Vertical Crustal Displacements on the Croatian Territory

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Abstract

At the territory of the Republic of Croatia and its neighbouring countries, Bosnia and Herzegovina and Slovenia there have been three height networks of geometric levelling of the highest accuracy orders established in the period of about eighty years. These are the network of the Austrian Precise Levelling – APN (1874-1908) from the period of Austro-Hungarian Monarchy and the network of the I high accuracy levelling – INVT (1946-1963) and the II high accuracy levelling – IINVT (1970-1973) from the Yugoslav period. A certain number of identical bench marks have been identified by means of processing and analysis of archival levelling measurements APN and IINVT data, that were made in two mutually most distant time epochs. These bench marks have made it possible to determine their height displacement and have offered the insight into the vertical crustal movements of the Earth's crust at the territory of Croatia, Bosnia and Herzegovina, and Slovenia.

Keywords: Levelling, Vertical Crustal Displacement, Croatia

Zusammenfassung

Auf dem Territorium der Republik Kroatien und ihren Nachbarländern Bosnien-Herzegowina und Slowenien gibt es über einen Zeitraum von über achtzig Jahren drei geometrisch nivellierte Höhennetze der höchsten Genauigkeit. Dabei handelt es sich um das österreichische Präzisionsnivellementnetz – APN (1874-1908) aus der Zeit der österreichisch-ungarischen Monarchie und das Präzisionsnivellement I Ordnung – INVT (1946-1963) und II Ordnung – IINVT (1970-1973) aus jugoslawischer Zeit. Eine gewisse Anzahl von identischen Festpunkten konnte durch die Verarbeitung und Analyse von Archivmaterial der Nivellementmessungen aus den APN und IINVT Daten identifiziert werden. Diese beiden Messungen stellen die zeitlich voneinander am weitesten entfernten Epochen dar. Die identen Festpunkte haben es ermöglicht die Änderungen in der Höhe zu bestimmen und Erkenntnisse in die vertikalen tektonischen Bewegungen der Erdkruste auf dem Gebiet von Kroatien, Bosnien-Herzegowina und Slowenien zu gewinnen.

Schlüsselworte: Nivellement, Vertikalkrustenbewegung, Kroatien

1. Introduction

The Earth is a "living organism" changing continuously under the influence of complex systems of endogen and exogenous forces. The force systems act globally, regionally, locally, and to larger or smaller extent change geometric and physical properties of the Earth's body with different time dynamics. For many reasons the changes occurring as the consequence of natural force activities in the Earth's crust, the surface part of the Earth's body structure, are especially interesting and reflect in changes of the position and shape of the contact surface with the atmosphere, i.e. the topographic surface. These changes are indicated by continuous and discontinuous movements and motions of the topographic surface that result in plastic and elastic deformations.

The most accurate and the most precise determination of movements and deformations is performed by means of geodetic positioning methods and procedures, and through periodical monitoring the position of a limited number of discrete points on the topographic surface. The data of periodical position determination grow more valuable along with the greater frequency of measurements and if they encompass longer periods of monitoring the positions of the same points. It is thereby unavoidable to materialize the points permanently on the topographic surface with adequate construction objects. In this respect, very large and significant information and data source about movements, motions and deformations of Earth's crust and topographic surface, at the national and trans-national level, regionally or continentally, can be found among the data of national geodetic control networks referring to the permanently stabilized geodetic control points that have been preserved within longer time periods and have been periodically reobserved.

Concentrating on vertical movements and displacements at Croatian territory, being a part of the south-eastern Europe, a very important information sources for determining vertical movements is contained in the measurement data of national highest order geometric levelling networks that have been created at its territory from the second half of the 19th Century until today [13]. These are three networks of geometric levelling known under the following titles: Austrian Precise Levelling-APN carried out in the former Austro-Hungarian Monarchy and I High Accuracy Levelling-INVT, and the II High Accuracy Levelling-IINVT carried out in former Yugoslavia.

Consistently with the so far performed works on the processing and analysis of the archival levelling measurement data [1], [2], [4] there have been a certain number of bench marks identified in the APN (1878-1908) and IINVT (1970-1973) levelling network that are included into both networks at the same time and that were encompassed by levelling measurements in two different time epoch's with large time interval between them [3]. The bench marks are placed, apart from Croatia, partially in Bosnia and Herzegovina and Slovenia, because the height networks have been established over their territory as well. The data obtained from surveying these networks have made it possible to determine vertical positions of identical bench marks in two different time epoch, i.e. of their vertical displacement, and to gain the insight into the movements of the Earth's crust and topographic surface occurring in a quite long time period.

2. Austrian Precise Levelling

The first systematically established levelling network at the present territory of Croatia is the APN network made in the second half of the 19th Century as a part of the levelling network of the Austro-Hungarian Monarchy. Apart from Croatia it encompassed also the territory of Bosnia and Herzegovina, Slovenia and Vojvodina. The works on the network had been performed gradually and in a long surveying time interval, to be more exact from 1874 till 1908. The network was established by the Military-Geographic Institute from Vienna in accordance with contemporary and clearly defined scientific, professional and technical criteria of that time. All work phases were

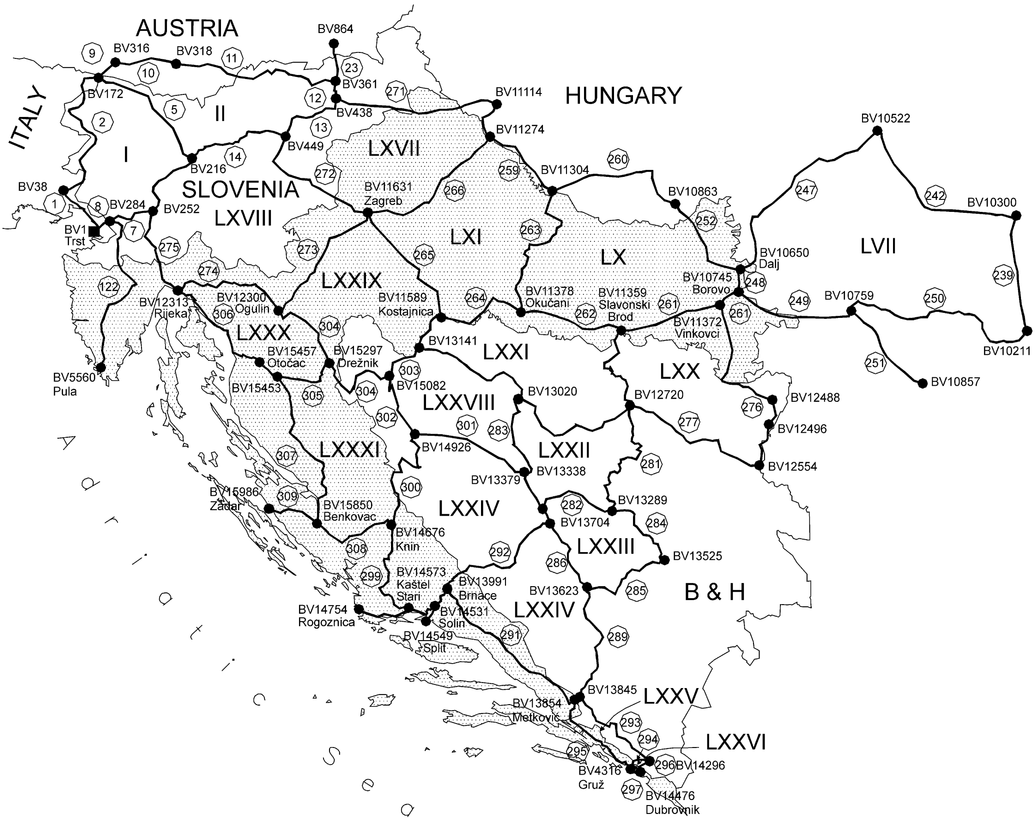

Fig. 1: Geometric configuration of the APN levelling network.

completed successfully, from designing the geometric configuration of the network and defining the levelling figures up to the publication of survey data and adjustment results. The geometric configuration of the network and its relationship to modern borders of Croatia, Bosnia and Herzegovina, and Slovenia are illustrated clearly on Fig. 1. Relevant data referring to the APN network are contained in the publication of the Military-Geographic Institute from Vienna [8], [9], [11].

The stabilization of the bench marks contained in the APN network was done along road and railway routes. Wherever it was possible, already builded objects as: buildings, houses, economic objects, traffic objects, sacral objects, solid rocks etc. were used for stabilization. Two ways of stabilizing the bench marks were used. Congruent to the original classification these are the I order bench marks and the II order bench marks [10]. Unlike the II order bench marks (so called “STEINMARKE“ or “STRICHMARKE“), the I order bench marks (so called “HOEHENMARKE“) were much better stabilized from the points of view of stabilization quality and their long life [12]. They were stabilized as bench marks with metal or stone body that was horizontally installed into vertical walls of already built objects intended mostly for public purposes. The height marks on the bench mark body were defined with centrically placed small horizontal holes, and the object walls were equipped with rectangular cast iron plates on the front side of bench marks body, when it was a metal variant. There was an inscription on one of the three languages on the bench marks: “BILJEG VISINE“ in Croatian, or “HOEHENMARKE“ in German or “MAGASSAGJEGY“ in Hungarian. Fig. 2 and Fig. 3 show both variants of I order bench mark stabilization, with metal and stone body [6], [11].

Height difference measurements in levelling lines of APN network was made with adequate instruments and accessories. The height differences of levelling lines and figures were

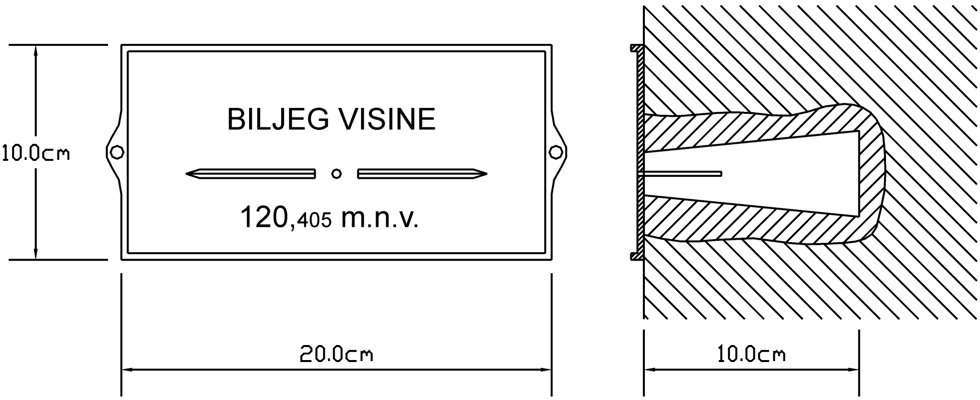

Fig. 2: I order bench mark (“HOEHENMARKE“) – the first variant.

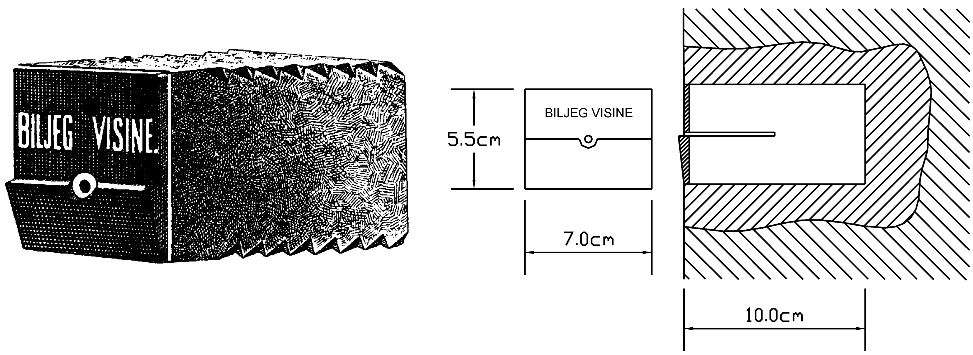

Fig. 3: I order bench mark (“HOEHENMARKE“) – the second variant.

determined by double measurements. The measurements were corrected by the levelling rod scale corrections and normal orthometric corrections. Since during the work on the network there were no gravimetric measurements made, the system of normal orthometric heights was adopted for the height system. The measurement data were processed and adjusted according to the least squares method using the functional model of conditional measurements.

The height datum for the determination of heights is defined with the mean sea level of the Adriatic Sea determined on the tide gauge in Trieste [7]. The position of the mean sea level is determined on the basis of one year period of observing the water level in 1875. Referring to the mean sea level, the height of the initial bench mark of the height system, i.e. the bench mark HM 1 was determined in the levelling line No. 1 placed at the tide gauge in Molo Sartorio in Trieste with its height above the mean sea level being 3.3520 m.

It should be pointed out that the network APN has never been computationally processed and adjusted as a coherent and unique network for the entire territory of the Austro-Hungarian Monarchy. It has been adjusted in several groups, i.e. parts since the works on the network survey were divided into time intervals and individual parts of the monarchy. Thus, the network encompassing the territory of Croatia, Bosnia and Herzegovina, and Slovenia presented on the Fig. 1 was adjusted in three separate but mutually connected parts. The north-western and northern part of the network were adjusted in two separate parts and part of the network at the territory of Bosnia and Herzegovina were adjusted gradually, levelling figure by levelling figure following the continuity of the field survey.

The height datum and the height system realised on the basis of the APN network were used actively for a long time at the territory of Croatia. They have been used in spite of the fact that APN network had some deficiencies regardless of the undisputable systematic field survey and adequate primary measurement data processing. The material component of the network, i.e. the bench marks, has been subjected to destruction in the course of time. The II order bench marks were extremely destroyed, due to the way they were stabilized and to the selection of stabilisation locations.

However, in spite of deficiencies and destruction of bench marks, and considering the determination of vertical displacements, a few elements should be pointed out having universal significance for the performance of systematic geodetic and surveying works. First of all, the final data of surveying and adjustment for the APN precise levelling were systematically published by Military-Geographic Institute from Vienna and have been available for more than hundred years. The measurements of height differences were performed systematically, in details and in accordance with modern criteria in performing geometric levelling of the highest accuracy at that time. The I order bench marks have proved themselves to be very permanent and reliable solutions referring to the way of stabilization and the selection of micro-locations for their stabilization [12]. Namely, regardless of the fact that there were two World Wars and the Croatian Homeland War (1991-1995) happening in the meantime along with regular development and construction activities in urban areas at the territory of Croatia, Bosnia and Herzegovina, and Slovenia, a certain number of I order bench marks has been physically preserved.

3. II Levelling of High Accuracy

In former Yugoslavia the need to define and implement a new height system definitely became ripe at the sixties. Namely, after the II World War the APN network was renewed and innovated in the period between 1946–1963 by applying the so called I levelling of high accuracy – INVT. Accompanied by some smaller changes in geometric configuration of the network APN, the bench marks along the existing levelling APN lines were additionally stabilized because of their high destruction level. A new height difference survey was made gradually in a longer time interval. The measurements were adjusted partially in each smaller part of the network APN leaning on preserved I order APN bench marks being previously checked and analysed regarding their stability. However, the innovated height system revealed a series of deficiencies, because the new survey was made in pretty inadequate and moderate after-war circumstances, with heterogeneous instruments, partly with unsatisfactory measurement accuracy and adjusting the new measurements into the framework of the old APN network. At the same time, the discrepancy of bench mark heights and physical reality, i.e. the sea level, presented a great problem in designing and performance of various construction works leaning on the height system, especially along the Croatian Adriatic coast. Namely, the original deficiencies of the height datum and the height

Fig. 4: Geometric configuration of the IINVT levelling network.

system of the Austro-Hungarian Monarchy came into picture conditioned by the "error" of the height datum realization in Trieste on one hand, and by significant distortions of the network caused by the procedure of measurement adjustment on the other [1], [5], [13].

After substantial preparations at the sixties, in the period between 1970–1971, a completely new high accuracy levelling network at western part of former Yugoslavia was performed, the so called II precise levelling - IINVT that encompassed the territories of Croatia, Bosnia and Herzegovina, and Slovenia. A completely new network geometric configuration was designed and carried out, mostly independent of the networks APN or INVT like APN network improvement, Fig. 4.

The levelling lines and figures were designed mostly with new routes following modern road and railway communications. On the parts where the levelling line routes of IINVT partly overlapped or intersected with the routes of APN or INVT, the preserved bench marks were included into the IINVT network [2]. It is especially important that considering the long life, the IINVT measurements encompassed the I order bench marks of the network APN wherever it was possible.

IINVT network is connected with tide gauges on the eastern coast of the Adriatic Sea because it was necessary to define a new and updated height datum. The tide gauges Koper in Slovenia, and Rovinj, Bakar, Split and Dubrovnik in Croatia are included into the network. The sea level was observed at all tide gauges in the full observation period of 18.6 years. The tide gauges are correctly arranged along the whole eastern coast of the Adriatic Sea and correctly referred to the IINVT network geometric configuration. At all tide gauges as the reference surface for the height determination one has adopted the mean sea level defined for the epoch 1.7.1971 on the basis of water level observations from the period of 18.6 years. The field measurements for the IINVT network were performed systematically in the period 1970–1973 with unified methods, instruments and accessories used. There were also clearly defined scientific and professional criteria used in accordance with international recommendations for carrying out the high accuracy levelling. The height differences were determined by double measurements, corrected with the correction of the levelling rods scale and normal orthometric corrections, because unfortunately no systematic gravity measurements had been done along the levelling lines. The IINVT network leaning at the same time on all 5 tide gauges, adjusted uniquely with the least squares method and with the functional model of indirect measurement.

The height datum and the height system implemented by means of the IINVT network realization has been introduced in official usage at the territory of Croatia recently due to a series of complex circumstances, because Croatia does not have more recent, modern and high quality levelling network at its disposal. Without going into details of height datum and height system implementation by means of IINVT network, and from the point of view of determining vertical bench mark displacements, a few elements should be referred to. The results of survey and data processing of IINVT network have been systematically published and available to be used, the height difference measurements have been done systematically and in accordance with recent criteria in implementing the geometric levelling of the highest order of accuracy. Adequate measuring accuracy has been achieved, and a part of preserved I order APN bench marks has been included into the IINVT network. In such a way, basis for the determination of their vertical positions in two significantly different time epoch exists.

4. Data Processing for the Purpose of Determining Vertical Displacements

In order to determine reliably the vertical positions and displacements of identical bench marks included into levelling networks, in various time epochs, one should take care of a few basic principals:

- The heights of the same bench marks from various time epochs should be referred to the same height datum and should be determined by using the same type of heights.
- Levelling networks from various time epochs should be processed computationally and adjusted with identical procedure and adjustment method as integral and homogeneous networks.
- The levelling networks that include identical bench marks and belonging to various time epochs should be of the same or at least of similar geometric configurations, covering the territory of approximately the same size.
- There should be no doubts about the fact whether the bench marks encompassed by the networks from various time epochs are or are not identical bench marks regarding the possibility of their undocumented restabilization, possible wrong identification during survey or other error sources.
- Bench marks should not indicate their own movements at micro-locations being the consequence of the instability of objects that they are stabilised at, but representative movements of wider area.
- The accuracy of levelling network measurement from various time epochs should be adequately congruent.

Hence, although the preserved I order bench mark (HOEHENMARKE) height data and adjustment results (heights) referring to the APN and IINVT network have been published and are available, they are not compatible for direct comparison, especially regarding to the height displacement determination. The reason does not lie in the fact that both height systems are theoretically defined and then practically realized as normal orthometric systems, but in the fact that the height systems are realized with significantly different realizations of height datums.

As it has been already mentioned, in the APN network case the height datum was realized on the location of the tide gauge in Trieste with the mean sea level from the one year period of water level observation for 1875, and in the IINVT network case with the mean sea levels from the period of water level observation of 18.6 years, from 1962 to 1980, and they were determined on the locations of 5 tide gauges (Koper, Rovinj, Bakar, Split and Dubrovnik) simultaneously. On the basis of a few so far made researches and published results, the "error" of the height datum determined in Trieste has been identified, and it runs up to 12 cm [1]. Therefore, due to various height datums it is not possible to perform direct comparison of normal orthometric heights of identical bench marks.

The problem of height datums is followed by the problem of heights system realization by means of the APN network. Namely, as already mentioned, the APN network has been computationally processed and adjusted in few parts, i.e. not as an integral and homogeneous network at the whole observed territory, which brought up systematic influences on the adjustment results. These influences have resulted in considerable and irregular network distortions affecting on the values of bench mark heights and preventing reliable determination of vertical displacements [5], [13].

Referring to the congruity of geometric configurations of the levelling networks APN and IINVT, the situation is not ideal. Namely, the networks have actually no identical configurations although they encompass the same territory and the levelling lines and figures are designed with pretty congruent dimensions. Nevertheless, there are some contact zones in which some lines or some networks parts are identical and there are also some locations in which the levelling lines are intersected. These contact zones are the origins for the identification of the I order APN bench marks that are enlisted and encompassed by the measurements in both networks. The detection of identical bench marks in both epochs has been provided by originally published network data that have been adequately systematized and translated into digital form that enabled simple data search and the identification of bench marks.

Also, it is rather important to look back at the achieved accuracies of measurements in the networks APN and IINVT. As a relevant indicator one can state reference mean errors in measurements computed on the basis of discrepancies in closing the levelling figures. In the case of APN network, the accuracy of measurements expresses with reference mean error runs up to

$$m_{\mathrm{F}} = \pm 4.9\,\mathrm{mm}/\sqrt{\mathrm{km}}$$

and in the IINVT network

$$m_{\mathrm{F}} = \pm 1.2\,\mathrm{mm}/\sqrt{\mathrm{km}}$$

In spite of some difference, it would be appropriate to estimate that there is a satisfactory relation between the achieved measurement accuracies supporting the possibility of reliable determination of the bench mark vertical displacements, especially if the displacements assume to be at decimetre size order or higher.

5. Determination of Bench Mark Vertical Displacements

For the purpose of eliminating the influences of various height datums and distortion effect contained in the APN network, there has been separate and independent adjustment of each network made, i.e. the APN and IINVT network. The network adjustments has been made applying the method of least squares and the functional model of indirect measurements. In the process of adjusting both networks, there has been the same height datum introduced. Based on fact that normal orthometric height difference measurements were published and accessible the height system of normal orthometric heights is adopted like most convinient solution. The height datum realized with the mean sea level at the tide gauge in Bakar was adopted for the epoch 1971.5, determined from the full interval of sea water level observation of 18.6 years. Referring to the mean sea level, the BV bench mark height at the tide gauge in Bakar was defined as the reference bench mark for computing heights in both networks and it amounts to 2.6601 m. The bench mark BV has been adopted as the reference bench mark of the height systems for both networks, regardless of the different time epochs, since its vertical stability during time has been proven. The tide gauge in Bakar is the oldest tide gauge at the territory of Croatia with the longest continuous period of sea water level observations, and it has got a quite centric position related to the geometric configurations of both levelling networks along the coastal line.

On the basis of the APN levelling network adjustment the height of all nodal bench marks have been determined, as well as the heights of all bench marks contained in individual levelling lines. On the basis of the adjustment, there was the measuring accuracy achieved that is expressed with the reference mean error running up to

$$m_{\gamma} = \pm 5.0\,\mathrm{mm}/\sqrt{\mathrm{km}}$$

On the basis of the adjustment of the IINVT levelling network there were also the heights of all nodal bench marks of the network determined, as well as the heights of all bench marks in individual levelling lines. The measurement accuracy achieved on the basis of adjustment is expressed with the mean error running up to

$$m_{\gamma} = \pm 1.1\,\mathrm{mm}/\sqrt{\mathrm{km}}$$

It can be seen from the presented measurement accuracy indicators that there is a similar mutual agreement reached like in case of the accuracies obtained by measurement mean errors determined from levelling figure discrepancies. In spite of certain difference in achieved measurement accuracies, it can be said that the bench mark heights determined by means of adjusting the levelling networks, obtained with previously described procedures, can be used for determining the bench mark height displacements. Nevertheless, it is necessary to emphasize the fact that the system of normal orthometric heights is not completely appropriate for the determination of vertical movements, but in the concrete case it is on one hand the simplest solution referring to the availability of published height differeces measurement data, and on the other hand it is the pragmatic solution considering the fact that for both networks there are no adequate gravimetric measurement data available.

On the basis of mutually compatible and systematically organized measurements and adjustments data, the I order APN bench marks have been searched and identified that have been included in both networks. On the territory of Croatia, Bosnia and Herzegovina, and Slovenia, there have been altogether 67 of such bench marks found and identified. The basic data about these bench marks are in the Table 1 that has got the following informations for each of the found bench mark: original APN bench mark number, IINVT and APN levelling line number, geographic latitude and longitude, the height determined by means of APN network adjustment, the height determined by means of IINVT network adjustment and bench mark vertical displacement, i.e. the difference in vertical position (the sign "+" denotes raising, and the sign "–" lowering of bench mark height position related to the initial position from the time epoch of the APN).

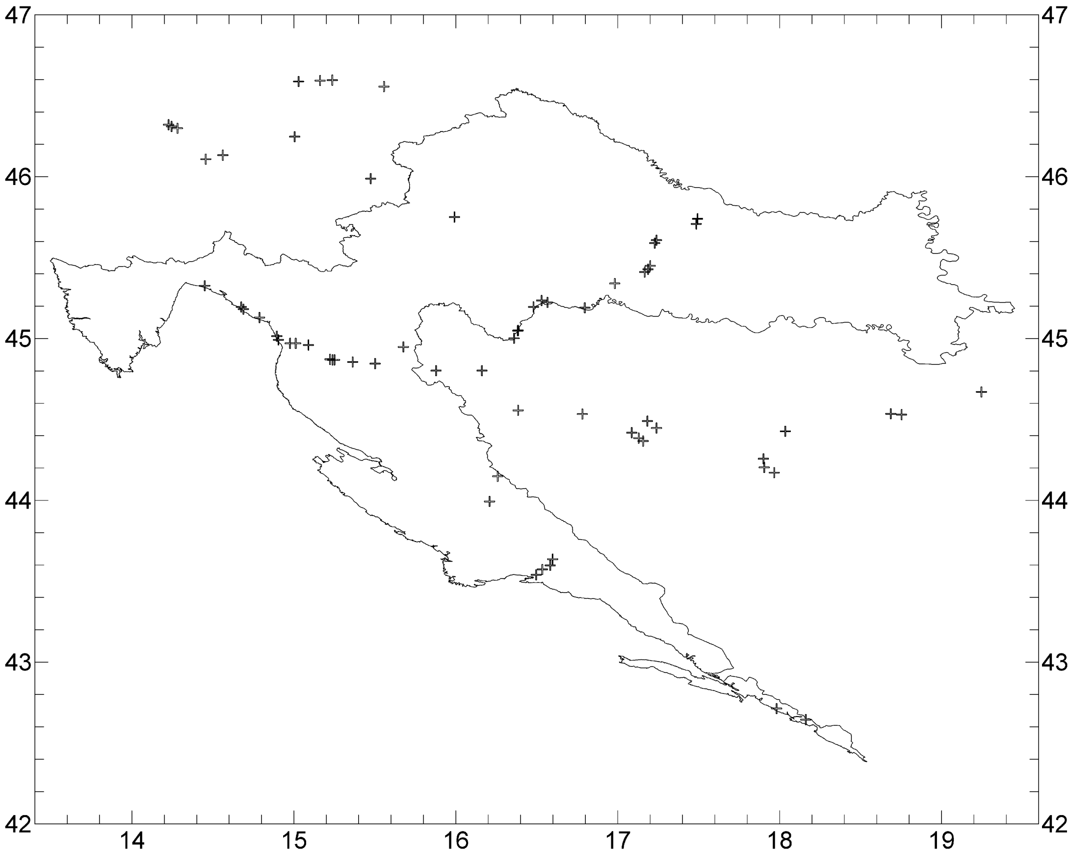

Fig. 5: Position of identical bench marks encompassed by the APN and IINVT network.

Benchmark No.	Line No. APN	Line No. IINVT	Geographic latitude	Geographic longitude	Height APN m	Height IINVT m	Displacement mm
HM 220	7	5	46 6 30	14 14 24	320,5271	320,5875	60,4
HM 228	7	5	46 17 57	14 14 52	451,7633	451,7874	24,1
HM 229	7	5	46 18 37	14 14 42	395,0500	395,1276	77,6
HM 232	7	5	46 19 16	14 14 36	460,4944	460,5599	65,5
HM 367	13	11	46 33 27	15 15 23	289,4192	289,4238	4,7
HM 394	13	11	46 35 50	15 15 16	324,1095	324,0986	–10,9
HM 399	13	11	46 35 40	15 15 44	335,2457	335,2295	–16,1
HM 404	13	11	46 35 18	15 15 46	348,5741	348,5551	–18,9
HM 478	7	14	46 7 59	14 14 42	300,4313	300,4723	41,0
HM 498	7	14	46 14 52	15 15 18	309,4511	309,6013	150,2
HM 10732	66	227	46 9 22	19 19 41	92,3669	92,2840	–83,0
HM 11469	18	223	45 44 23	17 17 35	131,5279	131,5193	–8,6
HM 11474	18	223	45 45 30	17 17 6	137,2707	137,1933	–77,5
HM 11524	18	223	45 45 29	17 17 23	189,0488	189,0054	–43,4
HM 11530	18	223	45 45 23	17 17 44	157,1018	157,0481	–53,7
HM 11559	19	223	45 45 56	17 17 4	172,8934	172,8256	–67,8
HM 11560	19	223	45 45 42	17 17 15	166,5743	166,5069	–67,4
HM 11562	19	223	45 45 40	17 17 0	150,1545	150,0265	–128,0
HM 11603	20	224	45 45 25	16 16 49	102,3593	102,2874	–71,9
HM 11616	20	224	45 45 24	16 16 55	124,9940	124,9110	–83,0
HM 11636	21	225	45 45 4	15 15 31	115,8105	115,7652	–45,3
HM 12221	8	222	45 45 17	15 15 29	168,5463	168,5430	–3,2
HM 12496	49	226	44 44 12	19 19 48	107,1151	106,9329	–182,2
HM 12636	50	227	44 44 48	18 18 12	273,2425	273,1605	–82,0
HM 12642	50	227	44 32 6	18 18 12	235,3367	235,2699	–66,7
HM 13169	22	220	45 45 42	16 16 48	119,0671	119,0317	–35,3
HM 13180	20	220	45 14 6	16 16 48	175,7109	175,6628	–48,1
HM 13184	20	220	45 45 24	16 16 0	112,1185	112,0804	–38,0
HM 13195	22	220	45 3 0	16 16 6	122,1095	122,0204	–89,1
HM 13236	40	221	44 44 36	18 18 6	238,9521	238,8561	–96,0
HM 13273	40	221	44 44 24	17 17 0	306,4818	306,3466	–135,3
HM 13278	40	221	44 44 12	17 17 18	326,4600	326,2604	–199,6
HM 13285	40	221	44 44 18	17 17 0	342,8003	342,6852	–115,1
HM 13402	36	223	44 44 48	17 17 24	276,2170	276,1327	–84,3
HM 13412	36	223	44 44 24	17 17 0	249,1910	249,1079	–83,1
HM 14296	61	223	42 42 42	18 18 42	262,5282	262,3919	–136,3
HM 14356	63	225	42 42 48	17 17 54	95,5391	95,4129	–126,1
HM 14494	29	228	43 43 12	16 16 54	364,0357	363,8666	–169,1
HM 14507	29	228	43 43 54	16 16 0	312,5066	312,5478	41,2
HM 14515	29	228	43 43 24	16 16 6	344,3801	344,2304	–149,6
HM 14530	29	228	43 43 24	16 16 48	11,2450	10,9970	–248,0
HM 14693	25	229	43 43 36	16 16 30	251,2423	251,0334	–208,9
HM 14780	25	330	44 8 54	16 16 30	348,4022	348,1676	–234,6
HM 14926	27	330	44 44 24	16 16 6	675,6331	675,5113	–121,8
HM 15049	27	331	44 25 6	17 17 12	605,3454	605,2299	–115,4
HM 15060	27	331	44 23 6	17 17 48	488,6336	488,5356	–98,1
HM 15063	27	331	44 22 0	17 17 24	438,7317	438,6450	–86,7
HM 15077	27	331	44 32 0	16 16 54	265,8716	265,7162	–155,4
HM 15148	24	332	44 48 6	16 16 42	175,3826	175,2934	–89,2
HM 15152	22	333	45 2 54	16 16 0	122,2026	122,0806	–122,0
HM 15159	22	333	45 0 6	16 16 36	129,2965	129,1875	–109,0
HM 15297	23	334	44 44 54	15 15 36	423,9256	423,8521	–73,5
HM 15340	23	334	44 48 6	15 15 42	225,3623	225,0807	–281,7
HM 15428	23	335	44 44 42	15 15 6	753,8732	753,8139	–59,4
HM 15444	23	335	44 44 18	15 15 48	513,8192	513,7448	–74,4
HM 15454	23	335	44 52 6	15 15 6	462,0665	461,9778	–88,7
HM 15462	23	336	44 52 6	15 15 18	458,0671	457,9834	–83,8
HM 15464	23	336	44 44 18	15 15 24	457,0022	456,9185	–83,7
HM 15486	23	336	44 44 36	15 15 24	479,3753	479,3158	–59,5
HM 15497	10	336	44 44 12	15 15 42	608,1335	608,0774	–56,2
HM 15511	10	336	44 44 12	14 14 36	349,1082	349,0576	–50,6
HM 15524	11	336	44 44 30	14 14 18	3,6802	3,7436	63,5
HM 15532	11	336	45 0 54	14 14 42	28,0507	27,9841	–66,7
HM 15569	11	336	45 7 48	14 14 18	8,0857	8,0389	–46,8
HM 15594	11	336	45 45 42	14 14 30	90,9890	90,9640	–25,0
HM 15649	12	336	45 45 36	14 14 0	4,4928	4,4763	–16,5
HM 15660	11	336	45 45 54	14 14 18	5,1741	5,1417	–32,4

Table 1: Identical bench marks data in the network APN and IINVT.

On the basis of the data from the Table 1, the positions of all identified bench marks are presented on Fig. 5, related to the territorial shape of Croatia.

Fig. 5 presents clearly the positional distribution of identified bench marks at the territory of Croatia. It can be clearly seen, that the total number of bench marks is small as related to the entire observed area, and that there is very irregular and uneven positional distribution of bench marks. At certain smaller areas there is the concentration of bench marks present in form of clusters, and very large areas have got not bench marks at all. The presented situation is actually not too much surprising, because it results from the incompatibility of the APN and IINVT network geometric configurations. But, it is by all means very inconvenient, because it prevents to large extent the process of analysis and making conclusions that would be more precise and more detailed, about possible patterns of vertical changes along observed teritorry, especially regarding their continuity or discontinuity.

In spite of that, the values of vertical displacements given in the Table 1 and their positional distribution on the observed area undoubtedly speak for the fact that significant and irregular changes of height relations on the topographic surface have appeared in the period of about eighty years, as related to the achieved measurement accuracy in both levelling networks. Total range of vertical displacements runs up to about 430 mm, the largest lowering of bench mark in relation to the epoch APN is at the level of about 280 mm, and the larger rising of bench mark at the level of about 150 mm. The most bench marks have got negative signs of vertical displacements, apart from the north-eastern part of the observed area, i.e. Slovenia, which proves that in the course of time there has been a general trend of topographic surface being lowered. The average value of vertical movements determined on the basis of the data in the Table 1 running up to about 70 mm.

Its important to point out that there is a certain inconsistency present in the determined vertical displacement data, Table 1. That should be taken into consideration and should be paid attention to in using and interpreting the vertical displacement data. Its especially noticeable in the mutual comparison of vertical displacements of bench marks contained and closely lined up in some clusters. Namely, on the basis of the Voronoi cluster map design at least in two clusters (cluster defined with the bench marks: HM 15497, HM 15511, HM 151524, HM 15532 and cluster: HM 14494, HM 14507, HM 14515, HM 14530) it occurs that the vertical displacements at the position of very close bench marks are mutually extremely incongruent with reference to the value and sign of the displacement (i.e. bench mark HM 14507 and HM 15524). This phenomenon does not coincide with the expectation that close bench marks should co-respond in indicating vertical displacements of wider observed area, and not their own movements. Since the surveying field books are not available, documenting the performance of concrete field measurement on these bench marks, it can be logically concluded that some bench marks might have primarily indicated the changes in the course of time being the consequence of the instability of the objects that they were stabilized at, and not representative movements of wider areas where they are placed. Although logical, the reason need not always be correct, because the unavailability of appropriate documentation referring to the maintenance of bench marks in operative status during time does include the possibility of renewed and un-documented stabilization of the same bench marks at the same locations. The noticed inconsistency makes the process of making more precise and more detailed conclusions about the changes of height relation in the observed area additionally difficult, because the number of bench marks that is very small anyway, should be additionally reduced by the number of bench marks with inconsistent vertical displacements due to local instability or un-documented stabilization renewal (bench mark HM 14507 and HM 15524 should be further analysed). Anyway, bench mark vertical displacements at the observed area are calculated as accurate as possible, taking into account quality and availability of the initial measurement data and vertical displacement determination methodology.

6. Conclusion

Referring at this stage of investigation only and exclusively to the geometric aspects of vertical bench mark displacements, and not correlating any physical parameters whatsoever, relief, seismics, geology, regional and local rift zones and other physical elements characteristic for the territory of Croatia, Bosnia and Herzegovina, and Slovenia, it has been found out that in the period between the time epochs (1874 – 1908) and (1970 – 1973) some significant changes happened in the height relations on the topographic surface. The height changes can be recognized in general lowering of the topographic surface as related to the initial time epoch that is irregular and discontinuous referring to the quantity of vertical displacements and the location of bench marks that they were determined at. The rising of the topographic surface can be noticed in the smaller north-eastern part of the observed area, i.e. at the territory of Slovenia, and it is essentially smaller than the lowering of the topographic surface. The total range of vertical movements is within the interval of approximately 400 cm which undoubtedly indicates the significance of the changes in vertical relations, as well as of the fact the APN and IINVT networks were used very well for the purpose of their determination, in accordance with the achieved measuremets accuracy.

One should be very careful by all means, when connecting vertical displacements contained in the Table 1 with the physical reality and the aspects of other geosciences because of a series of inconvenient circumstances. Normal orthometric height system is not entirely reliable for the determination of vertical displacements. Vertical displacements are determined only from the geometric point of view. The number of bench marks at which the vertical displacements are determined is small as compared with the size of the observed territory. The positional distribution of bench marks is very irregular and inconvenient. Some bench marks indicate the presence of their own vertical movements being most probably the consequence of the instability of their microlocations.

Along with all inconvenient circumstances, the first and concrete numerical results of the vertical displacements at observed teritorry are presented based on the geometric levelling measurements data. They are very indicative because they reveal a general trend of changes in height relations and serve as the basis for further more detailed investigations.

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