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The Use of Virtual Reference Station of the Multifunctional Positioning System ASG-EUPOS to Optimize the Reference Layout of the Basic Realization Network**

1. Introduction

In Poland in the last decade, and particularly since June 2008, when the nationwide, multi-function system of precise satellite positioning – ASG-EUPOS, managed by the Head Office of Geodesy and Cartography was launched, very clearly the use of measurement technology GNSS (Global Navigation Satellite System) has increased. Now, in principle, there is no geodetic company, which would not be equipped with this modern technology of measurements. Coordinates of the reference station of ASG-EUPOS system, were determined with high precision (this system is currently: PL-ETRF2000 for the epoch 2011.0) and now constitute the basic state geodetic network in Poland. Due to the fact, that the network covers all the area of the country, and the GNSS technology theoretically has no limitations on the range of satellite measurements, this allows its broad utilization as a multifunction network, suitable for performing local measurements. The system provides to users three services in real-time positioning (NAWGIS, KODGIS, NAWGEO) and two post-processing services (POZGEO and POZGEO-D). POZGEO service enables automatic post-processing of the observations submitted by the user based on selected reference stations using a special application.

Particularly noteworthy is the service POZGEO-D, which provides the official coordinates of the station and allows for the acquisition of observational data from any physical reference station of the system as well as a virtual reference station, which can be created at the request of the user of the system, basically anywhere. These observations after processing them in the appropriate software along with the coordinates of the stations may be used to refer various types of geodetic networks created for economic purposes in that realization networks for different types of objects. This approach ensures high accuracy, uniform scale and orientation of

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network, and ultimately decides on the most important parameters, that affect the quality of surveying and mapping works in the given area. The paper takes research on the qualitative optimization of geometric structures, constituting a reference to the designated network realization. Studies were carried out, aimed at optimizing the layout of reference system of the determined test network, using four alternative options for the measurements processing.

2. The Physical Reference Station

POZGEO-D service provides observations of selected physical reference station of the system (Continuously Operating Reference Station – CORS). This allows the user to independently perform calculations using his own software, with the standard approach, that reference stations will be used as points of references in the process of static measurements GNSS adjustment. The general concept of this solution is shown in Figure 1, on example, of referring the determined object to the physical reference stations located in Małopolska Voivodeship in the south-eastern Poland.

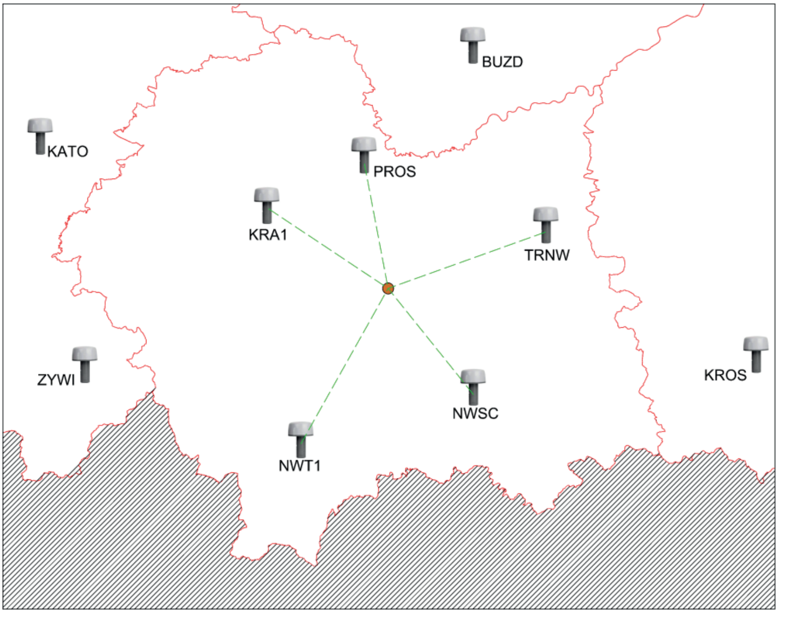

Fig. 1. The use of physical CORS station to establish reference of the static measurements

The user in this case has a possibility to choose the reference stations as the reference points to solve his own network, however, due to the fact, that the CORS stations are spaced approximately 70 km this choice can be significantly reduced. It is well known however, that the resulting final accuracy of thus determined coordinates is dependent on several factors including the length of the referring vector. The longer are the vectors, the longer observation sessions are recommended, and it is conditioned by modeling error propagation of signals in the atmosphere and determination uncertainty.

3. Virtual Reference Station

The concept of a virtual reference station is to create mathematical (non-physical) reference station based on a set of simulated measurements for the point of precisely preset coordinates. These types of virtual points are possible to generate within networks of physical reference stations and this enables specialized software [2]. Simulated virtual observations are generated on the basis of specified coordinates of virtual VRS points and the coordinates of satellites, and more precisely the distances of simulated point to each satellite [6, 7]. The general concept of using virtual reference stations to establish references of determined points in the studies undertaken in the work consisting in shortening the length of reference vectors is shown in Figure 2.

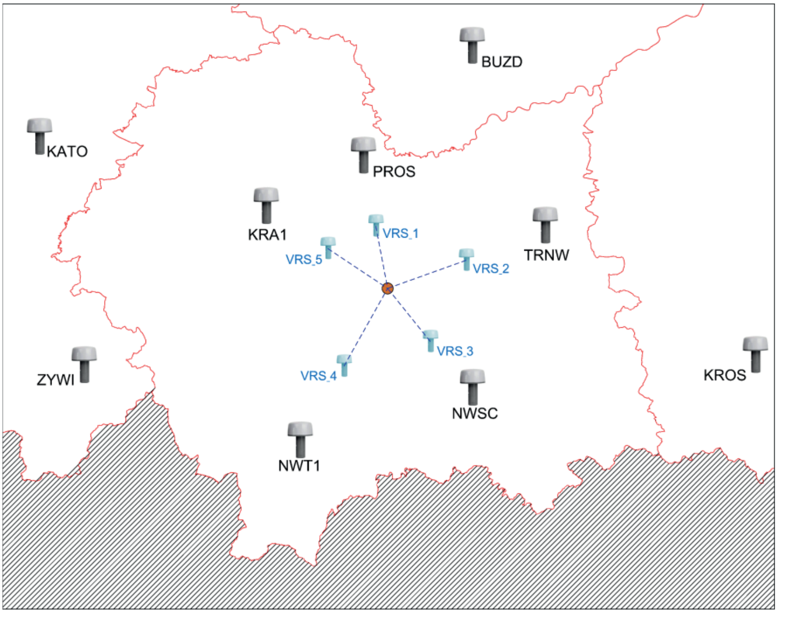

Fig. 2. The concept of using a virtual reference station to establish reference of static measurements

Board (broadcast) satellite ephemeris are subject to errors, thus the distance to the satellites will also be affected by these errors. Other types of errors occurring at stations are the physical errors determining time and errors of the impact of the ionosphere and the troposphere. These errors can be quite accurately determined on the physical reference stations (depending on the class of the station and provided equipment). It is assumed, that the area close to the physical reference station is charged with errors of a similar scale, therefore, by the generation of simulated observations for virtual station they are also charged with a set of errors established for the nearest physical reference station. In this work I will try to answer the question to what extent it is right.

VRS points are currently successfully used in the real-time measurement techniques, eg. in the RTN type network solutions (Real Time GNSS Network), in this study their suitability in elaboration of static measurements performed in the post-processing is examined.

For this purpose, the virtual stations have been used to establish a reference of a new created network shortening the length of the reference vectors and examine how this will affect the final results of the new network elaboration. Studies of this type were carried out previously by various researchers [1–5] and their results showed some improvement of the solutions in relation to those obtained using the CORS observations. However, the studies were carried out using GPS observations. But in this study for elaboration were used the GNSS (GPS and GLONASS) observations.

4. The Object of the Test Researches

This paper presents the results of the research on the determination of coordinates using static GNSS measurements and POZGEO-D and POZGEO services. These services are available to authorized users within the nationwide system of ASG-EUPOS managed by the Head Office of Geodesy and Cartography. The test object was a small surface, realization network, consisting of six points, spaced apart by about 125 m to 350 m. This network has been measured by the static method in a single observation session lasting 3.5 hours, with six satellite receivers Trimble R8 model 3.

The measurements were performed with data logging interval of 1 second, at the horizon cut-off angle of 10 degrees to the GPS and GLONASS satellites. Object was located in such way, that the distance to the nearest reference station (KRA1) was about 5.1 km while to the farthest approximately 81.5 km.

The basic elaboration of the measured test network was made with the classical approach by performing the reference to the seven nearest physical reference stations (CORS): KRA1, KATO, ZYWI, LELO, BUZD, NWSC, TRNW. For this purpose, using the POZGEO-D service, which is made available in the ASG-EUPOS system, for the above-mentioned stations used to establish reference measurements were taken synchronously with the measurements taken on the points of created realization network. Figure 3 shows the location of the test object in relation to physical reference stations of the ASG-EUPOS system accepted to establish reference. Processing of so prepared data was made using TBC ver. 3.60 firmware, using precise orbits of a "final orbits" type and antenna "IGS absolute" models. In this way, the Cartesian coordinates of a test network in ETRS89 were determined and in a later stage of the study served as comparative coordinates for solutions based on the use of virtual reference stations.

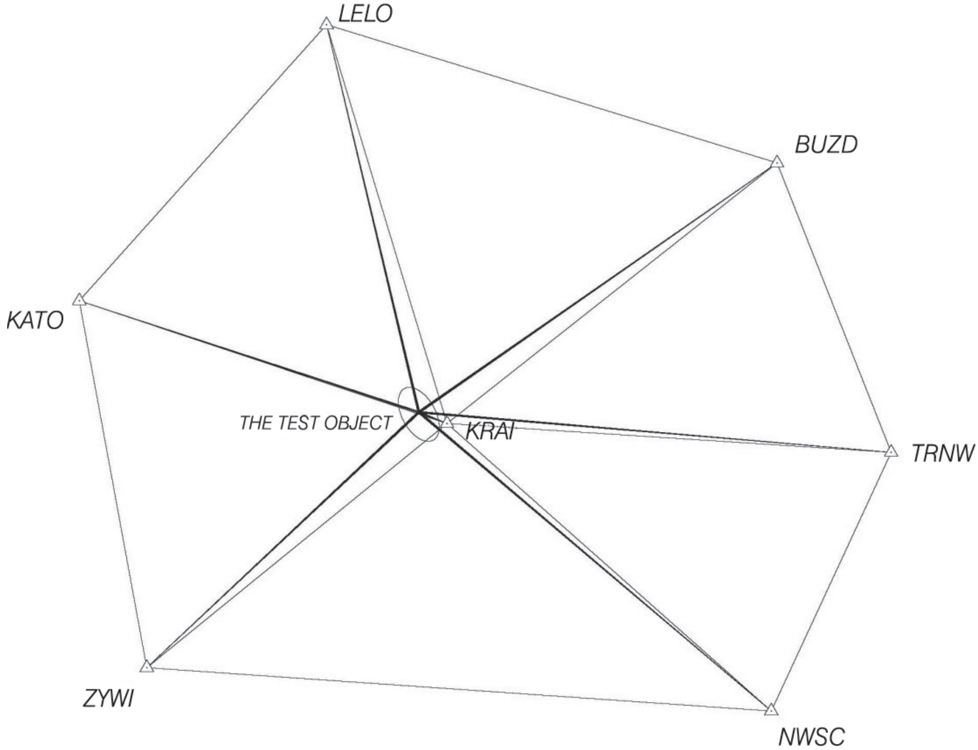

Fig. 3. Location of test object in relation to points of references

5. Alternative Ways of Data Processing

The created research network was measured independently by performing three static observation sessions, lasting three hours each, at determined points. These sessions were performed in one week intervals on 13, 20 and 27 July 2015. Then the results were processed autonomously in thirteen alternative variants. The idea of consecutive variants of the processing was to shorten average length of reference vectors of the network of about 5 km. Practically, it was realized in this way, that using special software available in the ASG-EUPOS system, consecutive reference points were generated as virtual stations. In this way, the average length of the reference vector was reduced from about 75 km to about 6 km.

In Tables 1–3 the results are shown for three consecutive tests for the first variant in the form of coordinates of the determined points and their mean square errors, with the maximum lengths of the reference vectors (about 75 km), configuration of the virtual stations, according to Figure 4.

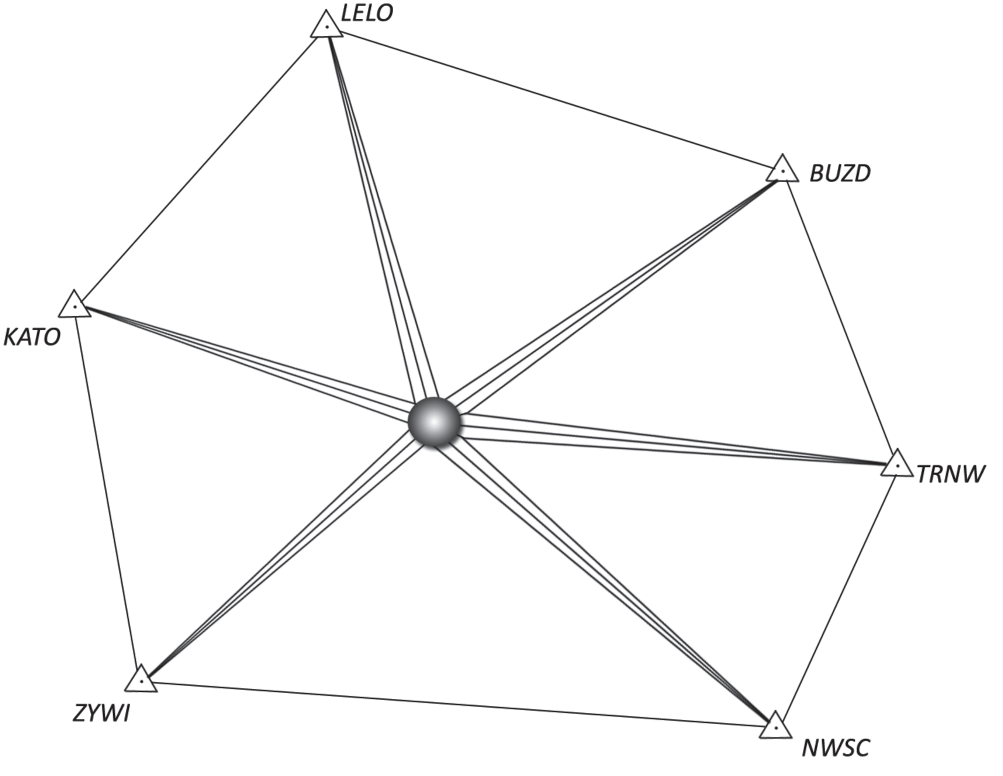

Fig. 4. The location of the test object
in relation to virtual points of reference – variant VRS_00

6. Elaboration and Analysis of Results

In Tables 1–3, the mean errors of adjusted coordinates for three consecutive tests carried out at the maximum lengths of reference vectors are presented. Reference points were generated in every case, as virtual points (VRS) exactly for the locations of the six physical reference stations (LELO, BUZD, TRNW, NWSC, ZYWI, KATO).

Table 1. Mean square errors of the adjusted X coordinate

Point	Error			Deviations from the average value		
	mX_1	mX_2	mX_3	eX_1	eX_2	eX_3
	[m]	[m]	[m]	[m]	[m]	[m]
1394	0.0057	0.0053	0.0059	0.0002	0.0000	0.0001
2042	0.0055	0.0053	0.0058	0.0000	0.0000	0.0000
2044	0.0056	0.0054	0.0058	0.0001	0.0001	0.0000
2046	0.0054	0.0052	0.0059	–0.0001	–0.0001	0.0001
2047	0.0055	0.0054	0.0055	0.0000	0.0001	–0.0003
2053	0.0055	0.0053	0.0059	0.0000	0.0000	0.0001
	The mean values			Mean square values		
	0.0055	0.0053	0.0058	0.0001	0.0001	0.0001
	Average value			Average value		
	0.0056			0.0001		

Table 2. Mean square errors of the adjusted Y coordinate

Point	Error			Deviations from the average value		
	mY_1	mY_2	mY_3	eY_1	eY_2	eY_3
	[m]	[m]	[m]	[m]	[m]	[m]
1394	0.0026	0.0025	0.0029	0.0001	0.0001	0.0000
2042	0.0025	0.0024	0.0030	0.0000	0.0000	0.0001
2044	0.0025	0.0024	0.0030	0.0000	0.0000	0.0001
2046	0.0025	0.0024	0.0030	0.0000	0.0000	0.0001
2047	0.0025	0.0024	0.0029	0.0000	0.0000	0.0000
2053	0.0024	0.0024	0.0028	–0.0001	0.0000	–0.0001
	The mean values			Mean square values		
	0.0025	0.0024	0.0029	0.0001	0.0000	0.0001
	Average value			Average value		
	0.0026			0.0001		

Table 3. Mean square errors of the adjusted Z coordinate

Point	Error			Deviations from the average value		
	mZ_1	mZ_2	mZ_3	eZ_1	eZ_2	eZ_3
	[m]	[m]	[m]	[m]	[m]	[m]
1394	0.0060	0.0058	0.0063	0.0001	0.0001	0.0001
2042	0.0059	0.0057	0.0063	0.0000	0.0000	0.0001
2044	0.0059	0.0057	0.0061	0.0000	0.0000	–0.0001
2046	0.0059	0.0057	0.0062	0.0000	0.0000	0.0000
2047	0.0060	0.0058	0.0062	0.0001	0.0001	0.0000
2053	0.0059	0.0057	0.0060	0.0000	0.0000	–0.0002
	The mean values			Mean square values		
	0.0059	0.0057	0.0062	0.0000	0.0000	0.0001
	Average value			Average value		
	0.0060			0.0000		

Average values of the mean square errors in the subsequent solutions (Tabs 1–3), for the individual coordinates of points of the research network (mX = 5.6 mm, mY = 2.6 mm, mZ = 6.0 mm) and the corresponding values of mean square deviations (eX = 0.1 mm, eY = 0.1 mm, eZ = 0.0 mm) demonstrate, that adjusted network is homogeneous, not charged with outliers, precisely measured and properly adjusted in numerical terms. Similar results were obtained for the other 12-solutions (VRS_01 – VRS_12), for which the lengths of the reference vectors were shortened each time creating a new system of reference points. On this basis, the results for the each of the three series of elaborated measurements were averaged for each variant of references executed independently at weekly intervals; further tests were carried out for average values.

In Table 4 and in Figures 5–7, are presented changes in average values of the mean square errors of adjusted coordinates, depending on the adopted reference vector length, for each variant of solutions of the test network.

Table 4. Overview of the mean square errors of adjusted coordinates depending on the adopted solution variant

Solution variant	mX [m]	mY [m]	mZ [m]	Average length of the reference vector [m]
CORS	0.0051	0.0024	0.0056	74639
VRS_00	0.0056	0.0026	0.0060	74639
VRS_01	0.0062	0.0029	0.0067	69906
VRS_02	0.0061	0.0028	0.0065	64212
VRS_03	0.0054	0.0025	0.0057	58496
VRS_04	0.0060	0.0026	0.0067	52422
VRS_05	0.0057	0.0025	0.0064	46850
VRS_06	0.0055	0.0025	0.0062	40786
VRS_07	0.0043	0.0019	0.0049	35043
VRS_08	0.0036	0.0017	0.0041	29304
VRS_09	0.0029	0.0014	0.0034	22628
VRS_10	0.0025	0.0012	0.0029	17205
VRS_11	0.0022	0.0011	0.0025	11810
VRS_12	0.0016	0.0008	0.0018	6029

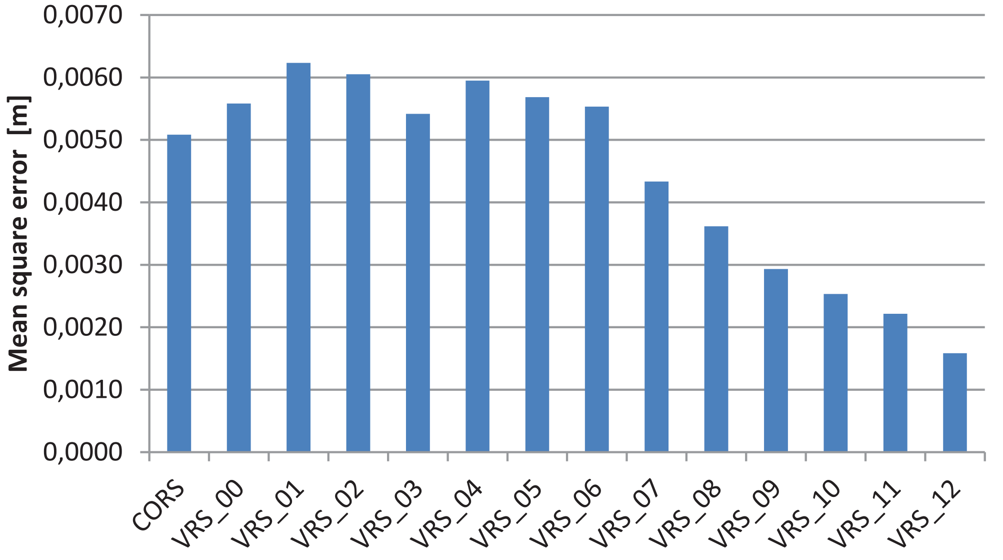

Fig. 5. Distribution of the size of the *X* coordinate errors, dependent on the length of the reference vector

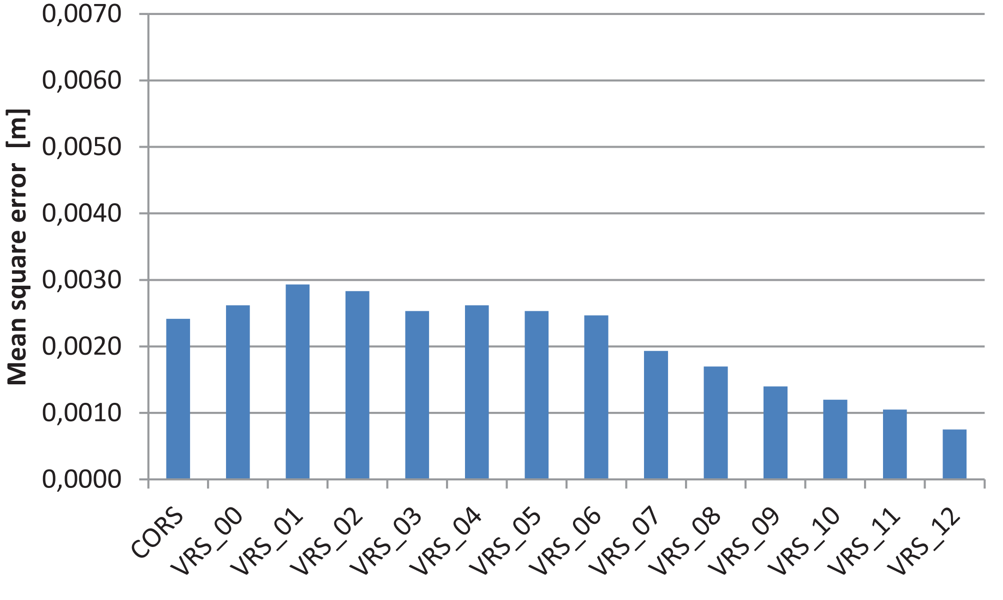

Fig. 6. Distribution of the size of the *Y* coordinate errors, dependent on the length of the reference vector

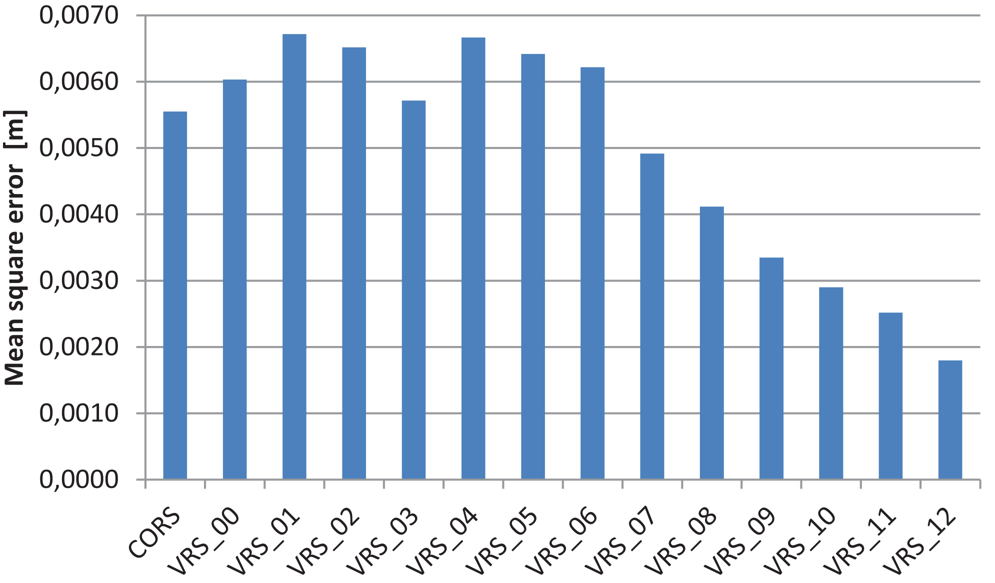

Fig. 7. Distribution of the size of the *Z* coordinate errors, dependent on the length of the reference vector

7. Conclusions

This paper presents the results of research on the determination of coordinates from the static GNSS measurements using the POZGEO-D services of the ASG-EU-POS system. Two approaches were used, the first, in which the reference stations constituted direct reference for the network of determined vectors, the second, using the virtual reference stations. In both cases, the post-processing used 3.5 h observations, from two positioning systems GPS and GLONASS, manually developed with a company program TBC v. 3.60. The first approach was regarded as classics, commonly used in setting up geodetic control networks, to which the solutions using virtual reference stations, allowing for the shortening of the length of the reference vectors were compared. As can be noticed from the Table 4 and the graphs presented in Figures 5–7, in the first step, during creation of references of the determined vectors and passing from the physical stations (CORS) observations to observations from the virtual stations (VRS) there is an increase in the mean square errors of the adjusted coordinates. Errors reach their maximum values, when virtual reference points are located at a distance of about 75 km from the physical reference stations (solution VRS_01). Subsequent shortening of the length of reference vectors at an interval of 5 km initially causes a decrease in the mean square errors of the adjusted coordinates, and then again their abrupt increase, what can be noticed in variant VRS_04. This situation is illustrated graphically by bimodal distributions of the mean square errors for successive determined coordinates (*X*, *Y*, *Z*) shown in Figures 5–7.

The actual reduction of the mean square errors of adjusted coordinates for the studied test network using a virtual reference station, in relation to the basic solution using the physical reference stations (CORS) was obtained in variant VRS_07, when reference vectors lengths have been reduced by more than half, to about 35 km. This resulted in the decrease in the mean square errors of determined coordinates on average of about: 16% for *X* coordinates, 21% for *Y* coordinates and 12% for *Z* coordinates.

Generally, studies have confirmed, that the lengths of reference vectors have direct impact on the value of the mean square errors of the newly determined 3D points. It has been shown empirically that along with the shortening of the lengths of reference vectors occurs the decrease of the values of the mean square errors of determined coordinates (Tab. 4). For the created research network the shortening of the average length of the references vectors from about 75 km to about 6 km improvement was achieved of the mean square errors of coordinates of about 68%. At this stage of the study it should be noted that this is the only numerical results. It should be noted in here that the generation of virtual reference station for such a small area as in option VRS_12 (limited to the radius of about 6 km) makes that actually generated observations should be treated as if they originated from one, the same physical station. This causes that the reliability of such a solution is low and thus may entail certain dangers relating to the actual accuracy of the determination of coordinates in the field. This may require performing of independent, additional control measurements.

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