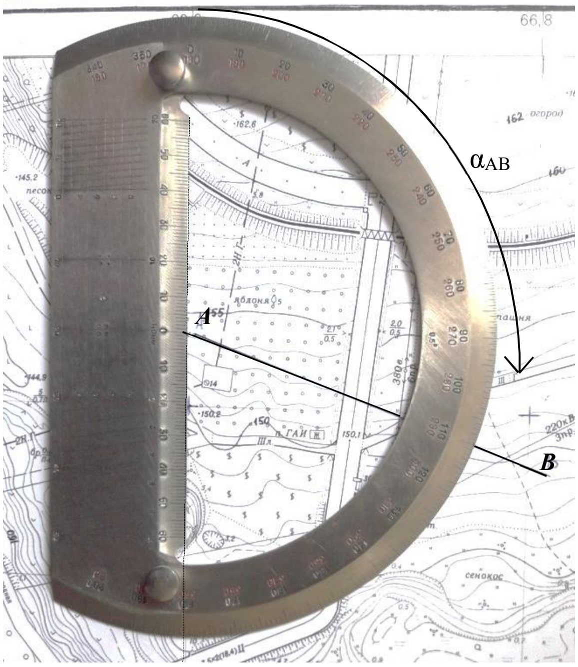


Figure 1.11 – Directional angle of the line AB

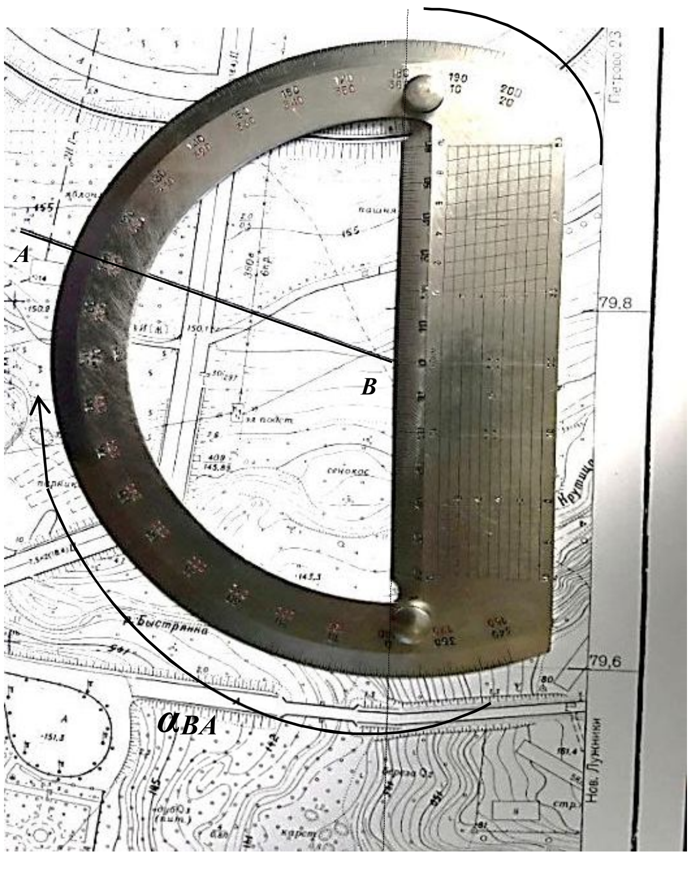


Figure 1.12 – Directional angle of the line BA

For determination of the directional angle of the line *BA* (fig. 1.12), the protractor is rotated on 180º around point *B* and is aligned with the center of the arc of the protractor and a count is take on the «red scale», which starts from 180º to 360º, in our example α_{BA} = 290º30'.

The accuracy of measuring of the directional angles of the lines by a geodetic protractor is 30'. The difference between the directional angles of the forward (*AB*) and reverse (*BA*) directions should be 180°.

Checking: $\alpha = \alpha_{BA} - \alpha_{AB} = 219^o30' - 110^o30' = 180^o$.

If the checking reveals a difference between the directional angles more than 2º, the measurement must be repeated.

Questions for self-control:

1. What is a plan?
2. What types of plans do you know?
3. Why is the base scale 1: 500?
4. What are the types of scales and where are they indicated on the plan?
5. What is scale accuracy? Why is it equal to a scale of 1: 5000?
6. What are the ways to measure distances on a plan? Which of these methods is the most accurate?
7. How to determine the rectangular coordinates of a given point on the plan? How are their measurements controlled?
8. How to determine the directional angles of the given directions on the plan?
9. What is the difference between the forward and reverse directions of the directional angles of the line?

LABORATORY CLASS №2

Relief. Solving tasks on the topographic plan using contour lines

The purpose of the class. Get acquainted with the relief and ways of its image. Get acquainted with the definition of elevation between points with specified heights. Learn to determine the heights of points using contour lines, the slope and inclination angle of the line. Draw a profile in a given direction.

Equipment and implements. Dividers, drawing ruler, topographic plan of scale 1:2000, topographic map of scale 1:10000, pencil 2T, engineering calculator form for laboratory class №2.

THEORETICAL MATERIAL

1 Relief and ways of its image. Heights of points, definition of elevation between points

Relief is a set of irregularities of the physical surface of the Earth, which were formed as a result of millennial activity of various physical and geological processes in the Earth's body (fig. 2.1). Knowledge of the relief of the Earth's surface is very important in solving engineering tasks: design and construction of engineering structures, in agriculture, military affairs, space research and more.

A special science – geomorphology – studies the types of relief, their origin, development and patterns of its distribution.

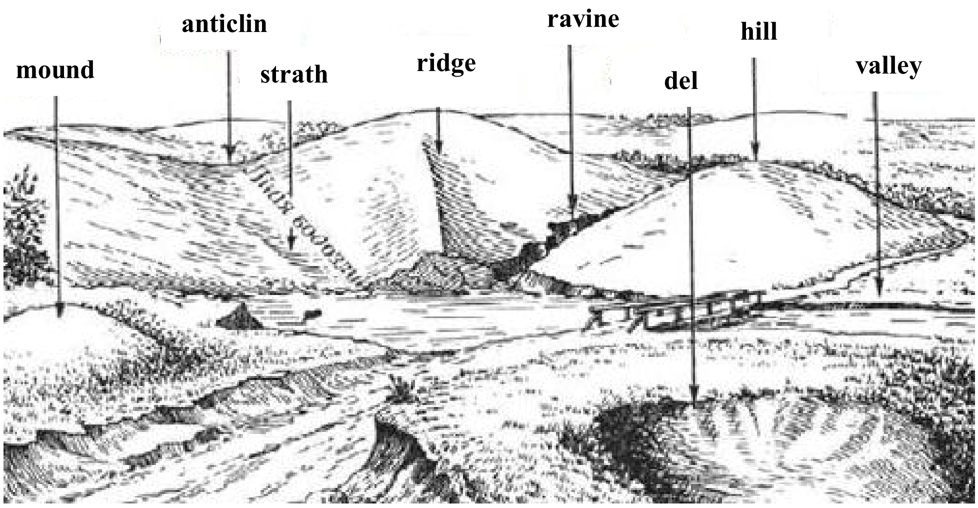


Figure 2.1 – The main forms of relief

The relief is depicted on topographic maps or plans by contour lines (isolines). A ***contour line*** is a conditional curved line that connects points on the Earth's surface with the same absolute (sometimes conditional) heights. The contour line can also be represented as follows from the intersection of the Earth’s surface with the horizontal plane (fig. 2.2).

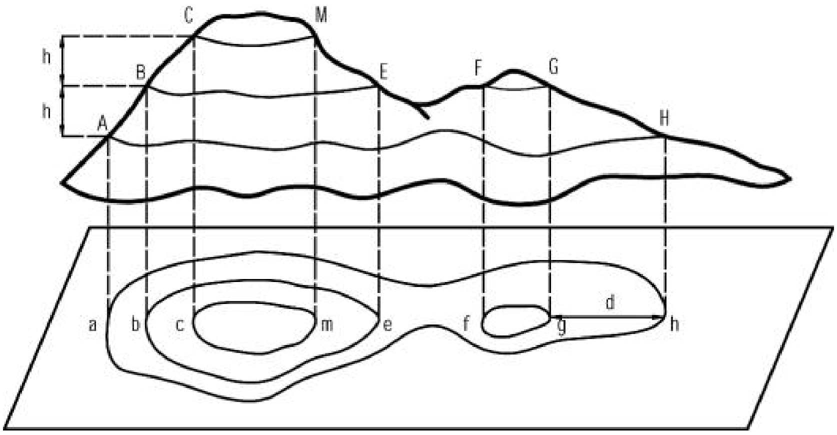


Figure 2.2 – Relief image by contour lines

The distance between adjacent horizontals along the steep line is called the ***height of the intersection of the relief*** (*h*), it is signed on each sheet of the map under a numerical scale. The distance between the contour lines on the plan is called the ***laying*** (*d*).

It is believed that the normal height of the intersection of the relief is equal to 0.2 mm of denominator of the numerical scale of the map. The relief is divided into ***plain, hilly and mountainous***. Depending on this, the height of the intersection of the relief for different scales of maps and plans are taken differently.

Values of heights of contour lines are signed in their gaps. The top of the numbers is directed up to the slope. Contour lines are depicted in brown, and they are not crossed out on reservoirs, ravines, cliffs, landforms of artificial origin.

Thus, the image of the relief by contour lines allows to recognize on a map forms and elements of a relief, and also to receive a number of quantitative characteristics of these various forms. The image of the main forms of relief by contour lines is shown in figure 2.3.

The considered forms do not meet in the nature in isolation, usually they are combined, passed one into another forming more difficult complexes of forms.

As can be seen from figure 2.3 – the contour lines do not give a clear spatial idea of the terrain relief. The mountain and the del by contour lines have the same shape and can be distinguished only by the direction of the slopes. For this purpose on contour lines spend a slope-strokes are applied towards downhill decrease. In the ridge, the slope-strokes are showed from the contour line on the convex side, and in the ravine – from the concave side. For solving topographic tasks it is necessary to know the properties of contour lines. Their main properties are as follows:

– all points that lie on the same contour line have the same mark;

– all contour lines are indissoluble;

– cannot intersect or split;

– the distance between the contour lines on the plan characterizes the steepness of the slope – if the smaller the distance (laying), than the slope is steeper and vice versa;

– the smallest distance between the contour lines corresponds to the direction of the greatest steepness of the slope;

– watershed lines and axes of the plane are intersected by contour lines at angle 90°;

– contour lines, which represent an inclined plane, have the form of parallel lines.

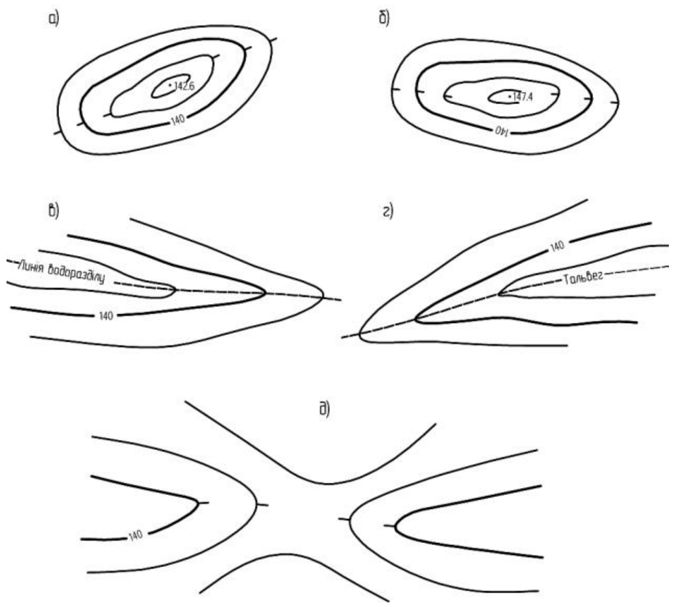


Figure 2.3 – Images of the main forms of relief by horizontals:
a) mountain; b) del; c) ridge; d) ravine; e) anticline

The heights of the points are determined relative to the level surface, which is taken as the surface of the seas and oceans at quite state, imaginary under the continents (fig. 2.4). The distance along the plummet from a given point on the Earth’s surface to the level surface is named the ***absolute height*** – H_B (mark or altitude) of the point. If the height is determined relative to any conditional surface, it is named the ***relative height*** of this point – H'_B.

The level surface in Ukraine is the surface that passes through the zero of the Kronstadt footstock. The footstock is a copper plate fixed in the ledge of the bridge across the Bypass Canal in Kronstadt. The horizontal line applied to the plate corresponds to the average water level in the Baltic Sea, which has been observed since 1825. Therefore, the altitude system in our country is called the Baltic.

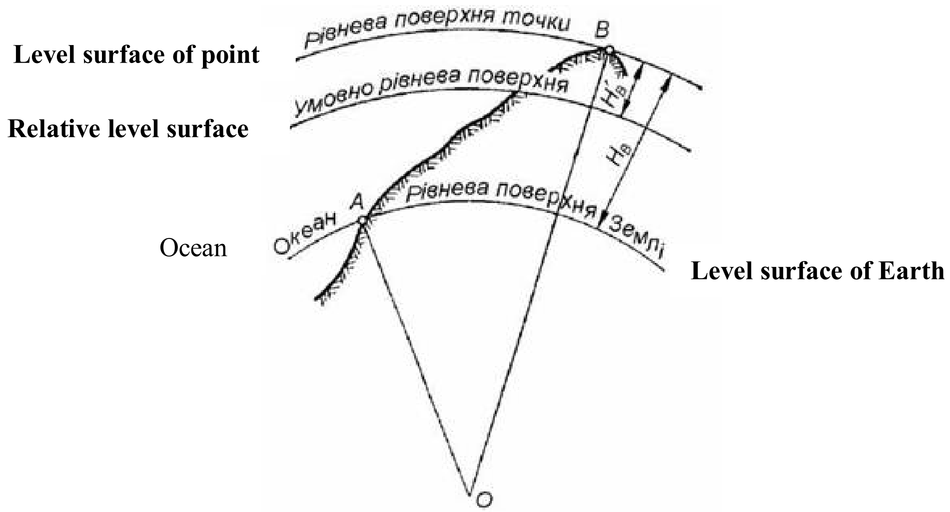


Figure 2.4 – Absolute and relative heights of points

If the heights of the two points H_A and H_B are known, the elevation between them h_{AB} is calculated by the formula:

$$h_{AB} = H_B - H_A. \tag{2.1}$$

2 Determining the heights of points by contour lines

There is a task of determining the heights of points on the Earth's surface according to topographic plans in vertical design. The initial data for solving this task are the signatures of the heights of the contour lines, the height of the intersection of the relief *h* and the direction of the slope of the terrain.

The height of the intersection of the relief is signed on topographic plans under a linear scale, for example: «Solid contour lines are drawn through 5 m». It means that for this topographic plan $h = 5\ m$.

When you are working with a fragment of a map or plan, the height of the intersection of the relief can be determined by the number of intervals *n* and elevation ΔH between the signed contour lines. The height of the intersection of the relief *h* is calculated by the formula:

$$h = \frac{\Delta H}{n}, \tag{2.2}$$

where ΔH – elevation between the signed contour lines;

n – number of intervals.

Example. The number of intervals are $n = 4$, and the elevation between the signed contour lines is *180 m* and *170 m* is equal to: $\Delta H = 180 - 170 = 10\ m$ (fig. 2.5). Then for this example by formula 2.2:

$$h = \frac{10}{4} = 2{,}5\ m.$$

That is, the height of the intersection of the relief is 2.5 meters.

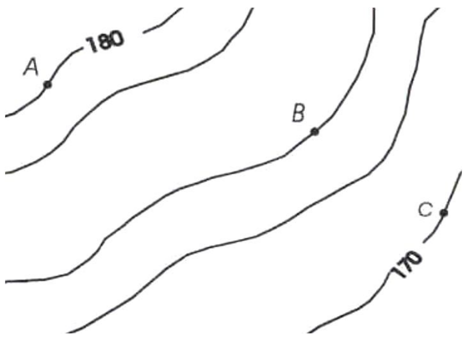


Figure 2.5 – Determining the height of the intersection of the relief

When you determine the heights of points by contour lines, three cases are possible.

1. The point is placed on the contour line. In this case, the height of the point is equal to the height of this contour line. If the contour line on which the point is placed is not signed, then the height of contour line, and hence the point, is determined from the neighbouring signed contour line, taking into account the height of the intersection of the relief *h* and the direction of the slope.

$$H_B = H_A - n \cdot h, \tag{2.3}$$

or

$$H_B = H_C + n \cdot h. \tag{2.4}$$

2. The point is placed between the contour lines. If the point is between the contour lines (fig. 2.6), it is found in the following sequence:

- determine the heights of two adjacent contour lines H_A, H_B;
- perpendicular to them through the point *C* draw a line *A'B'* and measure the length of laying *d* (in mm);
- measure the distances *l* and *p*;
- the height of point *C* is calculated by the formulas:

$$H_C = H_A + \frac{l}{d} \cdot h; \tag{2.5}$$

or

$$H_C = H_B - \frac{p}{d} \cdot h, \tag{2.6}$$

where h – height of the intersection of the relief between adjacent contour lines.

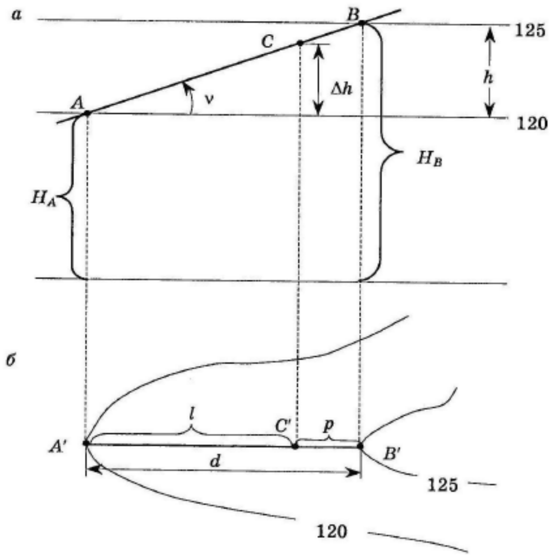


Figure 2.6 – Determining the height of the point that is located between the contour lines

3. The point is a characteristic point of the terrain. Characteristic points of the terrain are located on the catchment lines, watersheds, mountain tops, bottoms, etc. The heights of these points are signed on topographic plans and maps. In the absence of signatures of characteristic heights, they are calculated approximately by increasing or decreasing the height of the closest countour line to the point by half of height of the intersection of the relief (fig. 2.7).

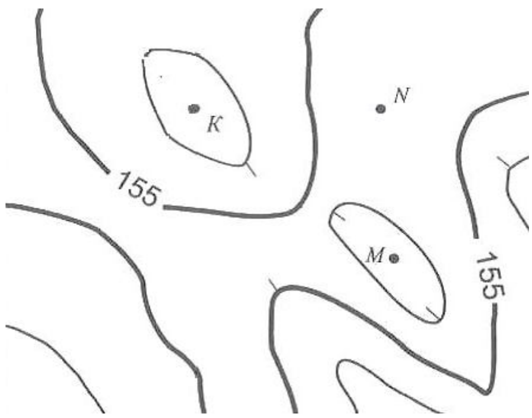


Figure 2.7 – Determination of the height of the characteristic points of the relief

3 Determination of slope and inclination angle of the line

The degree of decrease or increase of terrain is characterized by inclination angle v or slope i.

The steepness of the slope determines ***the angle of inclination v***, which this line forms with the horizontal plane (fig. 2.6). The steepness of the slope is expressed in degrees and is calculated by the formulas:

$$tgv = \frac{h}{d}; \tag{2.7}$$

or

$$v^{\circ} = arctg\frac{h}{d} = 57{,}3^{\circ} \cdot \frac{h}{d}. \tag{2.8}$$

where h – height of the intersection of the relief; d – lying, the horizontal distance between adjacent contour lines, which is determined by measuring on a topographic plan or map.

The degree dimension of the angle of inclination characterizes the steepness of the slope of this line of terrain.

In practice, when solving various engineering tasks often do not use the angle of inclination in degrees, but use the slope.

The slope is called the tangent of the inclination angle of the line on the ground and is calculated by the formula:

$$i = tgv = \frac{h}{d}. \tag{2.9}$$

Slope i are expressed as a percent (%) or promile – thousandths of a unit (‰).

4 Drawing of the terrain profile in a given direction

The design of structures of considerable length (power lines, gas pipelines, highways, railways, etc.) is required knowledge of the terrain profile in both directions – along the axis of the structure and across the route.

Profile of terrain is a trace of the cross-section of the terrain by a vertical plane, is drawn on this plane in a given horizontal and vertical scales. The basis for the profile can be a topographic map or plan. On the plan with contour lines is specified the profile direction *AB* (fig. 2.8).

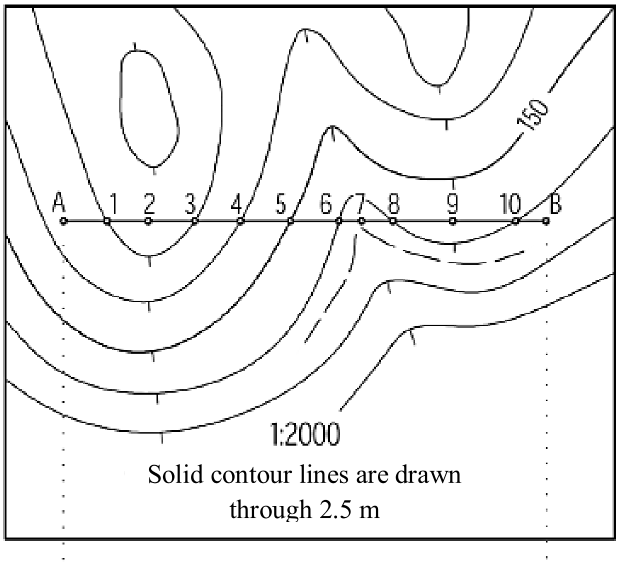


Figure 2.8 – The profile of the terrain in a given direction

The profile is drawn on different scales. The horizontal scale is chosen, as a rule, equal to the scale of the plan, the vertical scale for the profile is taken to be 10 times larger than the horizontal scale (for hilly terrain).

THE ORDER OF WORK IMPLEMENTATION

1 Determination of the elevation between points with known heights

Example. Determine the elevation between points *A* and *B* with known heights $H_A = 144,0\ m$ and $H_B = 141,5\ m$ on the plan. The elevation between them is determined by formula 2.1:

$$h_{AB} = H_B - H_A = 141,5 - 144,0 = -2,5\ m;$$
$$h_{BA} = H_A - H_B = 144,0 - 141,5 = 2,5\ m.$$

The results of the calculation of elevation are recorded in the form with the task.

2 Determining the heights of points by contour lines

2.1 Determining the height of a point that is placed on the contour line

Example. Determine the height of the point that is placed on the contour line (contour line is not signed). According to figure 2.5, the heights of the points are equal to $H_A = 180\ m$, $H_C = 170\ m$, height of the intersection of the relief $h = 2,5\ m$. Determine the height of the point H_B.

For determining the height of point *B* the property is used according to which the elevation between any contour lines is equal to the result of multiplication of the number of intervals *n* between these contour lines by the height of the intersection of the relief h. In this example, taking into account the direction of the slope (the bases of the numbers are directed downwards), point *B* is below the contour line with 180 m, and the number of intervals between the contour lines with points *A* and *B*, as well as *B* and *C* is two.

Therefore, the height of contour line on which the point *B* is placed, and hence the height of the point *B* according to formulas 2.3 and 2.4 equals:

$$H_B = H_A - n \cdot h = 180{,}0\,m - 2 \cdot 2{,}5 = 175{,}0\,m;$$
$$H_B = H_C + n \cdot h = 170{,}0\,m + 2 \cdot 2{,}5 = 175{,}0\,m.$$

2.2 Determining the height of a point that is placed between the contour lines

Example. Determine the height of the point *C*, which is placed between the contour lines. According to figure 2.6, the heights of points *A* and *B* are equal to $H_A = 120\ m$, $H_B = 125\ m$, $h = 5\ m$, measured distances $d = 34\ mm$, $l = 24\ mm$, $p = 10\ mm$, then by formulas 2.5 and 2.6 we have:

$$H_C = 120 + \frac{24}{34} \cdot 5 = 123{,}5\,m;$$

or

$$H_C = 125 - \frac{10}{34} \cdot 5 = 123{,}5\,m.$$

2.3 Determining the heights of points that are characteristic points of the terrain

Example. According to figure 2.7 determine the heights of points that are characteristic points of the terrain. Point *K* (fig. 2.7) is located on a hill (slope-strokes are directed toward lowering the relief), height of the intersection of the relief $h = 2{,}5\ m$, then:

$$H_K = 157{,}5\,m + 1{,}25\,m = 158{,}75\,m = 158{,}8\,m.$$

The height of the point *M*, which is in the hollow, is equal to:

$$H_M = 152{,}5\,m - 1{,}25\,m = 158{,}25\,m = 158{,}3\,m.$$

The height of the point *N*, which is located between the contour lines of the same name in the saddle, is equal to:

$$H_N = 155{,}0\,m - 1{,}25\,m = 153{,}75\,m = 153{,}8\,m.$$

3 Determining the slope and inclination angle of given line

Example. Determine according to figure 2.6 the slope and the inclination angle of line *AB*, if lying $d = 34,7$ *м*, heights of points $H_A = 120,0$ *м*, $H_B = 125,0$ *м*.

The elevation between points A and B is found by formula 2.1:

$$h_{AB} = H_B - H_A = 125{,}0 - 120{,}0 = 5{,}0\ m.$$

The slope of the line *AB* is found by formula 2.9:

$$i = \frac{h}{d} = \frac{5{,}0}{34{,}7} = 0{,}1441 = 14{,}41\ \% = 144{,}1\ ‰.$$

The slope is determined by formula 2.8:

$$\nu^{\circ} = 57{,}3^{\circ} \cdot \frac{h}{d} = 57{,}3^{\circ} \cdot 0{,}1441 = 8{,}2^{\circ}.$$

The slope and the inclination angle of the line can also be determined by graphs of the scale of the foundations, which are located in the south-eastern corner of the sheet of the topographic plan.

4 Drawing of the terrain profile of a given direction

Example. Drawing of the terrain profile of given on the plan direction *AB* (fig. 2.8) is performed in the following sequence:

a) the end points of the direction *A* and *B* are connected by a straight line on the topographic plan;

b) on the line *AB* the points of its intersection with the contour level lines (1-10) and its points of intersection with the characteristic structural lines of the terrain (with the watershed (2, 9) and the catchment (7), and if available – with peaks and saddles) are marked and numbered;

c) on paper with millimeter divisions or on a graph to build down from the line of the conditional line of the profile grid: «height of points», «distance between points» and «point number», adhering to the specified sizes of lines (fig. 2.9);

d) to build on the profile of the horizontal distances between the points of intersection use a strip of paper to which these points are transferred, because the horizontal scale of the profile coincides with the scale of the plan and the horizontal distances are preserved. This strip on the plan is applied to the line *AB* and on it mark points of intersection of a line with ccontour lines and characteristic lines of a relief, sign their numbers and heights with accuracy of 0,1 m. Heights of the points are placed on watersheds and spillways (thalwegs), to define previously considered method;

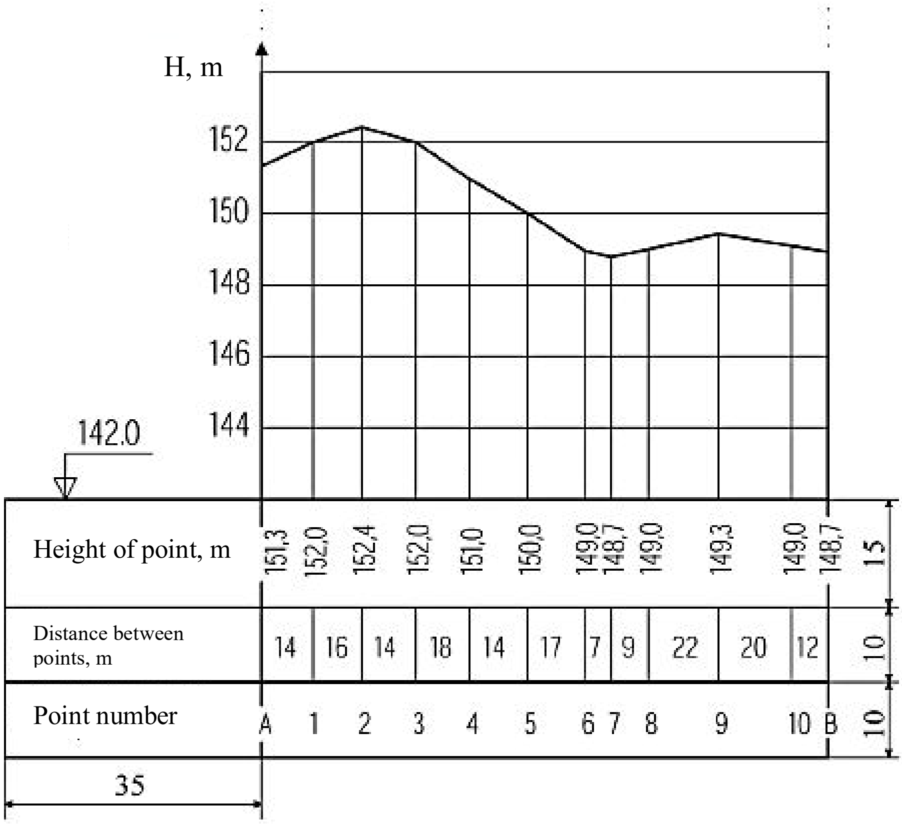


Figure 2.9 – Drawing of a relief profile of the direction AB

e) from a strip of paper to transfer points, their numbers and heights on a grid of a profile in corresponding lines;

f) to calculate the height of the line of the conditional level line H_{con}. It is determined in such a way that the point of the profile with the minimum height H_{min} is located 3 ÷ 5 cm above it. For example, if $H_{min} = 148.7\ m$ (fig. 2.9), and a vertical scale 1: 200, the height of the conditional level line (rounded to whole meters) is equal to $H_{con} = H_{min} - (3\ cm \times M \times 10^{-2}) = 148,7 - (3 \times 200 \times 10^{-2}) = 148.7 - 6,0 = 142,7 \approx 142,0\ m$ (M is the denominator of the vertical scale);

g) according to the selected scale to sign the scale of heights trough 1 cm. The price of centimetre division of vertical scale is equal to:

$h_n = 1 \times 200 \times 10^{-2} = 2,0\ m.$

The line of the conditional level is taken as the upper line of the profile grid or another (higher) line parallel to it.

From the line of the conditional level, on the perpendiculars constructed to it in characteristic points of a profile, heights of points are postponed. Adjacent points are connected by straight lines. As a result, a broken line is obtained, which characterizes the terrain profile in the direction AB that determined on the plan (fig. 2.9).

Questions for self-control:

1. Define the relief.
2. Name the landforms.
3. Name the properties of the topographic surface.
4. Define the contour line.
5. What properties of contour lines do you know?
6. Define the absolute and relative heights of the point.
7. Define the slope and in which units it is determined.
8. Define the inclination angle of the line in which units is determined.
9. Define the terrain profile.
10. Name the order of drawing of the terrain profile.

LABORATORY CLASS №3

Determining the boundaries of the catchment area. Determination of areas of the plots on the topographic plan and map

The purpose of the class. Learn to determine the boundaries of the catchment area. Acquire skills in determining the area using the palette, graphical and analytical methods.

Equipment and implements. Drawing ruler, square, 2T pencil, engineering calculator, transparent tracing paper, topographic plan scale 1: 2000, topographic map scale 1: 10000, form for laboratory class №3.

THEORETICAL MATERIAL

1 Determining the boundaries of the catchment area

The problem of determining the boundaries of the catchment area is solved in the design of hydraulic structures, roads, railways and reclamation systems, to determine the parameters of dams, culverts at the intersection of the ground with the thalweg, surface drainage systems and more.

The catchment area or pool is the area from which snow and rainwater under the conditions of relief is collected in this drain (river, ravine, coomb) (fig. 3.1).

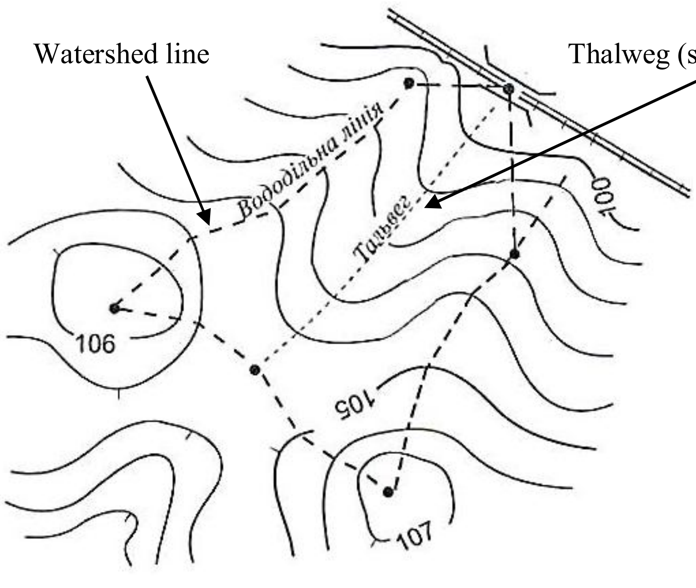


Figure 3.1 – Determining the boundaries of the catchment area

The boundaries of the catchment area are watershed lines. They pass on perpendiculars to convex contour lines, on lines of ridges, through tops and the middle of saddles. The pool limits of these lines in the upper part and on the sides, and in the lower part – the dam, the ground of the highway or railway (fig. 3.1).

Therefore, to determine the catchment area on the map you determine the position of the watershed lines that limit it. The boundary of the catchment area must be closed.

In Figure 3.1, a gorge is formed by contour lines, the surface of which gradually decreases towards the railway. The line passing along the lowest points of the ravine forms a spillway line or thalweg.

Watershed lines pass through the points from which the slope lines diverge in different directions, thalwegs – through the points at which the slope lines converge. Such points are placed in places of the greatest curvature of horizontals. After gaining some experience, the need for a large number of slope lines disappears. An example of an orographic scheme is given in figure 3.2.

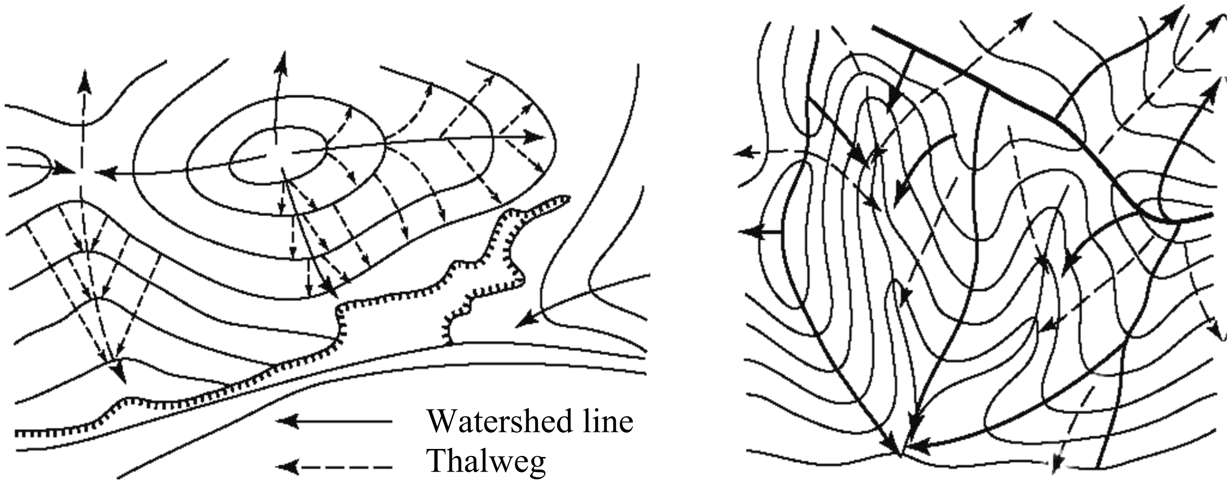


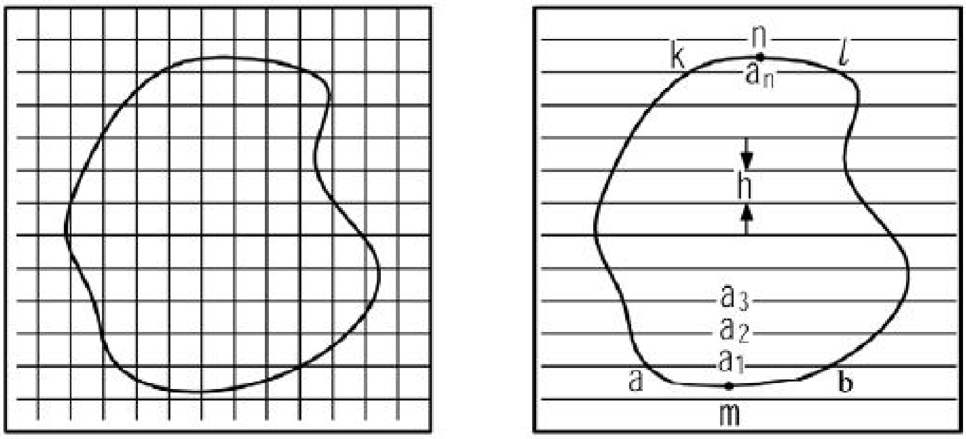
Figure 3.2 – Example of orographic scheme

The orographic scheme of the terrain is the result of mapping the lines of watersheds and thalwegs.

2 Determination of areas on the topographic plan and map

Under the definition of the plot area on a topographic map or plan means a set of measuring and computational works, as a result of which plot area is calculated in the land measure units (m^2, ha, etc.). Moreover, the area is determined not by the physical surface of the terrain R_f, but its projection P on the horizontal plane. Depending on the required accuracy of the results, different methods are used to determine the area: ***using a palette, graphic, mechanical, weighing, analytical, photoelectronic.*** Each of the methods can be used alone or in combination with others. In the laboratory class, graphic, analytical and with the help of a palette methods of determining the area are considered.

Determining the area using a palette. Palettes are graphic constructions in the form of a grid of squares, parallel equidistant lines with the sides of 2:4 mm, executed on any transparent basis (fig. 3.3). To determine the area of the plot, the palette is placed on the measured area and the number of its distributions (complete and incomplete), enclosed within the contour of the area, is counted.



a) б)

Figure 3.3 – Determining the plot are using palettes:
a) square; b) linear

To express the measured area of plot P in the land measure units (m^2, ha, km^2), calculate the area of one square in the area by the formula:

$$S_{sq} = a^2 \cdot M, \tag{3.1}$$

where M – denominator of the numerical scale of the plan or map;

a – the size of the side of the square.

The palette is placed arbitrarily on the map (plan) on the contour of the area, the area of which is determined and the number of complete squares n_1 is calculated. Incomplete squares are estimated by eye to 0.1 square, add them and get the number of incomplete squares n_2.

The total area is calculated by the formula:

$$S = S_{sq} \cdot (n_1 + n_2). \tag{3.2}$$

The measurements are repeated, changing the position of the palette relative to the primary, and the palette should be applied each time so that the contour of the section intersects as few distributions of the palette, the final value of S is the arithmetic mean of the two measurement results.

It is recommended to use square palettes to determine the area of small plots (up to 3 cm²) with curved boundaries. In approximate calculations, they are used to determine the area of large plots. The main disadvantage of such palettes is the possibility of gross miscalculation in determining the number of squares of the palette.

The probability of gross miscalculations decreases when using a linear (parallel) palette. The contour measured by such a palette is divided into figures close in shape to trapezoids with the base $a_1, a_2 ..., a_n$, the height of which h is constant (fig. 3.3, b).

When using a linear palette, the extreme points of the section n and m (fig. 3.3, b) are located approximately in the middle between the parallel lines or combined directly with the lines of the palette, if possible. Using a drawing ruler or a dividers and a transverse scale, measure the lengths of the distances that are cut off by the desired plot: $a_1, a_2, a_3, ..., a_n$ (in m). The total area is calculated by the formula:

$$S = h \times (a_1 + a_2 + a_3 + a_n), \quad (3.3)$$

where h – the distance between the lines of the palette, m.

Graphic method. If the area on the plan has the shape of a polygon, it is divided into the simplest geometric shapes: triangles, quadrilaterals and trapezoids, etc. (fig. 3.4).

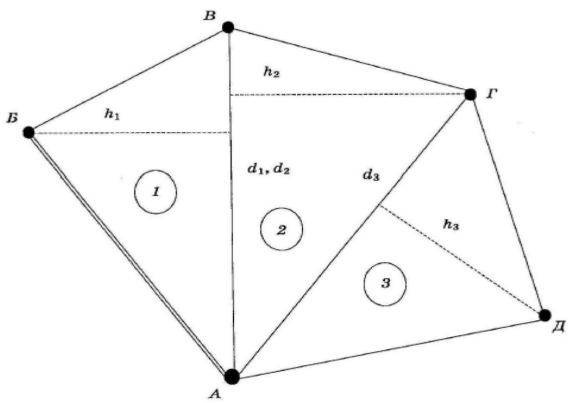


Figure 3.4 – The scheme of division of the area into triangles

Directly on the plan with the help of a dividers and a scale ruler measure the elements of geometric figures (heights h_i, sides a_i, b_i, c_i, etc.) and using the geometry formulas the areas of individual figures ($S_1, S_2, ..., S_n$) are calculated.

For control areas of the plots are determined twice S', S''). The permissible difference between the measurement results should not exceed:

$$|S' - S''| \leq \Delta S = 0{,}04 \sqrt{S \cdot \frac{M}{10000}}, \quad (3.4)$$

where S – calculated plot area in hectares.

When the difference in absolute value does not exceed ΔS, the final result is taken as the average value:

$$S = \frac{(S' + S'')}{2}. \tag{3.5}$$

Analytical method. When the area is bounded by a broken line and the rectangular coordinates of its vertices (X_i, Y_i) are known or measured on a topographic plan or map, the analytical method is used (fig. 3.5).

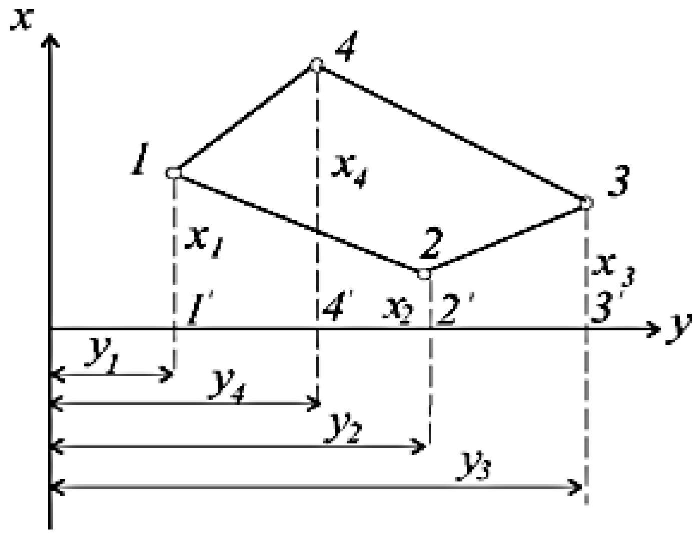


Figure 3.5 – Scheme of analytical method for determining areas

The area of the plot is calculated by the formulas:

$$S = 0{,}5\sum_{1}^{n} y_i \cdot (x_{i-1} - x_{i+1}), \tag{3.6}$$

or

$$S = 0{,}5\sum_{1}^{n} x_i \cdot (y_{i+1} - y_{i-1}), \tag{3.7}$$

where n – the number of vertices of the plot;

i – vertex number;

(i-1) and *(i+1)* – numbers of adjacent vertices to the left and right to the vertex and in the direction of the polygon.

That is, the area of the polygon is equal to half the sum of the multiplication of the ordinates of each point and the difference of the abscissa of the previous and next points; or the area of the polygon is equal to half the sum of the multiplication of the abscissa of each point and the difference of the ordinates of the next and previous points.

Errors in determining the area in an analytical way depend only on the errors in measuring the coordinates of the vertices of the plot on the ground or on the plan. It is approximately assumed that the relative error of determining the area in this method is equal to twice the relative error of measuring lines (coordinates).

For example, for average conditions for measuring the length of lines with a tape, the relative error is 1: 2000, then the relative error of determining the area will be 1: 1000. That is, the accuracy of determining the areas ΔS by analytical method is:

$$\Delta S \leq \frac{S}{1000}. \qquad (3.8)$$

To determine the area of polygons with a large number of vertices computers are used that have the appropriate programs.

Areas of small plots can be determined using a calculator by filling out a special form.

THE ORDER OF WORK IMPLEMENTATION

1 Determining the boundaries of the catchment area

Example. On a 1:10000 scale ma, you need to determine the boundaries of the catchment area.

To solve this task in the upper part of the ravine the saddle (point 1) and the nearest peaks (points 2 and 3) are found. Draw a watershed line 2-1-3 between them (fig. 3.6).

The watershed lines on both sides of the ravine (2-4) and (3-5) are drawn perpendicular to the convex horizontals. From point K to points 4 and 5 of the watershed line are drawn the lines of the bigest slope of the terrain. The line K-4-2-1-3-5-K, thus perpendicular at all its points to the contour lines and bounding the catchment area for the point K, is thus obtained.

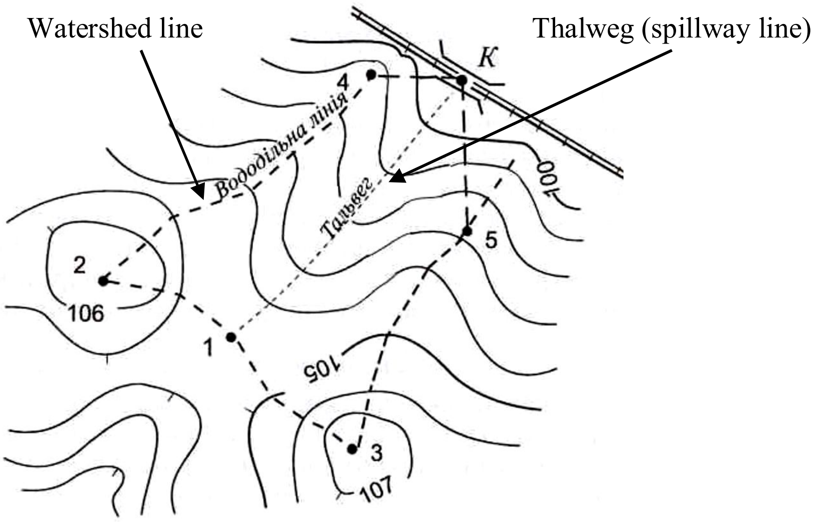


Figure 3.6 – An example of drawing a catchment area

2 Determining the are of plot a on the topographic plan and map

2.1 Determining the area using a palette

Example. On the topographic map of scale 1:10000 to define the area of the range (fig. 3.7).

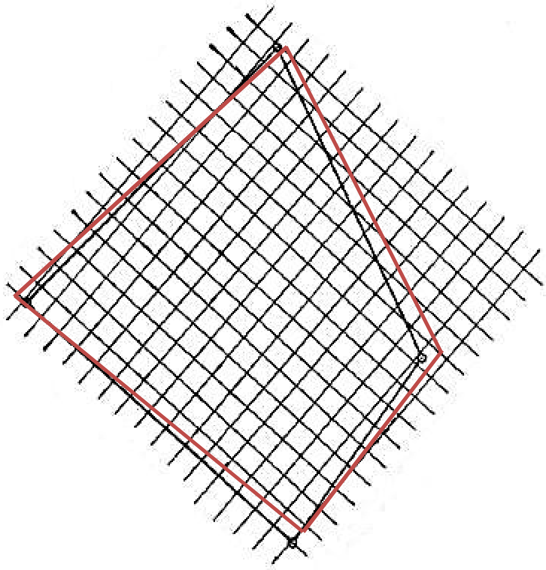


Figure 3.7 – Determining the area of the plot

Task sequence:

a) on a tracing paper of size 10x10 cm draw a grid of squares 2×2 mm (palette);

b) the palette is placed on the contour of the figure fixed on the plan and transfer it to the palette;

c) count the number of whole squares in the middle of the contour, and then the number of incomplete squares (fractions of squares, determined with an accuracy of 0,2 S_{sq});

d) calculate the total area of plot according to formula 3.2.

In our example, n_1 is the number of complete squares = 150, n_2 is the number of incomplete squares = 17, the area of one square for a scale of 1:2000 is determined by formula 3.1:

$$S_{sq} = a^2 \cdot M = 0{,}2 \cdot 0{,}2 \cdot 10000 = 400\ m^2 = 0{,}04\ ha,$$

then the total area of the plot is determined by formula 3.2:

$$S = S_{sq} \cdot (n_1 + n_2) = 0{,}04 \cdot (150 + 17) = 6{,}68\ ha.$$

The using of a square palette ensures the accuracy of determining the area with a relative error of 1:50 – 1:1000 of the measured area.

The area plot is 6.68 hectares.

2.2 Determining the area by graphical method

Example. Determine the area of the plot drawn on a topographic map at a scale of 1:10000 (fig. 3.8).

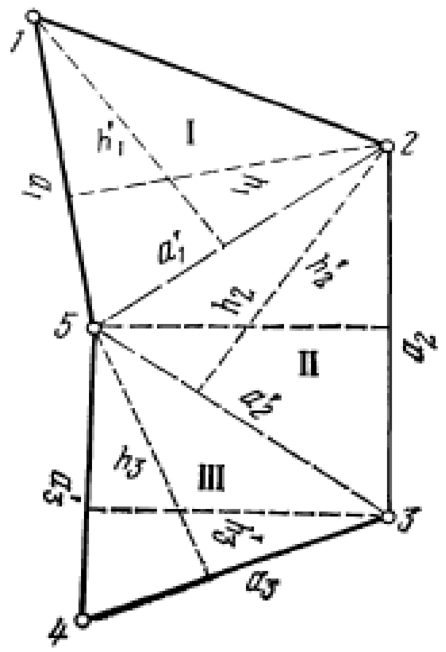


Figure 3.8 – Determining the area by graphical method

Task sequence:

a) the plot is divided into triangles;

b) the bases and heights of triangles are measured on the scale of the plan in (m) (they are chosen so that they are not repeated in adjacent triangles (fig. 3.8)), the area is determined by the formulas of geometry;

c) the results of measurements and calculations are entered in table 3.1.

Diagonals are drawn on the plan from point 5 (fig. 3.8), which divided the polygon into three triangles. The results of measurements and calculations are entered in table 3.1 to determine the area of the plot.

Table 3.1 – The results of measurements and calculations of the plot area by the graphical method

Triangle	Measure-ment	Measurement results		The results of calculations			
		basis a, m	height h, m	area S, ha	divergence ΔS, ha	permissible value ΔS, ha	average value S, ha
I	1	1073	922	49,46	0,16	0,28	49,54
	2	1037	957	49,62			
II	1	916	831	38,06	0,09	0,24	38,10
	2	865	882	38,15			
III	1	972	744	36,16	0,10	0,24	36,11
	2	913	790	36,06			

$$\sum S = 123{,}75\ ha.$$

The plot's area is 123.75 hectares.

To checking the areas of the plots are determined twice (S', S''). The permissible difference between the measurement results should not exceed the value that calculated by formula 3.4. If the difference in absolute value does not exceed ΔS, the final result is taken as the average value (formula 3.5).

Dividing a polygon into triangles is sometimes difficult when its boundaries have a large number of turning points with short sides of the polygon on the plan. In such cases, it is better to determine the area of plot by the coordinates of the vertices of the polygon, measured on the plan or on the ground.

2.3 Determination of the area in an analytical method

Example. On the topographic map the theodolite tracking (fig. 3.9) with the following coordinates of vertices is set: *1* (X_1, Y_1); *2* (X_2, Y_2); *3* (X_3, Y_3); *4* (X_4, Y_4).

The coordinates were measured on the ground using geodetic instruments, the results are entered in table 3.2, columns 2, 3.

The area of the polygon of the theodolite tracking is calculated by formulas 3.6 and 3.7. The area of the polygon S is calculated twice for checking.

For convenience the calculation is in tabular form (table 3.2).

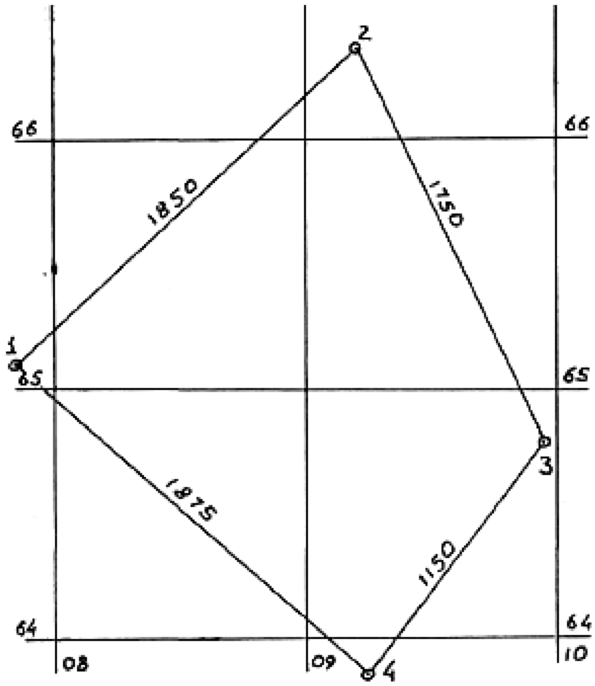


Figure 3.9 – Determination of the area in an analytical method

Table 3.2 – Sheet for determining the area of the polygon

point	Coordinates, m		$Y_{i+1}–Y_{i–1}$	$X_{i–}–Y_{i+1}$	$X_i(Y_{i+1}–Y_{i–1})$	$Y_i(X_{i–1}–Y_{i+1})$
	X	Y				
1	2	3	4	5	6	7
1	65100	7850	–50	–2500	–3255000	–19625000
2	66350	9200	+2100	+325	+139335000	+2990000
3	64715	9950	+50	+2500	+3238750	+24875000
4	65850	9250	–2100	–325	–134085000	–3006250
			0	0	+5233750	+5233750

The intermediate checking of calculations is the equality of the sums of the differences of coordinates, which in columns 4 and 5 of the information is equal to zero. The sum of the multiplications in columns 6 and 7 must be the same. The area of a given polygon is equal to:

$$S = \frac{5233750}{2} = 2616875\ m^2 = 261{,}69\ ha.$$

Questions for self-control:

1. Define and name the main lines of the catchment area.
2. Define the principle of drawing of the catchment area.

3. What methods of determining the area on a topographic plan or map do you know?

4. How are areas determined by palettes? What is the accuracy of determining the area of the palettes?

5. How are areas determined graphically? What is the accuracy of determining the area graphically?

6. How are areas determined analytically? What is the accuracy of determining the area in an analytical method?

7. Name the advantages of one method of determining areas over another.

LABORATORY CLASS №4
The structure of the theodolite 2T30M

The purpose of the class. Get acquainted with the structure and geometric scheme of theodolite 2T30M. Learn to centring and bring the instrument to a horizontal position, take readings in a horizontal and vertical circle.

Equipment and implements. Theodolite 2T30M, tripod ШР-120, stand, plumb, form for laboratory class №4.

THEORETICAL MATERIAL

Theodolite is a device for measuring horizontal and vertical angles. You can also use a theodolite to measure the length of the line, perform trigonometric leveling with a horizontal beam.

Theodolites are used to measure angles in triangulation and polygonometry of different classes and categories, surveying networks, topographic surveying, transfer of projects on the round, control of work during construction, observation of deformations of buildings and structures, other geodetic works.

Theodolites are distinguished by accuracy, design, purpose and scope.

By accuracy theodolites are (m_β – root mean square error of angle measurement in seconds):

- high-precision – m_β = 0,5"÷1,0" (T05, T1);
- accurate– m_β = 2"÷5"; (T2, T5)
- technical – m_β = 15"÷30" (T15, T30).

By design:

- simple –has only a fixing screw or a device for turning and fixing the limb;
- repeated – structurally has independent rotation due to fixing and adjusting screws of a limb and alidade. This makes it possible to increase the accuracy of angular measurements, modern theodolites have a repeated system;
- mechanical – has metal horizontal and vertical reference circles (limbs);
- optical – has glass limbs;
- electronic – in which code disks are used as reading devices.

According to the purpose and scope of use there are:

- astronomical;
- geodetic;
- surveying;
- autocollimation;
- special theodolites.

According to the standard, theodolites are denoted by the letter T followed by letters that denote the construction of the theodolite:

К – with a compensator of a vertical circle;

П – with a direct viewing in the telescope;

М – surveying performance;

А – with an autocollimation eyepiece.

The following types of theodolites are serially issued: T05, T1, T2, T15 and T30. The number means the root mean square error of measuring the angle in one repetition. If the telescope of the theodolite has a direct view, the letter П (Т30П) is added to its designation. In the presence of a compensator near the vertical circle add the letter K (2T15K). If a new modification is developed on the basis of a single basic model, the number 2 is added at the front, and the letter M (2T30M) indicates the surveying performance.

The main structural elements of optical theodolites (fig. 4.1) are the *telescope 3*, which forms the line of sight for distant objects of terrain and buildings. It gives an inverted or imaginary and enlarged image.

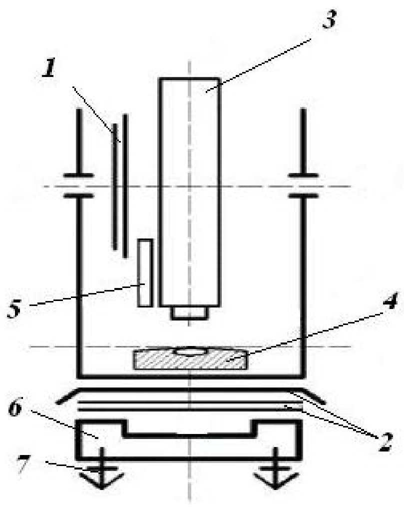


Figure 4.1 – The main structural elements of optical theodolites

Cylindrical level 4 is designed to set the device or its individual parts in a certain position relative to the horizontal plane (level surface). ***Counting devices 5*** by which the divisions of the limbs of the horizontal and vertical circles are counted. Limb is a working measure of a theodolite in the form of divisions of a circular scale applied to a glass circle of optical theodolites. Scale or bar reference microscopes are used in optical theodolites of technical accuracy. ***Vertical circle 1*** is designed to measure vertical angles. ***Horizontal circle 2*** with limb and alidade is designed to measure horizontal angles. ***Stands 6*** and ***leveling screws*** *7* are used for bringing the device to a horizontal position (working position).

Geometric scheme of the theodolite. Each type of theodolite has its own design features, but the same mutual placement of the following axes of the theodolite is required: sight axis of the telescope ZZ_1, level axis on the alidade of the horizontal circle UU_1, horizontal axis of rotation of the telescope HH_1 and axis of rotation of the device (main) II_1 (fig. 4.2).

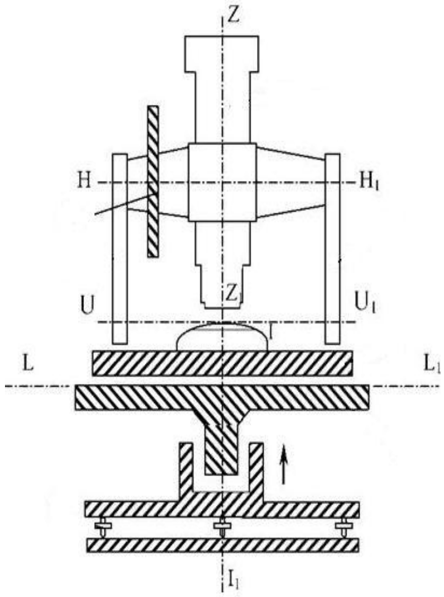


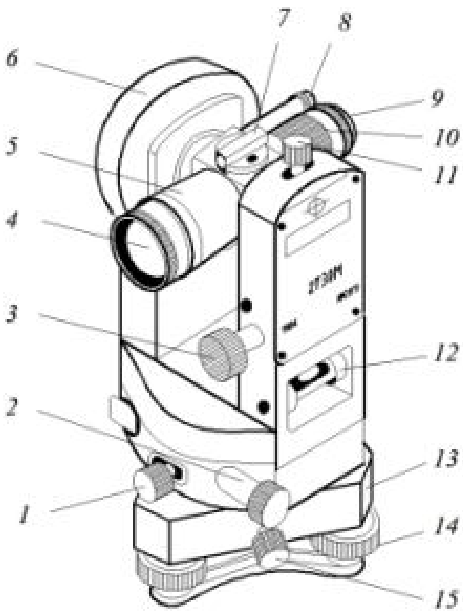
Figure 4.2 – Geometric scheme of the theodolite

The schematic diagram of the theodolite ensures the performance of the basic geometric conditions: the axis of rotation of the device must be vertical; limb plane LL_1 – horizontal; sighting area – vertical. When you measure angles, it is most important to observe the mutual arrangement of theodolite parts in accordance with the following conditions: $LL_1 \perp II_1$, $UU_1 \perp II_1$ or $UU_1 \parallel LL_1$, $ZZ_1 \perp HH_1$, $HH_1 \perp II_1$, $HH_1 \parallel LL_1$. This is due to their significant variability in the process of operation and transportation.

THE ORDER OF WORK IMPLEMENTATION

1 The structure of the theodolite 2T30M

Theodolite 2T30M is an optical-mechanical device designed to measure horizontal and vertical angles. According to the accuracy class, it belongs to technical theodolites; the accuracy of measuring the angle is 30″. Figure 4.3 shows a general view of the theodolite 2T30M. A tripod is used to set the theodolite to a height convenient for the observer. The theodolite is attached to the tripod with a stand screw (fig. 4.4).



1 – Upper motion clamp
2 – Upper motion fine adjust screw
3 – Telescope fine adjust screw
4 – Telescope objective
5 – Telescope
6 – Vertical circle
7 – Pointer sights
8 – Microscope eyepiece
9 – Telescope eyepiece
10 – Telescope focus ring
11 – Telescope clamp
12 – Plate level
13 – Tribrach
14 – Leveling screw
15 – Lower motion clamp

Figure 4.3 – Theodolite 2T30M

Figure 4.4 – Tripod ШР 120

2 Preparation of the theodolite for work

Preparation of the theodolite for work includes the analysis and estimation of an external condition and completeness, an estimation of working capacity of moving parts and modes of separate functional elements, their bringing in a working condition, check and adjustment.

The appearance of the theodolite is checked visually. This detects damage to the optical and mechanical parts of the theodolite. Check the installation of levels and correction devices, image clarity and uniformity of lighting of the reference system. The telescope and optical devices must give clear, undistorted and uncolored views. Level bubbles when moving the levelling screw should move smoothly in the tube. Particular attention is paid to the following conditions:

a) the fixed index of the reference microscope when set to zero on its scale must coincide with the offset reflection of diametrically opposite strokes of the limbs;

b) the illumination of the field of view of the telescope must be uniform, so as not to distort the view;

c) views of limb strokes should be visible without refocusing the microscope eyepiece.

When inspecting the tripod, pay attention to the attachment of its parts. The tripod legs should rotate relatively tightly at the hinge to the head.

The final conclusion about the suitability of the theodolite to implementation the work with due accuracy is made after the inspections and the corresponding regulation.

3 Bringing the theodolite into working condition

Bringing the theodolite into working condition includes centring, levelling the device and focusing the telescope.

Centring – setting the centre of the limbs or the axis of the alidade on the same vertical line with the vertex of the angle.

For centring, the theodolite is moved together with the tripod over the point until the plumb is located above it. Then loosen the stand screw and move the theodolite on the horizontal head of the tripod until plumb not compatibles with the point. At the end of the operation, the stand screw is torqueid.

Levelling of the theodolite – bringing the plane of the limbs in a horizontal position or the axis of the alidade in a vertical position with three levelling screws. Levelling is implemented by bringing the bubbles of a cylindrical level to the centre of the ampoule. Levelling is implemented using levelling screws in the following sequence:

1. The cylindrical level is set parallel to the direction of the two levelling screws. Rotating these screws simultaneously in opposite directions, bring the bubble to the middle of the level (fig. 4.5, a).

2. Rotate the theodolite by 90 ° and, by rotating only the third lifting screw, the bubble is moved to the middle of the level (fig. 4.5, b).

3. Return the theodolite to its original position. The bubble must remain in the middle of the level, or deviate from it by no more than one division. If the condition is not met, repeat the steps are described in paragraphs «1» and «2» until it is fulfilled.

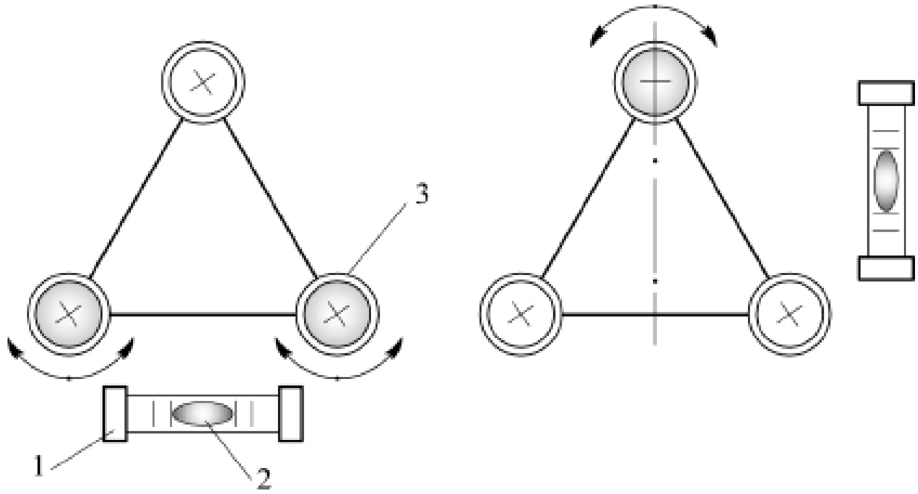


Figure 4.5 – The scheme of bringing the bubble of the cylindrical level to zero point: 1 – cylindrical level; 2 – level bubble; 3 – levelling screw

Focusing of the telescope – obtaining in the field of view of the telescope a clear view of the grid of threads and the object that being observed.

To obtain a clear view of the grid of threads, the telescope is aimed at the illuminated object. Rotating the eyepiece *9*, a clear view of the grid of threads is achieved. A clear view of the object is obtained by rotating the ring of the focusing lens *10*.

4 Taking counts on the vertical and horizontal circle

Loosen the fixing clamps of the horizontal *1* and vertical circle *11*. Using the pointer sights *7*, the telescope is directed to the sight mark specified by the teacher (fig. 4.6). Tighten the fixing clamps of the horizontal circle and the telescope. Then, looking into the eyepiece *9*, the intersection of the grid of threads is directed to bring on the center of the sight mark, as shown in figure 4.6, using the adjust screws of horizontal circle *2* and vertical circle *3*.

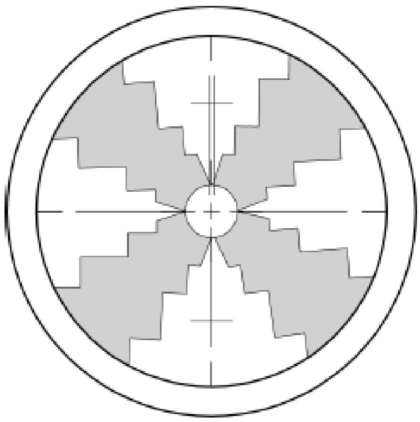


Figure 4.6 – Guidance of a grid of threads on the center of a sighting mark

In the telescope of the reference microscope *8* to take a count on the scale of the horizontal and vertical circles.

Figure 4.7 shows the field of view of the reference microscope of theodolite 2T30M. The upper part of the field of view gives the view of the scale and divisions of the limbs of the vertical circle ***(B)***, the lower – horizontal ***(Г)***. The scale division price is 1'. Tenths of the scale division is estimated by eye, so the count is implemented to 0.1'. During measuring the angles, one of the degree strokes of the limb coincides with the scale (88 – for the horizontal circle in fig. 8). This stroke determines the number of integer degrees. Minutes are counted from left to right from the zero division of the scale to the degree bar. The number of divisions is equal to the number of minutes.

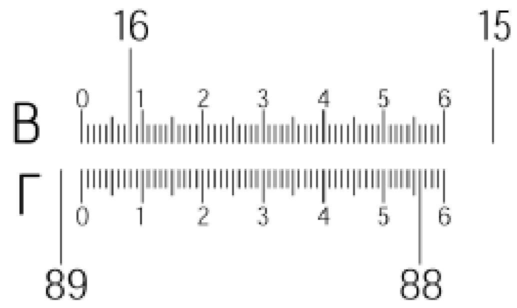


Figure 4.7 – Field of view of the microscope:
a) count from a horizontal circle 88º56';
b) count from a vertical circle 16º08'

The obtained results should be entered in the form for laboratory class №4 on the field of a scale microscope.

Questions for self-control:

1. Name the requirements that must be met by theodolites.
2. What types of theodolites do you know by design and accuracy?
3. What geometric conditions are embedded in the design of the theodolite?
4. List the main nodes of theodolites.
5. Name the structure and purpose of vertical and horizontal circles.
6. Name the purpose of the telescope of the theodolite.
7. What types of reading devices do you know?
8. Name the structure of levels and their purposes.

LABORATORY CLASS №5
Measurement of horizontal and vertical angles

The purpose of the class. Gain practical skills in working with theodolite 2T30M in measuring of horizontal angles by the method of reception and the sequence of mathematical processing of measurement results. Learn the principle of measuring of inclination angles and the sequence of mathematical processing of measurement results.

Equipment and implements. Theodolite 2T30M, tripod ШР-120, stand, plumb, form for laboratory class №5.

THEORETICAL MATERIAL

Angular measurements are implemented in order to determine in space or in the horizontal plane the relative position of the terrain points. Horizontal angles are measured to determine the position of the points on the plan. To determine their position in height vertical angles (angle of inclination) are measured.

1 Measurement of horizontal angles

Measurement of horizontal and vertical angles on the ground is implemented by a special device – a theodolite.

During measuring the horizontal angle *BAC* between the directions *AB* and *AC*, which come from the top of the measured angle – point *A* (fig. 5.1), these directions are projected on the horizontal plane, and between the projections *Ab* and *Ac* a horizontal angle β is formed, which is measured by a theodolite. The horizontal plane in the theodolite is a circle called a limb. The scale of degree divisions is put on it. Degree divisions of the limb are signed clockwise from 0° to 360°.

During measuring an angle, the limb center should be on the same vertical line with the vertex of the measured angle – point *A*. For marking the projections of the directions *AB* and *AC* on the limb, over fixed limb the second round rotates, it is called – alidade.

On the alidade the reading device in the form of a stroke or scale by means, of which takes a count on a limb, is put.

Limb and alidade form a horizontal circle of the theodolite (fig. 5.2). To measure the angle β (fig. 5.1) the telescope theodolite is directed on the right point *C*, the count U^R from the limb is taken. Then, without rotating the limb, the alidade is rotated; the telescope of theodolite is directed on the left point *B*, a count of U^L on the limb is taken.

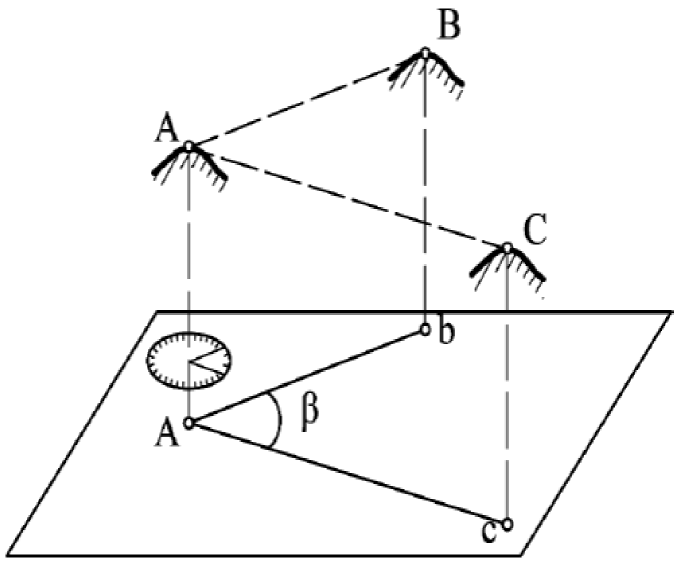


Figure 5.1 – Scheme of measuring of the horizontal angle

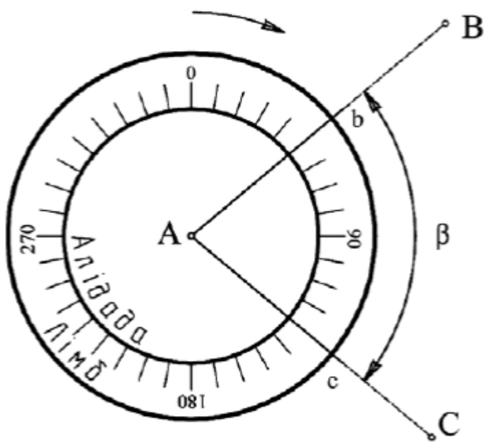


Figure 5.2 – Horizontal circle of the theodolite

Since the divisions on the limb are signed clockwise, the count of U^R will be biger than the count of U^L, and the horizontal angle β will be equal to:

$$\beta = U^R - U^L. \tag{5.1}$$

If the U^R count is less than the U^L count, 360 ° must be added to the U^R count. And the formula for calculating the horizontal angle, respectively, has the form:

$$\beta = U^R + 360° - U^L. \tag{5.2}$$

2 Measurement of vertical angles (angle of inclination)

The principle of measuring the angles of inclination, which are in the vertical plane, is to determine the angle between the horizontal line and the direction to the point of sight.

For the vertical circle of the theodolite the condition must be met: at connecting the zero of the limb with the reading stroke, the sighting axis of the telescope must be in a horizontal position. This condition is not always implemented. The count on the vertical circle at the horizontal position of the sighting axis of the telescope is called the place of zero (*PZ*) of the vertical circle (fig. 5.3). The value of the zero-point *PZ* is determined by sighting on one and the same point, preferably closer to the horizon line (approximately 0º on the scale of the vertical circle).

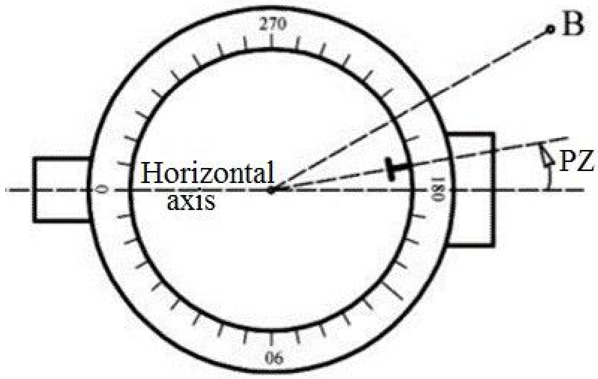


Figure 5.3 – Vertical circle of the theodolite

The place of zero is measured twice (at two positions of the vertical circle *CL* and *CR*) and calculated by the formula:

$$PZ = \frac{CL + CR + 180^{\circ}}{2}. \qquad (5.3)$$

At the same time, 360º must be added to the count less than 90º. It should be noted that each teodolite has its own constant value of *PZ*, it should be approximately in the range from 0º÷2′. If the place of zero is biger, the theodolite needs to be calibration.

After determining the *PZ* of the theodolite, you can calculate the value of the angle of inclination by one of the formulas:

$$\nu = CL - PZ, \qquad (5.4)$$

$$\nu = PZ - CR \pm 180^{\circ}. \qquad (5.5)$$

THE ORDER OF WORK IMPLEMENTATION

1 Determination of the horizontal angle

1. Receive a form from the teacher with a task to laboratory class.

2. Set on the station tripod, number of which is specified by the teacher. Set the tripod legs into the holes in the stand. Attach the theodolite to the tripod on stand screw.

3. Set the theodolite in working position.

3.1 By rotating the focus ring to establish in the telescope a clear view of the grid of threads.

3.2 Implement the centering of the instrument.

Centering is implementation using a plumb. First, a pin is hung on the hook of the estate screw, and a plumb is hung on the pin. Adjust the length of the thread so that the plumb was as close as possible to the floor. If the height does not coincide with the center of the point, then its position is adjusted by changing the height of the legs of the tripod, until the deviation of the plumb from the center of the point does not exceed 3-4 mm.

4. Levelling the theodolite

Levelling is implemented by bringing of bubble of a cylindrical level to the centre of the ampoule. Levelling is implemented using levelling screws.

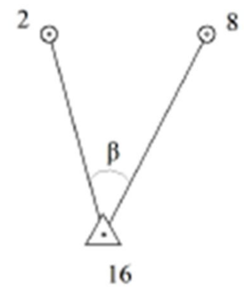
5. Measure the horizontal angle between the directions on the two sight marks, the numbers of which will be indicated by the teacher. In our example, there are points 2, 8.

5.1 In the log of measurement of a horizontal angle (tab. 5.1, column 7) to draw the scheme of mutual arrangement of points.

5.2 Implement the actions of the half-reception.

- Unlock the screw the fixing clamps of the horizontal circle and the telescope.
- Set the vertical circle of the theodolite on left relative to the telescope and make the appropriate mark (*CL*) in the horizontal angle measurement log (table 5.1, column 3).
- Using a pointer sight, direct the telescope at the left sight mark – point 2.
- Lock the fixing clamps of the horizontal circle and the telescope.
- Observing through the telescope eyepiece and using fine adjust screws, bring the intersection of the thread grid to the center of the sight mark, as it is shown in figure 4.6.

Table 5.1 – Log of measuring the horizontal circle

Points		Vertical circle position	Count from horizontal circle	Horizontal circle		Location scheme
station	sighting			half-reception	average	
1	2	3	4	5	6	7
16	2	CL	10º10'00"	90º20'30"	90º21'00"	
	8		100º30'30"			
	2	CR	190º10'00"	90º21'30"		
	8		280º31'30"			

– In telescope of the reference microscope take the reading U_2^{CL} on the scale of the horizontal circle. Write the obtained count in the log of horizontal angle measurements (table 5.1, column 4, line 1).

– Unlock the fixing clamps of the horizontal circle and the telescope. Direct the telescope to the right sight mark and take a count U_8^{CL} on the scale of the horizontal circle. Write the obtained count in the log of horizontal angle measurements (table 5.1, column 4, line 2).

– Calculate the value of the horizontal angle by formula 5.1:

$$\beta = U^R - U^L = 110°30'30" - 10°10'00" = 90°20'30".$$

That is, the horizontal angle is equal to the difference between the readings obtained from directing to the right and left points. The result is recorded in the log of horizontal angle measurements (table 5.1, column 5, line 1).

5.3 Implement the actions of the second half-reception (implemented for control the measurements).

– Transfer the telescope through the zenith and change, thus, the position of the vertical circle to the opposite – «CR».

– Repeat the steps of the first reception, receiving readings on the horizontal circle U_2^{CR} and U_8^{CR}. Record the results in the horizontal angle measurement log (table 1, column 4, lines 4 and 3, respectively).

– Calculate the value of the horizontal angle at the position of «CR» by formula 5.1:

$$\beta = U^R - U^L = 280°31'30" - 190°10'00" = 90°21'30".$$

Record the result in the horizontal angle measurement log (Table 5.1, column 5, line 3).

5.4 Compare the obtained results. The following condition must be implemented:

$$|CL - CR| \leq 1'. \tag{5.6}$$

When implementing it, calculate the average value of the horizontal angle by the formula:

$$\beta_{av} = \frac{\beta^{CL} + \beta^{CR}}{2}. \tag{5.7}$$

In our example, the condition is satisfied because:

$$|90°20'30" - 90°21'30"| = 1'.$$

Therefore, you can calculate the average value of the horizontal angle of the full-reception:

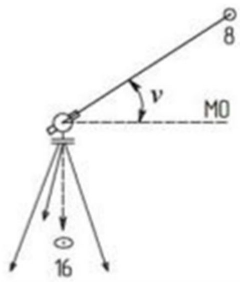
$$\beta_{av} = \frac{\beta^{CL} + \beta^{CR}}{2} = \frac{90°20'30" + 90°21'30"}{2} = 90°21'00".$$

The result is entered in column 6, table. 5.1. If the condition is not implemented, the horizontal angle measurements are repeated until condition is implemented.

2 Measurement of the vertical angle

Then, continuing to stand at the station, we choose one of the sighting marks, which were already indicated when determine the horizontal angle, and determine the place of zero *PZ* for it. The angle of inclination is measured twice at two positions of the vertical circle *CL* and *CR* in our example point (mark) №8. The results are entered in table 5.2 in column 4 of lines 1, 2. All actions are implemented similarly to the actions in determining the horizontal angle, but the readings are taken on a vertical limb scale.

Table 5.2 – Log of measuring of the inclination angle

Point		Vertical position circle	Vertical circle count	PZ	Angle of inclination, ν	Location of point
station	sighting					
1	2	3	4	5	6	7
16	8	CL	9º05'30"	0º00'30"	9º05'00"	
	8	CR	170º55'30 "			

After taking the counts on the vertical circle limb, at first the zero place (*PZ*) is calculated, and then the inclination angle (ν) is calculated according to formulas 5.3 and 5.4.

$$PZ = \frac{9°05'30" + 360° + 170°55'30' + 180°}{2} = \frac{720°01'00"}{2} = +0°00'30".$$

$$\nu = CL - PZ = 9°05'30" - 0°00'30" = 9°05'00".$$

The result is entered in columns 5 and 6, table. 5.2. If the condition is not implemented, repeat the horizontal angle measurement until it is implemented.

It should be noted that if the zero place PZ ≥ 360º, then 360° must be subtracted from the obtained result.

Questions for self-control:

1. What is the place of zero?
2. Name the sequence for measuring the horizontal angle.

3. Name the vertical angle measurement sequence.
4. What is the difference between measuring a horizontal angle and a vertical one?
5. Give a definition to the concept of «half-reception».
6. Give a definition to the concept of «reception».
7. What is the formula for calculating the horizontal angle?
8. What is the formula for calculating the vertical angle?

LABORATORY CLASS №6
The structure of the level Н-10КЛ and rod РН-3

The purpose of the class. Get acquainted with the structure and geometric scheme of the level Н-10КЛ. Learn to bring the instrument to a horizontal position, take the counts on the levelling rod РН-3.

Equipment and implements. Level Н-10КЛ, tripod ШР-90, stand, rod РН-3, form for laboratory class №6.

THEORETICAL MATERIAL

A level is an optical-mechanical instrument – an altimeter for constructing a horizontal ray in space

Types and classification of levels by design and accuracy. According to the ***design*** and method of setting a horizontal sight ray levels are divided into:

- levels with a cylindrical level on the telescope;
- levels with a compensator for automatic setting of the sighting axis of the telescope into a horizontal position;
- electronic.

Depending on the ***accuracy*** levels are divided into three groups:

- high-precision – type Н-05, Н-1, Н-2;
- exact – type Н-3, Н-3К, Н-3КЛ;
- technical – type Н-10, Н-10КЛ.

According to the standard, the levels are denoted by the Russian letter Н, then there are letters that indicate the design of the level:

- ***Л*** – level with limb;
- ***К*** – level with compensator;
- ***КЛ*** – level with the compensator and limb.

Geometric scheme of the level. The main feature of the levels is the sighting axis, which is assign to them, must be horizontal, that is, it must have a device for horizontal setting of the sighting axis. According to the method of setting the horizontal sighting ray, levels are available with a compensator and with a level.

The level has a number of requirements that related to the position of its main axes (fig. 6.1): $II' \parallel ZZ'$, $II' \perp VV'$, $VV' \perp ZZ'$.

When implementing checks you must control the correctness of the relative position of the axes and parts of the level.

Levelling rods. Levelling rods are the working measures for measuring of elevations. According to the standard out three types of rods: РН-05, РН-3; РН-10 are produced. The code PH means levelling rod, and the number indicates the root mean square error of measurement of elevation per 1 km of double tracking.

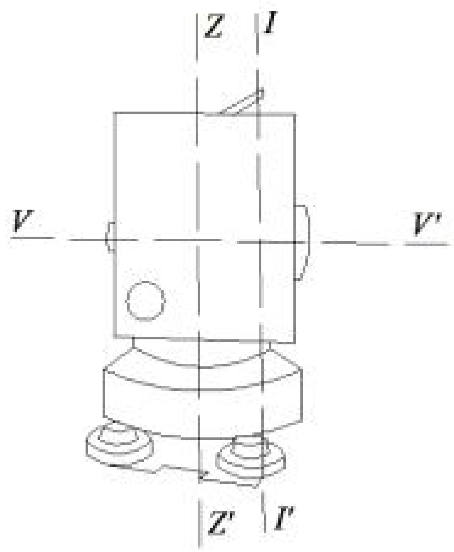


Figure 6.1 – The main axes of the level with the compensator H-10КЛ:
ZZ' – the axis of rotation of the level; VV' – sighting axis of the telescope;
II' – the axis of the circular level

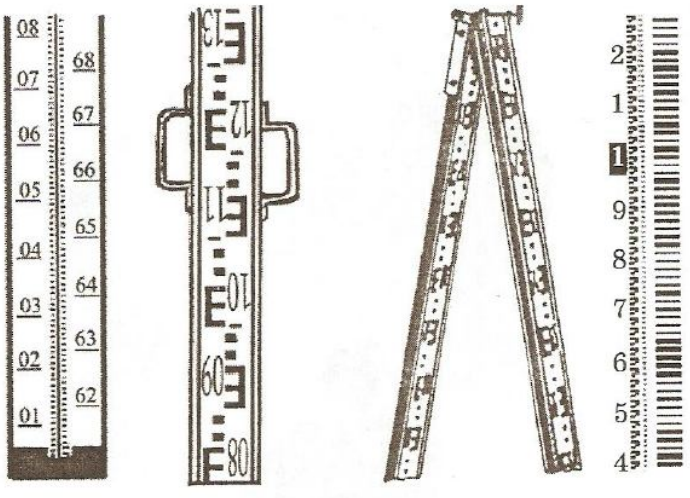
Rod PH-05 is wooden with invar strip, one-sided length is 3 m. It has a main and additional scales with divisions of 0,5 cm (for special works use the same rods with a length of 1 m), designed for high precision levelling (fig. 6.2, a).

Levelling rods PH-3 and PH-10 are wooden, 3 and 4 m long. They are solid and folding double-sided with scale divisions of 1 cm in the form of checkers. On one side there are checkers of black and white colours (black side), on the other – red and white colours (red side). Decimetre rod divisions are digitized. There are rods with both direct and inverted digitization of scales, respectively, for telescopes with direct and inverted views (fig. 6.2, b).

The lower part of the rod, lined with a metal plate, is called the heel of the rod. On the black side of the rod, zero coincides with the heel and the divisions increase upwards; on the red side of the rod with the heel in different rods can match such values as 4687, 4787, 4700 or 4800.

During levelling, the black scale is the main one, and the red scale is measured by the difference of the heels (4681 – 4800) within the levelling accuracy. This allows you to implement reliable control of the work, because on different digital counts are got the same result.

Levelling rods PH-3 are intended for levelling of III and IV classes, and PH-10 – for technical levelling. To increase the accuracy on the side of the rods a round level and two handles are fixed. They are allowed you to put the rod vertically on the levelling point.



a b c

Figure 6.2 – Levelling rods:
a – fragment of solid rods PH-0.5, PH-3;
b – foldable rod; c – code rod

Code rods (fig. 6.2, c) are used during levelling with electronic levels.

THE ORDER OF WORK IMPLEMENTATION

1 Checking the external condition and completeness of the level

The check is carried out by visual inspection. The level must correspond to the following basic requirements:

− the completeness of the level must correspond to passport data, the requirements of GOST 10529-86 and technical documentation;

− the level and the case must not have mechanical damage, traces of corrosion and other defects that will complicate the work with it and affect the implementation, metrological characteristics and preservation of the equipment;

− the level must have a quality optical system, clear field of view of the telescope. Observation in the eyepiece checks the quality of the strokes of the grid of threads. Defects that prevent the use of the level for its intended purpose are not allowed.

2 Checking the efficiency of the level

The level is inspected after setting on a tripod and its fixing by the stand screw:

- The upper part of the level must rotate freely, without delay.
- The rotation of the focusing ring of the eyepiece and the microscope should be smooth.

– The view of the object, the grid of threads in the field of view of the telescope must be clear.

– The levelling screws must not have any damage to the thread and must rotate smoothly and effortlessly.

– During inspecting the rods, pay attention to the preservation of the heels and the operation of the lock in the complex rods. Heels of pair of rods must have the same value.

3 Round level checking

Geometric condition: the axis of the round level must be parallel to the vertical axis of rotation of the level (fig. 6.3).

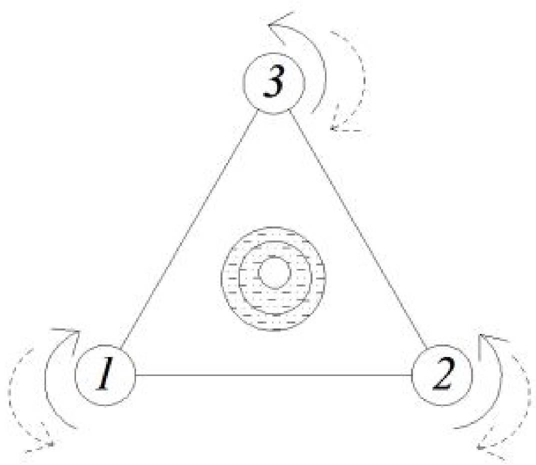


Figure 6.3 – Round level checking

Lifting screws are brought the bubble of round level into the centre (fig. 6.3) and rotate the level 180 ° around the vertical axis. If the level bubble has shifted from the centre, it is moved by level correction screws by half the deviation. Checks and corrections are performed several times.

4 Checking the mesh of threads telescope

Geometric condition: the horizontal stroke of the grid of threads must be perpendicular to the vertical axis of rotation of the level.

On the rod, established vertically 40-50 m from the level, the telescopes is directed so that the view of the rod comes to the edge of the field of view, and then takes the count on the rod. Then the telescope is rotated until the view of the rod is shifted to the opposite edge of the field of view of the telescope, and then takes the second count on the rod (fig. 6.4).

If the counts do not differ by more than 1 mm – the condition is met. Otherwise, the level must be calibrated.

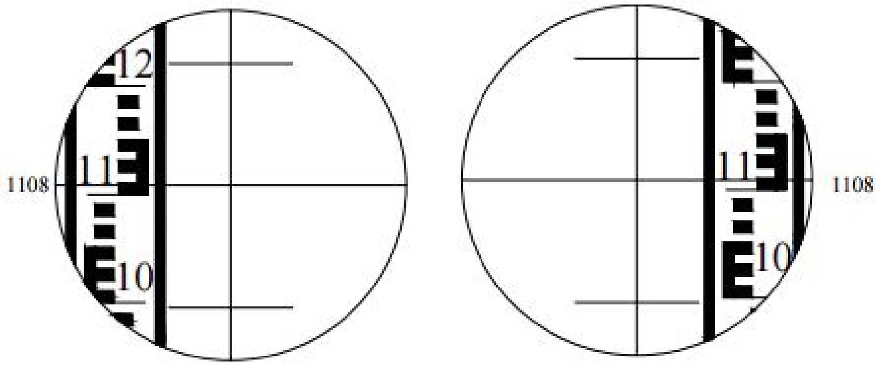


Figure 6.4 – Checking the mesh of threads telescope

Based on the results of checks of the level, a conclusion is made about the suitability of the instrument for work. The materials of inspections are properly executed and attached to the form of laboratory class.

5 The structure of the level H-10КЛ

In laboratory class the level is used in which there is a compensator of an inclination of a sight axis is used. Such a level has only a spherical level to bring the level into working position – the approximate setting of the sighting axis horizontally.

The horizontality of the line of sight is ensured with the required accuracy by the compensator. Compensators allow to increase the accuracy of readings on rods and labour productivity. It allows to work on unstable soils.

Figure 6 5 shows a general view of the level H-10КЛ.

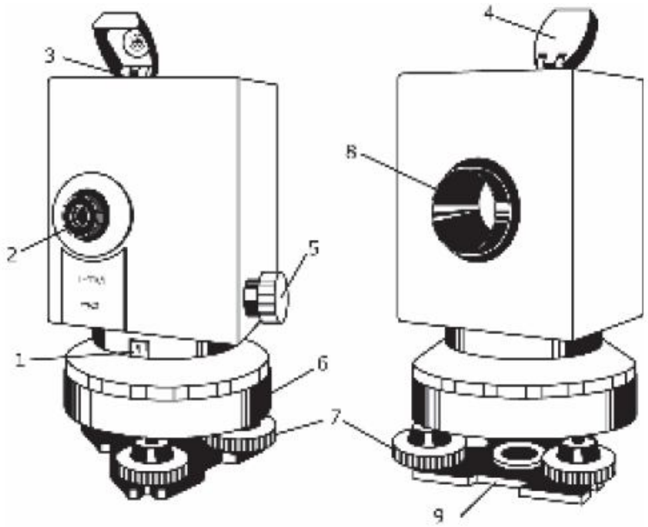


Figure 6.5 – Level H-10КЛ:
1 – limb; 2 – eyepiece ring; 3 – round level; 4 – cover-mirror; 5 – the screw of the mechanism of refocusing; 6 – stand; 7 – levelling screws; 8 – objective; 9 – spring plate (treher)

This is a technical level with a compensator and a limb. The minimum focusing distance is 1,5 m. In the telescope of the level, which has a magnification of 20". The inverted telescope gives an earthly view of objects. In a level there is a horizontal circle with the price of division 1°, an adjusting level (on fig. 6.5 it is located under a mirror) with the price of division 10' and a mirror for its supervision, a support with levelling screws.

6 Taking counts on the levelling rod

Aiming on the levelling rod is implemented in the following sequence:

- direct telescope on the levelling rod by hand;
- achieve a clear view of the grid of threads and rod using the eyepiece ring *2* and focusing screw *5* (fig. 6.5);
- take a count on the horizontal thread of the telescope (fig. 6.6).

A count on the levelling rod is taken in the following sequence:

- the number of signed decimetres (*16*);
- the number of full centimetre divisions (*5*);
- tenths of an incomplete centimetre division are estimated «by eye» (*2*).

The total count will be *1600 + 50 + 2 = 1652 mm.*

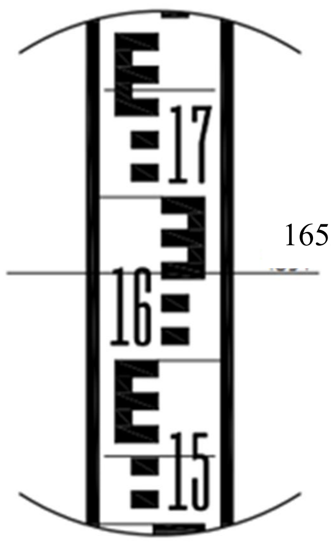


Figure 6.6 – Field of view of the level Н-10КЛ by rod РН3

The distance from the level to the rod can be determined from the along the rangefinder threads.

Example. If the upper count is *1760* and the lower – *1539*, the distance will be: *d = 1760 – 1539 = 221 mm = 22,1 cm* (fig. 6.6).

If the coefficient of the thread rangefinder $K = 100$, then 1 cm on the rod corresponds to 1 m of line length on the ground, then the distance will be: $d = 22{,}1\ cm \times 100 = 22{,}1\ m$.

The results are entered in the form of laboratory class №6.

Questions to self-control:

1. How to classify levels by structure and accuracy?
2. What is the main requirement for a level of any type?
3. How to take counts on the rods?
4. Name the main parts of the level Н-10КЛ.
5. How to bring the level to a horizontal position?
6. What is a «grid threads»?
7. Why are the black and red sides used on rods РН-3?
8. How to determine the distance using the rod?

LABORATORY CLASS №7

Geometric leveling. Work at the station

The purpose of the class. Learn the procedure of work at the station during of implementation of geometric levelling from the middle and the sequence of mathematical processing of measurement results.

Equipment and implements. Level Н-10КЛ, tripod ШР-90, stand, rod РН-3, form for laboratory class №7.

THEORETICAL MATERIAL

Levelling is necessary to create a height basis for topographic surveys, study of landforms and determine the difference in height of points during topographic surveys, design, construction and operation of various structures and buildings. Levelling results are important for solving scientific and practical tasks in geodesy.

Elevations can be calculated by the difference between the heights of points on the map, plan or construction drawings. On the ground, the elevation between the specified points is determined by levelling.

Elevation is the difference in heights of points on the earth's surface or building structures.

In engineering geodesy the following methods are used of geodetic levelling:

- *geometric* – the principle of horizontality of the sighting ray of the telescope is used;
- *trigonometric* – the principle of an inclined ray of a telescope is used;
- *hydrostatic* – based on the properties of the free surface of the liquid in the connected vessels – to be at the same level;
- *barometric* – based on the dependence of changes in atmospheric pressure on changes of the height of the point;
- *automatic* – the principle of transformation of an inclined vector of movements of the device into vertical components by means of special devices is used;
- *stereophotogrammetric* – based on the measurement of elevations on the model of the object, we obtain as a result of consideration of the stereo pair of photographs of the area.

Geometric, trigonometric and hydrostatic levelling are mainly used in construction.

Geometric levelling is a method of determining the elevations between points on the earth's surface using a horizontal sighting ray and special levelling rods. To obtain a horizontal ray level is applied.

Depending on the location of the level, there are two ways of geometric leveling: ***«from the middle»*** and ***«forward»***. In the laboratory class the method of geometric leveling from the middle is considered.

Geometric levelling from the middle and work at the station. To measure the elevation between points *A* and *B*, the level is set in the middle, and the rods – plumb over the points. Bring the level in working condition. Direct the telescope at the black scale of the back rod and take the count ***a***. Rotate the telescope on the black scale of the forward rod and take the count ***b*** (fig. 7.1).

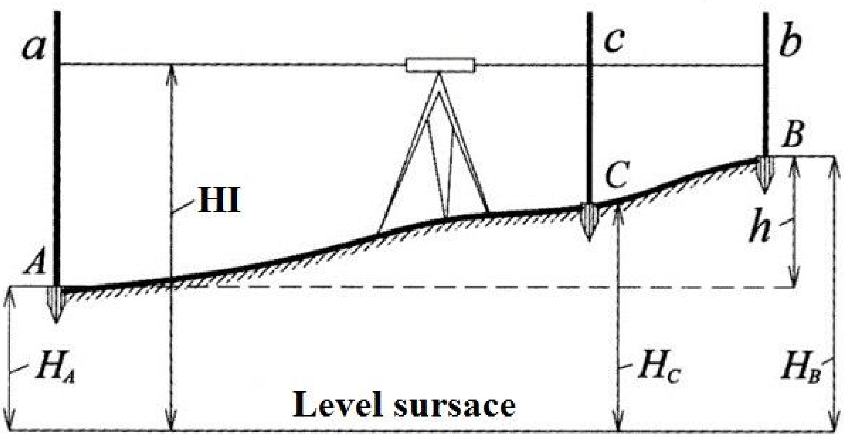


Figure 7.1 – Geometric levelling from the middle

The elevation is calculated by formula 7.1:

$$h = a - b. \quad (7.1)$$

Repeat the levelling, turn the rods on the red side of rods.

If the difference between the calculated of elevation is not more than 5 mm (technical levelling), then determine the average elevation. With a known height of the back point, you can calculate the height of the forward point by formula 7.2:

$$H_B = H_A + h. \quad (7.2)$$

If add cunts on the black sides of the rods to the known heights of the points, we get the height of the horizon of the instrument (***HI***) by formulas 7.3 and 7.4:

$$HI_{back} = \mathrm{H_A} + a; \quad (7.3)$$

$$HI_{forward} = \mathrm{H_B} + b. \quad (7.4)$$

If the condition ($HI_{back} - HI_{forward}$) < ±10 mm (technical levelling) is implemented, then the average value of the horizon of the instrument is calculated according to formula 7.5:

$$HI = 0{,}5\left(HI_{back} + HI_{forward}\right). \quad (7.5)$$

The height of the intermediate point *C* is calculated by formula 7.6:

$$\mathrm{H_C} = HI - \mathrm{c}, \quad (7.6)$$

where *c* – the count on the black side of the rod that set at point *C*.

The order of work at the station.

1. Set the level approximately in the middle between levelling points *A* and *B*, but not necessarily in the line *AB*, you should set the level, that the distances between the instrument and the rods were approximately the same.

2. Bring the bubble of round level to the middle using the levelling screws and direct the telescope of the level on the black side of rod of back point *A*.

3. Direct the telescope at the forward rod *B* and take counts respectively on the black and red sides of the rod.

4. Direct the level telescope on the back rod A, and take the count on the red side of the rod.

5. If it is necessary to additionally, determine the heights of the intermediate points *C1* and *C2*, the back rod *A* is sequentially set at these points and take readings *C1* and *C2* on the black side of the rod. The results of observations at the station are recorded in the levelling log.

6. To control the reports on the rods, calculate the differences of the zeros of the heels of the rods.

7. Calculation of elevation. The elevation is equal to the count on the black rod minus the count on the forward rod. If the difference of values does not exceed 5 mm, then the measurements are implemented correctly. The arithmetic mean value is taken as the final elevation at the station.

The following calculations in the levelling log are implemented in cameral conditions.

THE ORDER OF WORK IMPLEMENTATION

1. Get a form the teacher with a task to implementation of laboratory class.

2. Receive level H-10КЛ, tripod and levelling rods PH-3.

3. Choose a convenient place in the class to set the level, so as to ensure the visibility of the points, the levelling of which is implemented (table 7.1, column 2).

4. Lay out a stand on the floor of the audience. Unscrew the screws on the tripod legs; extend the legs up to a comfortable height for working with a spirit level. Set the tripod legs into the holes in the stand. Attach the level to the tripod with a stand screw.

5. Set the level in the working position:

– by rotating the eyepiece ring to establish a clear view of the grid of threads in the telescope;

– levelling the level.

6. Direct the telescope to the first connecting point specified in the task (conditionally on the back rod). Use the refocusing screw to set a clear view of the rod in the telescope.

7. Take counts on the black and red sides of the rod. The results are recorded in the table. 7.1 (column 3, line 1 and 2, respectively).

Table 7.1 – Levelling log

Station	Point	Count of the rod, mm			Elevation h, mm				Horizon of the instrument HI, m	Point height H, m
		back U_{back}	forward $U_{forward}$	intermediate U_{int}	measured		average			
					+	-	+	-		
1	2	3	4	5	6	7	8	9	10	11
1	A	2190							102,190	100,00
		6840			1640		1639			
	B		0550		1638					101,63
			5202							
	C			1166						101,02

8. Aiming the telescope to the second (forward) point. Take the counts on the black and red sides of rod and enter them in table 7.1 (column 4, line 3 and 4, respectively).

9. Aiming the telescope to the third (intermediate point) and take the count on the black side of the rod. Record the result in table 7.1 (column 5, row 5).

10. Implement mathematical processing of measurement results.

10.1 From the counts obtained on the scales of the back and forward rods, calculate the elevation between them. To do this, use the formula 7.1. Record the results in column 6 or 7 of table 7.1 (according to the sign of elevation).

10.2 Compare the obtained results. The following condition must be met:

$$\left|h^{blak} - h^{red}\right| \leq \pm 5\ mm. \tag{7.7}$$

If the condition is met, then the average value is calculated using the formula:

$$h_{av} = \frac{h^{blak} + h^{red}}{2}. \tag{7.8}$$

The obtained result is entered in column 8 or 9 of table. 7.1 (according to the sign of elevation). If the condition is not met, the measurement of elevation is repeated until it is fulfilled.

10.3 Calculate the height of the forward connecting point by the known height of the back point and the elevation between them by the formula:

$$H_{forward} = H_{back} \pm h_{av}. \tag{7.9}$$

Record the result in table 7.1 (column 11, line 3).

10.4 Calculate the height of horizon of instrument *HI* according to the formulas 7.3–7.5. Record the result in table 7.1 (column 10, line 1).

10.5 Calculate the height of the intermediate point by formula 7.6. Record the result in table 7.1 (column 11, line 5).

12. Prepare a report on laboratory class.

Questions for self-control:

1. What is a level called?
2. What levelling methods do you know?
3. What is the main requirement for a level of any type?
4. Name the principle of trigonometric levelling and instruments and accessories that for its implementation.
5. Name the principle of barometric levelling and the instruments and accessories that for its implementation.
6. In what sequence is the level brought to working position?
7. Name the methods of geometric levelling.
8. Name the order of work at the station of geometric levelling.

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Виробничо-практичне видання

Методичні рекомендації
до виконання лабораторних робіт та самостійної роботи
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«ОСНОВИ ГЕОДЕЗІЇ»

*(для студентів першого (бакалаврського) рівня вищої освіти
спеціальності 191 – Архітектура та містобудування)*

(Англ. мовою)

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Відповідальний за випуск *О. Є. Поморцева*
За авторською редакцією
Комп’ютерне верстання *М. О. Пілічева*

План 2021, поз. 453М

Підп. до друку 17.02.2021. Формат 60 × 84/16.
Друк на ризографі. Ум. друк. арк. 2,43
Тираж 50 пр. Зам. №

Видавець і виготовлювач:
Харківський національний університет
міського господарства імені О. М. Бекетова,
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Свідоцтво суб’єкта видавничої справи:
ДК № 5328 від 11.04.2017.