CHANGES OF BENCH MARK HEIGHTS BEING THE CONSEQUENCE OF INTRODUCING THE NEW CROATIAN HEIGHT SYSTEM

N. ROŽIĆ[1]

In the period between 1994-2002 there were rather extensive works carried out in the Republic of Croatia on the improvement of national levelling networks and the height system based on the existing (archive) data of geometric levelling measurements. The results of these works are the basis for introducing the improved (new) Croatian height system into official usage. The differences in definition and realisation between the improved (new) and existing (old) Croatian height system are, among other things, directly reflected on the changes of national levelling bench mark heights. On the basis of the bench mark heights comparison it is possible to define and analyse the level of mutual disparity and distortion of height systems. For this purpose, the bench mark heights in the national geometric levelling networks have been analysed, as very indicative, in the northern part of the territory of the Republic of Croatia.

1. INTRODUCTION

The systematic works on the improvement of the existing height system, that was initially defined and realised in the period 1875-1914 as Croatia was the integral part of the Austro-Hungarian Monarchy and that was additionally updated and modernised with numerous new works on geometric levelling of various orders in the period 1945-1970 as Croatia being the part of former Yugoslavia, started during the year 1994 and were completed by the end of 2002. The stated systematic works were based on the repeated computing processing of the existing (archive) data referring to the levelling network measurements, considering the objective and material circumstances that the Republic of Croatia found itself in at the beginning of the nineties after gaining its independence, with introduction of the "new" fundamental height network, as well as the new height datum. The network of the so-called II. levelling of the high accuracy (IINVT) that had been made at the territory of the western part of former Yugoslavia in the period 1970-1973, leaning on five tide gauges along the Adriatic coast (Koper, Rovinj, Bakar, Split and Dubrovnik), was introduced as the "new" fundamental height network at state territory. Due to some objective circumstances, i.e. very long period of analysis and data processing, network was not used until 1992. The detailed data about the previously mentioned works on the improvement of the height system in Croatia can be found in the reports and articles presented at EUREF symposia in previous years ***Feil et al. 1992, Feil et al. 1993, Klak et al. 1996, Rožić et al. 2000, Rožić 2003***, and the informations about various aspects and problems connected with the national levelling networks and the height system at the territory of Croatia can additionally be found in ***Feil et al. 1999, Feil et al. 1999a, Rožić 1999, Rožić 2001***.

Considering the fact that there is the process of putting of the new height system into the official usage going on at the moment, the issue of investigation the congruence level, i.e. the differences between the bench mark heights included into national geometric levelling networks is being raised as a very interesting issue. The differences between the height systems and their influence on bench marks heights, in the geometric levelling networks at the northern part of the Republic of Croatia, are very indicative and usable for that purpose.

2. OLD HEIGHT SYSTEM

The old height system (at the moment still the official height system) of the Republic of Croatia was established during the time of the Austro-Hungarian Monarchy as a normal orthometric height system, and it was realized through the network of the so called Austrian Precise Levelling (APN). The origin bench mark in the system was the bench mark HM 1 placed in the vicinity of the

[1] Nevio Rožić: Croatian Geodetic Institute, Savska c. 41/XVI, p.p.19, Zagreb, Croatia, Fax. +385-1-6312410, e-mail nevio.rozic@hgi.htnet.hr.

tide gauge at Molo Sartorio in Trieste. It absolute height is defined in relation to the mean value of the Adriatic Sea water level obtained from the one-year measurements in 1875, and it is 3.3520 m. After the Second World War, referring to about forty years that passed after the establishment and the realisation of APN network, and considering a great number of destroyed bench marks, the network was reconstructed through an extensive new bench mark stabilisation and through the repeated levelling of levelling lines within the frame of performing the so called I. levelling of high accuracy (INVT) of former Yugoslavia. In the realisation of the INVT network some discrepancies occurred relating to the geometric configuration of the APN network, first of all for the purpose of eliminating a few longer levelling lines in Dalmatia and defining geometrically closed and firm figures. The measurements of INVT were made gradually and in a longer period of time, from 1945 till 1963, and the determination of bench mark heights (measurement adjustments) were made successively and in accordance with the survey dynamics, whereby the new measurements were adjusted on the old (preserved) APN network bench marks, Fig. 1.

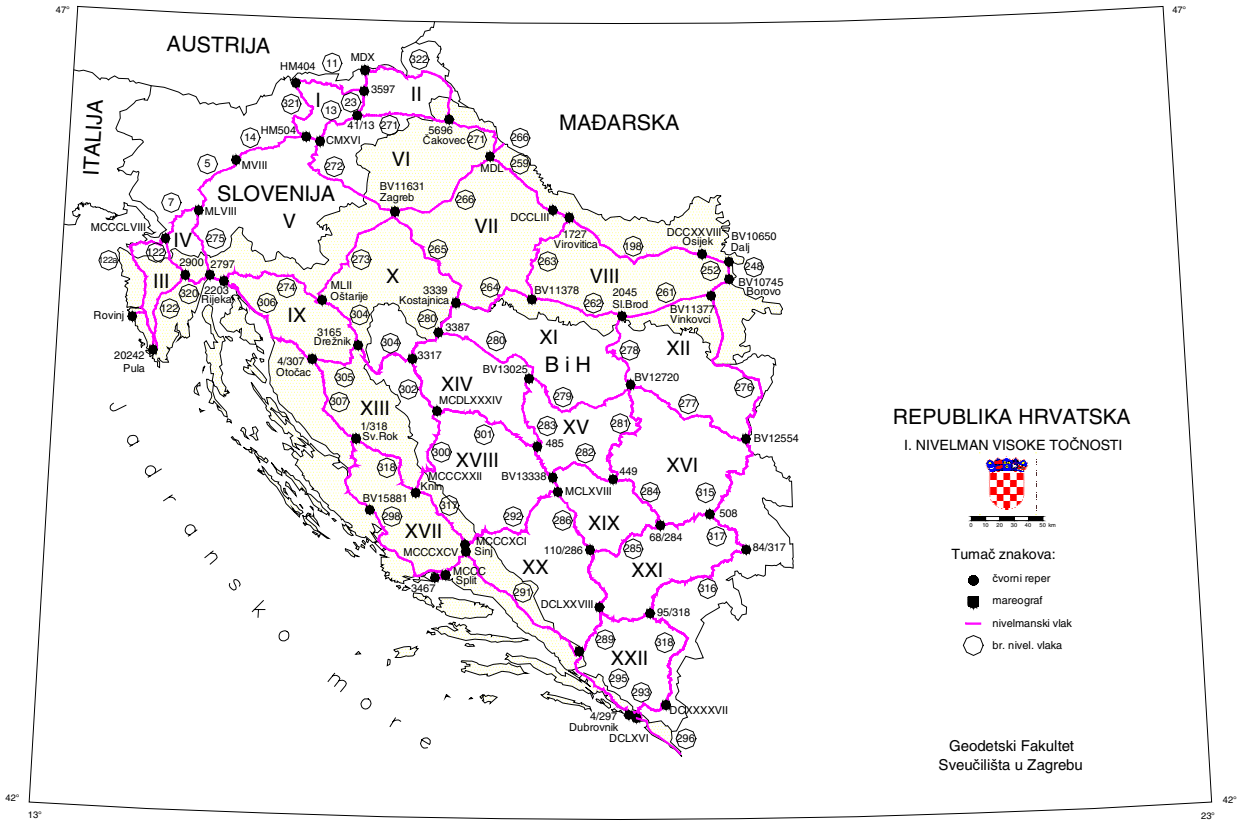

Fig. 1. INVT levelling network at the territory of the Republic of Croatia

Along with the realization of the INVT network, there were also many levelling works on lower order geometric levelling networks made (precise levelling - PN, city levellings - GN, technical levelling of increased accuracy - TNPT, technical levelling - TN) that cover relatively regularly the whole state territory. The adjustments of measurements in the lower order geometric levelling networks was made in a hierarchical order by lower order levellings leaning on higher order levelling networks, by applying the condition measurements adjustment using the method of least squares. It should be pointed out that in terms of accuracy the measurements were partly inhomogeneous, and in terms of hierarchic data processing the adjustments of more complex networks were avoided by simplifying their geometric configurations. The quantity of the performed works is expressed by the number of 423 levelling lines at the entire territory of the Republic of Croatia, i.e. in accordance with the classification into the accuracy orders: 36 INVT levelling lines, 77 precise levelling lines, 49 city levelling lines (networks), 149 increased accuracy technical levelling lines and 112 technical levelling lines.

3. NEW HEIGHT SYSTEM

In the period 1970-1973, a new high accuracy levelling network was made at the western part of former Yugoslavia, i.e. the network of so called II levelling of high accuracy (IINVT) that should have been used as the basis for the establishment of the new height system. The new height system should have removed the weakness of the existing system, which means that it should have been updated, it should have had adequate accuracy and removed the error in determining the origin bench mark height (bench mark HM1) in the old height system. The geometric configuration of the IINVT network is therefore designed and performed mostly in disparity with the existing INVT network, and the IINVT network is at the same time connected with five tide gauges at the Adriatic coast (Koper, Rovinj, Bakar, Split and Dubrovnik), Fig. 2. The absolute heights of the 5 new origin bench marks in the IINVT network were determined at all tide gauges in relation to mean water levels of the Adriatic Sea for the time epoch of 1971.5, from the measurement interval of 18.6 years.

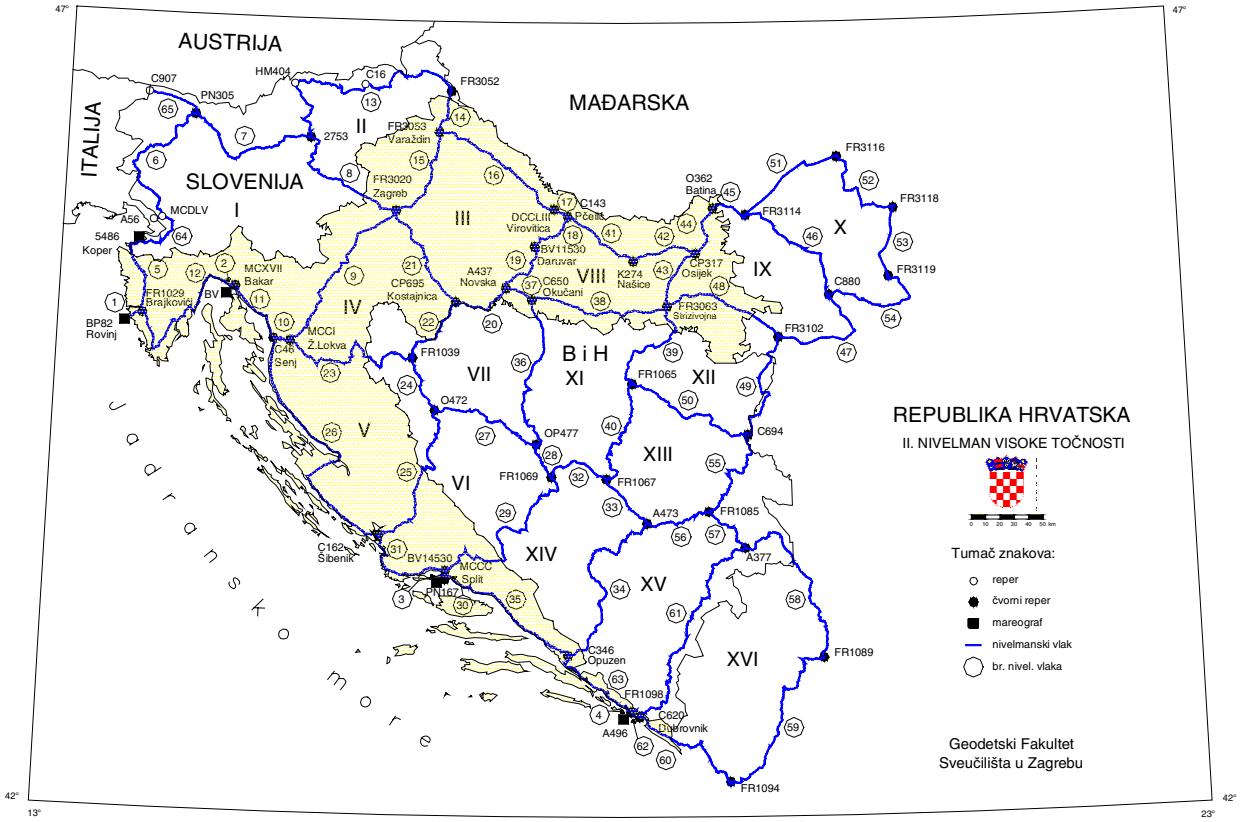

Fig. 2. IINVT levelling network at the territory of the Republic of Croatia

Referring to the fact that along the levelling lines in the IINVT network the gravimetric measurements have not been carried out completely and systematically, and that the measuring data processing and analysis was carried out during a very long period, i.e. between 1973 and 1992, it full implementation was not enabled till beginning of the nineties within the frame of the realisation of the new normal-orthometric height system to be practically used at the territory of the Republic of Croatia. In the period between 1994 and 2002, all existing low order geometric levelling networks were connected to this network, and in parallel with field revision of bench marks included into these networks, there was a complete and systematic computation and systematic processing of original measuring data made, i.e. the new network adjustments (readjustments). The measurements were adjusted consistently by indirect measurements adjustments using the least squares method and keeping the hierarchical order of processing, i.e. leaning the lower order geometric levelling networks to higher order networks, and in accordance with the pre-systematized geometric configurations of the networks without their simplification in spite of the complexity. With reference to the works done, a new and updated applicable documentation was made for all

preserved bench marks of levelling networks, including the sketches of levelling networks and figures, positional descriptions, positional bench mark coordinates in the state coordinate systems, heights etc.

4. RELATIONSHIP OF BENCH MARK HEIGHTS IN THE NORTHERN PART OF CROATIA

Referring to the fact that the old and the new height system of the Republic of Croatia are normal-orthometric systems realized at the same territory, to a great extent on the basis of the same measurement data, i.e. the same geometric levelling networks, they can be compared between each other. The most interesting is the comparison of the heights of all bench marks that are present in both systems at the same time, because it indicates congruity level of both systems, the size and regularity of difference distribution in heights and its influence on performing the practical works that require the knowledge of the heights. Considering the way of defining and establishing the height systems, it is clear that the differences in bench mark heights result from the mutual influence of a few various reasons:

- the difference in number, procedure and time epoch of determining the origin bench marks heights (height datum) in the fundamental height networks, and in their position as related to the geometry of these networks. In the case of INVT it is HM1 in Trieste (the epoch of the year 1875 - the mean of one-year see level measurements), Fig. 1, and in the case of IINVT these are the bench marks 5486 - Kopar, BP82 - Rovinj, BV - Bakar, PN167 - Split and A496 – Dubrovnik located at the five tide gauges (the epoch of the year 1971,5 - the see level mean from the interval of 18,6 years), Fig. 2.
- the difference of geometric configurations in the fundamental height networks, i.e. INVT and IINVT, as well as difference of the used adjustment methods for these networks, Fig. 3. In the case of INVT the individual levelling lines and the parts of the network have been adjusted separately referring to the fixed base (preserved bench marks) of the network APN, and the network IINVT has been adjusted as the homogeneous network using indirect measurements and the method of least squares.

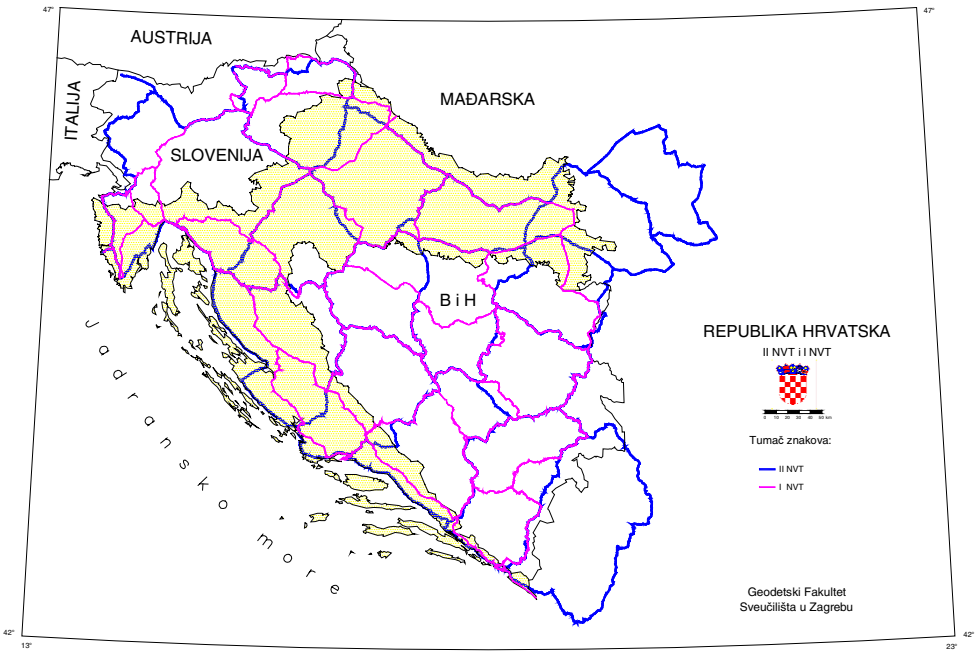

Fig. 3. Relation of the networks INVT and IINVT at the territory of Croatia

- the difference of geometric configurations and adjustment procedures (methods) in adjusting the networks of lower order geometric levellings being the consequence of their re-

systematization conditioned by the change of geometric configurations in fundamental networks that they are connected to, i.e. INVT and IINVT.

- influence of height instability of bench marks contained in the measuring data, referring to the fact that works on geometric levellings have been carried out in essentially different time epochs, i.e. the network APN in the period 1875-1914, the network INVT in the period 1945-1963, the network IINVT in the period 1970-1973 and the networks of lower order geometric levellings in the period 1945-1970.

The size, distribution and changes of the bench mark heights between the old and the new height system should be considered in the northern part of the Republic of Croatia determined by the II. and III. levelling figure of the IINVT network, Fig. 2. The mentioned area bordered by the state border of the Republic of Croatia with the Republic Hungary and the Republic Slovenia, as well as with the IINVT levelling lines: No. 8 (Dobova – Zagreb), No. 21 (Zagreb – Kostajnica), No. 20 (Kostajnica – Novska), No. 19 (Novska – Daruvar), No. 18 (Daruvar – Pčelić), No. 17 (Pčelić – Virovitica) and No. 74 (Virovitica – Terezino polje), contains altogether 2105 bench marks, Fig. 4., with: 182 IINVT bench marks (red), 108 INVT bench marks (violet), 274 PN bench marks (brown), 863 GN bench marks (blue), 416 TNPT bench marks (green) and 262 TN bench marks (black). The concentration of bench marks and their horizontal distribution referring to the entire territory of the Republic of Croatia is presented on Fig. 5.

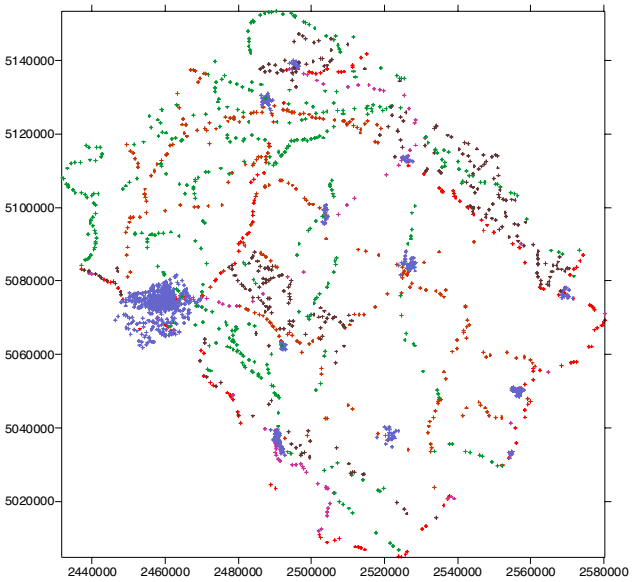

Fig. 4. Bench marks

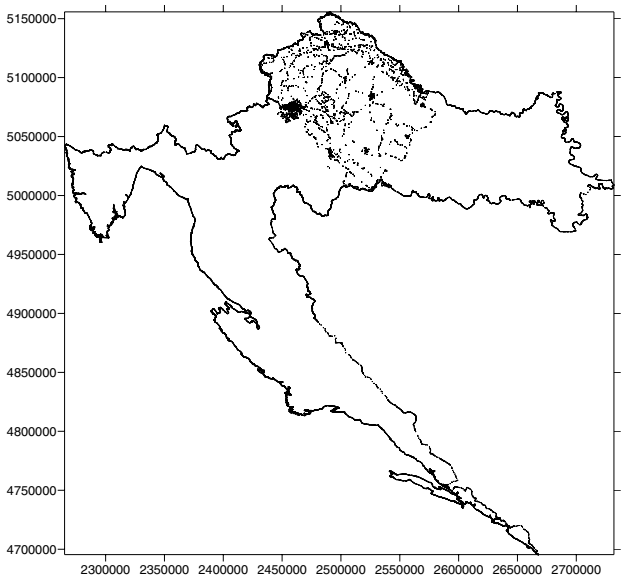

Fig. 5. Bench marks at territory of Croatia

The differences of bench mark heights *dH* at the observed territory ***Rožić 2003a*** obtained by subtracting the bench mark height in the new height system from the belonging value in the old height system have got the value between minimum 122.6 mm and maximum 250.2 mm, and they are all contained in the interval sized 127.6 mm. The statistic indicators describing their properties, as well as the properties of bench mark coordinates in the horizontal projection plane (*Yn, Xn)* are shown in the table 1.

The behaviour of the differences of heights at the arbitrarily selected discrete points at the entire observed territory defined on the basis of the dependence on their values at bench mark positions is graphically presented by the continuous spatial surface modelled by applying the method of "krigging" and the additional filtering. The spatial surface shape, the mutual relation between the surface and the bench mark positions are presented on Fig. 6. It should be pointed out that the shape of the surface outside the area borders is rather instable because it has been determined by means of data extrapolation. Fig. 7 presents the same surface, but orthogonally projected into the projection plane and supplemented with contour lines.

Table 1. Statistical indicators

Size	Yn	Xn	dH
Minimum	2431761 m	5004864 m	122.6 mm
Medium	2489510 m	5076343 m	171.1 mm
Maximum	2580206 m	5153316 m	250.2 mm
Interval	148445 m	148452 m	127.6 mm
Average	2493728 m	5082973 m	174.6 mm
Variance	1227780389 m^2	956324519 m^2	537.9 mm^2
Stand. error	35040 m	30924 m	23.2 mm

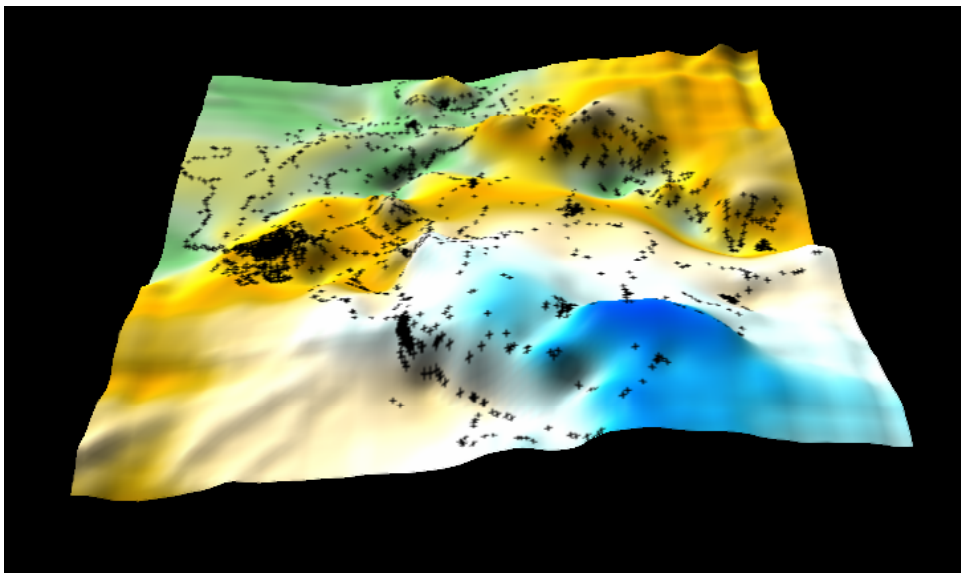

Fig. 6. Relation between the spatial surface and bench marks

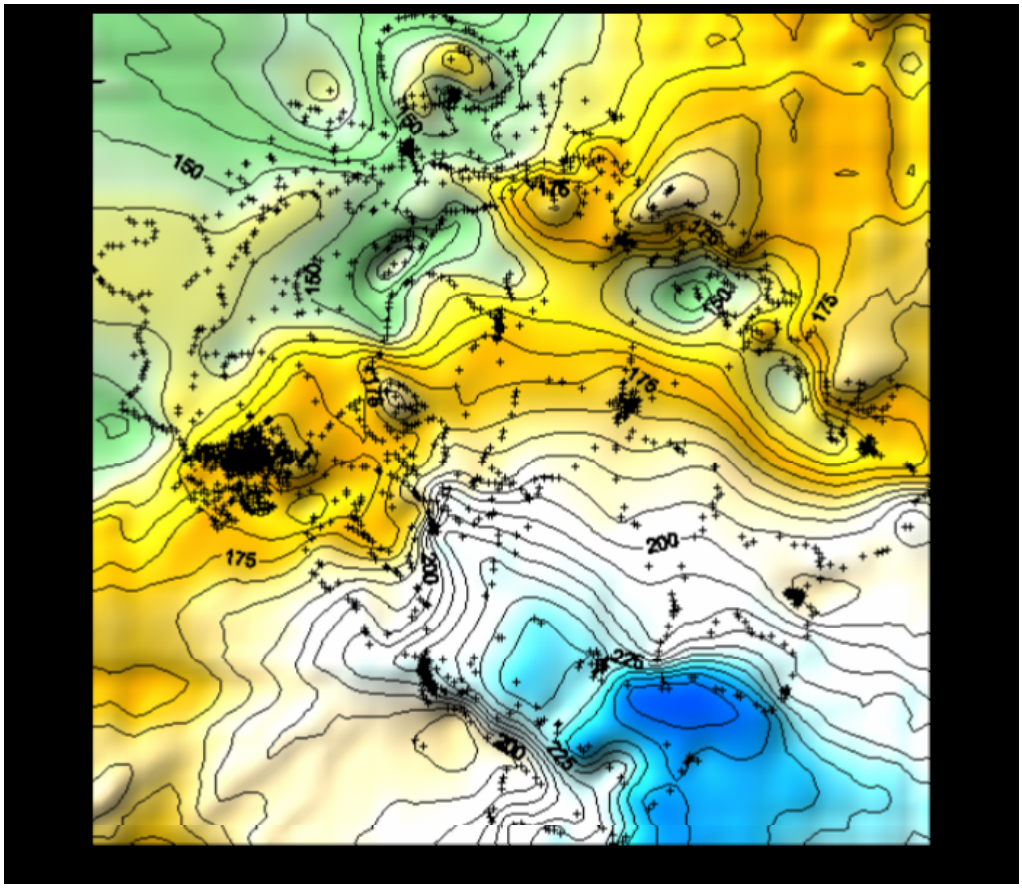

Fig. 7. Contour lines of height difference of bench marks

5. CONCLUSION

On the basis of the numerical data from the table 1 and graphic presentations on Fig. 6 and 7 it is possible to make principal conclusions that describe the empirical rules of behaviour in the height difference of bench marks encompassed at the same time by the old and new height system of the Republic of Croatia.

All height differences are positive, i.e. the bench mark heights in the old height system are bigger than the heights of the same bench marks in the new height system. This fact is in accordance with the results of investigation the relation of height datums in the old and new height system, i.e. with the error in determining the height of the origin bench mark (the bench mark HM1) in the network APN in the old height system for which the value has been defined to be about 12 cm **Feil et al. 1992, Feil et al. 1993**. It is very interesting that the minimum height difference of bench marks of 122,6 mm at the observed territory is also logically in congruence with previously cited value and shows that all official heights at the territory of the Republic of Croatia are initialy bigger than heights corresponding to correctly determined mean sea levels of the Adriatic sea at the locations of five tide gauges. At the same time mean see levels at all five tide gaugages are mutually in a very good accordance. The size of the interval where the height differences of bench marks are to be found is rather big and amounts at the observed territory up to 127,6 mm which indicates to the fact that significantly different fundamental networks, the changes of geometric configuration of the lower order networks have essentially affected the changes of heights along with various adjustment methods and procedures. The consequence of this influence is not only the difference of bench mark heights, but also their positional distribution and the pattern of changes depending on the position of bench marks in the plane coordinate system. The differences of bench mark heights show some trend regularities of changing depending on the bench mark positions in the plane, Fig. 7. This trend regularity is expressed especially in the direction north-south and much less expressed but still noticeable in the direction west-east. Certain areas of the observed territory indicate relatively high distortions. Generally speaking, the differences of bench mark heights are changing irregularly along the observed area and rather significantly referring to their size.

Considering the irregularities of changes and the size of differences in bench mark heights one can expect rather difficult determination of a model for the transformation of height data between the old and the new height system of the Republic of Croatia.

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