Quality Control of the Reference Network of the Tunnel Mala Kapela using the Standards for Expressing Geospatial Positional Accuracy

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Abstract

The positioning precision, as one of the most important component of geodetic control quality, has been expressed in various ways depending on the positioning method. The standards have referred to the precision of the observations, and not to the result, i.e. to the coordinates of geodetic control points. In accordance with the development of measuring technology, these standards have been changing as well. Mostly, the old standards have been using the expression dependant on the distance between geodetic control points. In this paper the new standards for reporting the precision of geodetic control positioning (horizontal and vertical), prescribing by international standards in the field of geospatial information (ISO 19113), that have been accepted as European, i.e. Croatian standards, will be presented. Current standards are related to the spatial position (coordinates) of geodetic control being independent of positioning methods or the survey instruments used. According to these standards, when reporting the precision of geodetic control positioning, two types of accuracy should be reported: *Positional uncertainty* (absolute) and *Local uncertainty* (relative), both for horizontal and vertical coordinates.

In this paper, the application of current standards for reporting positioning precision is presented on the example of the surface reference geodetic control (only horizontal) of the tunnel “Mala Kapela”, located in the Republic of Croatia.

Key words: geodetic control, accuracy standards, ISO 19113

1 INTRODUCTION

The most important part of measuring information, beside the *measurement result,* is the *quality* of that result. The positioning precision, as one of the most important component of geodetic control quality, has been expressed in various ways depending on the positioning method. Traditionally, the accuracy standards for geodetic control positioning were related to the precision of observations, and not to the result, i.e. to the coordinates of geodetic control points. In accordance with the development of measuring technology, these standards have been changing as well. There were no unique standards that could be applied regardless of the positioning method, so it was often impossible to make the comparison of measurement result quality. Apart from that, such standards are no longer adequate in the age of GNSS and GIS when it has become necessary to indicate the positional accuracy of spatial data. Hence, single standards for reporting the positional accuracy (horizontal and vertical) of individual points have been defined by means of international standards in the field of geospatial information (ISO 19113). These standards are related to the spatial position (coordinates) of geodetic control being independent of positioning methods or the survey instruments used. The paper presents these common standards that have been accepted as European, i.e. Croatian standard. ISO 19113: *Geographic Information - Quality principles* defines a data quality model and identifies *Positional accuracy* as one of a spatial data quality element with two sub elements: *absolute* or *external accuracy* and *relative* or *internal accuracy*. So, when reporting the precision of geodetic control positioning, two types of accuracy should be reported: absolute and relative, both for horizontal and vertical coordinates. In most engineering tasks it is more important to achieve and report relative accuracy rather than absolute.

In this paper, the application of current standards for reporting positioning precision of the geodetic control will be shown on the example of the surface reference network of the tunnel “Mala Kapela”, the longest tunnel in the Republic of Croatia.

2 POSITIONING ACCURACY STANDARDS FOR GEODETIC CONTROL

The traditional method of establishing a horizontal geodetic control (triangulation) remained mostly unchanged from the end of 18th century. The first significant technological advance came with the introduction of Electronic Distance Measurement (EDM) in the 1950s, which increased speed and accuracy of surveying. The accuracy standard of classical triangulation network surveys has been described by a proportional standard, which reflected the distance-dependant nature of terrestrial surveying uncertainties (e.g. distance accuracy 1:100 000). The accuracy of coordinates of individual points in the network has not been determined. The same concept was valid for vertical networks. The accuracy standards have been referring to the accuracy in determining height differences (not to the bench mark heights) and they have been proportional to distance: for differential levelling directly proportional to square root of distance, and for trigonometric levelling directly proportional to distance between points.

The second, more significant technological advance has been the development of Global Positioning System (GPS). Accuracy standards for GPS, being less distance dependant, are expressed in terms of maximum allowable base error and line-length error for relative position (e.g. 8mm+1ppm - at the 95% confidence level). It must be emphasised that new, statistical concept for reporting the results at defined *confidence level* was applied.

The use of multiple standards created difficulty in comparing the accuracy of coordinate values obtained by different survey methods. So, the new standards for reporting the precision of geodetic control have been introduced which are related to the spatial position (coordinates) of geodetic control which is independent of positioning methods used. These standards are prescribed by the ISO 19113: *Geographic Information - Quality principles*. Although those standards are referring primary on the points of the national reference geodetic networks, they can be used for every positioning project connected with the control points of known coordinates.

2.1 GEOSPATIAL POSITIONAL ACCURACY STANDARDS FOR GEODETIC CONTROL

According to ISO 19113, *Positional accuracy* is one of a spatial data quality element with two sub elements: *absolute* or *external accuracy* and *relative* or *internal accuracy*. They express the quantitative information about data quality. *Positional accuracy* (absolute and relative) have to be reported for both *horizontal* and *vertical* component of position.

Since the *Positional accuracy* consists of two sub-elements, the quantitative indication of the quality of coordinates requires two criteria to be defined and indicated. Many countries, in their national accuracy standards for geodetic control positioning, use different terms for absolute and relative accuracies (FGDC 1998, GSD 1996, ICSM 2004), but they refer to mentioned ISO standard. In Croatia, these terms are: *Positional Uncertainty* (absolute) and *Local Uncertainty* (relative) (Novaković 2006, DGU 2009).

Positional Uncertainty of a control point is the value that represents the uncertainty in the coordinates of the control point with respect to the geodetic datum, at the 95% confidence level. For horizontal coordinates, the Positional uncertainty of a point is the radius of the 95% confidence circle. For vertical coordinate, the Positional uncertainty of a point is the 95% confidence interval. Positional uncertainty measures how well coordinates approach an ideal, error-free datum.

Local uncertainty of a control point is a value that represents the uncertainty in the coordinates of the control point relative to the coordinates of other directly connected, adjacent control points at the 95% confidence level. The reported *Local Uncertainty* is an approximate average of the individual local uncertainty values between this control point and other observed control points. For horizontal coordinate, the Local Uncertainty of a point is computed using an average of the radius of the 95% relative confidence circles, between the point and other adjacent points. For vertical coordinate, the Local Uncertainty of a point is computed using an average of the 95% relative confidence intervals between a point and other adjacent points.

2.1.1 Determining Positional and Local Uncertainty of the geodetic control points

The Positional and Local Uncertainty (horizontal and vertical) of each point in the network can be computed using elements of a global variance-covariance matrix of the adjusted parameters (coordinates), produced from a least squares adjustment. This matrix contains the following information: standard deviations of the estimated parameters, correlations between the parameters, *absolute or point error ellipses* (or ellipsoids) and *line or relative error ellipses* (or ellipsoids).

Positional and Local Uncertainty of horizontal coordinates

Absolute or point ellipses are indicators of the confidence region of the adjusted coordinates (2-D) with respect to the constraining points. Relative or line ellipses indicate the precision of any point in a network relative to another point in that network. It is accepted that the precision of the geodetic control should be reported at the 95% confidence level. Therefore, the statistic used to represent the precision of the horizontal coordinates of the point (absolute and relative) is the 95% confidence ellipse. Once the standard (point) error ellipse is available, the radius r of the 95% confidence circle can be computed (Leenhouts 1985, GSD 1996, ICSM 2004). The radius of a 95% circle of uncertainty is output data in many least squares adjustment software (e.g. Columbus, Trimble Total Control). Hence, for horizontal coordinates, Positional Uncertainty of each point in the network will be expressed as a radius of absolute circle of uncertainty, and radii of relative circles of uncertainty will be used for computing *Local uncertainty* of each point, both at 95% confidence level.

Positional and Local Uncertainty of vertical coordinates (heights)

For vertical coordinate, Positional Uncertainty of each point in the network is the 95% standard deviation of the height and Local Uncertainty of each point is average of the 95% standard deviation of the height differences between that point and other points in the network. The standard deviation of the height and standard deviation of the height differences can be derived from the variance-covariance matrix of the estimated parameters.

More details on the calculation of Positional and Local Uncertainty can be found in (GSD 1996, ICSM 2004, Novaković et al. 2010).

2.1.2 Positional and Local Uncertainty of the geodetic control of the tunnel Mala Kapela

Positional and Local Uncertainty of the horizontal coordinates will be shown on the example of the surface geodetic control of the tunnel Mala Kapela, the longest tunnel in Croatia. The 5762m long tunnel Mala Kapela is located on the highway Zagreb-Split which connects the northern and southern parts of the country. Horizontal surface reference networks of the tunnel consist of two quadrilaterals (near northern and southern portal) and 6808m long precise surface polygon (traverse) for horizontal networks connection (Fig. 1).

Initially, the coordinates of the networks points were estimated using GPS method. At the demand of independent control measurements, the conventional (terrestrial) methods were used. To determine horizontal coordinates of the points, all distances and horizontal directions were measured. The re-observed networks are adjusted with minimum constraints by holding the original coordinates of one of the re-observed station fixed (S1 in the northern and J1 in the southern portal network) (Fig. 2).

For the adjustment of the networks and traverse, software *Columbus 3.8* was used. That software, as its output, shows all the precision standards explained before, i.e. Positional and Local uncertainties. Due to limited number of pages of the paper, only Positional and Local Uncertainties of the horizontal coordinates of the northern portal network (Tables 1. and 2.) and traverse is shown (Tables 3 and 4).

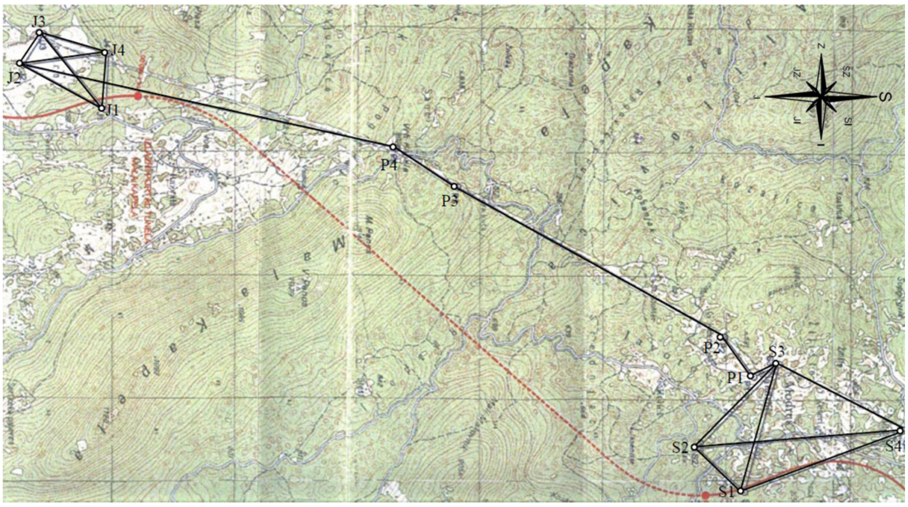

Figure 1 Surface geodetic control and major axis of the tunnel Mala Kapela

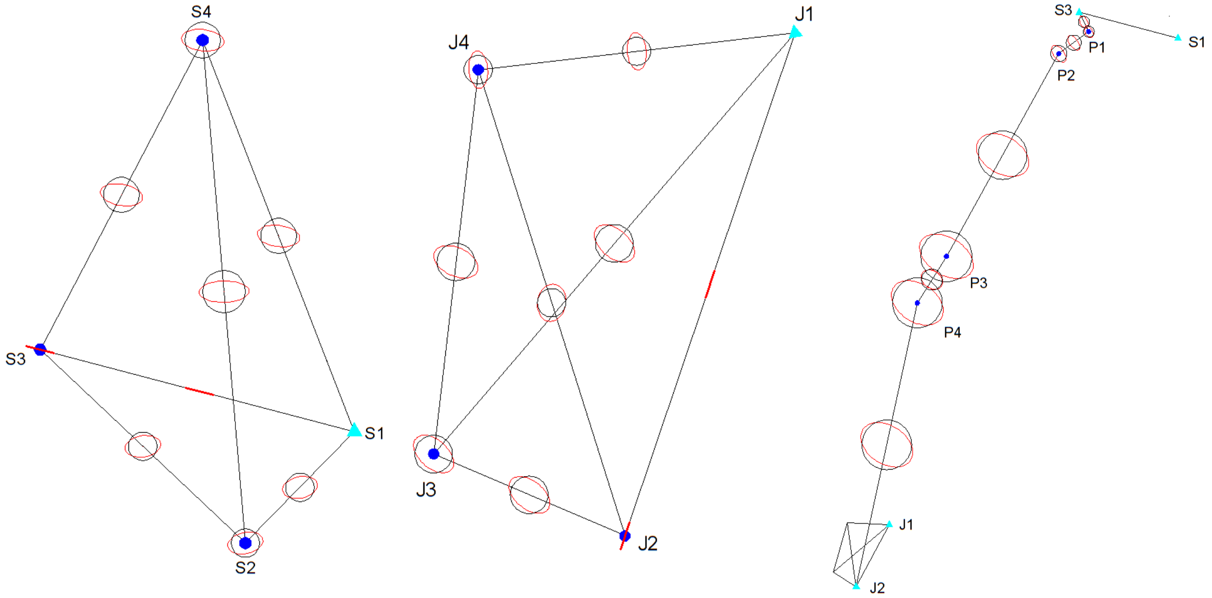

Figure 2 Absolute and relative error ellipses and circles of uncertainties (95% confidence level)
of the horizontal surface geodetic control of the tunnel Mala Kapela

Table 1 Positional Uncertainties (northern portal network)

No. point	***r*** [m]	***a*** [m]	***b*** [m]
S1	Fixed point		
S2	0.004	0.005	0.003
S3	0.000	0.005	0.000
S4	0.005	0.006	0.003

r - radius of the 95% circle of uncertainty

a - semi-major axis of the 95% error ellipse

b - semi-minor axis of the 95% error ellipse

Table 2 Individual local uncertainties (northern portal network)

No. point From-To		***r*** [m]	***a*** [m]	***b*** [m]
S1	S2	0,004	0,005	0,003
S1	S3	0,000	0,004	0,000
S1	S4	0,005	0,006	0,003
S2	S3	0,004	0,005	0,003
S2	S4	0,006	0,007	0,003
S3	S4	0,005	0,006	0,003

For example: reported Local Uncertainty of the point S2 is 0,005m ((0,004+0,004+0,006)/3)

Table 3 Positional Uncertainties (traverse)

No. point	***r*** [m]	***a*** [m]	***b*** [m]
P1	0,006	0,007	0,004
P2	0,014	0,017	0,008
P3	0,044	0,051	0,032
P4	0,043	0,049	0,033

Table 4 Individual local uncertainties (traverse)

No. point From-To		***r*** [m]	***a*** [m]	***b*** [m]
S3	P1	0,006	0,008	0,004
P1	P2	0,013	0,015	0,007
P2	P3	0,042	0,049	0,032
P3	P4	0,018	0,020	0,015
P4	J1	0,043	0,049	0,033

For example: reported Local Uncertainty of the point P3 is 0,030m ((0,042+0,018)/2)

3 CONCLUSION

The positioning precision, as one of the most important component of geodetic control quality, has been expressed in various ways. Depending on the positioning method. Instead of different standards that were depending on the positioning method, unique standards have been established, prescribing by international standards in the field of geospatial information. There is only one type of data used that the standards refer to, i.e. the coordinates of geodetic control points. Two types of standards have been defined: Positional and Local Uncertainty, which are compatible with the quantities Absolute Positioning Accuracy and Relative Positional Accuracy prescribed by ISO 19113. These quantities are computed using variance-covariance matrix of the estimated parameters, obtained after least squares adjustment.

New standards present a significant change in expressing the positioning accuracy of geodetic control points. They describe general classification that is based on the accuracy of spatial coordinates expressing at the defined confidence level. Principal changes included requirements to report numeric uncertainty values: a composite statistic for horizontal uncertainty (radius of confidence circle *r*) instead of individual component of uncertainty (s_x, s_y), and standard deviation for vertical uncertainty. Additionally, the concept of maximum tolerances is abandoned, and the statistical concept - confidence level is introduced.

Positional and Local Uncertainties are simple indicators of the quality of position. Positional uncertainty is global or absolute, computed with respect to the reference frame or datum and Local uncertainty is computed with respect to adjacent points within the same data set or source. Since the current standards do not refer to the quality of surveying being constantly changed due to the development of technology, these standards of reporting the positioning quality will not be changed so soon.

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