Precise Geodetic Setting Out Activities in The Construction of Engineering Structures with Orientation in Predetermined Direction

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http://doi.org/10.29227/IM-2024-01-42

Submission date: *9.5.2023* | Review date: *28.9.2023*

Abstract

In the construction practice, there are engineering structures, where some complex requirements in the process of their building have to be meet, e.g., their positioning, geographical orientation and geometric determination. The current publication examines the specificity of geodetic activities, regarding the orientating of the main construction axes of the foundation and the supporting structures of the terrestrial telecommunication antennas in a predetermined direction, for example, in the parallel direction to the geographical meridian. The focus is on the assessment of the accuracy and the choice of appropriate methods and equipment in order to create the required geodetic network, as well as to perform accurate setting out works. The combination of demands, namely for a specific geographic orientation and precise relative accuracy of the setting elements, implies a suitable transition from the ellipsoidal geodetic coordinates to the projection plane of the setting out project. In this connection, the influence of the meridian convergence on the accuracy of the planning setting out works is examined. A mathematical approach is proposed to assess the need of elimination of this factor, depending on the value of the constructional tolerance and the geographic location of the site.The necessary precision for determining the geodetic ellipsoidal coordinates by GNSS (Global Navigation Satellite System) measurements as well as the required accuracy of the planning and elevation setting out works are shown.Using different geodetic methods and tools, a preliminary accuracy assessment approach and the choice of the appropriate coordinate projection and height reference system is also proposed. The real data, which were obtained in different Earth's locations by the explained methodology, are presented. The established geodetic networks provide orientation of the main construction axes of the bases of the terrestrial communication antennas in the parallel direction to the geodetic meridian with an azimuth standard error - $M_A = \pm 2 \div 5'$ *(minutes)* and allowable error in distances and eleventions of the setting out elements, respectively - $M_{ds} \leq \pm 3$ *mm*, $M_{dh} \leq \pm 2$ *mm.*

Keywords: geodetic setting-out activities, engineering structures, geodetic network

Introduction

The publication examines geodetic activities in the construction of specific engineering facilities. Also, the complex requirements in the process of the structures, regarding their positioning, geographical orientation and geometric accuracy. In certain cases, the set norms are of a high order of accuracy and accordingly need the application of precise geodetic methods to achieve them. An example of a similar type of facilities are the terrestrial communication antennas. There are strict requirements for their installation accuracy, as follows:

1.1. The orientation of the main axis of the antenna in the "north-south" direction with the accuracy of the geographic (respectively, geodetic) *Azimuth* - $M_A \leq \pm 2 \div 10'$;

1.2. The allowable error in the distances between the fixed elements at the antenna foundation (anchor bolts) - $M_{dS} \leq \pm 3 \div 10 mm$;

1.3. The allowable error in the levels of the fixed elements of the foundation - $M_{dH} \leq \pm 2$ *mm*.

The pointing of the ground communication antennas to the corresponding satellites in the geostationary orbit is carried out by the orientation according to the predetermined angles. Of the greatest importance in the construction and installation process are the so-called angles of elevation (α_{EL}) and azimuth (α_{AZ}).

As is known, the communication satellites are located in the geostationary orbit, which usually lies in the equatorial plane. Relative to the point of observation from the Earth, they are at different angles to the Earth, namely, elevation and azimuth angles. The elevation angle is measured in a vertical plane, and is concluded between the Horizon and the axis of the receiving antenna (**Figure 1**).

The elevation depends mostly on the latitude of the receiving point - at the equator it is *90°*, and decreases with increasing Latitude. When the receiving antenna is located on the prime (Zero) meridian, the signals can be received from a satellite with an orbital position of *0°* degrees. In order to receive signals from other satellites, the antenna must be rotated in a horizontal plane at a certain angle called Azimuth (α_{AZ}) - (**Figure 1**). In fact, the azimuth indicates the rotation angle, relative to the "*SOUTH*" direction (*for the northern hemisphere*), so as to point to the orbital position of the corresponding (desired) satellite. The azimuth (*angle of rotation*) depends on to the greatest extent of the *Longitude* of the receiving point.

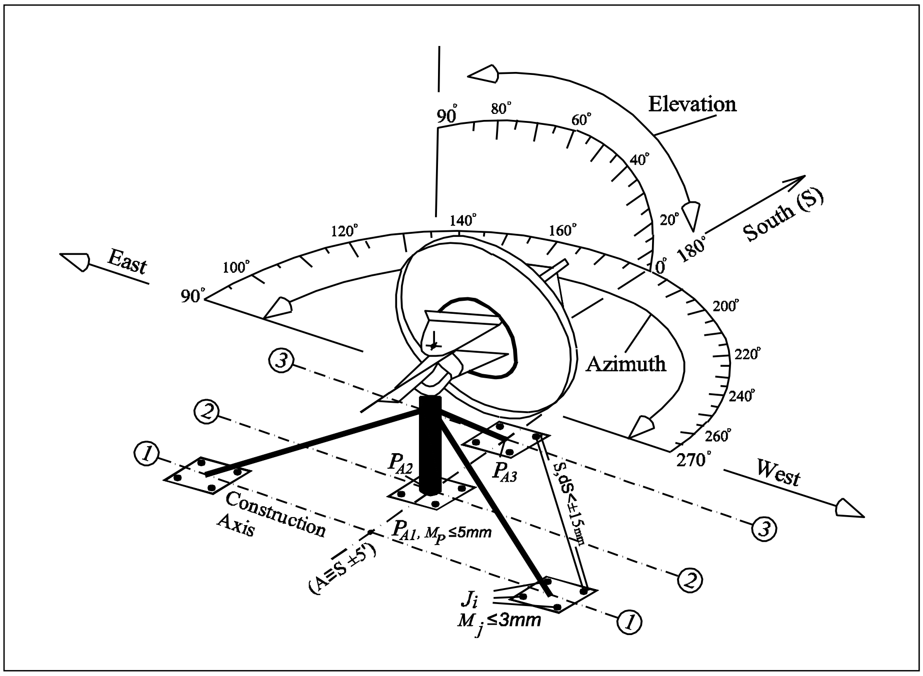

Fig. 1. Installation scheme of terrestrial antenna

To accurately pointing of the receiving antenna to a selected satellite, it is necessary to determine the values of its azimuth (***α****AZ*) and elevation (***α****EL*). With knowning geographical coordinates of the reception point and the orbital position of the satellite, these values can be calculated, following [3] by formulas (1).

$$\alpha_{EL} = arctg\frac{\cos\varphi_R \cos L - r/s}{\sqrt{1-(\cos\varphi_R \cos L)^2}}, \ \alpha_{AZ} = arctg\frac{tgL}{\sin\varphi_R} + 180^0 \qquad (1)$$

In equations (1), $L=L_R - L_S$ is the difference between the longitudes of the receiving point on the Earth and the satellite; φ – the geographical latitude of the receiving point; r – the radius of the Earth ($r \approx 6{,}378$ km), $S = r + h$ – Sum of the radius of the Earth and the height above the Earth's surface of the satellite's orbit *(h ≈ 35 000 km)*.

In the above formulas, the values for $\boldsymbol{\alpha_{AZ}}$ are reported as accepted in the northern hemisphere, relative to the "*north*" direction (for which $\alpha_{AZ} = 0^o$)

Example*: For the area of the city of Sofia with average values of* ***φ =42.6º*** *and* **L=23.4º***, to receive signals from "ASTRA"'s satellites, occupying an orbital position of* ***19.2º east longitude****, the antenna must be oriented at angles:* $\alpha_{EL} \approx 40.6\,^o$ *and* $\alpha_{AZ} \approx 186.2^o$.

Aiming the receiving antenna in elevation and azimuth to the selected satellite, in the case of larger antennas, is usually done using two servo motors. The publication draws attention to equipment with an antenna diameter of *6m, 9m and larger*, which are installed by means of a metal structure, on pre-prepared foundation slabs, using anchor connections. When installing these antennas, regarding the elevation angle (α_{EL}), it is only necessary to estimate in advance the possible obstacles that would interfere with the signal, including tall buildings, towers, large groups of trees, etc. The allowable distance to them can be calculated by formula (2), using the formula below:

$$l = h_{\max} tg\alpha_{EL} \qquad (2)$$

In formula 2 ***l*** is the required clear distance from the obstacles with the greatest height in the direction to the satellite (α_{AZ}). The distance determined above is used in the selection of a suitable location the receiving point and in the designing process.

More important is the orientation task of the main building axes of the structure, which nominally must be oriented in the "*north-south*" direction, respectively in the direction parallel to the *Geodetic Meridian*, with an accuracy of up to a few minutes. This will allow the automation to precisely and quickly orient the receiving antenna along the predetermined Azimuth (*to the east or to the west*), relative to the starting (*reference*) point - in this case, the initial position of the main axis of the antenna - *Axis "A"* (**Figure 1**), directed nominally in the "*South*" direction (*with precision ±5÷10'*).

In case of larger errors in the initial position "*South*" (*respectively - "North" in the southern hemisphere*), it could be impossible to rotate the Antenna, due to the physical limitations on the part of the metal structure, insufficient tolerance in automation, etc.

Sequence of the construction process

The technological sequence of the construction process passes through several main stages. Initially, the location of the concrete foundation of the antenna is determined. Setting out the contour of the trench and placing the concrete underlay.

Anchor locations are fixed on the underlying concrete in order to the metal structure of the antenna to be installed. The foundation of the antenna is built up to the specified design level, taking care not to change the position of the pre-fixed anchors. In the described construction technology, *Geodetic Setting out Works* (GSW) should be performed in the following order and accuracy:

2.1. GSW regarding the contour of the excavation for the foundations and the contour of the underlying concrete
$\pm 2 \leq M_i \leq \pm 5$ centimeters (cm) - *accuracy of a setting-out (fixed) point* ;
2.2. Setting out the building axes of the structure (*A, 1,2,3* – **Figure 1**) in the corresponding Azimuth direction
$\pm 5' \leq M_A \leq \pm 10'$ - *accuracy of the oriented main axis in the "north-south" direction;*
2.3. Fixing the locations of all anchor elements (*J* – **Figure 1**) on the underlying concrete according to the position and the height, as well as the intersection points of the building axes (*P* - **Figure 1)**
$\pm 3 \leq M_{dS} \leq 15$ millimeters (mm) – *a relative accuracy in the distances between fixed elements*
$M_{dH} \leq \pm 2$ mm – *relative accuracy in levels between fixed elements*
$\pm 2 \leq M_p$, $M_j \leq \pm 5$ mm – *an absolute accuracy of a fixed point;*
2.4. Setting out the contour of the concrete foundation and fixing the formwork elements
$M_k \leq \pm 10$ mm – *the absolute precision of a setting out point;*
2.5. Control measurements and executive surveying of the anchor bolts and structural elements in relation to the design level and position.

Geodetic SETTING-OUT works

GSW should be carried out according to the tolerances and accuracies described above, following the usual procedure for the construction of building structures, namely:

- Designing and stabilization of the Points and Benchmarks of Geodetic Setting out Network (GSN);
- Measurements and Adjustment of the coordinates and elevations of the Points/Benchmarks from the GSN in the chosen Coordinate and Height system
- Geodetic Design – Setting out Plan (SP) and Grading Plan/Layout (GP)
- Geodetic Setting out Works. Control measurements and executive surveying.

Geodetic Setting-Out Network (gsn)

In this particular case, the GSN should consist of one, common network - in which, some of the geodetic points will also be defined as benchmarks (*at least one*). Depending on the size of the site, most often from *3 to 5* geodetic points/benchmarks. The adjustment of the Plan and the Vertical network is done separately and independently of each other, since different accuracies of the obtained coordinates and elevations are required.

The basic steps for completing this task are listed below.

Planar Geodetic Setting-Out Network (Pgsn)

The Planned Geodetic Setting-out Network (PGSN) should be designed and adjusted as an independent *linear-angular* network. The coordinates of the known points, which will be used to define the coordinate system, need to be determined by GNSS measurements in the "*Static*" mode or by the trigonometric (classical) method.

The steps to reach the final, adjusted coordinates of the PGSN are as follows:

- *Fixing suitable locations of the geodetic points*

The position of the points are chosen to be close to the site, at a distance of up to *50-70 meters* from each other. A direct line of sight to at least two other points is preferable.

- *Coordination and orientation of the Pgsn*

This step includes the choice of a projection plane and the corresponding transformation from geodesic ellipsoidal coordinates to planar (orthogonal) coordinates. Also, the requirements concerning the accuracy of the geodetic measurements and the allowable errors in the position of the points have to be met.

In order to solve this task, the author has developed and applied in the practice two main approaches:

a.) ***Determination of the geodetic ellipsoidal coordinates (B, L) of the known points from the PGSN by GNSS measurements - accuracy tolerances.***

The emphasis here is on carrying out the subsequent transformation from geodetic ellipsoid coordinates (*B,L*) to the orthogonal coordinates in the projection plane (*x, y*), by choosing an appropriate projection plane (*map projection*). Respectively, transition from a geographic (geodetic) Azimuth (*A*) to a Direction angle in the projection plane (*T*) with minimal loss of accuracy, through the relation given below:

$$c = A - T \tag{3}$$

In this case, the *meridian convergence* value - *C* is essential, which can be determined following [3]. In order to maintain the equality in the transformation of the angles, it is the best to use a *Conformal projection*. As a result of the conformality of the image, the meridian convergence on the ellipsoid is equal to the meridian convergence in the plane (*A=A'*), (*T=T'*). Where *A', T'* are the corresponding images of *A* and *T* in the projection plane.

Given the above considerations, the most suitable for the purpose is a *Cylindrical* "*Gauss-Kruger*" projection, with a *Local/Standart meridian* (L_o) selected near the Site - *at a distance not greater than 2 km (which corresponds to* $dL=L-L_0\approx 2'$*).* In this case, the value of the *convergence* will be ***C ≈30" (seconds)***, which has a negligible effect on the accuracy of (*T*) - respectively on the azimuth (*A*). The meridian scale of this projection is $m=1$.

Another, convenient for the purpose, is the widely used *Universal Transverse Mercator Projection* - "*UTM*", which is also *Conformal*. Here, as is known, the scale along the main meridian is $m=0.9996$, but considering the small distances in this type of Sites, the *Distance reduction* is of negligible value!

In his practical work on the topic, the author used this projection - "*UTM*", with a properly selected *main/ standard* (*local*) meridian (L_O), for the specific Site. The implementation begins with a preliminary assessment of accuracy. Allowable standard deviations by both the Azimuth and the Position, described above are leading item 2.2 and item 2.3. This assessment is also sufficient to carry out the methods listed below:

1) Construction tolerance of the error in the orientation $M_A \leq \pm 5'$

Since the orientation of the main construction axis of the antenna - the *axis A* (**Figure 1**), depends on the mutual position of the already fixed points (*mainly - centers of the anchor bolts*), M_A must be calculated as a function of *RMS* (*Root-Mean-Square*) in the position of these already setting out points. At the distance between fixed points from one axis of $dS \sim 10m$ and tolerance for the $M_A \leq \pm 5'$, the *RMS* is obtained in the position of a setting out points $M_J < 10mm$. This is a cumulative error from *RMS* at the Base points from GSN (M_{GSN}) and *RMS* from the setting out operations (M_{SO}). From where it follows the tolerances → $\boldsymbol{M_{SO}}$, $\boldsymbol{M_{GSN} \leq 7}$ ***мм*** .

2) Construction tolerance of the error in the distance between two fixed points $M_{dS} \leq \pm 5$ *mm*

On the other hand, the tolerance in the distance between two traced points, must also be observed – *DRMS (Distance Root-Mean-Square),* $M_{dS} \leq \pm 5$ *mm*

Following this condition, we get → $M_p \leq 3.5$ *mm*, as a function of *DRMS* for the distance between two traced points. Considering again, that this is the cumulative error from *RMS* at the Base Points (M_{GSN}) and *RMS* from the Setting out operations (M_{SO}), it follows that for the *RMS* of the Base Points is reached → $\boldsymbol{M_{GSN} \leq 3}$ ***mm*** .

In the end, the lower value of ***1)*** and ***2)*** is taken, and it is set as a tolerance for *RMS* in the coordinates of the starting points → $\boldsymbol{M_{GSN} \leq 3}$ ***mm***.

From this accuracy, by analogy, the allowable accuracy of the geodetic ellipsoidal coordinates is derived → $\boldsymbol{M_L , M_B \leq 0.0001''}$ (*with the fact that 1 second along the meridian is ~33m*).

Conclusion: Allowable errors in measurements and final results for the coordinates of the GSN points:

$\boldsymbol{M_L , M_B \leq 0.0001''}$ **,** respectively → $\boldsymbol{M_X , M_Y \leq 3}$ ***mm*** ;

$\boldsymbol{m_r \leq 15^{cc}}$ ***(10'')*** *- allowable RMS for observed direction*

$\boldsymbol{m_s \leq 2}$ ***mm*** *- allowable RMS for measuring of distances (DRMS)*

The above conclusions were proven by the author in some practical measurements.

b.) *Trigonometric method - by Surveying / Geodetic Resection (Free station*)

Another method that can be used, is orientation to the points with known coordinates, by the *Surveying Resection* method. The goal is to determine the minimally necessary parameters, which define the coordinate system, the Base point (*one of the geodetic point from GSN*) and the orientation angle. An average value is used, an allowable accuracy for the points of the GSN → $M_{GSN} \leq 5$ *mm*

Respectively, the accuracy with which the coordinates of the GSN's points should be determined, by the *Surveying Resection* is $\boldsymbol{M_p \equiv M_{GSN} \leq 5}$ ***mm***.

For this purpose, in his practice, the author used the *Surveying Resection* method with only observed *Directions* and without measured Distances, considering the large distances to the *Known (Reference) points*, in most cases is $S_{PN} \geq 5$ *km*.

Using our known formulas [5], a preliminary assessment can be made regarding the required accuracy for the measured *directions* at the distances ($S_{PN} \geq 5$ *km*) from the *Resection point* (*P*) to a minimum of 3 /three/ points with known coordinates – N_i .

After applying the relevant formulas [5], it can be seen that in order to determine the coordinates of the detected point with an accuracy of $M_p \leq 10mm$, an *allowable RMS* for the measured direction is $M_R < 10 \div 15^{cc}$ at distances to the *Known points* $S_{PN} \leq 300m$. Without taking into account the influence of the other factors on accuracy.

Since these conditions are often practically unattainable, especially in terms of distances, the author has used the following approach:

b.1. The coordinates of one point of the GSN are determined, by means of a free station (*Resection*), with the actual achievable values for the *RMS* in the position in the interval $0.3 \div 0.7m$. (at $m_r = 15^{cc}$) and distances to the starting points in the interval 1 *km* $\leq S_{PN} \leq 5$ *km*;

b.2. The center of a *local* (*Independent*) coordinate system is established (with the center) at this point, which is assumed to be the starting point (with *RMS* - $M_p = 0$) and the orientation of the coordinate system to any of the most clearly visible Known points - N_i;

b.3. The remaining points of the GSN are coordinated in the established *local coordinate system*.

In this approach, due to the small distances between the points of the GSN, their *RMS*'s, defined in the local coordinate system, will have values for $M_p \leq 5mm$.

With regard to the orientation angle (*Direction angle - T*), which depends on the distance *error* in the mutual position between the *Resection point* (*P*) and any of the *Known points* (N_i), following the assumed linear error in **b.1)** - we will have the following accuracy criteria:

- In the case of an error in the mutual position between *P* and N_i → $dS \equiv M_S \leq 1m$ and distances $S \equiv S_{PN} \leq 5km$ the error in the *Direction angle* (M_T) will be calculated according to the lower dependence (4)

$$dT'' = \frac{dS}{S}\rho'' \quad , \qquad \rho^{cc} = \frac{200^{grad}}{\pi} = 636620^{cc} \rightarrow \rho'' = 206265'' \tag{4}$$

According to *formula (4)*, it follows → $dT \equiv M_T < 40''$, respectively for $1 \leq M_S \leq 3m$ and → $M_T \leq 120''$ for $5 \leq S_{PN} \leq 10km$, which is practically a small value of the error in *T* (*A*), given the set tolerance of $M_A \leq \pm 5' (\pm 600'')$, item 1.1.

However, it should be noted that with this approach, the GSN is oriented in the projection plane of the coordinate system of the *Known points*. And the transition *T→A* from the Direction angle *T* to the geodetic Azimuth *A,* should be performed. Namely, rotating the direction of the established coordinate system (*to the east / or west*) by an angle equal to the meridian convergence (***C***) for this projection, which means having a minimal information about the parameters of this projection, including the *Standard meridian* and the *longitude* at which the site is located.

Another possible approach, also used by the author in the field - preliminary supply of data from local sources for the ellipsoidal geodetic coordinates of the Known points (*B, L*) determined by an accuracy of **± *0.1''***.
Next, transformation to the orthogonal coordinates (*x, y*) [3], having linear accuracy in the position **±*3m*** in the projection selected of the site (*UTM with local meridian* - L_o).

Conclusion: Necessary and sufficient accuracy in the coordinates of a minimum of 3/three/ Known points to perform the *Resection* survey:
Accuracy in the position of the Known points: (N_i) - $(Mx, My \leq \pm 3м) \rightarrow (M_B, M_L \leq \pm 0{,}1'')$
Distance from N_i to the *Resection* point (*P*) $S_{NP}=5 \div 10\ km$.
Allowable RMS for *observed direction* $m_r \leq 15^{cc}$ *(10'')*

Height Geodetic Setting Out Network (Hgsn)

The height *system* is defined as a *local* one with a *base datum point* (one *Benchmark*), which is part of the geodetic points from the GSN. In this height system, the Heights of the other points of the GSN are also determined with an accuracy of $M_H < 2\ mm$. For this purpose, *geometric* or *trigonometric* leveling is used. The *Heights* of the new *Benchmarks* should be adjusted using an appropriate accuracy analysis model [2].

Geodetic Design – Setting Out In Plan. Grading Plan (GP)

This step begins with *geodetic surveying* and connecting the Site's situation and terrain in the coordinate and the height system of the GSN. Next, siting the design elements and choosing a suitable design level for the foundation slab (*zero-level*), followed by the calculation of the necessary *Setting-out data*, in the selected coordinate projection, respectively - *local, orthogonal coordinate system*. With regard to the *GP* and the level relationship with the surrounding situation and terrain, attention should also be paid to the proper *drainage* and the corresponding removal of the surface water [4].

Setting-out works in plan

1) Polar /coordinate/ method

With a specified construction tolerance of the distance error between two *fixed* points $M_{dS} \leq \pm 5\ mm$.
Allowable accuracies of the Setting out distance (m_S) and the direction (m_R) are determined by the known dependencies below [5] as follows:

$$m_S = \frac{m_{SO}}{\sqrt{2}} \leq 1.5mm \ ; \quad m_R = \rho^{cc}\frac{m_{SO}}{2S} \leq 12^{cc}, 20^{cc}, \text{ where } S \leq 50m, \leq 30m \tag{5}$$

(As for m_{SO} *(Setting-out operations),* the author used the following dependency →)

$$m_{SO} = \frac{M_p}{\sqrt{3}} = \frac{M_{dS}}{\sqrt{3}\sqrt{2}} \leq 2mm \tag{6}$$

2) Polar /coordinate/ - orthogonal method

This method, as is known, is performed in two stages. In the first one, the operational axis is setting out (in *the specific case - oriented in the "North-South" direction*), by turning an angle γ relative to a base line - materialized by two points of the GSN.

In the second stage – *orthogonal setting out*, by measuring the *abscissa* (∂X), raising a right angle ($\theta = 90^o$) and measuring the *ordinate* (∂Y), until reaching the design point (***P***). In these Setting-out works, in order to meet the tolerance of the fixed point, which has an absolute *RMS* in the position $M_p < 5\ mm$, the following allowable values of the the *measured (Setting-out)* elements should be observed:

- $m_\gamma \leq 20^{cc}, 10^{cc} \rightarrow S = 50m, 100m$ - where, ***S*** is the distance between the points of the GSN;
- $m_\theta \leq 80^{cc} \rightarrow \partial Y \leq 20m$ - where, ∂Y is the length of the ordinate;
- $m_{dX} = m_{dY} \leq 2.5m$ - *DRMS*, measuring the lengths of the abscissa and ordinate;
- $m_{GSN} \leq 3.5m$ - *RMS* in the position of GSN's points.

Setting-out of the levels

1) G*eometric* leveling

The assessment of the accuracy starts with setting an allowable value of the difference in the levels of the fixed points / *benchmarks* (*BM*) - $M_{dH} \equiv M_h \leq \pm 2$ ***mm***, which is identical to the error (*RMS* - M_h) of the measured *height difference (h)* between two *BM* - H_i and H_{i+1}.

The allowable error in the elevations of *BM* (M_H) is determined by expression (7)

$$(M_{dH})^2 \equiv (M_h)^2 = (M_{Hi})^2 + (M_{Hi+1})^2 = 2(M_H)^2 \rightarrow \qquad M_H = \frac{M_{dH}}{\sqrt{2}} \leq 1.8mm \tag{7}$$

A priori, and bearing in mind that the *leveling traverses* are very short (*[L]<200m*), an allowable value for m_{Hst} (*RMS for one level station*) is also determined:

$$m_{Hst} = \mu\sqrt{2l} \cong 0.2\mu \approx 0.3мм, \tag{8}$$

with *μ=1.5мм* (*RMS for 1km of leveled distance*) *and l≈0.020км – distance from the instrument to the rod (staf).*

The accuracy estimated above is at a *Confidence Level of P≈93%* - and more can be found in the research of *Cvetkov, V.* [2].

1) *Trigonometric* leveling

The local height of the point (***J***) obtained by some *angle-distance* measurements from the instrument stabilized in the Benchmark (***I***), can be calculated according to the *trigonometric leveling* formula (9), which is known from the literature [5]. By eliminating the influence of signal and instrument height's errors, the accuracy assessment can be reduced to examining the accuracy of the measured *height difference (h)*.

$$h_{IJ} = D_{IJ}.tg\gamma_J \tag{9}$$

Where ***γ*** is the measured *vertical angle*, and ***D*** is the horizontal distance.

When applying the law of ***K. F. Gauss*** for a function of measured elements, and after finding the partial derivatives. For the allowable value of the *RMS* (m_D, m_γ) for measured *Vertical angle* (respectively *Zenith angle–Z*) and distance, using the principle of equal influences, the following expression (10) can be written:

$$m_\gamma \leq \left(m_h \frac{\cos^2\gamma}{D_{IJ}.\sqrt{2}}.\rho \right) \quad ; \quad m_D \leq \left(\frac{m_h}{|tg\gamma|.\sqrt{2}}. \right) \tag{10}$$

Example: *Let the Distance to the observed point to be in the range* ***D(50÷70m)****, the height difference (h) tolerance and vertical angle are* $M_h \leq 2$ ***mm*** *and* $\gamma \leq \pm 5^{gon}$*, respectively, than according to* (10), the *allowable values of the RMS of the measured zenith angle and the distance will be:* $m_Z \leq 15^{cc}$ ***(5")***, $m_S \leq \pm 2$ cm.

In the specific case, due to the small distances, such factors as the *atmospheric refraction and the Earth's curve* do not affect the accuracy.

Control Measurements and Executive Surveying

The main surveying methods that are used to check the already fixed elements are*: the trigonometric method* and/or the *GNSS* in "*Static*" mode, depending on the specifics of the Site. According to [1], the results yielded by the modern ground laser scanning technology, are also promising.

In order to ensure the geometric determination and orientation of the engineering structure, these control measurements must be performed after each stage of the construction process.

conclusion

According to the statements above, the used methods ensure theoretically achievable accuracies of the Setting-out works, in the following order:

A) Setting-out works in the plan.

1. GNSS *in combination* with polar (*coordinate*) method: $M_A \leq \pm 3 \div 5'$; $M_{dS} \leq \pm 3 \div 5$ *mm;*
2. *Trigonometric* method for Azimuth orientation, with *coordinate* method: $M_A \leq \pm 5 \div 10'$; $M_{dS} \leq \pm 4$ *mm;*
3. *GNSS*, with the *polar-orthogonal* method: $M_A \leq \pm 3 \div 5'$; $M_{dS} \leq \pm 5 \div 10$ *mm.*

B) Setting-out of the heights.

1. *Trigonometric* leveling: $M_{dH} \leq \pm 2$ *mm;*
2. G*eometric* leveling : $M_{dH} \leq \pm 1$ *mm.*

The values given above are in an interval range, because the final accuracy is affected by other factors that are not the subject and are not investigated in this publication, including: the *atmospheric refraction, GNSS signal errors, geodetic equipment errors*, etc.

Working on real Sites (*in Bulgaria and in 4/four/ different countries from the Middle East*), the author applied the following combinations of methods (***A plus B***):

- **A1 + B1** (*2/two/ Sites in different geographical locations*); Practically achieved accuracy in control measurements after execution of rough construction: $M_A \leq \pm 4'$; $M_{dS} \leq \pm 3$ *mm*; $M_{dH} \leq \pm 2$ *mm*;
- **A3 + B2** (*2/two/ Sites in different geographical locations*); Practically achieved accuracy in control measurements after execution of rough construction: $M_A \leq \pm 4'$; $M_{dS} \leq \pm 5$ *mm*; $M_{dH} \leq \pm 1$ *mm*;
- **A2 + B1** (*1/one/ Site*); Practically achieved accuracy in control measurements after execution of rough construction: $M_A \leq \pm 7'$; $M_{dS} \leq \pm 3$ *mm*; $M_{dH} \leq \pm 2$ *mm*.

In view of the theoretical studies carried out and especially considering the presented practical results, it can be concluded that the most suitable combination of methods is (***A1 + B1***), which provides the necessary accuracy and at the same time speed and convenience in the implementation. The necessary surveying equipment for implementation is readily available from a logistical and technical point of view. On the other hand, (as is evident from the presentation made,) any combination of the methods mentioned above could satisfy the accuracy tolerances.

The choice of method(s) depends mostly on the logistical, technical and instrumental availability at the time of implementation. Other factors are also important, including *climatic, geographical, topographic, etc. peculiarities* in the specific location of performance.

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