Geometrical Expertise and Dimensional Control of the Elements of Construction to the Hydrotechnics Buildings

Constantin COŞARCĂ, Associate professor eng. Ph.D., Technical University of Civil Engineering, Bucharest, Romania, constantin_cosarca@yahoo.com
Dumitru ONOSE, Professor, eng. Ph.D., Technical University of Civil Engineering, Bucharest, Romania, topcadex@yahoo.com
Adrian SAVU, Teacher assistant, eng., Technical University of Civil Engineering, Bucharest, Romania, adisavu2002@yahoo.com
Aurel NEGRILĂ, Teacher assistant, eng., Technical University of Civil Engineering, Bucharest, Romania, negilaa@yahoo.co.uk

Résumé: *Le réseau géodésique (planimétrique et altimétrique), projeté et exécuté avec le but d'exécution les travaux de moderniser de l'Ecluse a doubles portes Porțile de Fier 1, correspond, comme densité des points et précision, aux exigences exprimées par le bénéficiaire et est d'après les normes en vigueur concernant ce type de travaille. L'exécution de ce réseau à hauts paramètres de qualité et précision assurera aussi la qualité de futures travaux topographiques que seront développer dans la phase d'études de projet et dans la phase d'exécution.*

Keywords: *geodetic network, hydrotechnics buildings, coordinate determination.*

1. Generalities

The design and construction-installation works, in an increasing number of fields are not feasible without using the technique of geodetic measurements, as well as the special techniques in civil engineering.

In the present context, in which the evolution of technology is on an exponentially ascending curve, it could be said that, in most of the industrial and civil engineering branches, the activity of *geodetic protection* is vital for tracing, technological assembly of some equipment and subassemblies, checking their behaviour in operation, as well as ensuring and controlling the quality of the end products.

In civil engineering, the proper measurement techniques for *guiding, managing and checking* the execution of a building have essentially changed, which requires accurate measurement methods. This has led to creating new specific technologies, which has implicitly been felt within the field of measuring instruments and devices as well. The range of classical geodetic measuring devices has been completed with new high-accuracy instruments, to which must be added measuring devices from the field of physics and mechanical engineering.

As a new large action field for the geodetic measurements, the notions of ***mechanization***, ***quality reliability*** and ***quality control*** have been introduced in civil engineering, mechanical engineering and industrial installations. In this field, an important part is played by the accurate determination of the spatial position of characteristic points on different objects, by means of measurement methods without direct contact, and in the shortest possible time.

Besides complying with the accuracy requirements, using geodetic measurement methods implies choosing the appropriate equipment and technologies. This choice is imposed both by calculating the "*a priori*" *(necessary or theoretical)* accuracy, starting from a given allowable maximum deviation, and by knowing the execution and assembly technologies.

When manufacturing a product and measuring a certain parameter (i.e. length, angle, declivity etc.), the theoretical measure, the real value respectively cannot be completely and accurately reached. In both cases, some inaccuracies may occur, which, in the production field, are known as “*deviations*”, whereas in the measurement field are called *“errors”* or *“deviations”* as well. The domain that restricts the allowable deviations is called *“tolerance”* in the technical field.

The tolerances in the field of civil engineering must allow the functional composition of the construction elements, despite all the unavoidable manufacturing inaccuracies, without any supplementary or adjusting works. It is necessary that the tolerance standards should be included in the contracts and complied with by architects, building contractors and specialists in measurements. The occurrence of some supplementary accuracy parameters requires a greater effort in production or at the size check and, implicitly, the increase of expenditure.

Supposing that the definitions of measuring errors, measuring instability, tolerance and allowable deviations are known, the variance and tolerance propagation must be discussed too.

In most of the cases, the results of the measurements in geodesy (e.g. direction and distance measurements) are included in the subsequent calculations for determining the coordinates of the points. As the individual measured values are affected by random deviations (random errors) represented by the standard deviations of the measured values, these deviations will influence the calculated function. The deviations of the measured values will *be propagated* to the calculated value (*The law of error propagation).*

Generally, one may start from a function (in the sense of *function tolerance*), defined by the relation:

$$F = F(x_1, x_2, x_3, \dots x_n) \tag{1}$$

as a function of x_i influence values, independent one from the other.

If the function is not linear, it will be linearized using the *Taylor* method, in which the expansion after the linear term will be annulled. The total differential is the following one:

$$dF = \frac{\partial F}{\partial x_1} \cdot dx_1 + \frac{\partial F}{\partial x_2} \cdot dx_2 + \dots + \frac{\partial F}{\partial x_n} \cdot dx_n \tag{2}$$

If dx_i is replaced by the allowable standard deviations $\sigma_1, \sigma_2, \dots \sigma_n$, then, at x_i measuring values, independent one from the other, *the law of variance propagation* is valid:

$$\sigma_F^2 = \left(\frac{\partial F}{\partial x_1}\right)^2 \cdot \sigma_1^2 + \left(\frac{\partial F}{\partial x_2}\right)^2 \cdot \sigma_2^2 + \dots + \left(\frac{\partial F}{\partial x_n}\right)^2 \cdot \sigma_n^2 \tag{3}$$

If $\boldsymbol{\sigma}$ value is not given, then the computation value s can also be introduced. For correlated measured values, the conformity of the law passes to *the law of co-variance propagation,* characterized by co-variances and co-variance matrix.

In civil engineering, especially at the calculations implied in the case of adjustments, simple functions of sums and differences firstly occur as it follows:

$$F = x_1 \pm x_2 \pm \dots \pm x_n \tag{4}$$

Here the special case arises:

$$\frac{\partial F}{\partial x_1} = \frac{\partial F}{\partial x_2} = \dots = \frac{\partial F}{\partial x_n} = \pm 1 \text{ şi } \left(\frac{\partial F}{\partial x_1}\right)^2 = 1 \tag{5}$$

From the equation (5) it results:

$$\sigma_F = \sqrt{\sigma_1^2 + \sigma_2^2 + \dots + \sigma_n^2} \tag{6}$$

For $\sigma_1 = \sigma_2 = \dots = \sigma_n = \sigma$, the relation $\sigma_F = \sigma \cdot \sqrt{n}$ is obtained.

If all the $\boldsymbol{\sigma_i}$ values come from the normally-distributed basic population, then σ_F belongs to a normally-distributed basic population and will present the statistical reliability P = 68,3 %. Theoretically, the equation (6) can be used without taking into account the distribution.

The present paper conforms to this context, representing a stage within the studies assignable to the project of rehabilitating the special constructions that are necessary for the operation in maximum safety conditions of **Porțile de Fier 1 Sluice**.

The final aim of this paper is the geometrical expertise of the actual state of the constructions annexed to the sluice (gates, included parts, running tracks, bollards, cofferdams, etc.), as an essential component for providing the design of the new technological components and equipment that are necessary for the general overhauls to which this construction objective will be submitted.

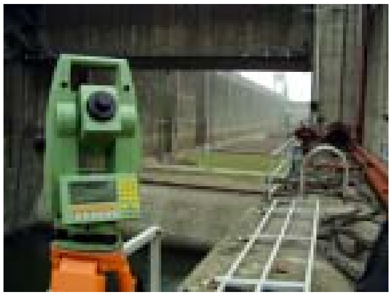

Fig. 1

Starting from a **1-mm** imposed value of the standard position deviation of the main points construction elements, a surveying engineering design was possible, for the purpose of determining the performances of the measuring devices that will be used for the measurement, and also the measuring methods that could result in accomplishing this desideratum.

One has started from the presumption of using the measuring/tracing polar coordinate method, one of the most used methods on the civil and industrial building sites. The process accuracy depends both on the angle and the distance measuring/tracing accuracy. In case of using this method, the sources of error are:

$\boldsymbol{\sigma_{di}}$ = the standard deviation produced by the errors of the reference network points (initial data);
$\boldsymbol{\sigma_{D}}$ = the standard deviation produced by the errors of measuring/tracing the horizontal distances;
$\boldsymbol{\sigma_{\omega}}$ = the standard deviation produced by the errors of measuring/tracing the horizontal angles;
$\boldsymbol{\sigma_{f}}$ = the standard deviation produced by the errors of fixing the traced points;

The standard deviation of determining/tracing the position of a certain **C** point will have the expression:

$$\sigma_C = \sqrt{2\sigma_{di}^2 + \frac{D^2}{\rho^{cc2}}\sigma_\omega^2 + \sigma_D^2 + \sigma_f^2} \tag{7}$$

If the value of the C point determining/tracing standard deviation is known and we apply the principle of equal influence of the angle and distance measuring/tracing errors, then the necessary (*expectation*) accuracies (the standard deviations) of the measuring/tracing works can be calculated. As errors of the initial data, the errors of mutual position of the points in which the measurement/tracing is performed, the reference network points respectively shall be considered.

In this case, from the initial relation (7) result the following relations:

$$\begin{aligned} \sigma_{di} &= \frac{\sigma_C}{\sqrt{6.2}} = 0.0004m \\ \sigma_\omega^{cc} &= \frac{\sigma_C * \rho^{cc}}{D\sqrt{3.1}} = 6^{cc} \\ \sigma_D &= \frac{\sigma_C}{\sqrt{3.1}} = 0.0005m \\ \sigma_f &= 0.2 * \sigma_C = 0.0002m \end{aligned} \tag{8}$$

From these calculations, the very high value of the necessary accuracy of determining the reference network points for measuring/tracing can be emphasized. This context is valid for all the references in the present paper.

2. General Outlook

For ensuring the reference system for detailed surveying measurements, setting up a supporting geodetic (planimetric and altimetric) network has been necessary, appropriate from the viewpoint of the accuracy level and the easy access to the points and which is going to be used as well during the stages of assembling the construction elements and the technological equipment.

Taking into account the accuracy requirements and the special character of such a work type, the design and execution of a new network has been decided, also aiming at including the existing points, which belong to the network of surveying the construction behaviour in time. It has been considered that the only solution for solving this task is the materialization and the signalization of a spatial (linear-angular) network on the steady construction elements of the sluice, from the points of which it should be possible to carry out accurate measurements of horizontal directions, distances and vertical angles. It has been considered this is the best solution, which can eventually lead to the determination of the spatial coordinates, values that can be subsequently used for determining smoothness, deviations from the vertical and the positions of some characteristic points of the construction elements submitted to the expertise, in the horizontal and vertical plane.

In conclusion, for determining the tri-dimensional (3D) positions of the points, it has been considered that the most appropriate hierarchical system of approach is:

- in the first stage, the determination of the 3D coordinates for the reference network points, in which a *sub-millimetre* accuracy should be provided;
- the determination of the 3D coordinates of the points on the construction elements, using as reference the coordinates of the points in the network.

Systems of Coordinates

In order to determine the geometrical elements of the special constructions and the deviations from verticality of the running tracks of the gates, a unique system of coordinates has been locally designed and carried out, so that its OY axis be parallel to the longitudinal (theoretical) axis of the sluice, and the OX axis develop in the cross profile of the sluice.

Fig. 2

This way of approaching the system of coordinates allows the easy determination of the deviations from the verticality of the running tracks, which can manifest either in a longitudinal plane (the X coordinate of the point remains constant and the Y coordinate varies – ***upstream-downstream deviations***) or in a cross plane (the Y coordinate of the point remains constant and the X coordinate varies – ***left-right deviations***), depending on the position of the rails.

For altitudes, the elevation mark system of the sluice has been taken, having control on a series of values of the elevation marks of some points from the network of surveying the constructions materialized on the sluice.

3. Materialization of the Points in the Reference Network

The materialization of the reference network points has been carried out by using metal dowels, on which the mathematical point of the station should be punched by a 0.1-0.2-mm diameter. We have considered this way of materialization to be necessary, because the network can also serve in the future for measurements during all the stages of constructions-assembling. Some points of the reference network have also been materialized on the existing metal elements, using the punching method, with a diameter of 0.1-0.2-mm.

4. Coordinate Determination of Support Network Points

4.1. Carrying out the Observations

The measurements of horizontal directions, vertical angles and distances have been carried out by total stations, such as ***Leica TCR 1104 and 1202*** (so that they could provide high accuracies for determining the network points). The measurements of horizontal directions have been carried out by the series method. The necessary accuracy for determining the distances has been provided by repeated measurements and by introducing the determination average into calculations.

Fig. 3

For providing the position accuracy of the points in the sub-millimetre field, a series of additional steps have been taken, in order to eliminate the effect of some measuring errors, which could have affected this parameter:

- when centring the instrument, the (laser) centring device of the machine has been used;
- mini-reflectors, mounted on specially-manufactured rods for high-accuracy measurements, have been also used;
- in order to take control on the altitude determination, a special attention has been paid to measuring the height of the machine and the projector;
- in each station, measurements for each aimed point have been carried out in the both positions;
- later on, at the office, the primary data have been analysed and the measurements that exceeded the tolerance have been removed;
- finally, the average values have been taken into calculation.

4.2. Processing the Observations Made in the Planimetric Network

It is worth mentioning that all the processes have been made using some specialized programs. The data acquired as a result of the measurements have been directly taken from the memory of the total stations. The operator's intervention has consisted only in renaming some points, if faulty names or points with the same name, but from different areas, have been registered.

Rigorous Processing

The measurements carried out in the spatial support network, finally made up of an overall number of 37 points, have been processed using the least-squares method, the indirect measurement procedure, as it follows:

➢ **1st stage:** Processing as a **free network**, with a minimum condition on all the 37 points of the network:

In this case, the following compensation parameters have resulted:

- the *a priori* standard deviation	1
- the *a posteriori* standard deviation	1.05
- the average standard deviation on the network	1.28 mm
- individual standard deviations, comprised between 0.4 and	1.2 mm

These parameters confirm the quality of the measurements, providing conclusive information about the geometry, respectively the internal accuracy of the network resulted from the measurements, without it being influenced by the errors of the initial data (the coordinates of the points considered to be fixed).

➢ **2nd stage:** Processing as a **constrained network**, using **S1** and **S7** as fixed points.

In this case, the following compensation parameters have resulted:

- the *a priori* standard deviation	1
- the *a posteriori* standard deviation	1.02
- the average standard deviation on the network	1.07 mm
- individual standard deviations, comprised between	0.3 and 0.8 mm

These parameters confirm the accuracy of the measurements and guarantee that the network complies with the accuracy requirements of the beneficiary.

The individual standard deviations of the network points, resulted from compensation, provide the certainty of acquiring the 3D coordinates of the object points at the same accuracy level.

The rigorous processing of the data resulted from the land measurements has been simultaneously carried out using two program packages: the **HANNA** program, from the program library of the Faculty of Geodesy in Bucharest and the **SIPREG** program, from the supply of the performer company. The results of the processing by the two programs have been practically identical. An example of an accuracy analysis report is displayed below:

PROGRAM-SYSTEM HANNA NETWORK: *PORTILE DE FIER SLUICE*

ENTRY PROTOCOL:

Fixed point coordinates:

PCT. NR.	Y (M)	X (M)
S1	5000.0000	1000.0000
S7	4751.4510	1000.0000

A PRIORI STANDARD DEVIATION = 1.00

EXIT PROTOCOL:

A POSTERIORI STANDARD DEVIATION = 1.02

COORD.	**STANDARD DEVIATION**		
	MIN. (MM)	MAX. (MM)	MEDIE (MM)
S_Y	0.34	0.92	0.68
S_X	0.33	1.53	0.81

ELEMENTS OF THE ERROR ELLIPSES

PCT. NR.	A (MM)	B (MM)	ORIENT. (GON)	AB.MEDIE (MM)
S20	1.2	0.8	97.50	0.6
S2	1.2	0.9	4.23	0.6
S3	1.2	1.0	396.47	0.6
S4	1.2	1.0	395.25	0.6
S5	1.1	1.0	395.15	0.6
S6	1.0	0.8	384.71	0.5
S8	1.2	0.9	383.63	0.6
S9	1.3	1.0	394.24	0.7
S10	1.8	1.0	2.97	0.8
S11	1.3	1.0	31.86	0.7
S12	1.7	1.2	10.21	0.8
S13	1.7	1.5	391.93	0.9
S14	1.8	1.6	0.08	1.0
S15	1.4	1.2	398.17	0.7
S16	1.2	1.0	365.58	0.7
S17	1.3	1.1	3.00	0.7
S18	2.3	1.6	2.24	1.2
S21	1.4	0.8	9.04	0.7
S30	2.1	1.4	13.03	1.0
S31	2.1	1.3	390.75	1.0
ID1	1.4	1.1	40.84	0.7
IS1	2.0	1.3	399.43	1.0
IS2	1.6	1.5	320.96	0.9
PD1	1.5	1.3	29.59	0.8
PS1	1.9	1.1	26.74	0.9

AVERAGE STANDARD DEVIATION ON THE NETWORK: 1.07 MM

INDIVIDUAL STANDARD DEVIATIONS
- PORTILE DE FIER SLUICE
LOCAL COORDINATES SYSTEM

NR. PCT.	s_X (MM)	s_Y (MM)
S1	0.0	0.0
S7	0.0	0.0
S2	0.5	0.4
S3	0.5	0.4
S4	0.5	0.4
S5	0.5	0.4
S6	0.4	0.3
S8	0.5	0.4
S9	0.5	0.4
S10	0.7	0.4
S11	0.5	0.4
S12	0.7	0.5
S13	0.7	0.6
S14	0.7	0.7
S15	0.6	0.5
S16	0.5	0.4
S17	0.5	0.5
S18	0.9	0.7
S20	0.3	0.5
S21	0.6	0.3
S30	0.9	0.6
S31	0.9	0.5
ID1	0.5	0.5
IS1	0.8	0.5
IS2	0.6	0.7
PD1	0.6	0.5
PS1	0.7	0.5

4.3. Processing the Observations Made in the Altimetric Reference Network

The landmarks of the points materialized in the reference network have been determined by trigonometric levelling, the measurement of the zenith angles being carried out in both positions of the rest. In the station points where it has been possible, the zenith angles have been directly and mutually measured. Finally, the mean of the measurements made in the two positions and the mean of the direct and mutual determinations have been taken into calculation. It has been aimed at A highly accurate measurement of the device height has been foreseen as well as placing the projector at the smallest possible height, in order to avoid the influence of the contingent accidental errors, which could have influenced the value of the point landmarks.

The level differences and the spans in the levelling ranges, resulted from the measurements, have been calculated. The values of these spans have been situated within the millimetre and sub-millimetre field, which confirms the accuracy of the measurement execution. For calculating the landmark values in a unitary reference system, the landmark values of the fixed points have been taken (provided by the beneficiary), used for surveying the vertical shifts of the sluice.

5. Conclusions

The geodetic network, conceived and made up with the purpose of executing the dimensional measurements of the included parts assignable to the safety gate and the intermediary gate of Portile de Fier 1 sluice, complies with the requirements expressed by the beneficiary, from the viewpoint of point density and accuracy.

The execution of this network at a very high quality and accuracy parameters will also ensure the quality of the next topographic works.

The achievement of these quality parameters has been possible by:

- using high performance devices;
- using some processing programs, which have been tested during many other works and provide safety and confidence;
- the result of processing the planimetric network confirms the quality of the executed measurements and the compliance with the requirements imposed by the beneficiary, thanks ***to the average accuracy on the network and the individual standard deviations***;
- the very small spans in the levelling ranges, resulted from the measurements, guarantees an accurate determination of the point landmarks.

By its complexity, accuracy requirements and the difficulties due to the ground conditions, specific to such a special construction, confers to this work a uniqueness for this type of measurements.

6. References

1. *Coşarcă C, Topografie Inginerească, Editura MatrixRom, 2003;*
2. *Onose, D., Coşarcă, C., Savu, A., Negrilă, A. - Măsurători dimensionale ale pieselor înglobate aferente porţii plane de siguranţă-cap amonte şi a porţii plane-cap intermediar. Ecluza Porţile de Fier 1. Contract de cercetare ştiinţifică, Universitatea Tehnică de Construcţii Bucureşti, 2006.*