

Preliminary Project of the Height System Reconstruction in the Republic of Croatia

I. Grgić, M. Lučić, D. Kršulović, E. Babić, I. Malović
State Geodetic Administration, Gruška 20, 10000 Zagreb, Croatia

Abstract. The old vertical datum that is still in use in Republic of Croatia, was defined referring to the mean sea level at the tide gauge in Trieste, derived from one year long observation. Benchmark heights were defined in the normal orthometric (spherical) height system. At the end of 20th century, it was clear that mean sea level at the tide gauge in Trieste deviates for 12cm from the ordinary defined sea level (18.6 long observation period). According to that, all benchmark heights in the official vertical datum are higher, and due to network error growth some benchmarks are 35 cm higher. From 1962 to 1981, measurements were taken on tide gauges in Dubrovnik, Split, Bakar, Rovinj and Kopar along the Adriatic coast. The origin of the new vertical datum has been defined by mean sea levels at these tide gauges. This height system definition is specific, because the system has not one, but five origin points. This approach has shown good results for the practical purposes, because tide gauge data and levelling measurements between tide gauges are well-aligned. Periodical reconstruction of the height system, benchmark heights and levelling networks is required for quality, reliable and accurate vertical datum. Preliminary project of the height system in Croatia respects new geopolitical relations in region and the emergence of new states. New definition of level polygons is designed, respecting scientific criteria and the form of new countries.

Keywords: Vertical datum, height system, reconstruction, levelling line, benchmark

1 Introduction

Height reference system of the Republic of Croatia, still in use, was built during a long period of time. It was established during the Austro-Hungarian Monarchy, and was

restructured by the measurements of I. levelling of high accuracy taken in the period from 1946 to 1953. In this way a reference frame was established and was densified during a long time by lower order networks. This network had many serious defects. Most important are: geometric configuration which is not adapted to the territorial shape of Croatia, error in the vertical datum definition, the network inhomogeneity and different procedures which were applied during the levelling network adjustment.

Mean sea level was calculated by one year tide gauge observation measurements. Thus, all benchmarks are higher from heights calculated by the ordinary defined sea level, from 12 cm in Istria and up to 35 cm in Eastern Slavonia and Dubrovnik (Rožić 2001). Height accuracy is not satisfactory according to the modern scientific and technical criteria.

Preparations for the implementation of the new height reference system begin in the 1960s. The new height datum was also defined, based on the mean sea level measurements at tide gauges in Dubrovnik, Split, Bakar, Rovinj and Koper (18.6 year long observation periods) (Fig 1).

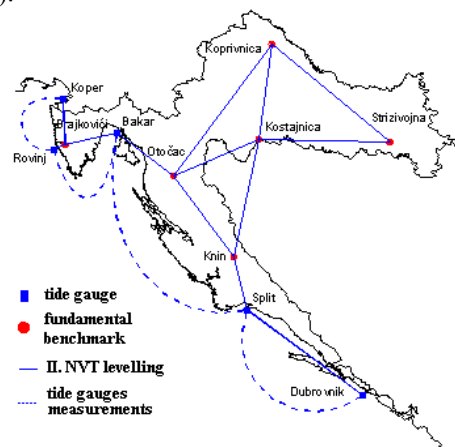


Fig 1 Tide gauges and fundamental benchmarks (II levelling of high accuracy) (Feil, Rožić 2000)

Measurements of the II levelling of high accuracy network were performed in the period from 1970 to 1973 by unified and clearly specified scientific and technical criteria for the high accuracy levelling. Processing of measurement results and network adjustment was carried out by scientists of the Faculty of Geodesy, the University of Zagreb.

The field of permanently stabilized benchmarks forms the basis of the official reference height, designated as the Croatian height reference system in the epoch 1971.5, (HVR571) (Fig 2).

2 Reconstruction of the height system

Periodical reconstruction of the height system, the field of benchmarks with normalized density and the geometric levelling networks is a logical process that provides quality, reliable and accurate height system.

Based on experiences of the height system arrangement (1991 - 2001), it would be the best to organize the reconstruction of heights in the stages. The stages will include precise planning and modification of goals, procedures, standards and criteria. Revision of the levelling polygons will be used for the basis of the future work planning. The reconstruction of the height system should be divided on two main phases. The first phase includes the reconstruction of the fundamental network (II NVT lines) considering the new regional geopolitical relationships. It is necessary to plan new levelling polygons respecting the territorial shape of Croatia. Second phase includes the reconstruction of levelling networks of lower order if necessary.

2.1 Division of network into orders

Present levelling networks are divided by the applied method of geometric levelling. Reconstructed levelling networks will be hierarchically organized by orders (Grgić et al., 2010):

- leveling network of 0th order
- leveling network of 1st order
- leveling network of 2nd order
- leveling network of 3rd order
- leveling network of 4th order

2.2 Reconstruction of the 1st order levelling network

Levelling network should be reconstructed regarding to scientific and professional criteria that provide realization of modern height system. Accordingly, 1st order reconstruction should be done considering new geopolitical balance in the region and new benchmark stabilization. All lines should be re-leveled and new gravity survey will be performed to provide geopotential height system. On the basis of geopotential height system it can be defined orthometric or normal height system. Current normal orthometric height system should be replaced with a orthometric or normal height system. In European countries the situation is quite different, e.g. in Germany the normal system is used, while on the other side France has the orthometric height system (URL-1). Most countries gives priority to normal system, and when choosing a new height system it should be considered that the United European Levelling Network (UELN) applied the normal system of heights, which is derived from the geopotential system. Following the modern international scientific and professional standards and recommendations it is entirely likely the introduction of geopotential, and for practical applications orthometric or normal height system. The underlying assumption is a gravity survey of levelling network of first order. From the height reconstruction aspect, the height system HVR571 will be used to solve the practical surveying tasks until the new geopotential and orthometric or normal height system will be applied (Rožić 2001).

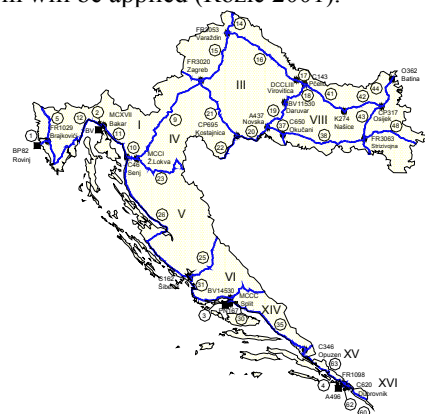


Fig 2 II levelling of high accuracy (II NVT) (Feil, Rožić 2000)

Reconstruction of the 1st order network can be done in several ways (Rožić 2001):

1. Complete reconstruction of the fundamental network, re-stabilization of benchmarks, creation of new level polygons regarding to a shape of country and respecting the route of the II NVT lines, correction of geometric configuration regarding size of levelling polygons, level height differences and gravity survey of the network.

2. Partial reconstruction of the fundamental network, re-stabilization of devastated benchmarks, stabilization of new benchmarks and planning a small number of new lines with a long-term aim of adapting the configuration of the fundamental network to the size and shape of the national territory, measure height differences by levelling of high accuracy but only in renewed and new lines, and perform gravity survey of the entire network.

3. Perform gravity survey of levelling network of 1st order, without re-stabilization of the existing benchmarks and planning new lines and without surveying height differences by levelling of high accuracy.

The goal of the height system reconstruction is improvement and enhancement of height system as an essential segment of basic geodetic works surveying. Preparation of continuous and systematic execution of works will follow.

The 1st order levelling network consists of 20 levelling polygons and levelling polygon of larger Adriatic islands (Krk, Cres, Rab, Pag, Dugi Otok, Ugljan, Pašman, Drvenik Veli, Šolta, Brač, Hvar, Korčula, Mljet and Šipan) connected to the mainland and the first order levelling network (Grgić et al., 2010). Connection with neighbor countries is also planned: Slovenia, Bosnia and Herzegovina, Serbia and Montenegro. Connection with Hungarian height system has already been made. The levelling polygons are designed along with II NVT level lines. Length of each polygon is up to 300 km according to other European height systems. Wherever it was possible levelling polygons were designed closer to the Croatian borders. If the local road did not meet the criteria of first order levelling network, the border was not a priority to define the shape of levelling polygons. In such cases, those level lines are planned as 2. or 3. order. Thus, the

reference height system of the Republic of Croatia would adapt to its maximum territorial form.

Geometrical configuration of the 1st order levelling network has experienced a certain changes, due to new regional geopolitical relations. Modification of the levelling network of first order, consisting of level figures, was carried out by intersecting with new level lines. In this way the polygons are approximated to the shape of scope. The organization of work, survey and the detection of gross errors will become easier.

Connection to the neighboring countries will follow old NVT line. Most important are connections to the Bosnia and Herzegovina (BH). Four parallel connections across BH territory are planned at the given configuration (Fig.3). Those lines will connect south and north levelling polygons in Croatia. Gravity values on the benchmarks in BH can be predicated or measured in cooperation with institutions in BH. A joint project of geometric levelling and gravimetric survey can be realized to achieve better geometry of the leveling network in Republic of Croatia (Grgić et al., 2010).



Fig 3 New levelling polygons (purple), old NVT lines (blue) and NVT lines across Bosnia and Herzegovina (red)

2.3 Name convention of level lines and benchmarks

Some levelling polygons can be redesigned concerning participation of the neighboring countries in a project of reconstruction of height system in Republic of the Croatia. Following should be anticipated:

- elimination of leveling lines with overlapping routes; retaining the numbering of lines with higher order
- introduction of lines second order levelling network
- densification of network

New height system will reach significant changes of network configuration that will result in increasing a number of levelling polygons. Level polygons and lines should be re-named (Table 1).

Network and line orders are classified according to accuracy order. Line number can be within certain borders. The goal is to ensure transparency of lines and network records. From line number it will be obvious order of levelling. Smaller number of line represents higher order of accuracy. To avoid name overlapping, level line that is shared between neighboring levelling polygons is attached to levelling polygon of lower number (Grgić et al., 2010).

Table 1 Numbering of leveling lines

| The order of levelling | Number of lines | Observation |
|------------------------|-----------------|--------------------------------|
| 0. | 0001-0004 | Tide gauges |
| 1. | 0005-0099 | Leveling polygons |
| 2. | 0100-0699 | Second order and city networks |
| 3. | 0700-1099 | |
| 4. | 1100-1600 | |

So far the benchmarks were numbered continuously starting from number 1. Accordingly the benchmark in each line is indicated in the numerator with a benchmark, and in the denominator with a level line number. All current benchmarks, had maintained the current numbers, and the numbers of destroyed benchmarks will not be in use anymore.

Because of easier data processing and simple, transparent and efficient data usage it will be advisable to switch to numeric or alphanumeric marking of benchmarks without using other characters that follows (Grgić et al., 2010):

xyzzzt

Where is: x-type of stabilization, y- Stabilization Mode, zzzz- number of benchmark and tttt - number of level lines.

Benchmarks within each level line are numbered in order of clear differentiation of levelling networks (Grgić et al., 2010):

- levelling network of 1. order – number of benchmarks from 0001 to 999 (fundamental benchmarks are numbered from 0-100),
- levelling network of 2. order – number of benchmarks from 2000 to 2999,
- levelling network of 3. order – number of benchmarks from 3000 to 3999,
- levelling network of 4. order – number of benchmarks from 4000 to 4999.

In the benchmarks location description should be connection with the old benchmark number before the reconstruction project of height reference system.

2.4 Measuring procedures in a project of renewal of reference height system

The requirements for technical levelling of higher order can be relatively easy to achieve. Hence technical levelling should not be divided into two groups. It is proposed to abandon former division on technical level of higher accuracy and technical levelling which needs to be replaced with unique term of technical levelling.

The maximum line of sight distance in technical levelling should be 60 m, differences of line of sight distance on the measuring point 1m, and the minimum line of sight distance from ground should be 0.5 m. It is also proposed to abandon division on precise and city levelling. City levelling are in generally performed in accordance of precise levelling. Measurement procedures in levelling network of 1 - 4 order would be performed to the corresponding measuring method (Grgić et al., 2010), Table 2.

Table 2 Application procedures for the measurement in leveling networks

| Levelling network | Measurement procedure |
|-------------------|--|
| 0 order | Levelling of high accuracy |
| 1 order | Levelling of high accuracy |
| 2 order | Precise levelling, trigonometric level. |
| 3 order | Technical levelling, precise level. , trigonometric level. |
| 4 order | Technical levelling, precise level., trigonometric level. |

Levelling network of 3 or 4 orders will be applied according to the degree of development of each area, the economic potential and current local interest.

2.5 Data adjustment

Height differences of 0., 1., 2. and 3. order in levelling network must be corrected by normal and orthometric reductions. Heights of 0., 1. and 2. order levelling network will be presented by 0.1mm, and in levelling network of 3. and 4. order by 1 mm.

If there is a partial re-measurement (supplementary) and adjustment, new heights will be used only if they differ from existing ones for more than 5mm.

Benchmark heights are defined by network adjustment, using the nodal points or individual level lines. Benchmark heights can be determined by adjustment in geopotential height system, if gravity data is available. In this case, metric values of normal and orthometric reduction must be pre-defined. Geopotential height system adjustment is convenient because it provides simple transformation to the normal or orthometric system. Following, new height system based on the gravity values would be best solution. Adjustment in geopotential heights also provides direct data exchange with UELN.

3 New geoid model HRGXXXX

Apart from the levelling and gravity measurements, GNSS measurements must be conducted. Gravity network of 1st and 2nd order, EUVN, geodynamic and other relevant points for upgrading density of GNSS/levelling points will provide precise calculation of geoid (quazigeoid) for Croatia.

Due to enlargement of utilization of GNSS networks, some countries again conducted measurements of 1st order levelling network using equivalent digital level instruments so as to precisely define quazigeoid. Gravity measurements were performed simultaneously. GNSS measurements are planned to carry on using static method on relevant points with duration 12-24 hours per point. Final purpose is to establish new levelling and spatial GNSS

network together with the geoid model for practical implementation. When ellipsoid height as an important component of GNSS levelling is defined precisely, it can be used for the shorter distances as well.

Republic Croatia has recently created new geoid model HRG2009 (Bašić 2009). The procedure required GNSS/levelling points measurements mostly by RTK method or alternatively by static method 15 min per point. This approach was established considering outdated levelling data. However, reconstruction of the referent height system requires specification of the set of raster 10x10 km GNSS which will be established by static method of CROPOS service in duration of minimum 6 hours per point. Established points will serve to create new geoid model with parameters which will be used as replacement for levelling network of 3rd and 4th order. Republic of Croatia already has established GPS network of 2nd order, so procedure of establishing GNSS network and re-measurement of levelling network should not last long.

Positional coordinates of vertical benchmarks are determined by RTK measurements with duration of 5 seconds with two independent initializations. Positional coordinates of horizontal benchmark can be determined by two methods (Grgić et al., 2010):

- By RTK measurements toward North, South, West or East with offset of a few meters. The offset is registered in the sketch of benchmarks measurements and correct coordinates are written in the main positional description. Compass is obligatory in order to precisely determinate offset direction.
- define coordinates by RTK measurements on two auxiliary points used for calculation of benchmark position by arc cross section.

4 Conclusion

Preliminary project of the height system in Croatia respects new geopolitical relations in region and the emergence of new states. New definition of level polygons is designed, respecting scientific criteria and shapes of new

countries. Reconstruction of the height system in Croatia will include many tasks in next few years:

- finalization of the second order gravity network,
- Re-observation of the 0. order gravity network and stabilization of new points – absolute gravity measurements,
- connection of the gravity network with neighbour countries,
- new adjustment of the gravity networks,
- improvement of the actual geoid model HRG2009 - GNSS/levelling measurements (12-24h)
- define the project stages of the height system reconstruction - geometric levelling and gravity measurements,
- definition of the new vertical datum.

References

- Bašić, T. (2009): Unique transformation model and new geoid model the Republic of Croatia. Izvješća o znanstveno stručnim projektima, p. 5-23. State Geodetic Administration, Zagreb.
- Feil, L., Rožić, N. (2000): Proposal of the official height datum of the Republic of Croatia. Faculty of geodesy, University of Zagreb.
- Grgić, I, Lučić, M., Repanić, M., Malović, I., Kršulović, D. (2010): Reconstruction of height system in Republic of Croatia, draft. State Geodetic Administration, Zagreb.
- Rožić, N. (2001): Study about Renewal and Maintenance of Height System of the Republic of Croatia. Faculty of geodesy, University of Zagreb. State Geodetic Administration, Zagreb.
- (URL-1):
http://www.bkg.bund.de/nn_164776/geodIS/EVRS/EN/Projects/03HeightDatumRel/height-datum-rel__node.html__nnn=true