MONITORING OF WEAK AND MODERATE EARTHQUAKES USING GNSS TECHNOLOGIES

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Abstract: *The geodetic monitoring results of the earthquake in the seismically active areas of the Republic of Armenia using GNSS technologies are presented. The necessity of using geodetic tools-equipment, in particular satellite technologies, in the process of seismic studies is substantiated, proving the fact of the validity and reliability of the data. The monitoring results of the horizontal-vertical shifts' coordinates of the permanent reference stations affected by the earthquake in Armenia on February 13, 2021 at different time intervals (5 days before the earthquake, 2 hours and 10 minutes before and after, as well as at the moment of the earthquake) were analyzed and the graph analyzes were given. The results show that it is possible to mark the time of earthquake registration by means of coordinates recorded at a frequency of 1s, and as a result of the earthquake, it is possible to monitor the Earth's crust displacement vectors at certain intervals through reference stations, recording the directions of horizontal and vertical displacement of the Earth's crust. At the same time, locating reference stations on hard rock will provide an opportunity to have a more accurate database, which will contribute to the development of geodetic monitoring in seismically active areas using GNSS technologies.*

Keywords: *Permanent reference stations, GNSS technologies, deformation, geodynamics, earthquake.*

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Introduction

The idea of using the potential of Global Navigation Satellite Systems (GNSS) in seismology was first discussed back in 1990. Measurements made through GNSS during the earthquake were studied, the results of seismic observations of earthquakes were described to measure large movements in a short period of time. The materials used for GNSS seismology, which are classified as high-class data, can be analyzed using the same models obtained for daily average position analysis. The difference between traditional geodetic surveys and high-frequency global navigation satellite systems is the function assessments. For most geophysical problems, the location of the point is determined once a day, and in the case of seismic applications, it can (and should) be done every second, considering that modern equipment has this capability [1,2].

We have reviewed the results of some international analyzes based on data from GNSS stations located in earthquake-prone areas [3,4,5]. GNSS's ability to detect seismic shocks was far greater than experts expected. Nowadays GNSS has been improved, there are analytical methods available to optimally measure GNSS seismic shifts, and we need to work with different professionals to use the obtained data more efficient.

Thus, high-class GNSS data has an invaluable role in excluding general analysis errors and distinguishing pre-seismic and post-seismic faults (deformations) during strong earthquakes. The use of GNSS geodetic data by seismologists in earthquake surveys can be done through GPS waves archiving. It should be noted that not all earthquake cracking are superficial, and not all GNSS receivers can be located in the direction of ruptures [6].

Studies allow to insist that the further work of GNSS seismology should develop the proposition that GNSS could be used to study the effects of large (strong) displacements, large-scale movements of the Earth's surface, and the engineering structures of that motion [2,6,7].

Materials and Methods

Data collection by thousands of GPS receivers around the world continues to be carried out regularly, collecting 1 Hz GNSS data. The data obtained are sufficient for earthquake studies, but they can be more valuable for earthquake studies if the receivers sample data at a higher frequency. However, higher frequency measurements also have their drawbacks, as high-frequency data collection poses overloading during remote sensing and archiving. This system is an important component of the study of multifactorial phenomena of modern geodynamics, due to changes in the combinations of spatial-temporal, natural-man-made, endogenous and exogenous influences, which leads to a situation where a sensitive instrument (method) measuring modern geodynamic processes becomes more effective not only by recording a useful signal but also by detecting malfunctions [8,9,10,11].

It should be noted that surface surveying methods, despite the laboriousness of fieldwork, are simple and easy to develop. In contrast, satellite observations are easier to measure, but much more complex in the development process, which can lead to significant distortions in the final assessment of the geodynamic state.

For large areas, according to GNSS measurements, the horizontal component of the Earth's surface was more than the vertical height. The technological properties of geodetic observations allow to measure the vertical component much more accurately by alignment, and the horizontal component by satellite. Hence, it is impossible to make a principled conclusion with the same measurements performed in combination, as each method has the degree of accuracy of the analysis of its measurement results. However, behind the basics of measurement theory is that the identification values of observation results should not depend on the measurement method. Otherwise, the conclusion of predominant vertical or horizontal displacements in the general course of the geodynamic process will reflect the level of technological capability of this or that measurement method.

GNSS measurement methods have a completely different way of receiving a signal, a separate methodology of point monitoring and signal processing in contrast to other new generation equipment. Regarding the problems of modern geodynamics, it is possible to point out two main difficulties in using the results of satellite geodesy observations. First, the vast majority of studies focus on the horizontal displacement component of the coordinate system. The second, the observation network has a lower density than the geodetic networks used in traditional measurement methods, which reduces their ability to study seismic processes in local areas. Thus, in order to make a comprehensive analysis, it is necessary to combine the traditional methods and satellite geodetic measurements data and to develop a single platform.

To solve these problems, a number of scientific studies are currently being carried out, comparing the accuracy of coordinate determination obtained by GLONASS and GPS systems, as well as comparisons between the results of observations of the use of traditional and geodetic satellite systems are carried out.These studies have shown that the GLONASS system has almost the same efficiency as GPS so the two systems can be used together in research. However, studies of traditional satellite measurements show that the average annual horizontal velocity, determined in two ways by separate analysis of the data obtained, differs to a certain extent. Therefore, there is a need for targeted studies to analyze the results of geodetic satellite and surface traditional surveys, combining them with spatial-observation systems, in order to properly identify deformations [12].

The coordinate basis for the study and detection of vertical and horizontal displacements of Earth's crust in the areas of active seismic ruptures in the territory of the Republic of Armenia are the main points of the RA National Geodetic 0, 1st and 2nd class nets, the pillars and stamps of the RA State Elevation Network, as well as the net of 12 permanent reference stations established in the Republic of Armenia in 2013. The permanent reference stations net (Akhuryan, Alaverdi, Aparan, Armavir, Artashat, Gavar, Ijevan, Khndzoresk, Meghri, Sisian, Vardenis, Yeghegnadzor) is distributed throughout the territory of the republic at a distance of about 70km[1].

Special polygons have been set up in some earthquake-prone areas of the Republic of Armenia to study Earth's crust movements. Based on accurate geodetic measurements in seismic zones, vertical-horizontal displacements can be calculated, according to which it is possible to detect regions of deformations, which in turn will lead to improved earthquake prediction.

Results and Discussion

We carried out certain researches in the Republic of Armenia by studying the earthquake that took place in Yerevan on February 13, 2021 at 3:29 pm (Yerevan time), to make the efficiency of the geodetic method more obvious using GNSS technologies, to record the moment of the earthquake, as well as to characterize the dynamics of horizontal and vertical movements of stations some time before and after the earthquake. The epicenter was reported 8km southeast of Yerevan, at 44.54 degrees east longitude and 40.11 degrees north latitude, with a depth of 10 km. According to the data of Territorial Service of Seismic Protection of RA MES, M=4.7, the strength of the underground shock in the epicentral zone was 6-7 points. Receiving and observing the diagrams based on the coordinate changes obtained in 2 hours, 10 minutes and 1 sec. intervals on February 13 at 3:29 pm at Armavir Permanent Reference Station near Yerevan, it is obvious that the deviation is especially significant when comparing latitude and ellipsoidal height coordinates. The station is located in the middle of a 3-story building roof in Armavir city. The geological structure of the site includes upper Pliocene and Pleistocene basalts, tuffs and tufa-breccias, which are placed in the form of overlays and flow on the tertiary sedimentary layers and covered by younger alluvial-proluvial-deluvial sediments.

The two-hour long-distance diagram shows a slightly downward-pointing wave, which reached its lowest point at 44.03963 at 11:30 am, then observed an increase in longitude coordinates until the earthquake at 3:29 pm. This increase continues until the end of the presented observation at 11:29 pm at which point the curve reaches 44.03965 east longitude, twenty times higher than the 44.039645 marked 5:30 am at the beginning of our observation. Interestingly, the longitudinal coordinate index recorded its lowest value 4 hours before the earthquake at 11:30 am (Fig. 1).

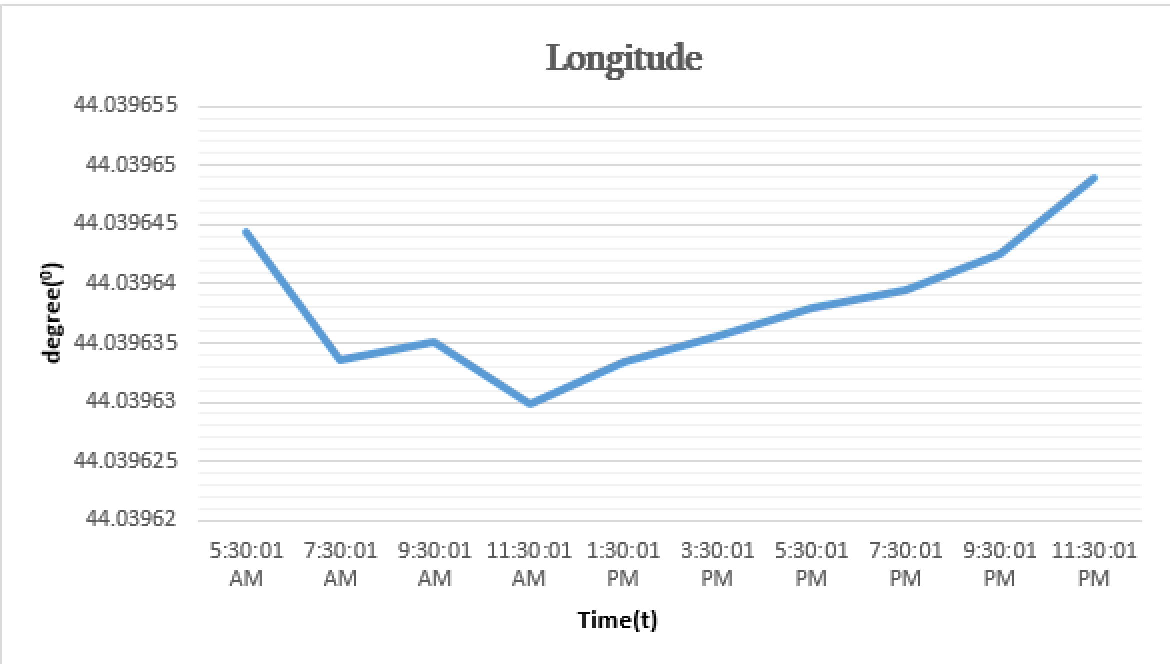

Fig. 1. *The longitude coordinates of Armavir permanent reference station on February 13 at 3:29 pm (Yerevan time)*

[1] http://www.euref.eu/TWG/EUREF%20TWG%20minutes/35-Bratislava2004/TWG-Bratislava-topic-02.pdf

We already have another image in the graphic diagram obtained by placing the latitude coordinates in 18 hours at the same time interval of two hours (Fig. 2). Here, from 40.15557544 degrees north latitude, we have a sharp increase in the curve from 7:30 am to 9:30 am. For the next 2 hours until 11:30 am the latitude coordinates are stored with a slight difference, and then until 1:30 pm a return to the morning data is registered. By the time of the earthquake, at 3:29 pm, we have a sharp rise in the curve again, which continues until 5:30 pm. After 5:30 pm, a slight decline of the curve is observed again.

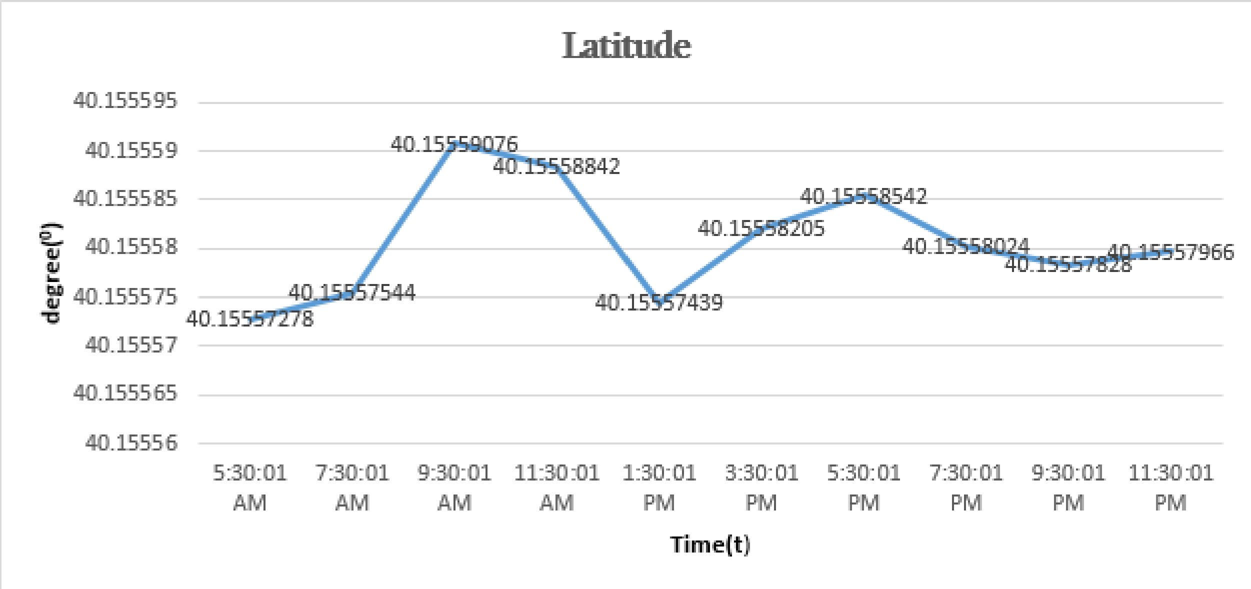

Fig. 2. *The latitude coordinates of Armavir permanent reference station on February 13 at 3:29 pm (Yerevan time)*

Thus, from 7:30 am, the latitude coordinates shifted in ascending order, at 1:30 pm returned to almost the same degree, then from 1:30 pm until the moment of the earthquake, and 2 hours after that the latitude coordinates increased. We could see another image in the diagram showing the coordinate displacements of the ellipsoidal height (Fig. 3).

Here at 5:30 am we have an altitude of 904.6041983m, which is almost unchanged for 4 hours until 9:30 am. Then, until 11:30 am, we have a sharp drop to 901.5548945m. In the following 10 hours, from 11:30 am to 9:30 pm, the height coordinates increase again, and from 9:30 pm, the height begins to decrease, reaching a figure slightly different from the initial observation height - 903.6532062.

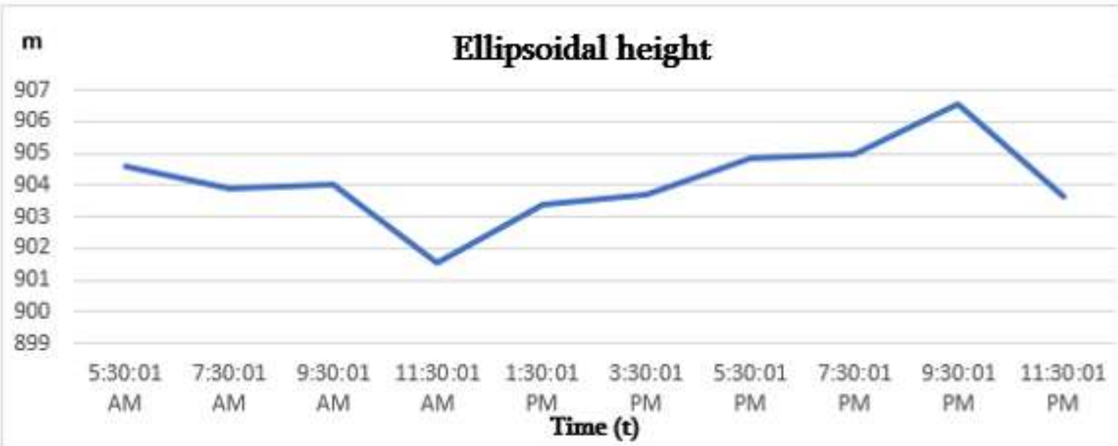

Fig. 3. *Ellipsoidal height coordinates of Armavir permanent reference station on February 13 at 3:29 pm (Yerevan time)*

After comparing the coordinates of Armavir permanent reference station in 2013 with the coordinates of the February earthquake registered on 03.29.2021 at 3:29 pm, we came to the conclusion that the coordinates are significantly deviated. The initial coordinates of the station are:

Latitude - 40.155576989,

Longitude - 44.039635743,

Height - 906.4403.

Let's compare with the coordinates registered at 3:29 pm on 13.02.2021

Latitude - 40.15558205,

Longitude – 44.039635,

height – 903.7192717.

The deviation is especially significant when comparing latitude and ellipsoidal height coordinates. It can be concluded that the effect of earthquakes due to the discharge of energy accumulations in a certain mass of the Earth's crust during the pre-earthquake period is obvious in the process of determining the coordinates of permanent reference stations. If we take into account the fact that the Republic of Armenia is in the zone of seismic activity, the significant deviations of the coordinate data of the stations can clearly help in the study of horizontal and vertical movements of the Earth's crust.

Next, at 10 minutes intervals, we have a slightly different image in the coordinate diagram. As a result of joining the longitude coordinates, we have already obtained an upward curve, which reached its highest point 44.03964397 at 3:00 pm, and at the time of the earthquake, at 3:29 pm, we already have a decrease in the eastern longitude 44.0396368 degree. It is important, that in the 10 minutes interval diagram of earthquake (in two hours before and after earthquake), we observed visible "abrupt fluctuation", that means, we have a sharply upward curve. In the two hour interval diagram from 1:30 pm to 5:29 pm there is a sloping, slightly straight section tending upwards, which has no sharp rises or fluctuations. At the first moment of the monitoring, at 1:30 pm, longitude 44.03962802 was marked, and at the last point of the chart 44.03963767, at 5:20 pm These data are especially visible in the following diagram, where the detailed coordinate data are recorded in more detail (Fig. 4).

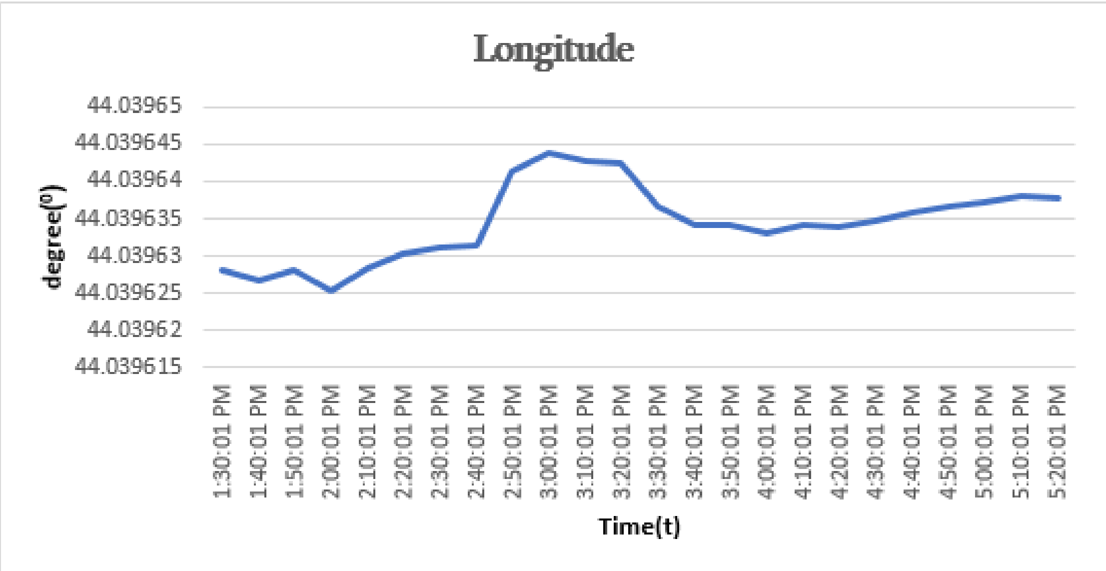

Fig. 4. *Graphs of longitude coordinates in 10 minutes intervals*

As a result of observation with 10 minutes intervals corresponding to latitude for 3 hours 50 minutes, we have a downward curve in the graph-diagram obtained by connecting 24 points, the minimum value of which was registered 9 minutes before the earthquake, at 3:20 pm. 40.15557923 degrees north latitude was registered at the starting point of the monitoring at 1:30 pm and at the end, at 5:20 pm, we have registered 40.1555851 degrees. If we try to move the chart to the corresponding part of the graph with a two-hour interval depicting our latitude, then we will see that here we have not a slightly deviated image, but a significantly different one, from 1:30 pm to 5:20 pm the graphic curve has not a decrease, but an increase (Fig.5).

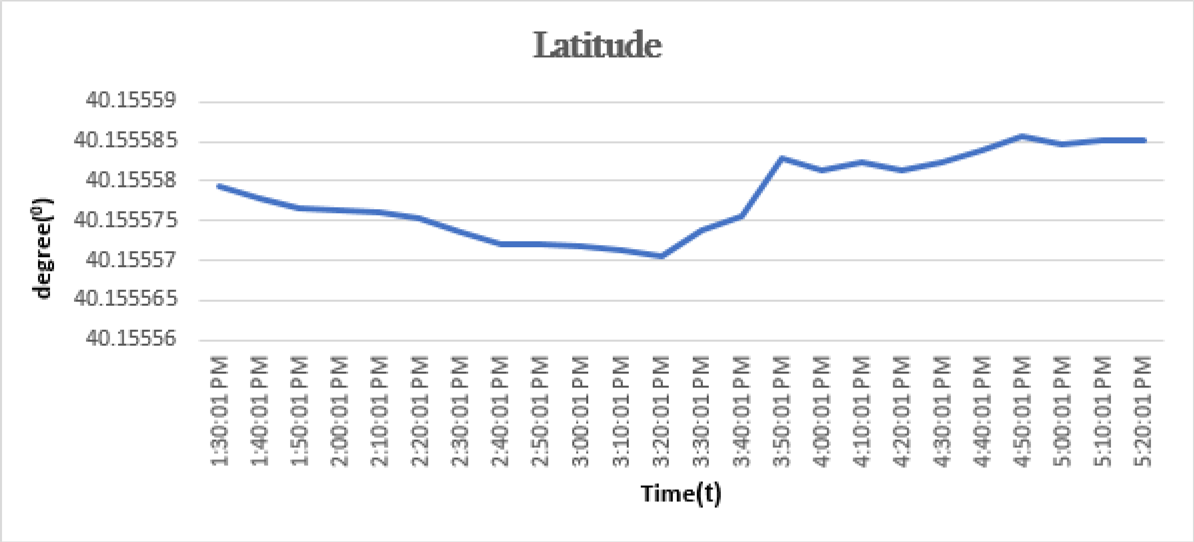

Fig. 5. *Graphs of latitude coordinate in 10 minutes intervals*

The discrepancy in the ellipsoidal height data is very insignificant, as there is almost no radical difference in the direction of the curve. While at the initial moment of the earthquake in our graph with two-hour intervals the ellipsoidal height was 903.7192717 (Fig. 6).

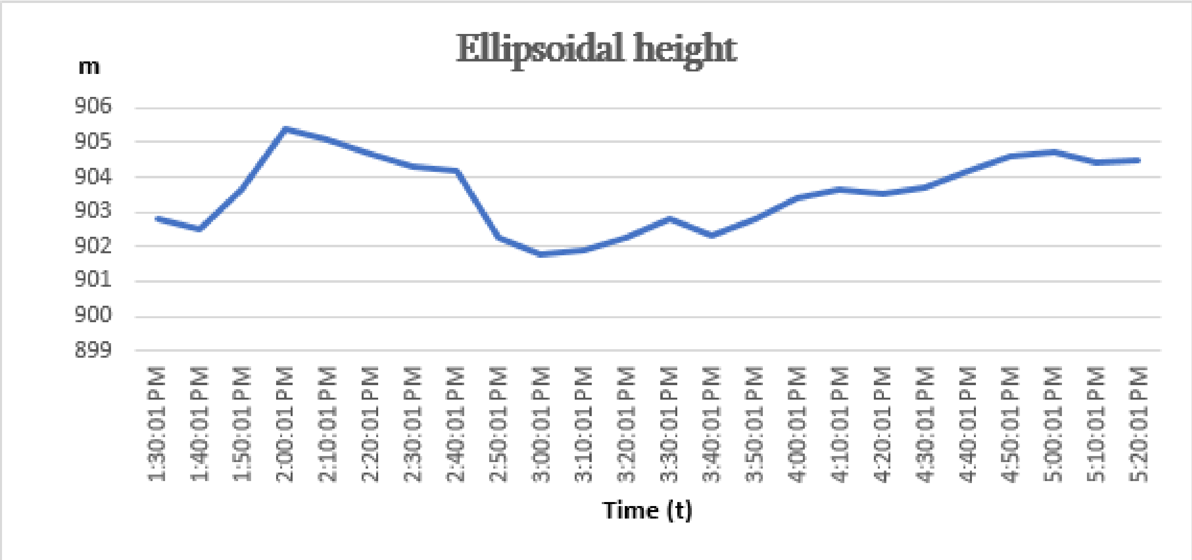

Fig. 6. *Graphs of ellipsoidal heights in 10 minutes intervals*

If we take into account the fact that the Republic of Armenia is in the zone of seismic activity, the significant deviations between the values of the coordinate data of the stations can clearly help in the study of horizontal and vertical movements of the Earth's crust.

Analyzing the graphs obtained with the interval of seconds during the earthquake registered at 3:29 pm, an obvious shift was recorded in all three components, which may indicate that the GNSS stations are reliable for recording earthquakes (Fig.7).

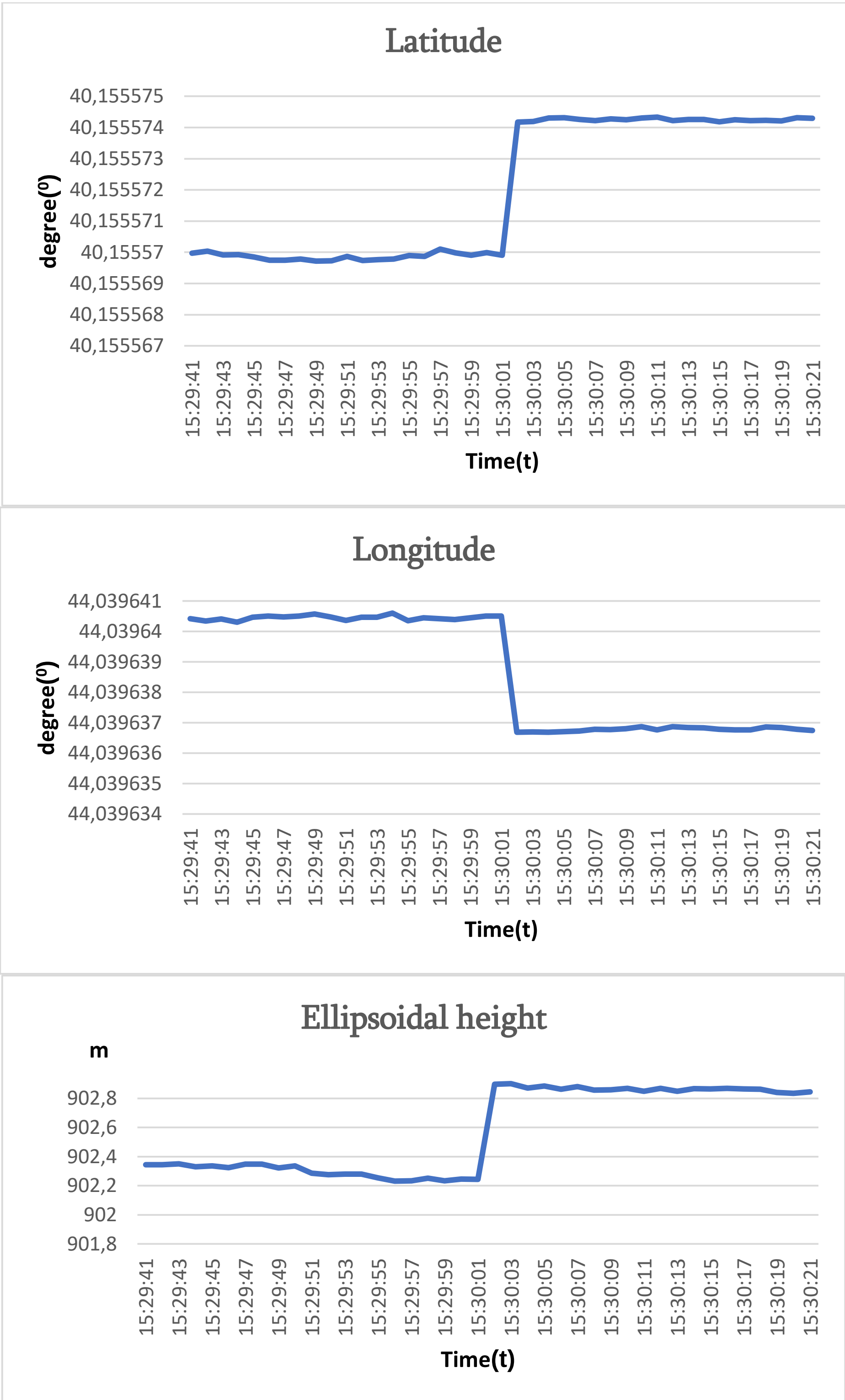

Fig. 7. *Analysis of data every 1 second of measurements*

Once again, to make sure that GNSS stations can get a realistic picture of the Earth's crust horizontal and vertical movements, the analysis of the difference in the balanced data of the same stations was carried out 5 days before and after the earthquake by the 9 reference stations coordinates of the RA Cadastre Committee, according to which no change was registered in the APAR reference station with Y and Z components, and 1mm shift was registered in the X component, changes in the ARMAV station are 3mm shift in the X direction, no shift in the Y direction, and a decrease of 1mm in the Z direction (Fig.8).

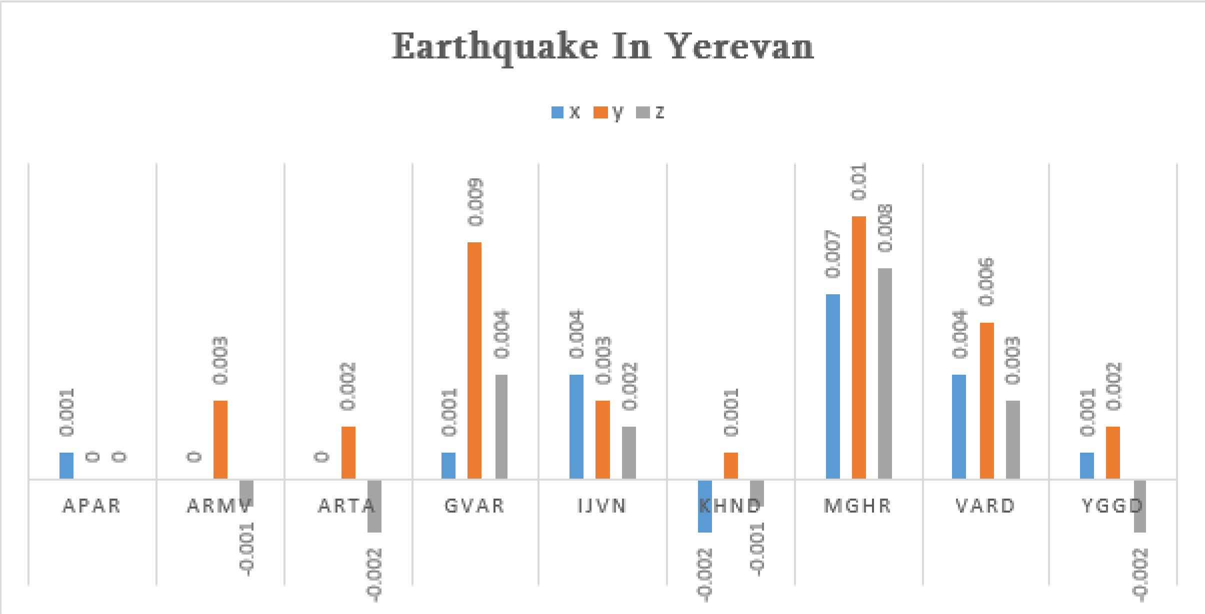

Fig. 8. *Analysis of monitoring 9 stations data for the periods of 08.02-12.02.2021 and 14.02-18.02.2021 (m)*

Summarizing the above, we can state that the 9 permanent reference stations net at the horizontal component moved in the northeast direction after the earthquake, and in the vertical component of the stations there is an increase, which once again proves that the data obtained through monitoring by GNSS stations are consistent. According to international studies, the displacement of the Arab-Eurasian plate area corresponds to the north-eastern direction, which is explained by the convergence of the Arabian plate to the Eurasian plate (Fig. 9).

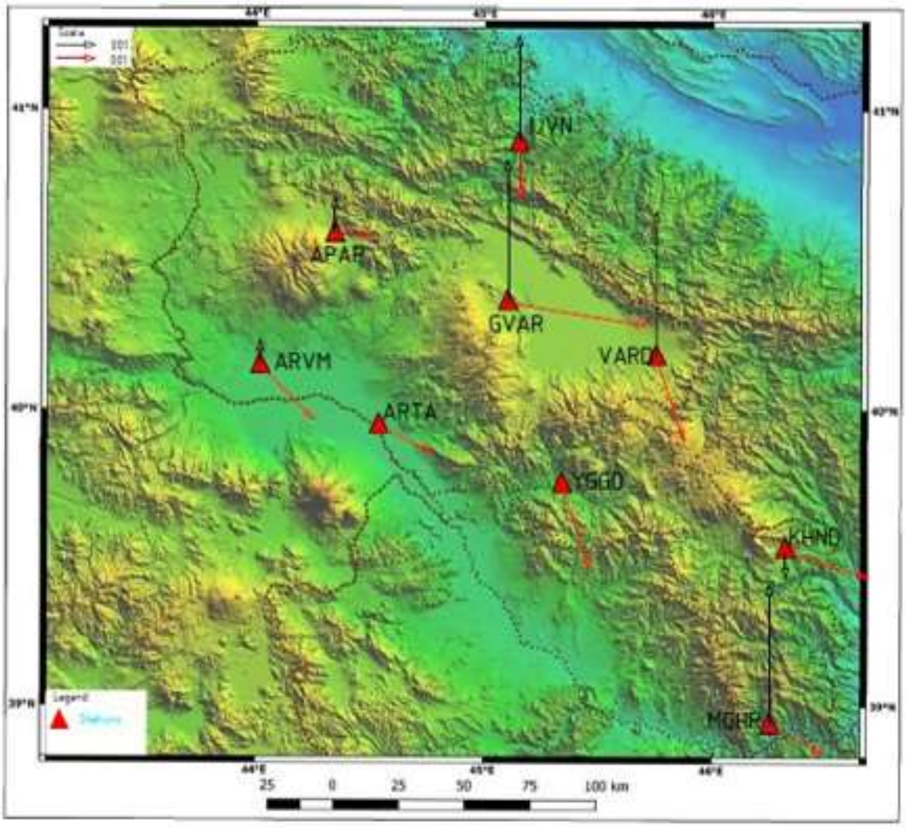

Fig. 9. *Analysis of permanent reference net data*

Conclusion

It can be concluded that the effect of earthquakes due to the discharge of energy accumulations in a certain mass of the Earth's crust during the pre-earthquake period is obvious in the process of determining the coordinates of permanent reference stations. On the basis of which the values of the horizontal and vertical shifts of the permanent reference stations due to the earthquake of February 13, 2021 in Armenia were analyzed and their graphs have been made.

Thus, the monitoring of the earthquake in Yerevan on 13.02.2021 by means of reference stations shows that it is possible to mark the time of earthquake registration by means of coordinates recorded at a frequency of 1 sec., and as a result of the earthquake, it is possible to monitor the Earth's crust displacement vectors at certain intervals through reference stations, recording the directions of horizontal and vertical displacement of the Earth's crust. At the same time, it should be noted that these reference stations are located on the roofs of buildings, and with our network of 18 complex reference stations, some of which will be located on hard rock, it will be possible to have a more accurate database which will contribute to the development of geodetic monitoring in seismically active areas using GNSS technologies.

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