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REPORT OF SCIENTIFIC RESEARCH NUMBER 2
RELATED TO THE PhD THESIS

"RESEARCH ON THE ANALYSIS OF THE SUBSIDENCE CAUSED BY THE EXPLOITATION OF THE STRATIFORM DEPOSITS"

THE TITLE OF THE SICENTIFIC REPORT:

CONCEPTS AND TECHNIQUES RELATED TO THE ANALYSIS OF THE SUBSIDENCE CAUSED BY THE EXPLOITATION OF STRATIFORM DEPOSITS

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SCIENTIFIC RESEARCH REPORT

Chapter 1 INTRODUCTION

1.1 Generalities

In the context of an existing energetic crisis worldwide, the last decades led to intense preoccupations for discovering new chemical-energy elements, for a superior use of the deposits, for the more careful management of the resources and for the increase of the production capacity of the stratiform deposits.

The scientific research in dedicated centres led to a better knowledge on the process of deformation of the surface of the ground and of the stability of the constructions. [69].

For the underground mining, the appearance of the subsidence phenomenon has as consequence the filling of the cavity formed through the extraction of the deposit and the spread of the phenomenon to the surface, with repercussions on the surface for an amplitudes of dozens of meters.

The movement of the surface due to the underground mining is very important especially in the case of the complete exploitation of the coal, in thick strata or to a suite of strata. Thus, rifts and cracks may appear in the areas with civilian or industrial buildings, leading to their destruction; holes may appear in farmlands and they are filled with water from precipitations; cracks and rifts can also appear in the infrastructure of the communication networks and in the water and gas pipes; the sinking of the surface is produced often instantaneously and the destruction of the equilibrium of the strata can lead to real catastrophes.

The underground exploitation of the stratiform deposits from the mining basin of Valea Jiului leads frequently to the movement or to the deformation of the surface, as well to the deterioration of the industrial and civilian buildings at the surface of the mining fields.

To solve the problem of protecting the industrial and civilian objectives at the surface of the mining fields, it is necessary to use protection measures against the sinking of the surface and it is also necessary to research the laws of the movement and deformation of the surface and the laws of variation of the tension in the construction elements.

To make observation on the movement and the deformation of the surface and of the objectives at the surface, there are mostly used the topographic measurements.

The observations are often limited to routes of geometric middle levelling on a network composed from tracking benchmarks and also the measurement of the distance between them.

The multitude of movement parameters (sinking and horizontal movement) and the deformation parameters (inclination, curvature, horizontal deformations) can be determined after the topographic measurements.

The problem of the movement of the rocks and of the surface under the influence of the underground mining was and still is important in the research of the underground mining and offers the possibility to apply the proper solutions for the protection of the industrial and civilian buildings at the surface . [57].

1.2 The definition of the terms used in the analysis of the subsidence phenomenon

Starting from the fact that the science of the terrestrial measuring has as study object the totality of the field operations and calculations in the field, performed in order to obtain a plan or map representation of a certain cartographic projection and topographic scale, we consider necessary to define the elementary notions related to this matter of national and international importance.

Thus, we will shortly define each term used in the research and the analysis of the subsidence.

The subsidence is defined as an ample process of slow and/or progressive descending of the terrestrial surface in the deposit basins depending on the accumulation of the extracted deposits.

The sinking bed represents the area at the surface that enters in movement under the influence of the underground works.

The sinking represents the vertical component of the movement vectors of all the points at the surface in the sinking bed .

The horizontal movement is defined as the horizontal component of the movement vectors of all the points placed in the synclinal of the movement.

The horizontal specific deformation is defined as the variation in the length of the interval between two consecutive points reported to the basic measurement.

The inclination is defined as the differential variation of the vertical movement obtained through the ratio between the sinking difference in the sinking bed and the distance reduced to the horizon between the points.

The curving is defined as the relation between the inclination difference of two neighbouring intervals and the horizontal distance between three consecutive points.

The sinking angles of the movement are the angles which are formed by the lines that unite the margins of the exploited space with the marginal areas of the sinking bed and a horizontal line.

The limit angles are defined as the angles exterior to the exploited space, formed by the horizontal direction and the other directions that unite the margins of the exploited space with the points at the surface, whose sinking is zero.

The conventional angles are determined in the same manner as the limit angles, but they determine points at the surface of the sinking bed with deformations that are not dangerous for the civilian and industrial buildings at the surface.

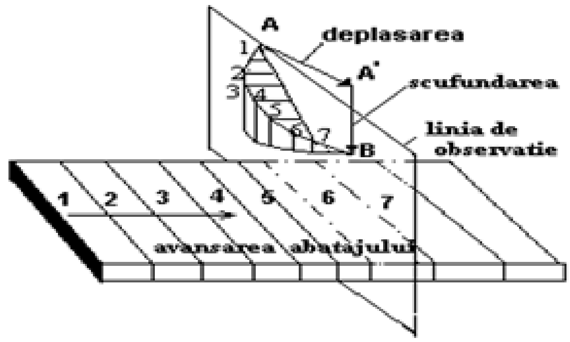
The breaking angles are the angles formed by the breaking planes with the horizontal line and ate noted with: β_r downstream, γ_r upstream and δ_r on direction.

The angles of the total movements are internal angles related to the exploited space, formed in the main vertical sections of the synclinal of the movement, on the plan of the strata and the lines that unite the margins of the mining works with the point of maximum sinking. They can be at the margins of the inferior mining works ψ_1, superior ψ_2 and on direction $\psi 3$.[57].

The angle of maximum compaction is defined as the angle from the direction of the fall of the stratum, formed on the main vertical section perpendicular on the direction of the stratum, by a horizontal line and the line that unites the middle of the mining work with the point of maximum sinking.

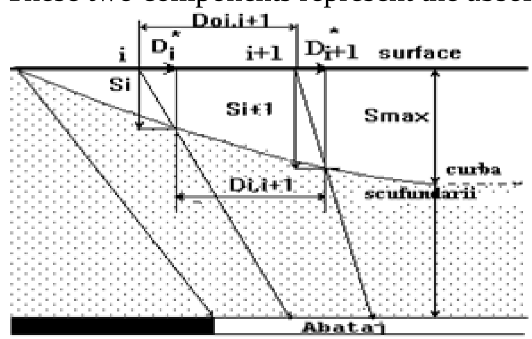
CHAPTER 2
TOPOGRAPHIC METHODS FOR DETERMINING THE PARAMETERS DEFINING THE SUBSIDENCE PHENOMENON APPEARED AS A CONSEQUENCE OF THE STRATIFORM MINING

A point at the surface situated in the area of influence of a mining exploitation always has a movement toward the exploited space. This point is described in space as a helicoidally curve, constantly in the direction of the centre of the coal-face front.



Drawing 2.1 The components of the absolute and differential movement [57]

In the final moment of the movement, this movement has a vertical component (S_i) and a horizontal component (D^*_i). These two components represent the absolute movements of the point.



Drawing 2.2 The components of the absolute movement at the surface [57]

2.1 The sinking

The sinking (S_i) represents the vertical component of the movement vectors of all the points at the surface in the sinking bed.

$$S_i = H^*_i - H_i, \text{ in mm} \tag{2.1}$$

Where: H^*_i is the elevation of point i to measurement zero;

H_i – the elevation of point i to a certain moment.

A landmark is considered as stable from a levelling point of view if the final sinking is smaller than 20 mm [57].

2.2 The horizontal movement

The horizontal movement (ΔD_i) is defined as the horizontal component of the movement vectors of all the points situated in the synclinal of the movement. Two neighbouring point placed at the surface reflect a similar route but it is remarked that the distance separating them initially ($D^*_{0_{i,i+1}}$) is not the same at the end of the movement ($D^c_{0_{i,i+1}}$).

$$\Delta D_i = D^c_{0_{i,i+1}} - D^*_{0_{i,i+1}} \text{, in mm} \tag{2.2}$$

Where: $D^c_{0_{i,i+1}}$ is the horizontal distance between two consecutive points for the present measurement.

$D^*_{0_{i,i+1}}$ - the horizontal distance between two consecutive points for the zero measurement.

If we establish the ratio of the variation of a length measured for an initial length, we may obtain a differential movement we call horizontal specific deformation.

2.3 The horizontal specific deformation

The horizontal specific deformation (ε_i) is defined as the variation of the length of the interval between two consecutive points relative to the length of the basic measurement. The horizontal deformation can be positive when we deal with an expansion and negative when we deal with a compression.

$$\varepsilon_i = \frac{\Delta D_i}{D^*_{0_{i,i+1}}} \text{, in mm/m} \tag{2.3}$$

Where: ΔD_i is the horizontal movement of the landmark *i*;

$D^*_{0_{i,i+1}}$ - the horizontal distance between the landmark i and the landmark $i+1$ for the initial measurement.

2.4 The inclination

The inclination (*I*) is defined in the literature as the differential variation of the vertical movement obtained by the ratio between the sinking difference between two consecutive landmarks and the distance reduce to the horizon between the two landmarks.

$$I_i = \frac{S_{i+1} - S_i}{D_{0_{i,i+1}}} \text{, in mm/m} \tag{2.4}$$

Where: S_i is the sinking of the present landmark *i*;

$S_{i,i+1}$ – the sinking of the consecutive landmark $i+1$;

$D_{0_{i,i+1}}$ – the horizontal distance between the two landmarks.

2. 5 The curvature of the sinking bed

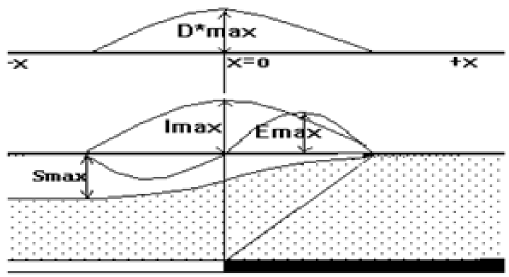
The curvature of the sinking bed (K) represents the ration between the inclination difference between two neighbouring intervals and the half-sum of these intervals.

$$K = \frac{I_{i+1} - I_i}{D_{0_{i,i+2}}}, \text{ in mm/m}^2 \tag{2.5}$$

Where: I_i represents the inclination of the field between landmarks i and i+1;

I_{i+1} – the inclination of the field between the landmarks i+1 and i+2;

$D_{0_{i,i+2}}$ – the horizontal distance measured between the points $i \rightarrow i+1$ and $i+1 \rightarrow i+2$.



Drawing 2.3 The components of the differential movement of the surface [57]

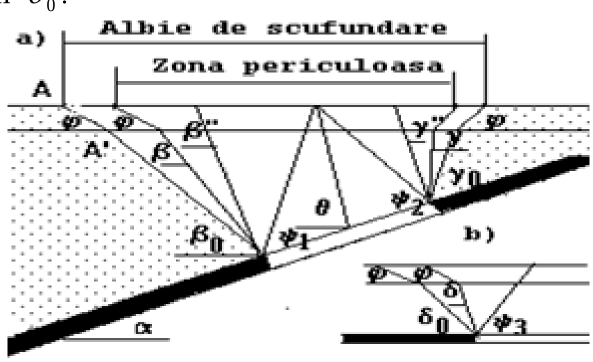
2.6 The sinking angles of the movement

These are the angles formed by the lines that unite the margins of the exploited space with the marginal areas of the sinking bed and a horizontal line [57].

These angles are classified as follows: limit angles, conventional angles, breaking angles, angles of the total movement and the angle of the maximum compaction.

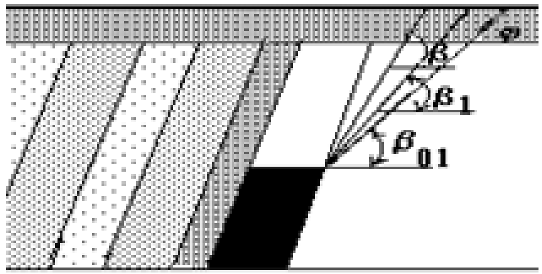
The limit angles are defines as those exterior angles to the exploited space, formed by the horizontal direction and the other directions that unite the margins of the exploited space with the surface points whose sinking is null. These angles are used to determine the dimensions of the sinking bed.

The drawing below shows the downstream limit angles β_0, the upstream angles γ_0 and on the direction of the stratum δ_0.



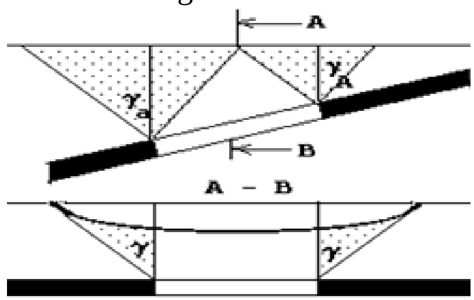
Drawing 2.4 The limit angles [57]

For the strata with a big inclination, the limit angle from the bed is noted with β_{01} .



Drawing 2.5 The angles from the bed for strata with big inclination [57]

In the French instructions, the limit angles are determined toward a vertical line to the limit of the coal face and the lines that unite the margins of the coal face with the surface points where the sinking is zero. A point has a sinking equalling zero, when the measured sinking is smaller than the precision of the polygonal course made through the method of the middle geometric levelling.



Drawing 2.6 The influence limit angles [57]

The conventional angles β, β_1, γ, δ are determined in the same way as the limit angles, but they determine points at the surface of the sinking bed with deformations which are not dangerous for the civilian and industrial buildings at the surface.

For the determination of the conventional limit and for the determination of the moving angles, the following deformation parameters are used [57]:

- inclination $I = 4$ [mm/m]
- curving $K = 0.2$ [mm/m^2]
- horizontal deformation $\varepsilon = 2$ [mm/m].

We consider as necessary to take into consideration the fact that the size of the deformations are not identical for various constructions and varies considerably depending on the destination of the constructions, their specificities and sizes.

The conventional or the movement angles are used to design the safety pillars and of the zones of influence that are not dangerous for the majority of the constructions and of the natural objectives.

The breaking angles are angles exterior to the exploited space, formed on the main vertical sections of the sinking bed by the horizontal lines and the lines that unite the margins of the exploited space with the nearest cracks of the synclinal of the movement [57].

These breaking angles determine very dangerous deformations in the coal deposits and serve for the design of the safety pillars for buildings of small importance for the deposits of minerals.

The angles of total movements are internal angles to the exploited space formed in the main vertical sections of the synclinal of the movement, by the plan of the stratum and the lines that unite the margins of the mining works with the point of maximum sinking. We can distinguish between the angles of total movement to the margins of the inferior mining works ψ_1, superior works ψ_2 and on their direction $\psi 3$.[57].

The angle of maximum compaction (θ) is defined as the angle from the direction of the fall of the stratum, formed by the main vertical section perpendicular on the direction of the stratum, by a horizontal line and the line that unites the middle of the mining work with the point of maximum sinking.

The angular parameters of the movement depend on the physical and mechanical properties of the rocks and by other geo-mining factors. Between the angular parameters of the movement, beside the geometric relations, we can establish empirical relation that permit the determination of the angles of the movement depending on the breaking angles, or the limit angles depending on the angles of the movement.

It is necessary to take in consideration that the precision in the determination of the angles of movement is considerable smaller than the precision in the determination of the limit angles as functions of the movement angles [57], [74].

2.7. The interpretation of the results obtained from the measurements

Once the parameters are calculated, the graphics and the situation for each parameter will be established. In the end, there will be determined: the maximum speed of sinking of the surface, in mm/month; the necessary time for the completion of the maximum sinking and the medium speed of exploitation, in m/month [74].

The sinking speed is calculated with the relation:

$$V_i = \frac{S_i}{N}\text{, in mm/month} \tag{2.6}$$

where: S_i is the sinking of the landmark i;

N – the number of months between the basic observation and the current observation.

The sinking angles are calculated with the relation:

$$(\beta, \gamma, \delta) = arctg\left(\frac{H_i - H_a}{x_i - x_a}\right) \tag{2.7}$$

where: (β, γ, δ) are the sinking angles;

H_i – the elevations of the marginal landmarks;

H_a is the elevation of the coal-face front;

x_i is the longitudinal coordinates of the marginal landmarks;

x_a – the longitudinal coordinates of the coal-face front.

The marginal landmarks are those landmarks for which the movements and the deformations do not exceed the values: $\varepsilon \leq 2$ mm/m and $I \leq 4$ mm/m. the sinking angles can be determined also graphically, based on the measurements in the transversal and directional measurements[41].

CHAPTER 3 TOPOGRAPHIC METHODS USED FOR THE DETERMINATION OF THE MOVEMENT OF THE SURFACE

3.1 The presentation of the topographic methods

The topographic methods for the tracking of the movement of the surface were the first methods that highlighted the influence of the mining on the terrestrial surface.

In time, these methods were perfected and due to the evolution of the techniques and of the instruments, they are nowadays the most used methods for monitoring the phenomenon [40].

The topographic-geodesic methods used to determine the movements and the deformations of the constructions are the most often used methods due to their specificities, offering the relative and absolute sizes of the observed deformations.

Determining the values of the parameters we mentioned in the first chapter is achieved through direct and indirect measuring, which are grouped in methods as follows:

- geodesic ;
- topographic ;
- photogrammetric;
- laser scanning;
- interferometry.

The geodesic methods for determining the movement and deformation parameters of the surface are performed after rigorous instructions, established and approved by the ministries [57].

According to the existing instructions, the geodesic methods are classified in regional measuring, for the entire surface of the mining bed, and local measuring, for each mining perimeter.

The regional measuring is performed periodically, through high precision levelling measurements (the middle geometric levelling), using fix landmarks placed outside the areas of influence of the mining beds.

The local measuring is the determination of the coordinates (x,y,z) of the landmarks of the tracking networks and alignments, from which the parameters of the moving process are determined.

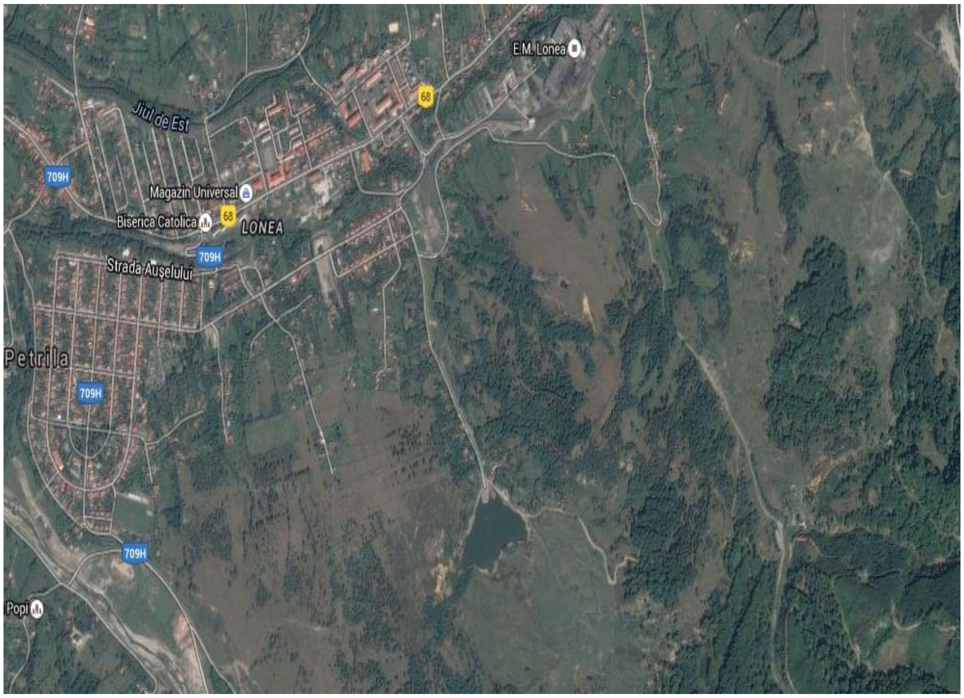
The topographic methods are the most used methods for the local measurements, being the base of tracking the movement of the surface and of the civilian and industrial objectives on the surface.

The topographic measuring is executed as a rule in tracking topographic networks or alignments places above the mining perimeters.

The photogrammetric methods are a result of the need to make available supplementary data to the science, technique, the measuring and the representation in plan of the surface, in order to explain phenomena that cannot be observed through topographic measuring.

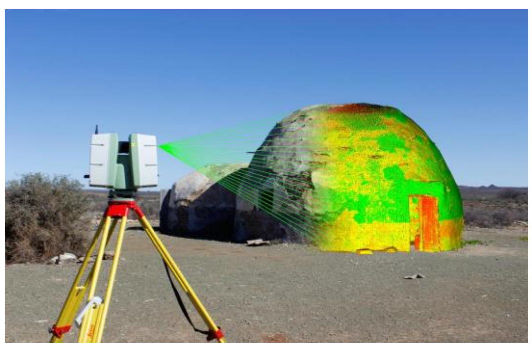
The photogrammetric methods ae used for the study of the subsidence in determining the deep cones of sinking, met during the mining, rarely for the stratiform exploitations.

They offer a higher precision for the determination of the form of the sinking bed, but they are less precise for the determination of the movement parameters, thus they are not so largely used [57].



Drawing 3.1 Ortho-photo-plan for Lonea, Hunedoara County, Romania.

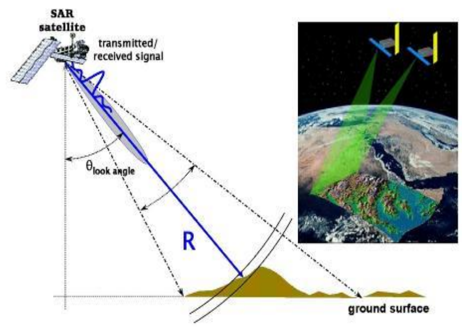
The method of laser scanning is a method of geodesic technique that helps to the complete and automatic measuring for the geometry of a structure, without the help of a reflecting environment, with high precision and at high speed. The result of the measuring is highlighted through a multitude of points, called cloud of points.



Drawing 3.2 Terrestrial laser scanning system [62]

The method of interferometry represents one of the most revolutionary methods used for the satellite monitoring of the movement of the Earth and is composed of a satellite equipped with a radar, with the antenna directed to the terrestrial surface and an inclination called nadir angle.

The use of the interferometry has as aim to detect and measure the movements of the surface to a small scale. This method implies the generation of two interferogramms from three images: am Interferogram of reference and a second one showing the changes at the surface of the field.



Drawing 3.3 The data acquisition using the technology DInSAR [62]

3.2 The design of the tracking networks necessary for the study of the subsidence

The construction of the topographic networks and alignments as well as the performing of the measuring is based on a project compound of a written part and a graphic part.

The written part of the project includes:

- general information of the research project and the objectives of the measuring;
- the aim, the field and the features of the observations;
- the geological, the mining and the exploitation characteristics of the deposit;
- the design for the construction of the tracking networks and alignments;
- the methodology for the geodesic measuring.

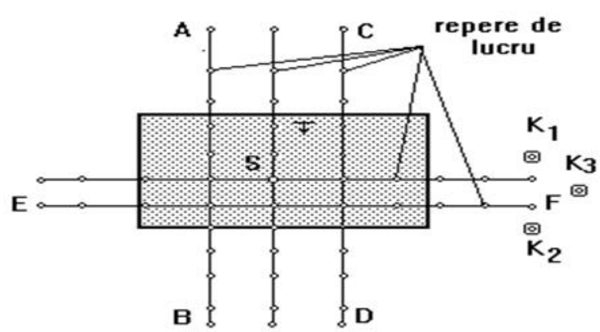
The graphic part of the project includes:

- the plane of the surface with the distribution mode of the topographic alignments;
- the plan of situation for the underground exploitation;
- the transversal and longitudinal geological profiles through the deposit (along the alignments);
- registration and calculation standard formulas of the geodesic measurements.

The networks or the alignments placed above the mining fields form a tracking network of the movement and deformation of the surface.

The tracking singular topographic alignments are placed above the coal-face, perpendicularly or parallel to the direction of the advancement of the fronts.

An assembly of parallel and perpendicular alignments form a tracking network [57].



Drawing3.4. Tracking network [57].

The tracking networks are the networks that determine the most precise the movement of the surface and are used for the following situations:

- when the coal-face fronts have irregular forms;
- for the concomitant extraction of several coal-faces from the mining field;
- in the case when the productive formation is affected by tectonic accidents;
- when the morphology of the field permits such placement [57].

The distance between the topographic tracking alignments, perpendicular on the development directions of the strata is established depending on the morphology of the fields.

For the tracking alignments places after the inclination of the strata is recommended a distance between them no longer than 50 m.

The tracking alignments contain the following topographic landmarks:

- main connection landmarks (K_1 ,K_2, K_3) ;
- support fix (end) landmarks, which are the beginning and the end of the tracking alignments (A,B,C,D,E,F);
- the working landmarks placed along the alignments.

The main connection landmarks are topographic points that are part of the triangulation network of the mine or of the basin. These landmarks must exist during the entire period of the measuring and fulfil the conditions of stability [57].

3.2.1 The placement of the fix landmarks and of the tracking marks for the subsidence phenomenon

The support landmarks are materialised for each alignment and are placed outside the influence areas of the exploitation; in some cases, they are points in the local network of triangulation of the mine.

The working landmarks and the tracking marks are placed at certain distances (see table 3.1), between the end marks [57].

The depth of the deposit [m]	The distance between the tracking points [m]	
	Placed in the sinking area	Placed outside the sinking area
50	5	10
50-100	10	15
100-200	15	20
200-400	20	25

Table 3.1**.** The distance between the tracking points[74]

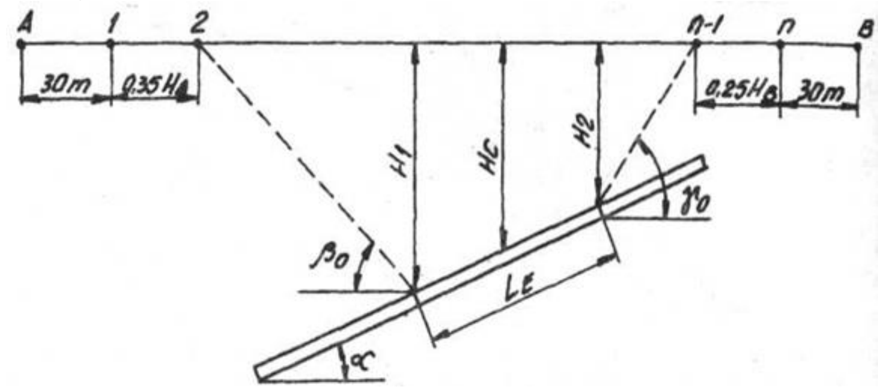
A tracking network us made of a series of points placed as a network of points, alignments of points or with isolated points.

The network of points can be: of long period of usage (5-20 years), if it is used for monitoring the movement of the surface exploited in pieces or when the covering rocks are hard, and the deformations appear after a long time, or of short period of usage (1-12 months), when it is used to determine the deformation speed of the field.

The points with special destination are planted near railways and pipe networks and are used for the measuring related to the movement and the deformation of the civilian and the industrial objectives.

The placement of the alignment points depends especially on the landscape, one alignment being placed on the direction of the deposit and the other perpendicular to it, both tracks oriented toward the centre of gravity of the deposit.

The length of the alignments is established depending on position, thickness, depth and the extension of the underground deposit. Thus, for the transversal alignments, the length is established by replacing a section surface-underground transversal to the deposit, where will be measured graphically H_1, H_2, H_C and L_e.[74] .



Drawing 3.5. Transversal alignments[74]

The length of the transversal alignment is given by the relation:

$$L_{tr} = 30m + (0{,}35ctg\beta_0)H_1 + L_E \cos\alpha + (ctg\gamma_0 + 0{,}25)H_2 + 30m \qquad (3.1)$$

where: α – the inclination of the stratum;

$$\beta_0 = \beta - 18^\circ + 1{,}5\ \alpha \qquad (3.2)$$

$$\gamma_0 = \gamma - \alpha - 15 \qquad (3.3)$$

The values of the angles α, β and γ were established experimentally to deposits similar as form, size, etc.

The distance between the transversal profiles is established according to the type of the deposit and should not exceed 100 m; this distance can be reduced to 50 m, depending on the variety of the geological, technical and mining factors.

The length of the directional alignment is calculated with the relation:

$$L_D = 2[30m + (0{,}25 + ctg\gamma_0) \cdot H_C + 0{,}5L_E] \qquad (3.4)$$

The end of the alignments will be considered support points and will be marked. The points of the network on the alignment are place to an interval of distances of 15 m.

The landmarks of the tracking marks are places so they can cover the entire movement bed, extending outside its limits, on an area sufficient for delimiting precisely the intersection contour of the movement surface with the surface of the field.

In the case of the inclined alignments, we will follow the inclination and the direction of the stratum, without omitting the observance of the singular points.

When the field does not permit it, we recommend the use of the network of points. There will be used topographic plans to the scales 1/1000; 1/2000; 1/5000. For the scales 1/1000, 1/2000, the polygonal course and the constructions at the surface will be reported.[74].

The length of the alignment outside the exploited area is:

$$D = H'' \cdot ctg(\delta - \Delta\varepsilon) \qquad (3.5)$$

where:

H"- is the height of the covering rocks on the alignment to the exterior points;

Δ – the sinking angle;

ε – the safety factor (10°-15°).

For the inclined stratum the sinking angles are different and the length of the alignments outside the exploitation area is:

$$D_1 = H_1^{"} ctg(\beta - \Delta\varepsilon) \tag{3.6}$$

$$D_2 = H_2^{"} ctg(\gamma - \Delta\varepsilon) \tag{3.7}$$

$$D = H^{"} ctg(\delta - \Delta\varepsilon) \tag{3.8}$$

$$H^{"} = \frac{H_1^{'} + H_2^{'}}{2} \tag{3.9}$$

In the case when the position of the exploitation is changes, the limits are prolonged so they coincide to the new situation.

The diagonal line is obtained on the inclination, after the formula:

$$q = \frac{H}{tg(90^\circ - 0{,}15\alpha)} \tag{3.10}$$

where α is the inclination of the stratum.

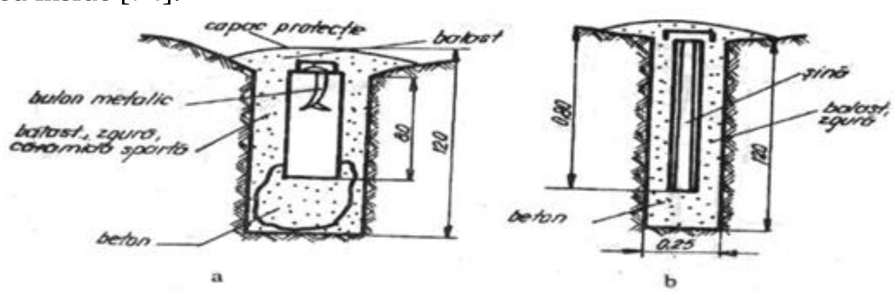
The marking and the signalling of the tracking points depends on the duration and the importance of the points. The tracking points can be classified as follows: basic or support points, alignment or working points and points on the objectives.

The basic points are the points used for verification, end points, belonging to the intersection of the alignments or breaking points of the alignments. When the points have the tendency to move together with the land, longer alignments will be made.

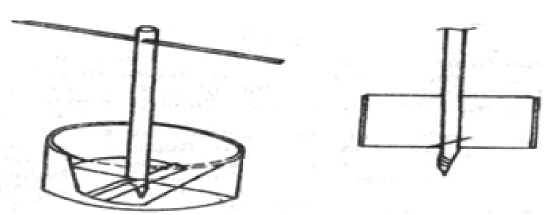
The basic points are materialised with bollards of Ø15, Ø20 and *h* = 60 - 90 cm, with a bolt at the end. These points are buried at a depth of at least 120 cm.

A railway *h* = 100 cm may be used instead of the concrete bollard.

The materialisation of the points is made in cavities obtained with the help of the manual drills, with a diameter of 25 - 30 cm. They are filled with concrete and the bollard or the railway is fixed inside [74].



Drawing 3.6 The materialisation of the basic points [74]



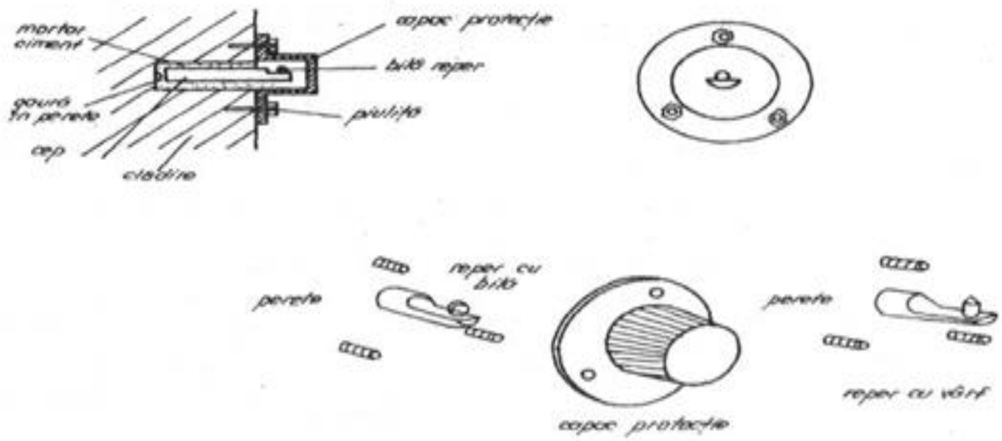
Drawing 3.7 The materialisation of the points with manual drills [74]

The planimetric position for the placement of the points is materialised in the field by tracking, using the technical data according to the execution project.

The points on the alignment have the role to register only the sinking movements of the exploited underground and must be protected from other movements.

If the points have a short duration, under 2 years, they will be marked by H hubs made of hard wood, with metallic nails in the hand the marking of the point on.

For the points with long duration, special markers will be used.



Drawing 3.8 Marking the landmarks on the buildings [74]

3.2.2 The frequency of the topographic measurements related to the subsidence phenomenon

Two measurements are always performed before starting the monitoring of a sinking phenomenon: one is considered to be the “zero” measurement and the other is the control measurement.

The frequency of the measurements depends of the depth of the exploitation, the advancing speed of the front and the direction of the stratum. These measurements are made after a certain planning, usually trimestral.

The depth of the exploitation	Method for the control of the pressure			
	Total collapse		Stowing	
	Levelling	Planimetry	Levelling	Planimetry
<100m	10 days	1 month	2 weeks	6 weeks
100-200m	2 weeks	6 weeks	1 month	2 months
200-300m	1 month	2 months	2 months	4 months
300-400m	2 months	4 months	3 months	biannual
>400m	3 months	Biannual	Biannual	yearly

Table 3.2 The frequency of the measuring [24]

3.2.3 The verification and the control of the stability of the fix marks

In order to ensure the stability during the entire existence of the topographic station of tracking, the control of the stability is necessary before the beginning of the measuring and to periods of time previously established. The first control measuring of the stability of the support landmarks are represented by the initial measuring.

The most frequent measuring used in the network or for the tracking alignments are the levelling measuring.

The evaluation of the stability of the landmarks through levelling measuring is made by comparing the level differences between the landmarks at the zero (basic) measurement and the same differences at the current measuring. The level differences between the studied landmarks must not be over the values given by the relations (3.11), (3.12):

$$\delta = \pm\sqrt{L(m_i^2 - m_c^2)} \tag{3.11}$$

where : m_i – the limit error/km to the zero levelling measurement ;

m_c - the limit error/km to the control measuring;

δ – the growth of the difference of level between the landmarks

$$\delta = \Delta H_i - \Delta H_c \tag{3.12}$$

where: ΔH_i – the differences of level between the landmarks at the basic measuring;

ΔH_c - the differences of level between the landmarks at the control measuring;

L – the length of the levelling route.

The admitted error for a levelling route of 1 km is:

- for a precision levelling m_0 = ∀ 2 mm;
- for a technical levelling m_0 = ∀ 7.5 mm.

Size δ is calculated for each segment from the levelling network uniting the landmarks on which measuring are performed.

The admitted value for δ is calculated with the relation:

$$\delta = \pm m_0 \sqrt{2L} \tag{3.13}$$

where:m_0 – the medium error of the two levelling measurements (m_0 = ∀2mm/km)

if the value for δ is larger than the admitted one, than one of the landmarks must be eliminated and cannot be taken in consideration for the measurements. After this first selection of the landmarks, it is recommended to continue the control measuring, considering at least three points at a distance of several hundreds of meters form the landmark considered to be stable.

It is recommended to use the precision levelling for the control measuring.

In the case of the usage of the technical levelling for the control measuring, the current measuring's will be made using the same type of levelling.

3.2.4 The determination of the stability of the control landmarks

The rigorous identification of the stabile control landmarks is necessary before making the compensation of the levelling.

The verification of the stability of the control landmarks is made by comparing the initial level differences with the current ones. If the obtained differences will not exceed the limits determined by the influence of the measuring errors, the corresponding landmarks will be considered stable.

For the calculation of the size of the square medium error of the balance unity, we use the relation:

$$\mu_0 = \pm\sqrt{\frac{[pdd]}{2r}} = \pm\frac{1}{2}\sqrt{\frac{\left[\frac{dd}{n}\right]}{r}} \tag{3.14}$$

where :

p – the balance of a single measuring of the level of difference to a bout polygon course with n station:

$$p_1 = \frac{1}{2n} = p_2 \tag{3.15}$$

The balance of the medium difference of level is:

$$p = p_1 + p_2 = \frac{1}{n} \tag{3.16}$$

d – the difference between the results of the bout measuring;

n – the number of station from the polygonal course of the levelling in a single direction;

r – the number of differences (in the same time the number of polygonal courses).

In order to determine the stability of the control landmarks there are taken into consideration two of them and a polygonal course with n stations is established between them, during the initial measuring and with n' stations during the current measuring.

We also take in consideration that between them is of h and h' (initially and current).

If the error μ_0 based on the entire material of observation, initial and current, was calculated, we will have:

$$\begin{cases} m_h = \pm\mu_0\sqrt{n};\ m_h^{'} = \pm\mu_0\sqrt{n^{'}};\ d = h^{'} - h = \pm\sqrt{m_h^2 + m_{h'}^2} \\ d = \pm\mu_0\sqrt{n+n^{'}};\ lu\hat{a}nd\ n = n^{'};\ \ d = \pm\mu_0\sqrt{2n} \approx 1,4\mu_0\sqrt{n} \end{cases} \tag{3.17}$$

The differences of level h and h' between two control landmarks can be different between them, meaning d can have a value up to $\pm\ 1,4\mu_0\sqrt{n}$.

Size d represents the difference between the relative elevations of the compaction landmarks determined to the bout control landmarks. The differences of level h and h' related to the two control landmarks can have a limit value in case of stability, which cannot be higher than d_{max} given by the relation:

$$d_{\max} = \pm 2\mu_0\sqrt{n} = \pm 2,8\mu_0\sqrt{n} \tag{3.18}$$

The control landmarks must be situated so the stability of each of them to be possible to be appreciated by at least one polygonal course leading to a control landmark.

The number of the observation stations n of each polygonal course must ensure the possibility to evaluate the stability of each control landmark in the limits adopted under the influence of the measuring errors ± m, permitting the observation of the movements bigger than ± m.

Using the expression of d_{max}, the above condition will be presented under the form:

$$2\mu_0\sqrt{n} \leq |m|;\ n \leq \left(\frac{m}{2\mu_0}\right)^2 \tag{3.19}$$

Substituting μ= ± 0,1 mm and | m | = 0,5 mm, we observe that for noticing the modification of the reciprocal position of the two control landmark measuring 0,5 mm, the number of the levels must fulfil the inequality n < 6. [46]

3.3 Topographic determinations in the tracking networks

The determination of the movements and of the deformations of the terrestrial surface is achieved using geodesic and topographic methods organised in the area of influence of the exploitations or using analytical methods from the dedicated literature or resulted from the interpretation of the topographic measuring.

The topographic measuring performed to the construction of the tracking networks may be grouped in:

- measurements for the construction of the support network, presented under the form of a network of micro-triangulation or as a precise polygonometry; the support network is placed to enclose the tracking station with stable points, sufficient as number.
- initial measurements residing in the enclosure of the support landmarks of the alignments in the network of triangulation and in the determination of the position of the working landmarks before the manifestation of the movements on the surface;
- control measurements executed to the adjacency of the working front, in the marginal area, with the aim of catching the moment of appearance of the movement at the surface;
- current measurements, periodically performed, to established intervals depending on the three stages of the movement on the surface.

In the alignments of the tracking networks for the determination of the movement parameters of the surface of the field, there are performed systematic measurements for the observation of the vertical and horizontal movements of the landmarks.

The basic observations are executed before the beginning of the exploitation and the current measurement are executed to established intervals depending on the stage of manifestation of the phenomenon.[57]

3.3.1 Topographic methods for the determination of the horizontal movements

The methods that are used to determine the horizontal movements of the tracking landmarks, as effect of the movement of the surface under the influence of the mining exploitation, are the direct method and the indirect method.

The direct method of determination of the horizontal movements of the tracking landmarks resides in periodical measurements on the tracking alignments. After the measurements of the distances between the points, the longitudinal horizontal movements are determined, the transversal movements being determined as differences between the deviations of the points to the direction of observation line.

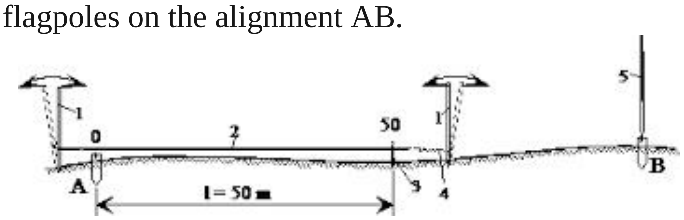
When the conditions in the field do not permit the execution of direct methods, the indirect methods are applied, they reside in the determination of the coordinates of the landmarks of the topographic alignments for the observance, applying methods as: triangulation, intersections or polygonometry, based on which the horizontal movements from the successive cycles of measuring are determined.

3.3.1.1 The direct method of the alignments

For measuring the alignments using the direct method, a team formed from an operator and two assistants is required.

The following accessories will be used: expanders 1, ribbon or ruler 2, cards 3, dynamometer 4 and flagpoles 5.

For the achievement of a correct measurement it is required to clear the field from vegetation and to put flagpoles on the alignment AB.



Drawing 3.9 The direct measuring of the length

The direct measuring of the distances with the ruler of with the invar stadia imposes the calculation of the necessary correction for the compensation of the measurements. The following relation is applied:

$$\delta_l = \frac{L_0 - L_i}{n - 1} \quad 4 \qquad (3.20)$$

where: L0 – the initial length of the measuring alignment;

Li – the length of the alignment in the cycle "i" of measurement;

n – the number of landmarks from the alignment.

The specific horizontal movement can be calculated as a result of the variation between the two consecutive landmarks from the alignment.

The specific horizontal deformation of a segment from the alignment is determined with the relation:

$$\varepsilon_m = \frac{l_i - l_0}{l_0} \quad 5 \qquad (3.21)$$

Where : l0 – the initial length of the segment;

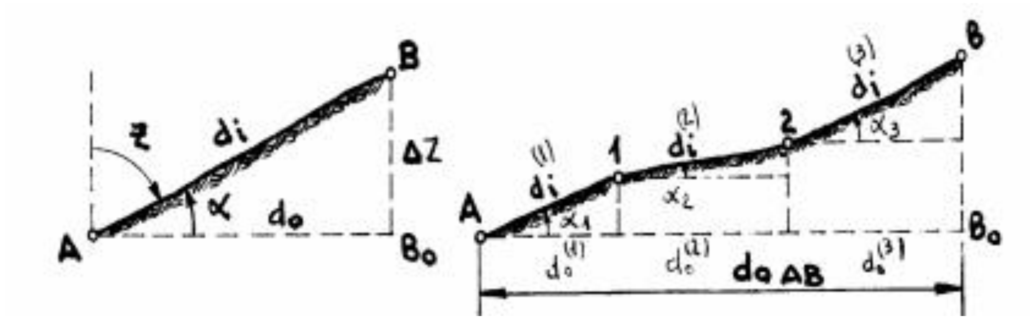
li – the length of the segment in the cycle "i" of measuring;

Considering that the measuring is executed with the same precision in each measuring cycle, the medium error for the determination of the horizontal deformation is calculated with the relation :

$$m_\varepsilon = \pm \frac{m_l}{l}\sqrt{2} \quad 6 \qquad (3.22)$$

where: ml – the error in the measuring of the length. Because the topographic plans include only the distances reduced to the horizon, all the inclined distances, measured directly in the field, will be reduced to the horizon, depending on the value of the descent angle (α) or of the zenith angle (Z) of the considered alignment.

For the case of the alignments with uniform descending, the reduction to the horizon of the inclined distances is made using the following relations, depending on the elements measured in the field.



Drawing 3.10 Reducing the distances inclined at the horizon.

The relation for the determination of the distance reduced to the horizon is:

$$d_0 = d_i * \cos\alpha \qquad (3.23)$$

where: d_0 – the distance reduced to the horizon;

D_i – the distance measured initially;

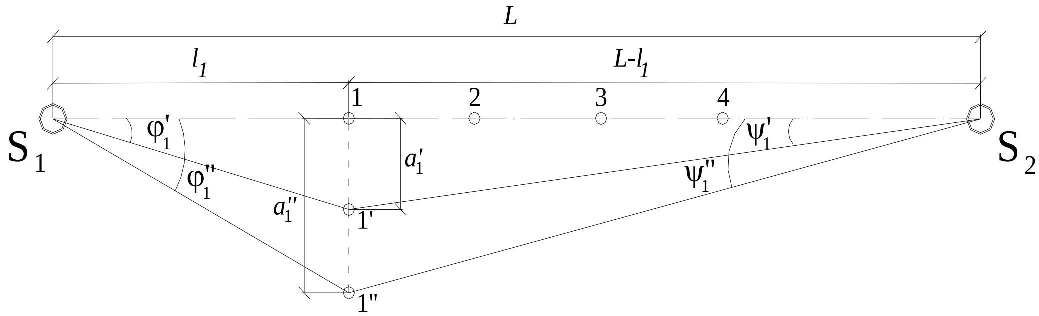
α - the angle made by the horizontal direction with the given slope..

3.3.1.2 The method of the observance of the parallactic angles

This method resides in establishing an alignment as close as possible to the line uniting the points of the observed elements.

Thus, we are given as points of the support network of the alignment the points *S1* and *S2*, serving as fix landmarks for the equipment. Metallic bushings are sealed and this is where will be installed in time the marks of stable sighting or simple metallic marks, which will be used for the determination of the horizontal angles.

The determination of the horizontal angles corresponding to the deviations a_i of the observed points (*1,2, ..., n*) is preferable to be executed with a high precision theodolite, placed in the station in the point *S1* for measuring the angles φ_i related to the *S1-S2* alignment and, analogously, from the station *S2*, the angles ψ_i; the measurement of the angles is made using the both position of the telescope of the theodolite. [46]



Drawing3.11. The method of the alignment – measuring the parallactic angles.

The distances between the points of the points of the support network *S1* and *S2* to the observed points is determined by direct or optical measuring. The measuring of the horizontal angles of the observed points, made in the two positions of the telescope of the theodolite, compound a series of observation, and a cycle of observation can contain between 3 and 5 series of observations. The media of the measured values φ_i and ψ_i, for each observed landmark, is calculated for each series. [46]

The size of the deviation $a_1^{'}$ corresponding to the movement of a point from the position 1 in the position 1' in the hypothesis of the collinearity of the points *S1 – 1 – S2* will be given by the relation:

$$a_1^{'} = l_1 \frac{\varphi_{1mediu}^{'(cc)}}{\rho^{cc}} = \left(L - l_1\right) \frac{\psi_{1mediu}^{'(cc)}}{\rho^{cc}} \tag{3.24}$$

The two values of the deviation obtained with the help of the angles φ_i and ψ_i are used to establish the deviation of the observed point that is accepted as their arithmetic mean.

When the initial position of the observed point is not collinear to the points *S1* and *S2* , characterising the working alignment, we determine first the initial position, in an analogue manner to a deviated position, calculating the initial deviation a_i to the alignment

The movement of the point from its initial position δ will be obtained as difference between the two deviations between the present cycle and the reference cycle or the initial cycle.

$$\begin{aligned} \delta &= a_i - a_1^0 \\ \delta_1 &= a_1^{'} - a_1^0 \end{aligned} \tag{3.25}$$

where: $a_1^{'}$ - the movement of the observed point from position 1 to position1';

a_1^0 - the deviation of the point 1 to the alignment *S1-S2*.

The procedure of the alignment for measuring the horizontal lines of deviation of the position of the points permit a simple determination of the size of the deviations but it requires a higher precision for the measuring of the deviation angles φ_i and ψ_i, the angular values being registered with a precision of $0{,}5^{cc} - 1^{cc}$. [46]

The determination of the precision of the measuring is made using the following relations:

- The square medium error of the medium value of the angle φ_i or ψ_i from *n* series:

$$m_{(\varphi,\psi)} = \pm\sqrt{\frac{[vv]}{n(n-1)}} \qquad (3.26)$$

where: *vv* – the residual value resulted from the difference between the value of the angle φ_i or ψ_i from a series to the media of the angle obtained from *n* series;

- The square medium error for the determination of the deviations of the marks on the construction:

$$m_a = \frac{m^{cc}_{(\varphi,\psi)} \cdot l}{\rho^{cc}} \qquad (3.27)$$

- The square medium error for the determination of the movement δ to the alignment, calculated as difference between the deviations a_1 and a_2 from two cycles of measuring:

$$\mu_\delta = \pm\sqrt{m^2_{a_1} + m^2_{a_2}} \qquad (3.28)$$

The advantages of this procedure compared to the procedure of the sighting along the alignment are:

- The disappearance of the necessity to use the mark with mobile disk;
- It is a method applied for constructions with a long form, where the movements can be relative big;
- The measurements from various cycles must have equal precisions.

The establishment of the fix marks is verified by planting safety columns or by including them in the tracking networks, verifying the stability of the points using several methods. [46].

3.3.1.3 The method of the observation of the supplementary parallel alignments

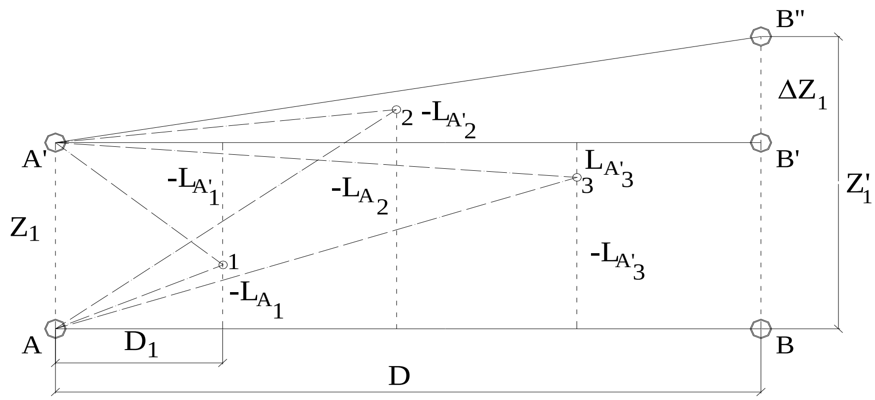
After a short period of time from the start of the exploitation of an objective, as a result of its stabilisation, the movement of the control points is less and less frequent. Thus, it is necessary to use ‚ensuring methods capable to offer a high precision, as the method of the supplementary parallel alignments. [46]

The methods resides in fixing a new alignment *A'B'*, parallel to the old alignment *AB*. Depending on the requests of the work, 2, 3 or more new alignments can be designed.

The distances *AA'* and *BB'*, between the old and the new basic points must be equal to the medium size of the deviations of the control points 1,2 and 3. For a precise measurement of these deviations, it is necessary to determine the deviations L_A şi L'_A, concomitantly for both alignments. [46]

The distance between the points *A* and *A'* is determined by the relation:

$$Z_1 = \frac{(L_A - L_{A'})_1\, p_1 + (L_A - L_{A'})_2 + \ldots + (L_A - L_{A'})_i\, p_i}{p_1 + p_2 + \ldots + p_i} \qquad (3.29)$$



Drawing 3.12 The method of observing the supplementary parallel alignments

where: $L_A si L_{A'}$ - the deviations of the control points related to the old and the new alignments;

i - the number of the control points;

$p_1, p_2, ..., p_i$ - the balance of the measured sizes.

When using several supplementary parallel alignments, the distances corresponding to the points of each new alignment related to the old one and also the value $Z_1^{'}$ between the ends *B* and *B'* is determined with analogue relations.

The linear size of the parallel misalignment of the two or more alignments is expressed by the relations:

$$\begin{aligned} Z_1 - Z_1^{'} &= \Delta Z_1 \\ Z_2 - Z_2^{'} &= \Delta Z_2 \\ &\ldots\ldots\ldots\ldots \\ Z_i - Z_i^{'} &= \Delta Z_i \end{aligned} \tag{3.30}$$

The next problem is to measure the deviations of the control points related to all the alignments, in a direct or reverse direction. For a supplementary parallel alignment, the size of the deviations in the point of control *i* measured in the two directions, are given by the relations:

$$\begin{aligned} L_i^I &= \frac{L_{A_I}^I + \left(Z_1 + L_{A_I^{'}}\right)^I}{2} \\ L_i^{II} &= \frac{L_{A_I}^{II} + \left(Z_1 + L_{A_I^{'}}\right)^{II}}{2} \end{aligned} \tag{3.31}$$

When the size of the parallel misalignment is obtained, the calculation of the deviations uses the relations:

$$\begin{aligned} L_i^I &= \frac{L_{A_i}^I + \left[\left(Z_1 + \frac{\Delta Z_1}{D} D_i\right) + L_{A_i^I}\right]^I}{2} \\ L_i^{II} &= \frac{L_{A_i}^{II} + \left[\left(Z_1 + \frac{\Delta Z_1}{D} D_i\right) + L_{A_i^I}\right]^{II}}{2} \end{aligned} \tag{3.32}$$

where: *D* – the length of the entire alignment;

D_i – the distance from the end of the alignment to the point of control i.

The final size of the deviation of each point of control is obtained as arithmetic mean od the measuring for both directions:

$$L_i = \frac{L_i^I + L_i^{II}}{2} \tag{3.33}$$

The horizontal movement of the control point produced between the two cycles of observations is determined by the difference related to the two cycles. Admitting that the measuring of the deviations related to the two alignments was made with the same precision, we may write the equality:

$$m_{L_A^I} = m_{L'_{A'}} = m_{L_A^{II}} = m_{L^{II}{}_{A'}} = m_L \tag{3.34}$$

We can also write the equality between the values Z_1 and Z_2:

$$m_{Z_1} = m_{Z_2} = ... = 0 \tag{3.35}$$

Sizes Z_i being determined with enough precision, the square medium error of the deviation of the control point will be given by the relation:

$$M_L = \frac{m_L}{\sqrt{2n}} \tag{3.36}$$

where: n – the number of alignments which enter in the determination of the deviations.

The square medium error of the horizontal movement of the control point will be:

$$m_{\Delta L} = \sqrt{M_{L^1}^2 + M_{L^0}^2} = M_L\sqrt{2} \qquad (3.37) \quad [46]$$

3.3.1.4. The measurement of the transversal deviations

The measurement of the transversal deviation of the alignment landmarks is done either using direct methods, the horizontal stadia or the coordinometer, or indirect (trigonometric) methods, performed with the help of the chain of triangles, of the acute angles measured with a theodolite fixed in the support landmark, the alignment of the top angles measured from the observance points or using the polygonal method.

<u>a) The direct method of measuring</u> with the help of the coordinometer resides in a graded ruler on which a panel with index, placed on the vertical centre of the panel, can move.

The instrument has a spherical leveller for keeping the ruler horizontally and a collimator for orienting the ruler perpendicular on the speed line. For determining the transversal deviations in the support point of the profile, a theodolite is installed and its sight point is brought in the place of the profile by seeing a second support point for the alignment. The coordinometer is installed above the working landmark, with the gradation zero of the ruler on the vertical of the working point "n". moving the mobile panel in the seeing plane, the deviation of the landmark compared to the plane of the alignment can be read directly on the ruler "L" of the coordinometer[57].

<u>b) Indirect methods of measuring</u>

<u>*b.1. The method of the chain of triangles*</u>

It helps to determine the transversal deviations of the points of the observation line by measuring directly the height of the triangles formed between the final points of the observation line.

Measurement are made inside each of this isosceles triangles (A-1-2),(1-2-3),(2-3-B) on the lines (e_1 ,e_2 ,e_3), with the help of the coordinometer. Knowing the length of the sides A-1, 1-2, ... we may calculate the angles α,β,γ in each triangle. E.g.: for the triangle A-1-2:

$$\alpha_1 = \frac{e_1}{\overline{\overline{A-1}}}\rho$$

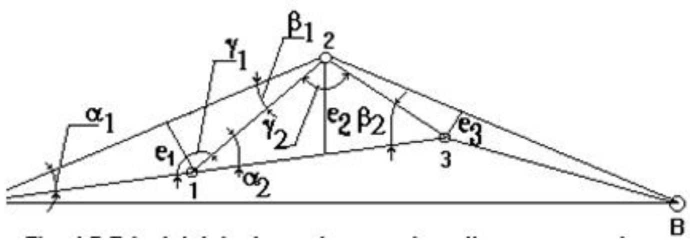
$$\beta_1 = \frac{e_1}{\overline{\overline{1-2}}}\rho \tag{3.38}$$

$$\gamma_1 = 180^0 - \frac{(\overline{A-1}) + (\overline{1-2})}{(\overline{A-1})(\overline{1-2})} e_1\rho$$

If we consider that the variable is the value e_1 ,the error in the determination of the angle γ is given by the relation:

$$m_{\gamma_1} = \frac{(\overline{A-1}) + (\overline{1-2})}{(\overline{A-1})(\overline{1-2})}\rho m_{e_1} \tag{3.39}$$

where: m_{e1} – the error of determination of the transversal deviation.



Drawing 3.13 the principle of determining the transversal deviations with the help of the chain of the acute angles. [57].

In a first stage, the deviation toward the axis x' , confounded with the axis A-1is calculated; next is calculated the deviation toward the initial direction of the alignment AB with the help of the rotation angle.

The determination of the transversal deviations with the help of the chain of triangles can be made by measuring the top angles by fixing the theodolite in these points, without measuring lengths [57].

b.2.The method of the acute angles

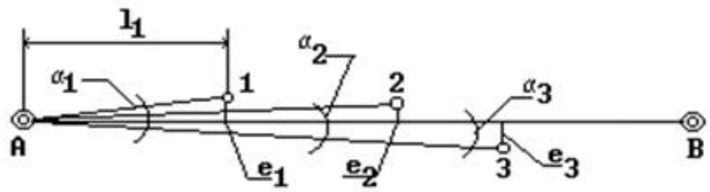
The theodolite is fixed for this method in the fix point A of the observance line AB, measuring the angles created by the directions of the points A-1, A-2, A-3, ... with the direction A-B.

The transversal deviation of a point "i" on the observance line is determined by the relation:

$$e_i = l_i \, tg \, \alpha_i \tag{3.40}$$

It can be written for very low values of the angle α_i as follows:

$$e_i = l_i \frac{\alpha_i}{\rho} \tag{3.41}$$



Drawing 3.14 the principle of determining the transversal deviations with the help of the acute angles [57]

The method is recommended for the observation lines with a short length, because the method depends on the error in the measuring of the distances (l_i) and of the angles (α) .

For longer observance lines, the alignments are split in two parts, by fixing an intermediary point in the middle of the alignment [57].

b.3.The method of the top angles

The measuring manner of the transversal deviation of the tracking points for the direction of the alignment – the transversal deviation "e" of the point 1 toward the observance line AB is determined by the relation :

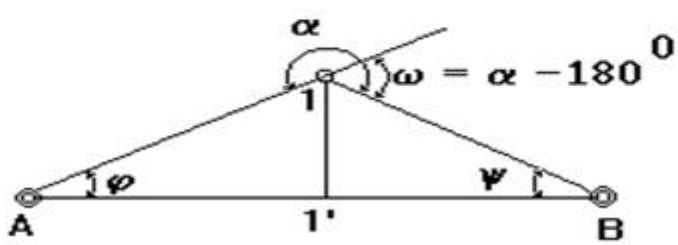
$$e = (\overline{A-1})\sin \_ \tag{3.42}$$

where :

$$\sin \_ = \frac{\overline{B-1}}{\overline{A-B}} \sin\omega \;;\; \acute{S}n\ care\ \omega = \alpha - 180^0 \tag{3.43}$$

In the end, the transversal deviation becomes:

$$e = \frac{(\overline{A-1})(\overline{B-1})}{(\overline{A-B})} \sin\omega \tag{3.44}$$



Drawing 3.15 The principle of determining the transversal deviation with the help of the top angles [57]

For values smaller than the angle ω, the relation (3.44) becomes:

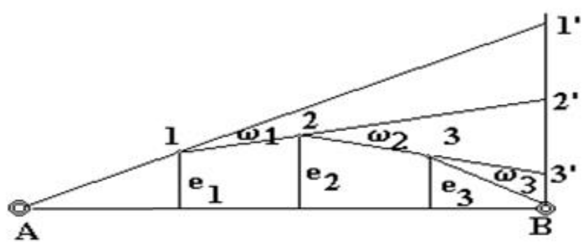
$$e = \frac{(\overline{A-1})(\overline{B-1})}{(\overline{A-B})}\frac{\omega}{\rho} \tag{3.45}$$

The method presented for the determination of the transversal deviations, with the help of the top angles measured from the observance points, can be used to determine the deviations of multiple points. To exemplify, we present the situation when the top angles 1, 2, 3 in the proximity if the side AB were measured. We may write due to the very acute angles:

From the similarity of the triangles A-1-1^0 and A-1-B, it results:

$$\begin{aligned} \overline{3'-B} &= (\overline{3-B})\frac{\omega_3}{\rho} \\ \overline{2'-3'} &= (\overline{2-3}+\overline{3-B})\frac{\omega_2}{\rho} \\ \overline{1'-2'} &= (\overline{1-2}+\overline{2-3}+\overline{3-B})\frac{\omega_1}{\rho} \end{aligned} \tag{3.46}$$

$$e_1 = \overline{1'-B}\,\frac{\overline{A-1^0}}{\overline{A-B}} = (\overline{1'-2'}+\overline{2'-3'}+\overline{3'-B})\frac{\overline{A-1^0}}{\overline{A-B}} \tag{3.47}$$



Drawing 3.16. Example of calculation [57]

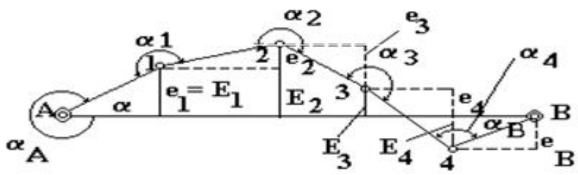
Replacing the relation (3.46) in (3.47), we obtain the final relations for the determinations of the transversal deviations:

$$\begin{aligned} e_1 &= \frac{\overline{A-1'}}{(\overline{A-B})\rho}[(\overline{1-2})\omega_1+(\overline{2-3})(\omega_1+\omega_2)+(\overline{3-B})(\omega_1+\omega_2+\omega_3)] \\ e_3 &= \frac{\overline{B-3}}{(\overline{A-B})\rho}[(\overline{2-3})\omega_3+(\overline{1-2})(\omega_2+\omega_3)+(\overline{A-1})(\omega_1+\omega_2+\omega_3)] \\ e_2 &= \frac{1}{(\overline{1-2})+(\overline{2-3})}[e_1(\overline{2-3})+(\overline{1-2})(\overline{2-3})\frac{\omega_2}{\rho}+e_3(\overline{1-2})] \end{aligned} \tag{3.48}$$

b.4.The polygonal method.

The transversal deviations on the line A-B can be determined based on the measurement of the acute angle and of the length of the sides. Also, we calculate the transversal movements of the pairs of points related with a direction parallel to AB. Considering that the orientation angle of the side AB is $\theta_{AB} = 0^0 00'00''$, we calculate first the direction angles of the sides:

$$\begin{aligned} \theta_{A-1} &= \pm\alpha_A \\ \theta_{12} &= \theta_{A-1} + \alpha_1 \pm 180^0 \\ &\dots\dots\dots \end{aligned} \tag{3.49}$$



Drawing 3.17. The measurement of the transversal deviation with the help of the polygonal method [57]

We calculate as follows the size of the transversal deviations of the points related to the present ones:

The transversal deviations of the points related to the side Ab are given by the relations:

$$\begin{aligned} e_1 &= \overline{A-1}\,\frac{\theta_{AB} - \theta_{A-1}}{\rho} \\ e_2 &= \overline{1-2}\,\frac{\theta_{AB} - \theta_{1-2}}{\rho} \\ &\dots\dots\dots \end{aligned} \tag{3.50}$$

$$\begin{aligned} E_1 &= e_1 \\ E_2 &= E_1 + e_2 \\ E_3 &= E_2 + e_3 \\ &\dots\dots \end{aligned} \tag{3.51}$$

It is necessary to establish in the relation (3.51) the signs of the deviations e_i resulting from the difference of the orientation angles. We apply the below relation for the control of the calculations:

$$\Sigma e_i = E_B = 0 \tag{3.52}$$

The absolute horizontal movements of the tracking marks can also be determined from the coordinates of the points obtained through intersections. We may use as support points the end marks of the alignments or fix points especially created for this procedure [57].

3.3.1.5 The measuring errors for the horizontal movements

The practice classifies the errors in errors of the direct measuring made with the help of ruler in the tracking alignments and the errors of the indirect measuring in networks of triangulation and polygonal tracks .

We mention that, when measuring with the steel ruler, in order to reduce to the horizon the distances, the correction due to the difference of level between marks will be applied. The relative error of measuring must be less than 1/10.000 .

The errors in the determination of the points in the networks of triangulation are various and depend on the size, the form and the type of the network and on the precision of the instruments. They are presented in extensor in the study [24],[57].

The most precise observations are obtained in network of triangulation and in the angular-linear networks, where the measuring is made with electrical and optical instruments, permitting the determination of the length of the sides for distances of 2 km with errors of only a few millimetres.

The errors in the determination of the movements in the polygonal networks depend on the type of the network, the precision in the measuring of the distances and the precision in the measuring of the angles. The errors of position for the points connected to one end can be calculated with the relations [24], [57].

$$m_x^2 = \sum_{i=1}^{n} \cos^2\theta_i \, m_{l_i}^2 + \frac{1}{\rho^2} \sum_{i=1}^{n} R_{iy}^2 \, m_{\alpha_i}^2$$
$$m_y^2 = \sum_{i=1}^{n} \sin^2\theta_i \, m_{l_i}^2 + \frac{1}{\rho^2} \sum_{i=1}^{n} R_{ix}^2 \, m_{\alpha_i}^2 \qquad (3.53)$$

where : θ_i – the angle of direction of the side "i";

$m_{l\,i}$ – the measuring error for the side l_i ;

$m_{\alpha i}$ – the measuring error for the top angle α_i ;

R_{ix} , R_{iy} – the projection of the segment R_i on the axis of coordinates.

In the rectilinear polygonal networks, where the side and the angles are measured with the same precision, the transversal and longitudinal errors can be calculated with the help of the approximate relations:

$$m_{long.} = \pm m_l \sqrt{n}$$
$$m_{transv.} = \pm \frac{m_\alpha}{\rho} L \sqrt{\frac{n}{3}} \qquad (3.54)$$

where : m_l – the measuring error of the sides;

m_α – the measuring error of the angles;

L – the length of the polygonal network;

n – the number of points.

The error in the determination of the position of the points in the alignments connected to both ends is determined with the relation:

$$m_{long.(i,n)} = \pm m_l \sqrt{\frac{i(n-1)}{n}}$$

$$m_{transv.(i,n)} = \pm \frac{m_\alpha}{\rho} l \sqrt{\frac{i^3(n-i)}{3n}} = \pm \frac{m_\alpha}{\rho} L \sqrt{\frac{1}{3} \frac{l^3}{n^3}(n-i)} \tag{3.55}$$

The increase of the precision in the determination of the absolute values of the horizontal movements can be obtained through:

-the increase of the precision in the measurement of the elements of the network (the length of the sides and the angles);

-the reduction of the number of the points and the increase of the length of the sides .

The error in the determination of the inclination is established based on the relation :

$$m_T = \pm \frac{m_W}{l} \sqrt{2} \tag{3.56}$$

where: m_W – the error in the determination of the elevations;

l – the distance between the landmarks.

3.3.2 Topographic methods for the determination of the vertical movements

The measurement of the vertical movements of the landmarks on the alignment is made by measuring the middle geometric levelling, based on the landscape of the field. For an uneven terrain, the trigonometric levelling is used.[41].

The topographic-geodesic methods are, in many cases, the only methods permitting the determination of the absolute movements and deformations, serving as control means for the size of the movements and deformations determined with other non-conventional methods.

The principle of the measurement of the movements and deformations vertically resides in determining repeatedly the measures in the control point.

Since the topographic-geodesic measures allow only an analyse depending on the character and the size of the vertical movement, they have to be correlated with the observance and the study of the underground terrain, and the mechanics of the rocks, with the aim to discover the origins of the movements and to show the possibility to eliminate them. [46].

Establishing the errors resulted in the topographic measuring of the vertical movements is very important in the calculation of the derived sizes, as the inclination and the curvature [57].

The determination of the vertical movements for scientific purpose is made at levels of high precision, resulting an error of m_0 = 0.5 mm/km.

The error in the determination of the elevation of the mobile marks depends on the type of the tracking topographic network, the length of each alignment and the distance between the mobile landmarks.

In the alignments connected to a single end, the error for the determination of an elevation for a landmark is given by the relation:

$$m_h = \pm m_0 \sqrt{n} \tag{3.57}$$

where: n – the number of stations at the polygonal course of the levelling.

For the alignments connected to two ends, the error of elevation for a landmark "i" is:

$$m_{h_i} = \pm m_0 \sqrt{\frac{i(n - i}{n}} \tag{3.58}$$

where: n –the number of alignment points.

When the tracking alignments are connected to the main levelling network (to one end), the determination of an elevation for any point N is determined by the relation :

$$m_{H_N} = \pm \sqrt{m_l^2 L_l + m_m^2 L_m + m_0^2} \tag{3.59}$$

where : m_l – the levelling error in the connection network;

L_l – the length of the connection network;

m_m – the levelling error in the measuring alignment;

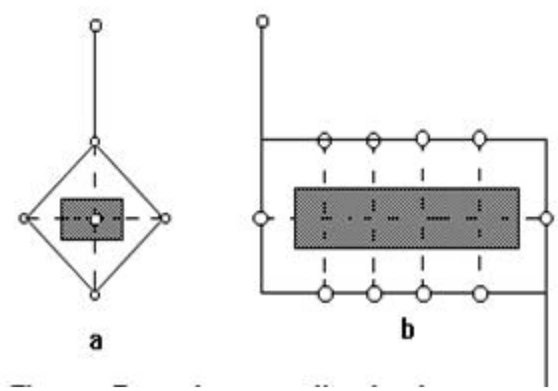
L_m – the length of the tracking alignment;

m_0 – the error caused due to the sinking of the landmarks in the period when the measuring was interrupted for the fields under the influence of mining.

Because the precision is the same for each cycle, the error in the determination of the sinking of point N can be calculated with the relation:

$$m_{\Delta H_N} = \pm m_{H_N} \sqrt{2} \tag{3.60}$$

The connection mode of the tracking alignments to the levelling network is represented in the drawing (3.18). The elevation difference between the two consecutive measuring must not be higher than the value δ # ∀ 2mm%2,and for the tracking alignments must be under the value δ # ∀ 2mm%n. [57].



Drawing 3.18 The connection of the tracking marks to the national altimetric network [57]

a) – with a single connection to the national altimetric network.

b) - with two connections to the national altimetric network

The trigonometric levelling has a more restricted applicability and is applied to the alignments placed on uneven terrains, where the points are hard accessible.

The error in the determination of the level differences is given by the relation:

$$m_{\Delta h} = \pm \sqrt{tg^2 \varphi \, m_D^2 + \left(\frac{D}{\cos^2 \varphi}\right)^2 \left(\frac{m\beta}{\rho}\right)^2} \qquad (3.61)$$

For small values of the angle ν, the influence of the length error is very little in relation to the error in the measuring of the angles, which can be described as:

$$m_{\Delta h} = \frac{D}{\cos^2 \_} \frac{=}{\rho} \qquad (3.62)$$

3.3.2.1. The method of the high precision geometric levelling

This is the method that ensures the highest precision for the measuring of the vertical movements of the researched objectives, being used for the experimental research of some constructions on models or to a natural scale, as well for following the behaviour in time of the movement and of the deformation of some field areas [46].

Depending on the type, form and size of the objective, a network of geometric levelling is created with various forms, depending on the nature of the studied.

We find in the componence of the network:

- control points, fixed in the neighbourhood of the working area, called in the literature mobile landmarks;

-fix landmarks, also called reference landmarks, placed on even terrains and outside the zone of influence that is researched.

The control points have the role of showing with the highest possible precision the vertical components of the movements.

They are included in the elements of resistance that need to ensure the verticality of the levelling rods. The tracking marks determined through high precision geometric levelling can be achieved as follows:

- Vertically sealed;
- Horizontally sealed;
- Horizontally or vertically mono-block sealed;
- Vertically or horizontally sealed with detachable bolt.

Other methods for the materialisation of the control points can also be used: graded marks, represented by suspended invar rods or regular rulers with millimetre divisions, bolt marks, nail marks, button marks, etc. [46]

The process of determining the vertical movements of the control point includes the following stages:

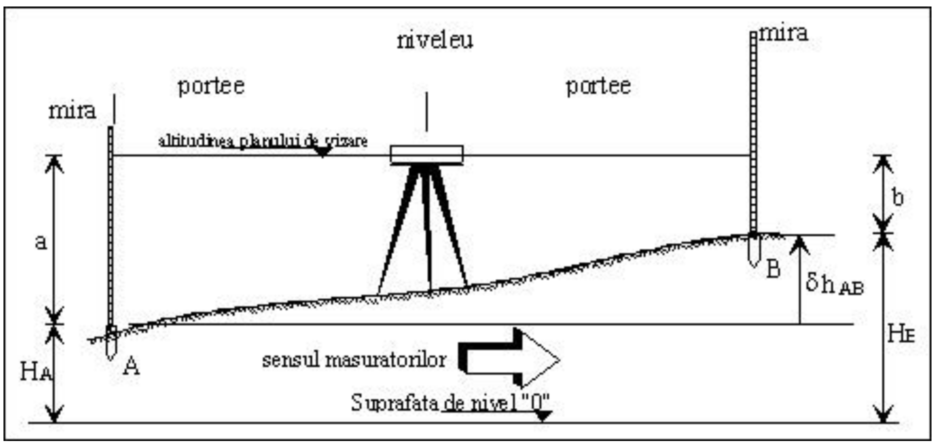
I) the stage of the measurement of the levelling to the place of the experiment, in the laboratory or in the field, where each measuring cycle contains:

- Verifying and correcting the instruments before each measuring cycle;
- Verifying the route related to the condition of the landmarks and of the platforms, in the case of the inclined routes;;
- The performance of measuring of middle geometric levelling, in optimum exterior conditions (no wind, no fog or excessive sun)

II) the stage of processing the measurements for the calculation of the vertical movements of the construction and the evaluation of the precision include:

- Testing the stability of the fix marks in the reference network; if t=some of the fix marks modified their vertical position, the b=necessary corrections will be made;
- The calculation of the vertical movement of the control points on the studied construction;
- The evaluation of the precision in the determination of the vertical movements and the establishment of the intervals of trust;
- The preparation of the technic documentation of the research[46].

The method of the geometric levelling is considered to be the most precise method for the measurement of the elevations. Starting from a known elevation point, it is performed a determination of the elevations through a middle geometric levelling on a bout course or on a unique course with changed horizons [23], [24], [41].



Drawing 3.19 Middle geometric levelling

To determine the level difference between two points or to determine the elevation of a point when the elevation of a neighbouring point is known, we may place a rod on each of the two points, and a leveller at the approximate middle of the distance (2-3 m difference), without the obligation to be placed in the same time on the alignment formed by the two points. Through the reading made by the two rods, we can determine the sizes described above.

We may observe in the drawing above that HA and HB is the elevations of the two points, where only the first elevation is known.

We have on the rods the readings a and b. If we note as dhAB the level difference between A and B, it results:

$$\delta h_{A-B} = a - b \tag{3.63}$$

We may say that the level difference is always the difference between the back and the front reading. If the field would have a reverse inclination reported to the one in the drawing above, the data of the problem would remain similar, so the level difference would have been negative, possible to obtain from the difference between "a-b" readings on the rod.

Considering as known the elevation of the point A, the elevation of the point B will be:

$$H_B = H_A + \delta h_{A-B} = H_A + a - b \tag{3.64}$$

Where we define the altitude of the sighting plan as the vertical distance between the zero level surface and the sighting axis of the levelling instrument:

$$H_v = H_A + a \tag{3.65}$$

Resulting that :

$$H_B = H_v - b \tag{3.66}$$

The measuring of the vertical movements through the middle geometric levelling is made with precision levels with a measuring error of m_o =0,5mm/km.

3.3.2.3. The method of the precision trigonometric levelling

The method of the precision trigonometric levelling is used for the measurement of the vertical movement of the control pints, especially of the far and hard accessible points at height. The principle of the precision trigonometric levelling resides in determining the elevation of the control points and the vertical movements are obtained from the differences of the elevations in the present cycle and the correspondences from the initial cycle.

Based on experiments in laboratories and in the field, it was proved that the precision trigonometric levelling with short sights, with lengths until 100m, permits the obtaining of a precision comparable to the geometric levelling.

Thus, in laboratory, it was proved the obtaining of a level difference with a square medium error $m_{\Delta h} = \pm 0{,}1 mm$. Based on the measurements in the field for the distance of 80 m, the level difference was determined with an error of $m_{\Delta h} = \pm 0{,}2 mm$.

The principle of the precision trigonometric levelling resides in the determination of the elevation of the control points. The vertical movements are obtained from the differences of the elevations in the present cycle and the correspondences from the initial cycle.

The measurement of the horizontal and vertical angles must be done with theodolites with an angular reading precision of $\pm 1^{cc}, \pm 0{,}5^{cc}$. The measurement of the vertical angles must be performed in the period of stability of the atmospheric refraction, due to the fact that in the moments of maximum atmospheric refraction (in the middle of the day) is low, thus the quality of the image is low, causing errors of focus for the image of the telescope.

For small distances, up to 100 m, the total correction due to the curving effect of the earth and for the atmospheric refraction is very low. For the determination of the vertical movements of the constructions, through the precision trigonometric levelling, the influence of the curving of the earth and the atmospheric refraction may be eliminated almost completely, through the working method, by the difference of the measurements between two cycles of observations.

For the measurement of the vertical movements, the dimension of the vertical angle of each direction is determined by three complete measurements, in both positions of the telescope, as follows: all for the three vertical lines (the horizontal reticular line and two stadiometric lines) or three times for the unique vertical line (the horizontal reticular line), depending of the form of the reticule of the instrument.

The method of the trigonometric levelling is used more and more often, due to the easiness in applying it and to the newly appeared technology.

Since it is a method using a theodolite or a total station, it is also called levelling with inclined sights.

Depending on the direction of the sight, there are two types of levelling: the trigonometric levelling with ascendant sights, when the point to be determined is situated above the line of the horizon, and the trigonometric levelling with descendant sights, when the point is placed under the line of the horizon.

The level difference is calculated according to the gradient angle or the zenith angle and the horizontal distance.

The trigonometric levelling with ascendant sights

To determine the level difference and the elevation of a point, the measuring instrument is placed in point A, with an elevation "i" and aims for a signal installed in point B with the elevation "s".

Considering as known the distance DAB, we may calculate the levelling of point B, observing that:

$$H_A + i + D * tg\alpha = H_B + s \quad (3.67)$$

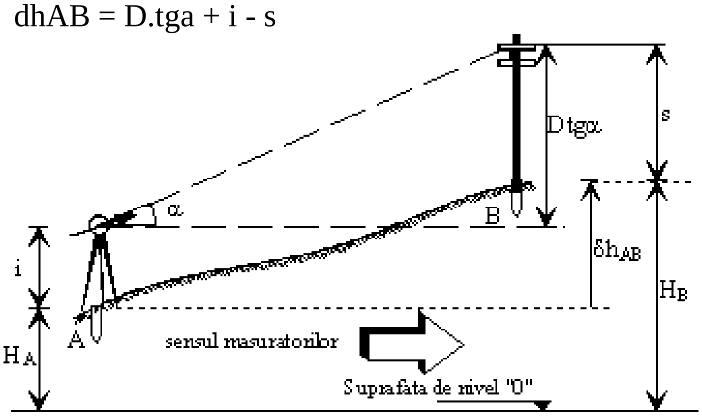
Resulting:

$$H_B = H_A + D * tg\alpha + i - s \quad (3.68)$$

Also resulting from the drawing the expression of the level:

dhAB + s = i + D.tga (3.69)

dhAB = D.tga + i - s (3.70)



Drawing 3.20 – Trigonometric levelling with ascendant sights.

Considering the relation between the gradient angle a and the zenith angle z as :

a + z = 100g (3.71)

we may express the calculation relations depending of the zenith angle z :

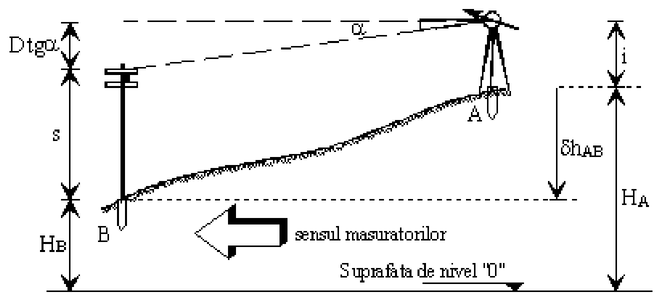
HB = HA + D.ctg z + i - s (3.72)

also:

dhAB = D.ctg z + i - s (3.73)

Trigonometric levelling with descendant sights

If point B is placed under the line of the horizon, passing through point A, the problem is resolved according to the drawing 3.21:.



Drawing 3.21 – Trigonometric levelling with descendant sights.

We will have:

$$H_A + i = H_B + Dtg\alpha + s \qquad (3.74)$$

Obtaining the expression for HB :

$$H_B = H_A - D * tg\alpha + i - s \qquad (3.75)$$

The difference of level is determined from the equality:

$$\delta h_{AB} = H_B - H_A \qquad (3.76)$$

Where the value of HB is replaced with the relation:

$$\delta h_{AB} = -D * tg\alpha + i - s \qquad (3.77)$$

The calculation relations for the difference of level and the elevation of the point, as presented above, are valid only in the case when the horizontal distance D is shorter than 500m.

If this value is longer, a correction must be applied due to the atmospheric refraction and sphericity, with the expression:

$$C = (1 - k)\frac{D^2}{2R} \qquad (3.78)$$

where:

- k is the coefficient of atmospheric refraction (k=0,13 on the Romanian territory),
- R is the medium radius of the earth (R = 6379 km)

This correction is always positive and is added to the difference of level.

The arithmetic mean of the values resulting from *n* measurements represents the probable value of the measured zenith angle:

$$Z_i = \frac{\sum_{i=1}^{n}\left[S_i + \left(400^g - D_i\right)\right]}{2n} \qquad (3.79)$$

The square medium error of a measured zenith angle is:

$$m_{Z_i} = \pm\sqrt{\frac{[vv]}{n-1}} \qquad (3.80)$$

The square medium error of a medium zenith angle will be:

$$m_Z = \pm\sqrt{\frac{[vv]}{n(n-1)}} = \pm\frac{m_{Z_i}}{\sqrt{n}} \qquad (3.81)$$

Due to the fact that, for shorter distances, the precision in the determination of the elevation of the points through the method of the trigonometric levelling is high, this method can be used successfully for the study of the models, especially when the measurement of the horizontal and vertical measurement is done in the same time. The determination of the vertical movements from the difference of the elevations obtained in the present cycle and those from the initial cycle requires an important volume of calculations. The determination of the vertical movements of the construction directly depends on the differences of the zenith angles, measured in the end points of a fix base, when the horizon of the instrument is modified in each cycle of observation. [46]

Chapter 4 CONCLUSIONS

The topographic methods used for the study of the subsidence, caused by the exploitation of the stratiform deposits, require the design and the materialisation of a tracing network formed from transversal and longitudinal alignments.

An important number of tracing marks and an important volume of observations are required in order to restore a movement as similar as possible of the surface.

Due to the practical difficulties in placing, materialising and preserving the tracing landmarks, the current practice uses tracing alignments with one or two stable ends.

The direct topographic methods consist of the measurement of the absolute movement of the landmarks that are usually reduced to the direct measurement of the distances between the landmarks and the determination of their elevation through the middle geometric levelling.

The topographic methods offer a higher precision for the determination of the movement and deformation parameters for the surface and are the most used methods.

The indirect topographic methods reside in the determination of the coordinates (x,y,z) of the landmarks, helping to determine the movements and the deformations of the surface by applying analytical relations.

The indirect methods were not developed too much due to the difficulties in the placement of the support network and to the lack of visibility of the working landmarks in the points of the support network.

The topographic methods offer the possibility to determine the absolute and differential movements of the surface for given conditions, without taking into consideration the physical and mechanical properties of the rocks.

The topographic methods are highly used as evaluation methods for the movement and deformation parameters of the sinking beds, transitory or final.

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