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Professional paper

THE NEW STATE REFERENCE SYSTEM OF THE REPUBLIC OF SERBIA AND DIVISION INTO MAP AND LAYOUT SERIES

Ganić Aleksandar[1], Milutinović Aleksandar[1], Trifunović Prvoslav[1]

Abstract: In terms of new legal regulations, this paper shows the new state three-dimensional, two-dimensional and one-dimensional reference systems in the Republic of Serbia. All of them are based on the European Terrestrial Reference System ETRS89, which applies GRS80 reference biaxial rotary ellipsoid. In this respect, positions of points and objects in the projection plane are being displayed by two-dimensional, rectangular, linear coordinates within the plane of a conformal Universal Transverse Mercator Projection now. Those changes have also resulted in an another way of division into the map and layouts series, which was shown in the example of coordinates of the first point within the mine traverse at the school mine "Crveni Breg" on the mountain Avala.

Key words: state reference system, GRS80, UTM projection, division into map and layouts series

1. INTRODUCTION

Since 1924, Bessel's ellipsoid is being applied in Serbia as reference ellipsoid, i.e. the measures of the biaxial rotary ellipsoid, established by German scientist Friedrich Wilhelm Bessel by applying the measurement method from 1831 till 1838. In the same 1924, Gauss-Krüger projection was adopted as state projection in Serbia. After nearly 100 years, since January 1st 2011, new state spatial reference system (ETRS89) is in use in the Republic of Serbia pursuant to the Law on State Survey and Cadaster (The Official Gazette of the Republic of Serbia 72/09 and 18/10), the new reference biaxial rotary ellipsoid (GRS80) was adopted and the new state projection (UTM) was adopted as well.

The reasons for those changes are primarily of global character. The ETRS89 reference coordinate system, which uses GRS80 ellipsoid, has been in use in Europe for many years. The fact that Serbia is currently undergoing the stage of executing and planning of many new geodetic surveys and development of various digital data bases, as well as the necessity to exchange spatial and space related data with other European countries, has been clearly the reason for implementation of the new reference coordinate system and reference ellipsoid GRS80 in connection with it.

The other reason is the fact that the measurements were performed by using satellite geodesy has shown the inhomogeneity of the existing state trigonometric network, which amounts 2 to 3 meters.

The state reference system represents the coordinate system, whose geometric and physical relation to Earth's body was determined by parameters of geodetic datum.

[1] University of Belgrade, Faculty of Mining and Geology, Đušina 7, 11000 Belgrade, Serbia,
e-mail: aganic@rgf.bg.ac.rs; amilutinovic@rgf.bg.ac.rs; trifp@rgf.bg.ac.rs

By those parameters, the shape and size of reference ellipsoid is to be defined as well as the origin of coordinates and the orientation in relation to the Earth. The positioning, determination of the external gravitational field and geodynamic researches are to be made within the state reference system for the purposes of state survey, establishing of information systems on the region, executing of engineering-technical works and for scientific purposes as well (The Official Gazette of the Republic of Serbia 19/12 and 95/12).

The following reference systems are to be defined in Serbia within the state reference system:

- spatial reference system (three-dimensional);
- reference system in projection plane (two-dimensional);
- vertical reference system (one-dimensional);
- gravimetric reference system;
- astronomic reference system.

2. SPATIAL REFERENCE SYSTEM

Spatial reference system for the Republic of Serbia is a geocentric terrestrial three-dimensional coordinate system, which, by definition of the origin of coordinates, orientation of coordinate axis, scale, length unit and time evolution, corresponds with the European Terrestrial Reference System – ETRS89. The designation for spatial reference system for the Republic of Serbia, which is called the Serbian Spatial Reference System, is SRB_ETRS89.

The positions of points and objects within the spatial reference system are given as three-dimensional, rectangular, linear coordinates X, Y, Z or as three-dimensional, rectangular, curvilinear coordinates, i.e. as geodetic latitude B, longitude L and height h. Those coordinates refer to the biaxial rotary ellipsoid of the geodetic reference system GRS80 (Geodetic Reference System 1980).

The adopted GRS80 ellipsoid is designed in such a way that it most optimally corresponds with the Earth as a whole. The geometry of the ellipsoid was defined by two parameters, and they most often are the length of the semi-major axis a and the length of semi-minor axis b or flattening of the ellipsoid f. The size of the semi-major axis a GRS80 is $a = 6378137.00$ m, and flattening is $f = 1/298.257222101$.

The spatial reference framework is to be materialized by stabilizing geodetic points and by determining of their coordinates based on geodetic surveying, i.e. by establishing state reference networks, such as:

- basic spatial reference network - EUREF-SRBIJA;
- national reference network of permanent GNSS stations - AGROS;
- spatial reference network - SREF;
- local spatial reference network.

2.1. Basic spatial reference network of the Republic of Serbia

Basic spatial reference network includes set of 12 permanently stabilized and accessible geodetic points uniformly distributed across the whole area of the Republic of Serbia at average distance from each other of 100 km. The minimum accuracy of relative horizontal position of points at the basic spatial reference network must be 5 mm + 1 ppm, and with relative vertical position of 10 mm + 1 ppm. Measurements within the basic spatial reference network of the Republic of Serbia are made by using measuring instruments and by applying methods of satellite geodesy.

2.2. National reference network of permanent GNSS stations – AGROS

The national reference network of permanent GNSS stations – AGROS, is the only system of permanent stations in the territory of the Republic of Serbia, which can be used for the purposes of executing surveying works that fall within the competence of the Republic Geodetic Authority, and it includes permanent stations, control center and back-up center. Permanent stations are to be distributed across the territory of the Republic of Serbia at the average distance from each other of 70 km.

AGROS is to be carried out through three basic services, such as:

- AGROS RTK, positioning by applying kinematic method with accuracy of 0.02-0.03 m;
- AGROS DGPS, positioning by applying differential method with accuracy of 0.5-3.0 m;
- AGROS PP, positioning by applying static method with accuracy of 0.01 m.

2.3. Spatial reference network of the Republic Serbia

Spatial reference network includes set of permanently stabilized and accessible geodetic points uniformly distributed across the whole area of the Republic of Serbia at average distance from each other of 10 km.

The minimum accuracy of relative horizontal position of points at the basic spatial reference network must be 5 mm + 1 ppm, and with relative vertical position of 10 mm + 1 ppm. Measurements within the basic spatial reference network of the Republic of Serbia are made by using measuring instruments and by applying methods of satellite geodesy.

2.4. Local spatial reference network

The spatial reference network is local implementation of spatial reference system in the area in which surveying works are to be executed. This network includes set of permanently stabilized, easy accessible points at the distance from each other of 1-4 km that almost uniformly cover area larger than the area of works.

Three-dimensional positions of points within the local spatial reference network are displayed in one of the following ways:

- three-dimensional, rectangular, linear coordinates;
- three-dimensional, rectangular, curvilinear coordinates, i.e. geodetic latitude, longitude and height;
- two-dimensional, rectangular, linear coordinates in projection plane.

The accuracy of the relative horizontal position of the local spatial reference network must be higher than 5 mm + 2 ppm, and the accuracy of the relative vertical position of points within the local spatial reference network must be higher than 10 mm + 2 ppm.

3. REFERENCE SYSTEM IN PROJECTION PLANE

Positions of points and objects within the reference system in projection plane are displayed as two-dimensional, rectangular, linear coordinates within the plane of a conformal Universal Transverse Mercator Projection (UTM) of GRS80 ellipsoid. The designation for the reference system in projection plane of the Republic of Serbia is SRB_ETRS89/UTM.

This projection divides the Earth's plane between 80^o South latitude and 84^o North latitude into 60 zones of equal longitudes of 6^o. Zones are marked by numbers 1 to 60, whereby numbers increase towards the East. Each of those zones is divided into 20 shelves 8° wide, which are marked by letters of English alphabet from C to X (letters I and O are omitted) towards North. Serbia is located in zone 34T (Figure 1).

Figure 1 - UTM zones in Europe (http://en.wikipedia.org)

Vertical axis of the coordinate system is a meridian at 21° East geodetic (ellipsoidal) longitude. The direction of ordinate is towards North and it is marked by N. The scale along central meridian is 0.9996. Horizontal axis of the coordinate system is equator. The direction of abscissa is towards East and it is marked by E. The constant of abscissa is 500,000 m, which enables the avoidance of negative sign of point coordinates located west to the 21° East geodetic longitude.

Reference framework in projection plane are all state and local reference networks, carried out within the spatial reference system with their two-dimensional, rectangular, linear coordinates in projection plane.

3.1. Local reference network in projection plane

Local reference network in projection plane is to be established if local spatial reference network was not established in larger area of works. Satellite and classic (terrestrial) measuring methods are being applied with the local reference network in projection plane.

Two-dimensional positions of points within the local reference network in projection plane are displayed by two-dimensional, rectangular, linear coordinates in projection plane.

Local implementation of the reference system in projection plane is accomplished by including at least three points of the state reference network, which, with their positions, cover the entire area of local reference network in projection plane.

4. VERTICAL REFERENCE SYSTEM

Vertical reference system is one-dimensional coordinate system, i.e. reference plane according to which the altitudes are expressed. The designation for vertical reference system for the Republic of Serbia, called the Serbian Vertical Reference System, is SRB_VRS12.

In the Republic of Serbian, reference plane of the natural vertical reference system represents the quasigeoid plane. The quasigeoid plane is defined as plane, where vertical distance of each point from the reference biaxial rotary ellipsoid of geodetic reference system GRS80 equals the distance between the point on physical Earth's plane and the point on the same normal, where real and normal gravity potentials are of the same value.

Positions of points and objects within the natural vertical reference system of the Republic of Serbia are displayed by one-dimensional coordinates, i.e. by normal heights when compared to the quasigeoid plane.

The reference plane of the natural vertical reference system of the Republic of Serbia has vertical position, which corresponds with the mean level of the Adriatic Sea established by marigraphic observations for the reference time period.

The vertical reference framework of the Republic of Serbia is accomplished by stabilizing geodetic points and by determining of their altitudes based on geodetic measurements, i.e. by establishin vertical reference networks and by determining of quasigeoid planes. Based on vertical reference networks the following is being established: the reference levelling network of the Republic of Serbia and local levelling reference networks.

4.1. Reference levelling network of the Republic of Serbia

The reference levelling network comprises of a system of closed polygons uniformly distributed across the entire territory of the Republic of Serbia. Average circumference of the polygon is approximately 115 km, with average distance of points at approximately 5 km.

Fundamental bench marks NVT2 and corresponding points of the SREF network, in terms of position, are at the same time the RNM points. The following dimensions are to be measured within the reference levelling network:

- differences in level;
- differences in gravity acceleration;
- coordinates of points within the spatial coordinate system.

Differences in level within the reference levelling network are to be measured by using the method of geometric levelling. Measurements by using geometric levelling are performed by applying both motorized and classic levellings. By applying classical method of leveling, differences in level are being measured only there where it is impossible to use motorized levelling due to the terrain relief and absence of suitable roads. The levelling method is always "back and forth".

Spatial coordinates are to be determined on all points of the reference levelling network. In order to determine coordinates, a method of relative kinematic positioning (RTK) is to be applied, for whose implementation AGROS is to be used.

The accuracy of relative vertical positions of points of the reference levelling network is higher than 2 mm per square root of their distance from each other expressed in kilometers.

4.2. Local levelling reference network

Local levelling reference network sets up vertical reference system locally in the area specified for works and it is to be established in form of local levelling network. This network comprises of a set of levelling lines, spatialy organized in form of closed levelling polygons, with permanently stabilized and easy accessible bench marks at the distance from each other that, along lines, cannot be smaller than 100 m nor larger than 1000 m.

Within the local levelling network, measuring of differences in level is to be performed by applying the method of geometric levelling. The accuracy of relative vertical positions of bench marks within the local levelling network must be higher than 2 mm per square root of their distance from each other expressed in kilometers. The horizontal position of the bench marks within the local levelling network must be determined with minimum accuracy of 50 m.

5. DIVISION INTO MAP AND LAYOUT SERIES

Switching over to the reference GRS80 ellipsoid, as well as implementation of the conformal, transversal, cylindrical Universal Transversal Mercator Projection, has caused the new Rulebook on the Division into Map and Layout Series in State

Projection (The Official Gazette of the Republic of Serbia, 8/12) to be drawn up. This Rulebook provides for the way and procedure of the division into the map and layout series and determination of designations (nomenclature) for official scales within the state projection, as well as determination of names given to map series, scale 1:250,000; 1:100,000; 1:50,000 and 1:25,000. The name for the topographic map series was determined upon the most renowned toponym on the map series observed.

The division into map and layout series is made within the plane of state projection STRS00/UTM and it includes official scales of topographic maps: 1:250,000; 1:100,000; 1:50,000 and 1:25,000; 1:10,000 and 1:5,000; digital orthophoto 1:5,000; 1:2,500 and 1:1,000 and layout series 1:5,000, 1:2,500, 1:1,000 and 1:500.

Contrary to the previously applicable Rulebook, the size of the map sheet, orthophoto and/or layout (useful space) is now uniform for all scales and amounts 600 x 400 mm.

The division area is 600,000 x 600,000 m. The beginning of the area of division into series is the point with coordinates E = 200,000 m and N = 4 600,000 m, located in the lower left corner of the division, and it extends to the point in the upper right corner of the division with coordinates E = 800,000 m and N = 5 200,000 m (Figure 2).

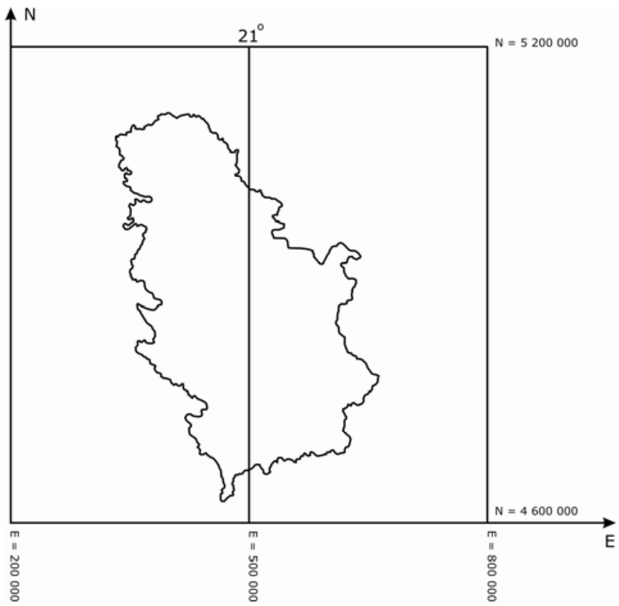


Figure 2 - Area of division for the zone of the Republic of Serbia

The division to series for scales 1:250,000; 1:100,000 and 1:50,000 is obtained by dividing the area of division. The division to series 1:25,000; 1:10,000 and 1:5,000 is derived from the scale 1:5,000. The division to series for scale 1:500 is derived from the scale 1:1,000.

The division to series of topographic maps and layouts, designations and names of series according to the new Rulebook is shown in the example of traverse point at the entrance into the lower drift of the school mine "Crveni Breg" on the mountain Avala. The first point on the mine traverse in this drift has coordinates according to the old Gauss-Krüger coordinate system:

$Y_1 = 7\,460\,836$ m; $X_1 = 4\,948\,922$ m

The coordinates of this point in UTM projection are:

$E_1 = 460\,415$ m; $N_1 = 4\,947\,945$ m

5.1. Topographic map, scale 1:250,000

Series of topographic map with scale 1:250,000 are obtained by dividing the area of division into four columns (from E1 to E4) and six rows (from N1 to N6). The dimensions of one series are:

0.6 m x 250,000 =150,000 m along horizontal axis E and

0.4 m x 250,000 =100,000 m along vertical axis N.

The designation of the series of topographic map with scale of 1:250,000 consists of: scale marking 250k, column mark and row mark (Figure 3).

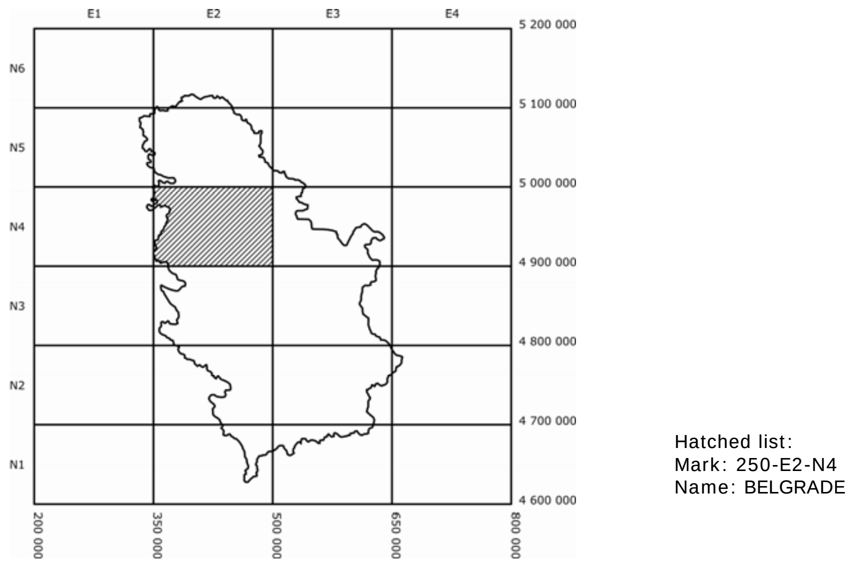


Figure 3 - Series of topographic map, scale 1: 250,000

5.2. Topographic map, scale 1:100,000

Series of topographic map with scale 1:100,000 are obtained by dividing the area of division into 10 columns (from E1 to E10) and 15 rows (from N1 to N15). The dimensions of one series are:

0.6 m x 100,000 = 60,000 m along horizontal axis E and

0.4 m x 100,000 = 40,000 m along vertical axis N.

The designation of the series of topographic map with scale of 1:100,000 consists of: scale marking 100k, column mark and row mark (Figure 4).

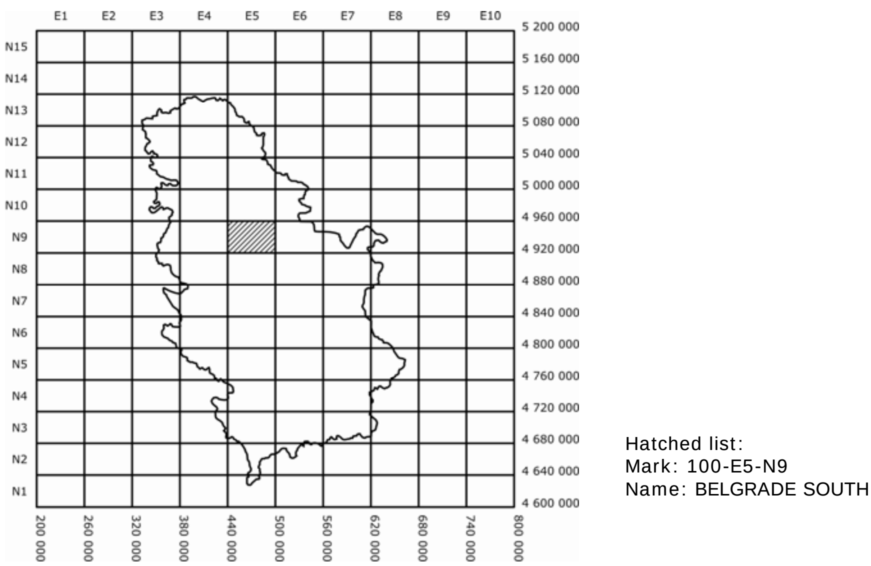


Figure 4 - Series of topographic map, scale 1: 100,000

5.3. Topographic map, scale 1:50,000

Series of topographic map with scale 1: 50,000 are obtained by dividing the area of division into 20 columns (from E1 to E20) and 30 rows (from N1 to N30). The dimensions of one series are:

0.6 m x 50,000 = 30,000 m along horizontal axis E and

0.4 m x 50,000 = 20,000 m along vertical axis N.

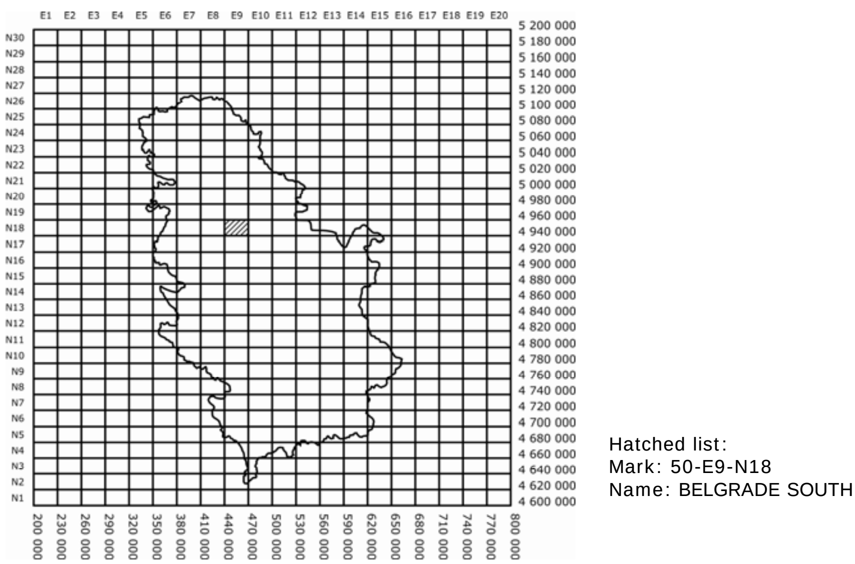


Figure 5 - Series of topographic map, scale 1: 50,000

The designation of the series of topographic map with scale of 1: 50,000 consists of: scale marking 50k, column mark and row mark (Figure 5).

5.4. Topographic map, scale 1:25,000

The division into the sheets of topographic maps with scale of 1:25,000 is derived from the sheet with scale 1:50,000, whereby the sheet with scale of 1:50,000 is to be divided into four sheets with scale of 1:25,000 (two rows and two columns). The dimensions of one sheet with scale of 1:25,000 are:

0.6 m x 25,000 = 15,000 m along horizontal axis E and
0.4 m x 25,000 = 10,000 m along vertical axis N.

Sheets with scale of 1:25,000 obtain markings from 1 to 4 within the series with scale of 1:50,000 beginning with the upper left sheet till lower right sheet as per rows. The designation of the series of topographic map with scale of 1:25,000 consists of: scale marking 25k, sheet number 25k within the series 50k, column mark and row mark 50k (Figure 6).

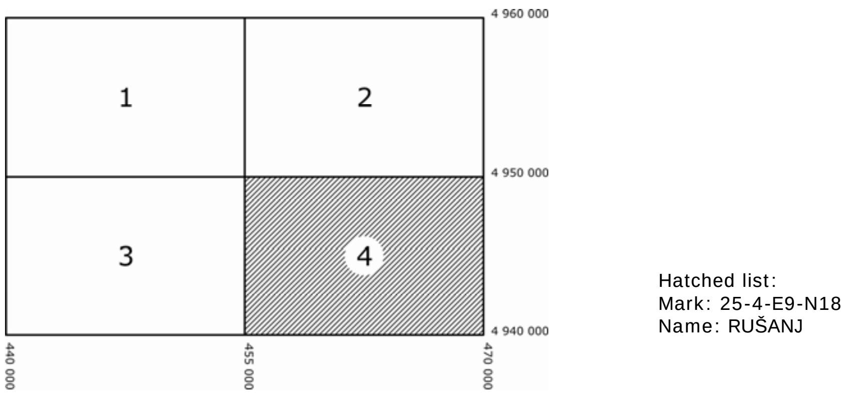


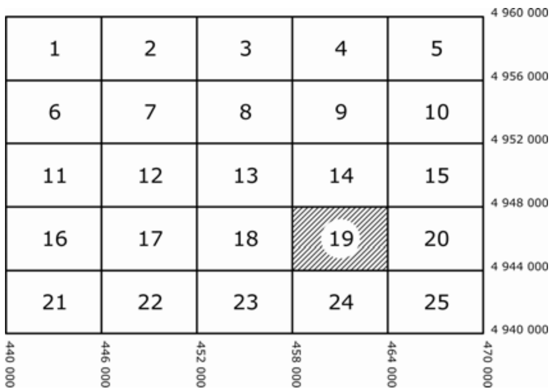
Figure 6 - Series of topographic map, scale 1: 25,000

5.5. Topographic map, scale 1:10,000

The division into sheets of the basic state map with scale of 1:10,000 is derived from the series with scale of 1: 50,000, whereby the sheet with scale of 1:50,000 is to be divided into 25 sheets with scale 1:10,000 (five rows and five columns). The dimensions of one sheet with scale of 1:10,000 are:

0.6 m x 10,000 = 6,000 m along horizontal axis E and
0.4 m x 10,000 = 4,000 m along vertical axis N.

Sheets with scale of 1:10,000 obtain markings from 1 to 25 within the series with scale of 1: 50,000 beginning with the upper left sheet till lower right sheet as per rows. The designation of the series of the basic state map with scale of 1:10,000 consists of: scale marking 10k, sheet number 10k within the series 50k, column mark and row mark of the series 50k (Figure 7).



Hatched list:
Mark: 10-19-E9-N18
Name: RUŠANJ-19

Figure 7 - Series of topographic map, scale 1: 10,000

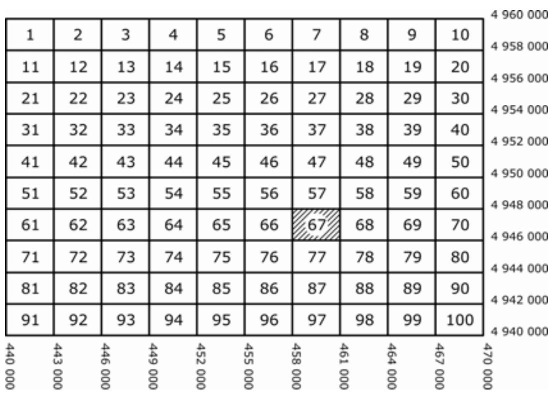
5.6. Series, scale 1:5,000

The division into sheets with scale of 1:5,000 is derived from the series with scale of 1:50,000, whereby the sheet with series with scale of 1:50,000 is to be divided into 100 sheets with scale of 1:5,000 (10 rows and 10 columns). The dimensions of one sheet with scale of 1:5,000 are:

0.6 m x 5,000 = 3,000 m along horizontal axis E and

0.4 m x 5,000 = 2,000 m along vertical axis N.

Sheets with scale of 1:5,000 obtain markings from 1 to 100 within the series with scale 1:50,000 beginning with the upper left sheet till lower right sheet as per rows. The designation of the series of the basic state map, cadastral map, topographic map, line plan and digital orthophoto with scale of 1:5,000 consists of: scale marking 5k, sheet number 5k within the series 50k, column mark and row mark of the series 50k (Figure 8).



Hatched list:
Mark: 5-67-E9-N18
Name: RUŠANJ-67

Figure 8 - Division into series, scale 1: 5,000

5.7. Series, scale 1:2,500

The division into sheets with scale of 1:2,500 is derived from the series with scale of 1:5,000, whereby the series with scale of 1:5,000 is to be divided into four sheets with scale of 1:2,500 (two rows and two columns). The dimensions of one sheet with scale of 1:2,500 are:

0.6 m x 2,500 = 1,500 m along horizontal axis E and
0.4 m x 2,500 = 1,000 m along vertical axis N.

Sheets with scale of 1:2,500 obtain markings from 1 to 4 within the series with scale of 1:5,000, beginning with the upper left sheet till lower right sheet as per rows. The designation of the sheet of cadastral map, topographic map, line plan and digital orthophoto with scale of 1:2,500 consists of: scale marking 2.5k, sheet number 2.5k within the series 5k, series number 5k and column mark and row mark of the series 50k (Figure 9).

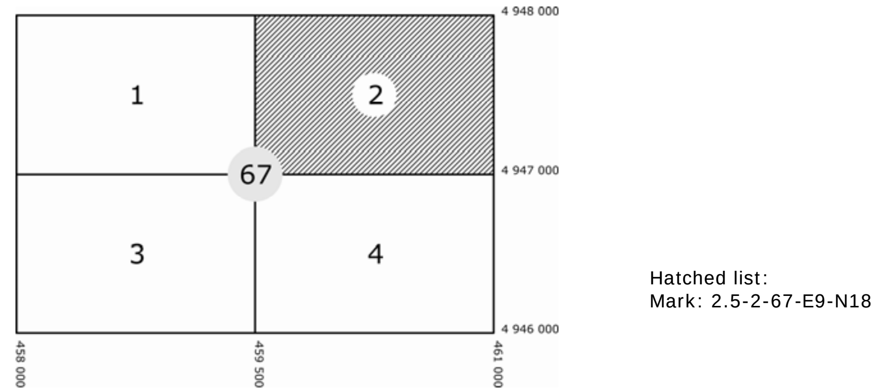


Figure 9 - Division into series, scale 1: 2,500

5.8. Series, scale 1:1 000

The division into sheets with scale of 1:1,000 is derived from the series with scale of 1:5,000, whereby the series with scale of 1:5,000 is to be divided into 25 sheets with scale of 1:1,000 (five rows and five columns). The dimensions of one sheet with scale of 1:1,000 are:

0.6 m x 1,000 = 600 m along horizontal axis E and
0.4 m x 1,000 = 400 m along vertical axis N.

Sheets with scale of 1:1,000 obtain markings from 1 to 25 within the series with scale of 1:5,000, beginning with the upper left sheet till lower right sheet as per rows. The designation of the sheet of cadastral map, topographic map, line plan and digital orthophoto with scale of 1:1,000 consists of: scale marking 1k, sheet number 1k within the series 5k, series number 5k and column mark and row mark of the series 50k (Figure 10).

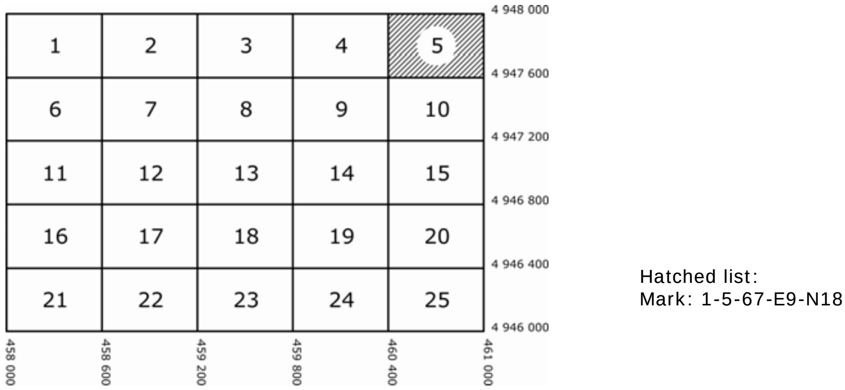


Figure 10 - Division into series, scale 1: 1,000

5.9. Series, scale 1:500

The division into sheets with scale of 1:500 is derived from the series with scale of 1:1,000, whereby the series with scale of 1:1,000 is to be divided into four sheets with scale of 1:500 (two rows and two columns). The dimensions of one sheet with scale of 1:500 are:

0.6 m x 500 = 300 m along horizontal axis E and

0.4 m x 500 = 200 m along vertical axis N.

Sheets with scale of 1:500 obtain markings from 1 to 4 within the series with scale of 1: 1,000, beginning with the upper left sheet till lower right sheet as per rows. The designation of the sheet of cadastral map, topographic map and line plan with scale of 1:500 consists of: scale marking 0.5k, sheet number 0.5k within the series 5k, series number 5k and column mark and row mark 50k (Figure 11).

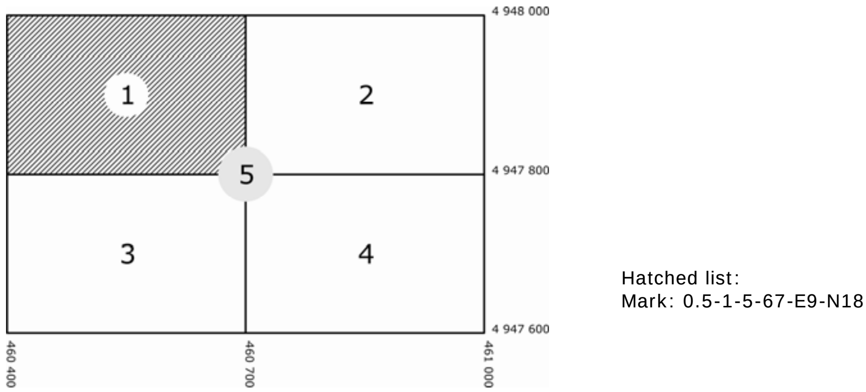


Figure 11 - Division into series, scale 1: 500

6. CONCLUSION

As of January 1st 2011, the new ETRS89 reference coordinate system is being applied in Serbia, which uses GRS80 ellipsoid. Moreover, the new state projection, the Universal Transversal Mercator Projection has been adopted. The reasons for abandonment of Bessel's dimensions of rotary ellipsoid and of Gauss-Krüger projection lies in the fact that on global level, the GRS80 ellipsoid better corresponds with the Earth, as well as that the majority of European countries have already switched over to the ETRS89 reference coordinate system, which will, in the future, help the exchange of geospatial data between Serbia and other European countries. In this way, satellite measuring is additionally encouraged, as well. Namely, as already known, GPS devices determine position of points on the WGS84 ellipsoid, which differs insignificantly from the GRS80 ellipsoid (semi-major axis a is identical for both ellipsoids, flattening of the GRS80 ellipsoid is $f = 1/298.257222101$, and of the WGS84 ellipsoid is $f = 1/298.257223563$, which causes that semi-minor axes of those two ellipsoids differ by 0.105 mm).

The fact that the existing state trigonometric network in Serbia is inhomogeneous and that its known (cadastral) coordinates determined by applying satellite geodesy differ up to 3 m have caused that the three-dimensional, two-dimensional, one-dimensional reference systems both gravimetric and astronomic are defined by the new Rulebook for basic surveying works. Moreover, the accuracy of determination of position of points forming those reference networks was defined, but also the way in which the measuring within those networks (by applying satellite or terrestrial geodesy) is to be performed.

Adoption of the new state projection has resulted in the fact that the points will have different coordinates now. First, coordinate axes are no longer to be marked with X and Y, but with N and E, and E coordinates (former Y) no longer include the number of coordinate system, which the point in question belong to, because now the entire territory of the Republic of Serbia is in one coordinate system (34T).

Further, this entailed the change of the method of division into series of maps and layouts that are displaying Serbia. Thus, the division into map sheets proceeds from the scale of 1:250,000. And finally, which is for all mining engineers perhaps the most important, is that the useful space of all maps and layouts is the same and amounts 600 x 400 mm, as well as the fact that layouts with scale of 1:2,000 are no longer in official use.

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